Improving decision-making in road widening projects: A real option tool?

The design of a real option tool and its added value for decision-making

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Preface

This is the master thesis ‘Improving decision-making in road widening projects: A real option tool?’ A real option tool was designed to assess the added value of such a real option tool in the decision-making process of road widening projects in this research. This thesis was written as part of the master Systems Engineering, Policy Analysis and Management at Delft University of Technology and was commissioned by Stratelligence. This research was performed from May 2016 to December 2016.

I wanted to gain better insights in decision-making processes in the Netherlands in this research, because this already had my personal interest during and before my study. What is the reason that many infrastructure projects fail? I hope that my research will contribute to a solution for this problem. Furthermore, this research allowed me to use my skills in modelling and designing, which I also enjoy very much. During this research, I was able to improve my skills in designing, doing research and interviewing significantly. However, I feel that my analytic skills have improved most during the last months. During this research, the design of a real option tool was most challenging. Therefore, I am proud on the real option tool that I developed during this research and the fact that all consulted experts agreed on the added value of such a real option tool. Some difficulties in the design of a standardised real option tool occurred. Ingenuity was needed, because outcomes from cost-benefit analysis were not valuable as input for the tool and were often unavailable.

I was not able to perform this research without the help of my graduation committee. I want to thank Bert van Wee for his valuable comments on my work and his support on performing this research. Secondly, I want to thank Jan Anne Annema for his guidance on taking decisions in this research and his help on holding me on the right track. Thirdly, I would like to thank Zenlin Roosenboom-Kwee for her comments on my work allowing me to improve it significantly. Furthermore, I want to thank Stratelligence and specifically Gigi van Rhee for giving me the opportunity to perform my research at Stratelligence. Working as an intern at Stratelligence made the practical relevance of this research very clear to me. Gigi, I have enormous respect for your expertise in a wide range of topics and your enthusiasm on improving decisions in the Netherlands. Your criticism helped me improve my work constantly. Lastly, I want to thank all experts who I interviewed for this research. Their insights and opinions were very important and helpful for this research.

For those interested in the conclusions of this research, I would like to refer to the summary on page v and the conclusions and recommendations on page 72. I wish you all enjoy reading.

Jorrit Penninga

Delft, 8 December 2016

Abstract

Context and problem description

It is expected that the intensity of traffic will increase in the coming years. However, the degree to which the traffic intensity is growing is uncertain and depends on among others, demography, economic growth, spatial developments, international energy and climate policy, and technological, behavioural, and policy developments. These are all uncertain variables. Therefore, it is unclear which measures should be taken to maintain traffic flow on the roads. The Dutch government has the intention to widen roads in the future. Decisions have to be made on which roads should be widened, because as a matter of course, a limited amount of money is available.

Decision-making in large infrastructure projects is usually complex and unstructured. As a result, cost-benefit analysis (CBA) was made mandatory. With CBA the costs, benefits, and the net present values (NPVs) of alternatives are calculated in two scenarios. In recent years, an increasing need for the incorporation of flexibility in decision-making arose, because future developments can be assessed with flexibility potentially leading to improved decisions. With the inclusion of flexibility, the decision to widen a road can be phased or delayed towards a situation in which more information on the growth in intensity becomes available. Current CBA is unable to evaluate the costs and benefits related to flexibility.

Real option analysis (ROA) is a method in which the costs and benefits of flexibility are analysed. A real option is "a decision taken today that makes it possible for decision makers to take a particular action in the future" (Bureau of Infrastructure, Transport and Regional Economies, 2014, p.13). ROA has proofed to be of added value for decision-making. However, ROA also has some difficulties in its application and is therefore not yet often applied:

- Multiple methods for the application of ROA exist.
- It is unclear how real options, such as delay and phasing, should be implemented.
- Multiple opportunities for the incorporation of uncertainty in ROA exist.

The result is that ROA is not yet standardised in the decision-making process, especially compared to the level of standardisation of CBA. Potentially, a real option tool could help to include ROA in the decision-making of road widening projects. It is however unclear how such a real option tool should look like in order to create most added value for decision-making. It is also unclear what the added value of a real option tool for decision-making is in road widening projects.

Research method

The research question in this research is as follows: *What is the added value of a real option tool for decision-making in road widening projects?* This research question is answered in three research steps. First, the requirements for a real option tool were analysed. These requirements were identified by researching theory on decision-making, ROA, CBA, decision support systems (DSS), and planning support systems (PSS). CBAs of road widening projects and tools

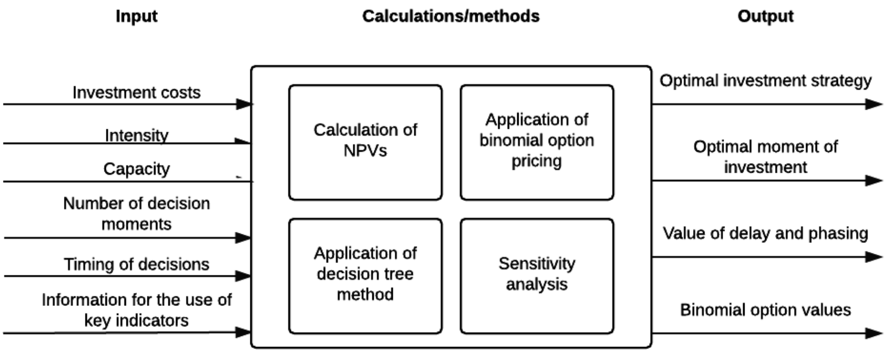
for decision-making were also analysed. Secondly, a real option tool was designed. The identified requirements were helpful in making decisions on a wide range of topics in the design, e.g. on the ROA method, the inclusion of uncertainty, the communication of results, and the implementation of real options. The tool was made in an iterative design process. Thirdly, seven experts were asked on their opinion on the added value of the real option tool. During the interviews the tool was shown and the most important design decisions were evaluated.

Requirements for the design of a real option tool

The requirements for the design of the tool consist of needs, variables, and constraints. The needs are the requirements of the tool from a user perspective. The following needs were identified. The tool should: support in decision-making, be transparent, have a high usability, be adaptable, be good in the use of data, be documented, and offer the possibility for training. However, documentation and training possibilities were not explicitly included in this research. Secondly, the variables, the most fundamental decisions in the design, were identified. These variables are: the uncertainty and scenario changes in road widening projects, the possible real options in road widening projects, the effects of road widening projects, the alternatives in road widening projects, the time horizon, and the ROA method. There was decided for the incorporation of the intensity as main uncertainty, delay and phasing as real options, all effects of road widening projects that are also assessed in CBA, and the simplified decision tree and binomial option pricing as ROA methods in the tool. Thirdly, the most important constraints in the design of the tool were identified. These constraints are the inclusion of the 'Leidraad MKBA', the software and its data capabilities, and the constraints concerning the use of the tool: to be assessed in a reasonable amount of time and standardisation in the assessment of road widening projects. The needs, variables, and constraints are summarised and ordered in seven design requirements. These requirements are good implementation of ROA, good assessment of road widening projects, good use of data, high adaptability, high transparency, good user interface, and high support in decision-making.

Design of a real option tool

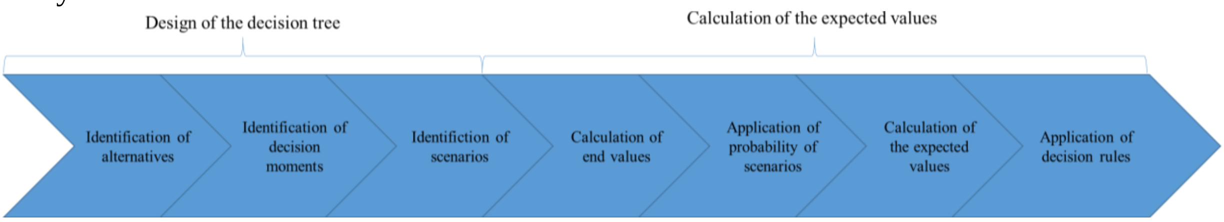
The real option tool consists of three parts: the output, the calculations/analysis (see Figure)



A real option tool should calculate the following output: the expected values and binomial option values of phasing and delay, the optimal decisions, the optimal year of investment, and the results of the sensitivity analysis. To calculate these outcomes of the tool, four types of analysis should be performed: the calculation of the NPV, the simplified decision tree method and binomial option pricing, and the sensitivity analysis.

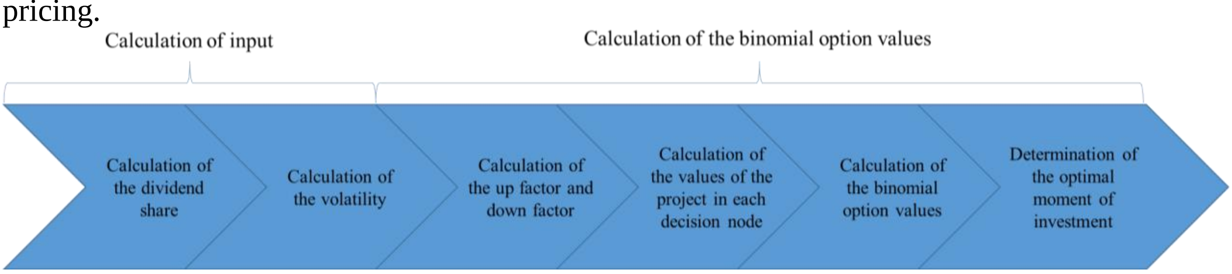
The NPVs of different sections of the road are calculated in the tool. The costs, direct effects, indirect effects, and external effects of each road section are calculated mainly based on key indicators. The calculation of the travel time effects requires some more explanation. The tool compares the ratio between the intensity and capacity on the road (the I/C ratio) in the project and current situation. This difference is related to a decrease in average speed and results in a difference in travel time between the project situation and the current situation. The travel costs, effects on excise duties, indirect effects, and external effects are calculated based on the number of generated vehicle kilometres. It is assumed that, on average, a road widening leads to a 4% increase in vehicle kilometres.

The steps shown in the next Figure were performed in the application of the decision tree analysis.



The real options that are assessed in the tool are phasing from the economic most optimal alternative towards the least optimal alternative and delay of the widening of all sections. A maximum of three and five decision moments are respectively used for phasing and delay. The scenarios high and low are used for which a growth per year is known for three different regions in the Netherlands. It is expected that traffic growth differs for different regions in the Netherlands. The end values in the trees are calculated for each combination of scenarios. The advantage of the use of the I/C ratio is that it allows for the calculation of a large number of results relatively easy. An equal distribution in the probability of scenarios high and low is used. This probability is multiplied with the outcomes in order to calculate the expected values in each decision node. The values in the decision nodes should be maximised in order to calculate the expected value. The alternative with the highest expected value should be chosen.

The steps shown in the next Figure were performed in the application of binomial option pricing.



The dividend share is represented by the annual benefits of the alternatives in the tool. The volatility is calculated based upon the growth of traffic intensity in the past. The geometric Brownian motion was used for easier calculation of the volatility. The optimal moments of investment are determined by the calculation of the moments in which the binomial option values exceed the costs that are related to the project in this decision node.

The next input is needed from the user in the tool: the implementation costs, the length of the road sections, the intensity, the capacity, and the timing of decision moments. Adjustments of all key indicators are possible in the tool.

Case, verification & validation

The practical relevance and application of this tool was described in a case test. The case test shows that the tool creates additional insights compared to the go/no go decision in CBA and that the tool can be used relatively easily in a real case with a limited number of assumptions in the input variables. The tool creates additional insights in the way flexibility can be incorporated and on the value of flexibility in the expected value of delay and phasing. Besides, the tool shows the optimal strategy for decision-making. The case test creates sufficient confidence that the tool can be used in a wide range of other cases. The tool is sensitive for changes in the input variables. Most outcomes change much when the input is slightly changed. It stands out that the sensitivity of the tool on the more questionable assumptions of ROA, such as the probability of scenarios, is relatively low.

Assessment of the tool

Respondents were asked on their opinion on the added value of the tool. Respondents mention that the tool could be of added value for decision-making. They state that the most important requirements of the tool are the connection with the user needs, the assessment of road widening projects, and the support in decision-making. Another important requirement often mentioned by respondents was the flexibility of the tool.

The tool scores well on its connection with the needs of users. First, the need for another ROA method besides the simplified decision tree was limited for all respondents. Secondly, binomial option pricing as additional ROA method has some drawbacks in practicality and theory for the respondents. This method is judged as too complex and not in accordance with current guidelines. Thirdly, the added value of including more scenarios was limited for respondents. Many decision makers are pleased that nowadays only two scenarios are required.

The tool does not fully satisfy in its assessment of road widening projects. Some respondents criticised the use of the I/C ratio in the tool as it leads to simplifications of reality. The relation between the I/C ratio and average speed is complex and may be nonlinear. Furthermore, the interrelated effects of phasing on other sections of the road, radiation effects, and a potential increase in maximum speed are not incorporated. Respondents also mention that the effect on vehicle kilometres is more complex than how it is modelled in the current tool.

The tool scores well on its support for decision-making. The respondents recognise that there are many projects in which this tool can be applied. External consultants were identified as potential users of a real option tool. The tool can be used by external consultants for creating competitive advantage or using it could be made mandatory. A paragraph with the results on the use of the real option tool can be added to CBA reports. Another proposal is to use the tool in discussions. Respondents mention that the tool could be of added value in the first phase of decision-making. Strategic tools are regularly used in the first phase of decision-making in road widening projects. Using a more tailored and complex real option tool in a later phase of decision-making could also be of added value.

Conclusion

The research question that was central in this research was: *What is the added value of a real option tool for decision-making in road widening projects?* A real option tool has added value for decision-making in road widening projects, because

- seven experts mention that the tool could be of added value for decision-making;
- a real option tool could be designed that incorporates all relevant requirements;
- a real option tool is currently not available in decision-making and can be used in the first phase of decision-making;
- the tool creates additional insights compared to CBA in road widening projects on the identification and valuation of flexibility in decision-making;
- the tool could potentially be used in a wide range of road widening projects;
- standardisation of ROA in a real option tool is possible.

Discussion

The limitations of this research concern the real option tool, the limited identification of user needs in the requirements, the limited assessment of binomial option pricing by the respondents, and the assessment of the added value. More concrete conclusions could have been drawn on the added value of binomial option pricing in this tool when this method would have been evaluated by the respondents in the interviews. A limited amount of time was available in the interviews and the added value of multiple ROA methods was indirectly assessed. A more extensive test of the real option tool to draw conclusions on the added value of this tool would have improved the quality of this research and the assessment of the added value. Besides, interviews could have been held with experts to identify the most important user requirements before the design of the tool.

This research shows the added value of the application of ROA as an analytical tool and that ROA is of added value in the identification of possibilities for flexibility in the first phase of decision-making. But it could also be of added value in a later phase of decision-making. This research also shows that a real option tool cannot be the Holy Grail for the incorporation of flexibility in decision-making. Difficulties exist that cannot only be remedied by a real option tool or by the application of ROA in decision-making.

The theoretical implications of this research are that DSSs could lead to the adoption of a specific method, that DSSs are valuable for decision-making, and that ROA can be applied in a standardised way in a tool. The practical implications of this research are that pilots could lead to the decision of the adoption of a real option tool and could further improve the tool. Positive experiences increase the aim of users to use the tool in a structural way and spreading the news about the availability of a real option tool. The policy implication of this research is that a real option tool could lead to better understanding of the effects of road widenings projects and the possibilities of flexibility.

Recommendations

For ROA in decision-making, the application of the simplified decision tree method seems to be most realistic, because the limited number of decision moments was not problematic for respondents and it seems that the implementation of multiple ROA methods in a tool is not of added value for respondents. However, for different types of problems different ROA methods might be valuable. Consensus on the ROA approach, as a way of thinking or as an analytical tool, should be reached to improve the adoption of ROA.

There are several recommendations for further research. It is recommended to improve the current tool. Specific recommendations were made in the interviews. More research is also needed for improvement: on the negative value of uncertainty, on the relation between the I/C ratio and the average speed, and on key indicators for costs and benefits of flexible alternatives. For road widening projects, it is recommended to apply the simplified decision tree method. More research should be done on the characteristics of projects that result in an added value of other ROA methods. The assessment of the added value can be improved by increasing the number of respondents in further research. Besides, it is recommended to test the tool in practice to further assess the added value of the tool and its practical applicability.

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List of abbreviations

CBA	Cost-benefit analysis
CPB	Centraal Planbureau (CPB Netherlands Bureau for Economic Policy Analysis)
DSS	Decision support system
HCM	Highway Capacity Manual
I/C ratio	Ratio between the capacity and intensity
INWEVA	INtensiteiten op WEgVAkken (Intensity on road sections)
MER	Milieueffectrapportage (Environmental impact report)
NPV	Net present value
NRM	Nederlands regionaal model (Netherlands regional model)
PBL	Planbureau voor de Leefomgeving (PBL Netherlands Environmental Assessment Agency)
PSS	Planning support system
ROA	Real option analysis
RWS	Rijkswaterstaat
VAT/BTW	Value added tax
VBA	Visual Basic for Applications

1. Introduction

In this chapter, the context of the research is described in section 1.1. Section 1.2 elaborates on the research problem. The research objective, the main research question and sub questions are described in section 1.3. The social and scientific relevance of this research is described in section 1.4. The last section covers the structure of this report.

1.1 Context

The Dutch government has the intention to widen roads in the coming years to reduce congestion and travel time (Rijksoverheid, 2016). The widening of roads could be needed in specific future bottlenecks due to an increase in traffic. Decisions have to be made by governments on which and when roads should be widened, because a limited amount of money is available. Cost-benefit analysis (CBA) is required to assess the profitability of infrastructure projects and to assist in decision-making (Eijgenraam, Koopmans, Tang, & Verster, 2000b; Ministerie van Infrastructuur en Milieu, 2016).

Since 1990, the number of new roads in the Netherlands is limited, but the number of road widenings was considerable (CPB, 2016). In the coming decades, investments in roads will only be profitable when there is a scenario of high demographic and economic growth (CPB, 2016). This is in consistency with options that introduce flexibility, which are only exercised when it is profitable to do so (Nembhard & Aktan, 2010). In current CBAs, most of the road infrastructure projects are profitable in a high scenario and unprofitable in a low scenario: the number of no regret infrastructure projects is limited (CPB, 2016). Besides the investment in road infrastructure, there is a growing trend in the implementation of different types of policy for infrastructure, e.g. influencing travel behaviour, optimising current connections, or responding to new technologies (CPB, 2016). There is a need to investigate on possibilities for flexibility, in delay of phasing, in decision-making, because no regret alternatives do usually not exist. With delay and phasing, the investment can be postponed to a situation in which more information is available, and therefore the outcome of the project is more certain.

Including flexibility reduces the risk of a specific measure and it creates the possibility to respond to new developments and changing circumstances (Eijgenraam, Koopmans, Tang, & Verster, 2000a; Romijn & Renes, 2013). ‘To accommodate uncertain change we need flexibility in both our thinking but also in the design of systems and infrastructure’ (Lyons & Davidson, 2016). In standard CBA, the net present value (NPV) is calculated and scenarios are used to take uncertainty into account, but the value of flexibility is not specifically assessed. Real option analysis (ROA) is a method that is able to assess flexibility and uncertainty in decision-making. ROA is not often applied in practice compared to the application of CBA, because, among other things, the number of calculations increases and models become less transparent for decision makers (Stratelligence, 2012). A calculation tool could improve the application of ROA in road widening projects, but it is currently unclear what the added value of such a tool is in the decision-making process. CBA is currently applied in the exploration phase of decision-making (Figure 1.1). ROA can be applied in many different phases of decision-making, but it is currently unclear in which phase of decision-making ROA should be applied (Figure 1.1).

Furthermore, it is unclear how ROA should be applied: as a qualitative or quantitative analysis. A tool may be of added value for quantitative analysis in ROA.

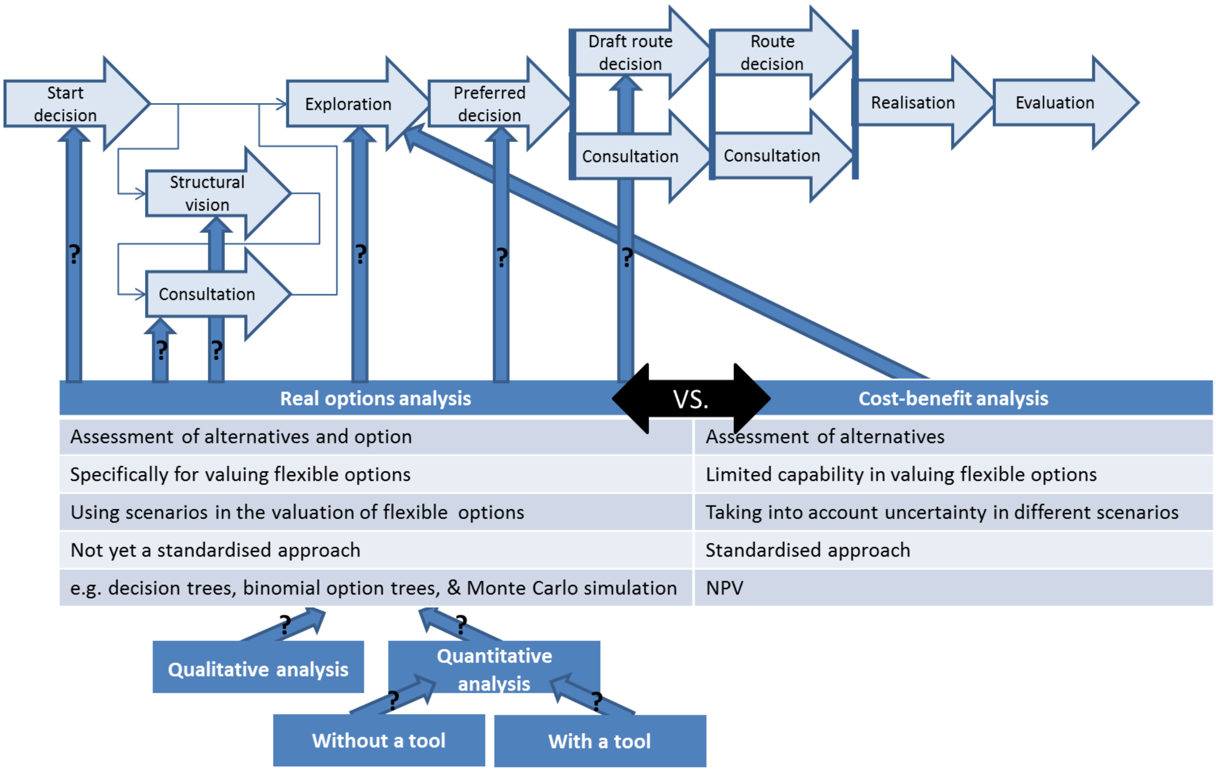


Figure 1.1: decision-making process in infrastructure projects in the Netherlands and the role of CBA and ROA and a real option tool in this process (Source: Rijkswaterstaat, 2016b)

1.2 Research problem

In this section, the research problem is described by first describing the problem of valuing flexibility in current CBAs and then introducing issues in the application of ROA in decision-making. In the end, a knowledge gap is presented and the problem is formulated.

1.2.1 Cost-benefit analysis

With CBA, the social costs and social benefits of alternatives are predicted by calculating the NPV to make the choice for an alternative more transparent (Van Goeverden, 2009). One of the main strengths of CBA is that it is a standardised approach of evaluating alternatives (Annema, Koopmans, & Van Wee, 2007). Taking uncertainty into account when decisions are made on road widenings is important, because additional lanes might be needed and economically justified later (Eijgenraam et al., 2000a; Reitsma & Van Rhee, 2011). An example of this necessity is the project 'Ring Utrecht', wherein the benefits of road widening were highly uncertain due to the large effect of the economic growth on the benefits (CPB, 2014). A risk-free discount rate and a fixed risk premium is used in CBA to take into account the uncertainty of benefits, to reflect risk avoidance, and to describe the preference of benefits on a short term. Besides, the costs and benefits in two scenarios are usually assessed. CBA assumes a static investment decision and assumes that strategic decisions are made once, without including the possibility to choose paths or options over time (Mun, 2002, p. 10). CBA has a limited capability in the identification of the costs and benefits of flexible options, such as delay and phasing.

1.2.2 Real option analysis

On the one hand, it can be valuable to delay or phase a project, because benefits are uncertain (Eijgenraam et al., 2000a; Verrips & Hoen, 2016). More information, e.g. on the economic growth, becomes available reducing the uncertainty of the benefits after a while. On the other hand, delay and phasing also leads to costs, because there are no benefits in the first years. ROA is able to assess the costs and benefits of dynamic solutions (Stratelligence, 2012; Reitsma & Van Rhee, 2011). ROA can be beneficial in road widening projects, because it allows for describing the flexibility in a structured way. ROA is useful for 'identifying, understanding, valuing, prioritising, selecting, timing, optimising, and managing strategic business and capital allocation decisions' (Mun, 2002). ROA is able to both recognise where options exist and in the introduction and strategically setting of options (Mun, 2002). Additionally, ROA may create added value in executing risky projects by assessing the postponement of risky investments (Paantjens, 2013).

Unlike in CBA, a standardised approach for calculating real options does not yet exist. There are several issues limiting the consensus on a standardised application of ROA:

- Different methods for the evaluation of real options exist (Table 1.1). Binomial option pricing, Monte Carlo simulation, and decision tree analysis are frequently used methods in business today (Block, 2007). There are also multiple types of decision trees available (Van der Pol, Bos, & Zwaneveld, 2016). Which ROA method should be used is unclear, because the preferred method may depend on the characteristics of projects (Gijsen, 2016). Applying a different method could lead to different outcomes, both in the results as in the types of results.
- It is unclear how real options, such as delay and phasing, should be implemented in projects. The options to phase or delay may differ among projects. The implementation of real options is very much related to the needs of decision makers and the characteristics of the project, also when only road widening projects are assessed. There are in fact multiple types of phasing in road widening projects. For example, a road can be widened from current situation to rush hour lanes to a full additional lane, but also the widening of different sections of the same road can be phased.
- Which and how scenarios should be included in ROA is currently unclear. The standardisation of ROA is difficult, because there are many different options in the incorporation of scenarios. In CBA, scenarios high and low are currently used for taking into account uncertainty. Scenarios such as policy decisions or regional developments may also affect the benefits of road widening projects and can be included in ROA.

In the further adoption of ROA, focusing on road widening projects has an added value, because these projects are more risky than projects in other policy areas (Steunpunt Economische Expertise, 2016). Investment costs are fixed and therefore flexibility in the decision-making process of these projects is not a foregone characteristic. Decisions need to be made on a range of issues in the standardisation of ROA.

ROA was applied in several case studies on road widening projects in the Netherlands in which different methods were used for the quantification of effects (Table 1.1). These case studies were applied ex-post or in a further stage of decision-making: the costs and benefits of alternatives were known from CBA. In all case studies, it was concluded that ROA has benefits for road widening projects.

Table 1.1: overview of case studies applying ROA in road widening projects

Reference	Case	ROA method (quantitative)	Identified benefits of ROA
Reitsma, 2010	Widening of the A27 motorway	- Binomial option pricing - Risk-adjusted decision analysis	Phased construction of roads and land reservation can be beneficial for projects.
Van der Pol et al., 2016	A fictitious case on road widening and the use of a land tunnel	- Simplified decision tree	Flexibility in land reservation can be beneficial.
Gijsen, 2016	Widening of the A44 motorway	- Binomial option pricing - Simplified decision tree	Flexibility leads to less negative alternatives.

1.2.3 Knowledge gap and problem formulation

Despite the fact that the use of ROA can overcome two major drawbacks of CBA: the use of a discount rate that does not account for project- or alternative specific risks and not recognising the value of adapting to future conditions (Van Rhee, Pieters, & Van der Voort, 2008), the number of studies on the practical use of ROA and the adoption of ROA in road widening projects is limited. One of the recognised steps in the adoption of ROA is the development of a calculation tool for valuing real options (In 't Veld & Schenk, 2008). There is lack of clarity on how ROA should be applied in decision-making and there is lack of clarity on how such a tool should look like. This makes the design of real option tool inconclusive.

There is a lack of clarity on the approach of ROA. Three different approaches of ROA exist: ROA as a way of thinking, ROA as an analytical tool, and ROA as an organisational process (Triantis & Borison, 2001). It is currently unclear which approach of ROA creates most added value for decision-making. ROA as a way of thinking 'highlights the notion of proactive planning and the ability to consider alternatives during any planning and strategy formulation situation' (Driouchi & Bennett, 2012). This shows that ROA could be used as well explicit as implicit in the decision-making in road widening projects. Especially when ROA as a quantitative tool is too complex for decision-making, using ROA as a framework for a qualitative approach might be of added value (Lyons & Davidson, 2016). Mun (2010) states that 50% of the value of ROA results from thinking about real options, 25% of the added value comes from the calculations, and 25% comes from the interpretation of the results and the explanation to decision makers. A real option tool could assess all of these approaches, but focuses clearly on the calculations in ROA and on ROA as an analytical tool.

Furthermore, there is a lack of clarity in the calculations in ROA. The current application of ROA in decision-making in Dutch governmental decisions could be limited due to the increasing number of calculations (Vis, 2006). Besides, a standardised ROA method for the increasing number of calculations is unavailable. This makes ROA hard to accept for practitioners (Janney & Dess, 2004).

For the implementation of ROA, three aspects are important: the right tools, the relevant human resources, and senior management buy-in (Mun, 2010). Tools are also able to bring theory to practice (Mun, 2010). Garvin & Ford (2012) state that models, tests, and tools can improve the adoption of ROA by practitioners. Calculation models were probably used in recent case studies (Table 1.1), but a standardised tool for the implementation of ROA is still not available. This makes the application of ROA cumbersome (Van der Pol et al., 2016; Martins, Marques, & Cruz, 2013). With a standardised real option tool, ROA could be applied in multiple projects in a standardised and relatively easy way. A tool is per definition the standard application of a specific method and in this way, the design of a real option tool can help to improve the adoption of ROA in decision-making by standardising the method and with a focus on ROA as an analytical tool.

However, it is still unclear how such a real option tool should look like. No standardised real option tools currently exist that can be used for the assessment of road widening projects. In consulting companies, real option spreadsheets might exist for road widening projects. Standardised real option tools probably do exist in business, but they probably cannot be used in public infrastructure projects, due to different project characteristics. Besides, there is complexity involved in the design of tools that creates drawbacks for the use of tools in practice. There are lots of reasons for not using tools in practice. Tools seem to be too generic, too complex, inflexible, incompatible with the complexity of planning tasks, not sufficiently problem oriented, incompatible with information needs, and too much focused on strict technical rationality (Te Brömmelstroet & Schrijnen, 2010). It is also currently unclear how the tool should be governed. To sum up, the implementation of a standardised real option tool in practice is not guaranteed and seems to be complex. Although, the specific design of a real option tool may have added value for decision-making.

How ROA should be applied in the decision-making process is currently unclear. A real option tool could help in standardising the method and could be beneficial for the adoption of ROA in practice and could be beneficial for decision-making in road widening projects. The following problem arises, which is also the problem statement for this research: *it is unclear what the added value of a real option tool is for decision-making in road widening projects.*

1.3 Research objective and research questions

This research focuses on the design and the assessment of a real option tool for road widening projects. In this way, the added value of a real option tool for decision-making in road widening projects can be described. The objective of this research is: *"to develop a real option tool for decision-making in road widening projects and to describe the potential added value of the tool for the decision-making process in road widening projects".*

The problem statement and research objective together lead to the following main research question:

What is the added value of a real option tool for decision-making in road widening projects?

There are three sub research questions. Firstly, the basic requirements should be researched: W*hat are the requirements of a real option tool for road widening projects?*

Secondly, the tool should be designed: *How do the requirements lead to a real option tool for road widening projects?*

Thirdly, conclusions on the added value should be drawn: *What can be learned from comparing the current situation of decision-making in road widening projects and the situation in which a real option tool is available?*

1.4 Social and scientific relevance

From a scientific perspective, this research contributes to the description of the relation between a tool and the application of ROA in road widening projects. It also contributes to the current state of affairs in ROA and research on decision-making processes. Describing the added value of a tool contributes to the level of knowledge on the application of technical tools in decision-making processes. Te Brömmelstroet (2012) suggested making planning support systems (PSSs) more transparent and flexible to use, to focus on simplicity, and to improve communications of tools. Te Brömmelstroet (2012) also mentions that the practical testing of these suggestions in the development of tools is largely missing. This research might contribute to the practical testing of recommendations for the design of tools. Besides, conclusions can be drawn on whether the development of a tool helps in the standardisation of a method.

The social relevance of this research consists of its policy relevance and practical relevance. The policy relevance of this research lies in its added insights in the incorporation of flexibility in decision-making on road widening projects. Projects with less robust outcomes could gain from insights to successfully conclude on the costs and benefits for society (CPB, 2001). As CBAs of infrastructure projects often lead to less robust outcomes, ROA can add valuable insights in the valuation of infrastructure alternatives. The practical relevance of this research lies in the potential adoption of a real option tool in decision-making. Reasons for not using ROA in practice may be: a lack of top management support, the fact that calculating the NPV is a proven and established method, the need for more sophistication, and the encouragement of excessive risk-taking (Block, 2007). This research focuses on making ROA less sophisticated for road widening projects and might lead to the adoption of a real option tool in the future.

1.5 Scope and orientation

This research takes into account road widening projects on primary and secondary roads in the Netherlands, named as A- and N-roads. These roads are most relevant, because some of these roads will be widened in the future (NOS, 2016). Potentially, the results can also be used in other western countries. But the results must be treated with care when it comes to countries with large differences in the decision-making process or nature of the projects. The evaluation of projects in CBA in the Netherlands is very specific and is often different in other countries. The added value of this real option tool in decision-making in the Netherlands cannot be guaranteed in other countries.

As the focus of this research is on road widenings, the number of lanes and the geographic location are the most important design parameter in which flexibility will be included.

However, it should be mentioned that road infrastructure projects include multiple design parameters in which flexibility can be included, such as the design speed, the width of right of way, the geometric shape, drainage, and intersections (Zhao, Sundararajan, & Tseng, 2004). Delay and phasing are used as real options in this research, because these options are often described in road widening projects (Van Rhee et al., 2008; In 't Veld & Schenk, 2008; Verrips & Hoen, 2016). Delay is defined as the delay of a decision "until more information becomes available or investment conditions are improved" (Van Rhee et al., 2008, p. 5). Phasing is defined as "the opportunity to divide a project or investment into separate investments that are phased in time" (Van Rhee et al., 2008, p. 5).

The real option tool is a decision support system (DSS). Multiple reasons for the development of DSSs exist: the user cannot provide functional specifications or is unwilling to do so, users do not know what they want, users' concepts of the task or decision situation need to be shaped, or users have sufficient autonomy to handle the task in a variety of ways (Keen, 1980). These are reasons to include a user perspective in the development of tools. Focusing on the user in this research is specifically beneficial, because it is currently unclear which additional information the user exactly needs in decision-making. Therefore, the description of the added value is based on the perception of potential users and experts in CBA, ROA, and decision-making in road widening projects. Potential users are persons and organisations that are involved in the decision-making process and that can benefit from using a real option tool. Potential users and experts can be found in organisations like: Rijkswaterstaat (RWS), national and regional governments. Also, external consultants that are currently involved in CBAs of road widening projects may be potential users of the tool. The governance aspect of the tool is also important to evaluate during the assessment of this real option tool, because many actors could be involved in the use of the tool.

This research focuses on the design of a tool and not on the implementation of this tool in practice. The implementation of tools is also important for the description of the added value of these tools (Sage & Armstrong, 2000). However, it is expected that the potential added value can be described without the implementation of the tool. Therefore, important issues for the implementation of the tool are taken into account. However, training and workshops are not assessed in this report. The added value that is assessed in this research is the potential added value for implementation of a real option tool. The tool should be applied and researched in a real case to address the real added value of a real option tool in decision-making.

1.6 Structure of this report

Section 2 elaborates on the methodology of this research. Section 3 describes most important requirements for the design of a real option tool. The design of the real option tool and the choices that were made in this design are explained in section 4. The assessment of the tool in interviews and the reflection on the outcomes of these interviews are described in section 5. Section 6 gives the conclusions and recommendations and contains a personal reflection.

2. Methodology

This chapter describes and explains the research method. The first phase of research, in which the requirements of design are identified, is described in section 2.1. The method for designing the real option tool is assessed in section 2.2. Section 2.3 elaborates on the use of the real option tool in practice in comparison to the current situation of decision-making.

2.1 The requirements of design

It is currently unclear how a good real option tool looks like to be of added value for decision-making. The requirements of a real option tool were described to be able to design a tool. Decisions were made on multiple aspects in the design of the tool based on the requirements of design.

First, the requirements from a user perspective were identified: the needs. These needs are especially important in the design of a real option tool, because the tool should be used in decision-making and in decision-making processes usually many stakeholders involved. These needs were also used to make decisions on the added value of the tool and were used in the interviews on the added value of the tool.

Secondly, the requirements were used to make decisions in the design. However, also some more fundamental decisions were made in the design of the tool. The fundamental aspects on which decisions were made are called the variables for design. A change in these main decisions for design results in a fundamentally different real option tool.

Thirdly, some aspects of the tool limit the number of decisions in the design of the real option tool substantially. These restrictions are named constraints. Without the inclusion of these aspects in the design, the tool would not be a real option that could potentially be of added value for decision-making.

Concluding, as well the needs, variables, and constraints were researched to define the requirements for design and to make decisions in the design of a real option tool. These decisions were needed, because it was unclear how a real option tool should look like to be of added value for decision-making before this research. Figure 2.1 visualises the relation between needs, variables, constraints, and requirements.

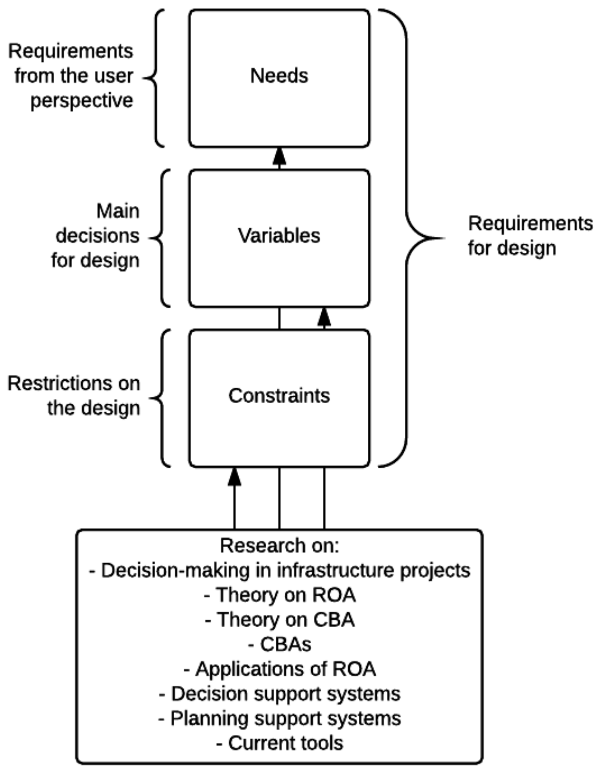


Figure 2.1: relation between variables, constraints, needs & requirements (Based on Sage & Armstrong, 2000)

The following theory was researched and the following analyses were performed to identify the needs, variables, constraints (Figure 2.1).

- Theory on decision-making processes in infrastructure projects provided insights in e.g. the desired output or the available input in road widening projects. Some basic characteristics of decision-making, e.g. the need for transparency or the phases of decision-making, were also identified based on this theory.
- Theory on ROA and CBA, from the current state of affairs in these fields, was used to describe requirements. In this way, new and relevant insights from theory, such as the incorporation of effects in CBA and insight in the adoption of ROA, were included.
- CBAs of road widening projects and applications of ROA were analysed to reflect on decisions that have already been made in the application of ROA and CBAs. Insights in these decisions helped in making decisions in the design of this real option tool. A disadvantage of this research method was that these reports were written for another purpose than this research. This might result in a lower validity of the results of this research (Verschuren & Doorewaard, 2010). But to prevent this, a requirement of the data was that the CBAs were performed in accordance with guidelines from the 'Algemene Leidraad MKBA'. This document contains guidelines for the application of CBA (Romijn & Renes, 2013).
- Theory on the application of tools in decision-making processes was researched. In this way, insights from the development of other tools and the assessments of the added value of other tools were used to improve the quality of this tool. This area of research is DSS, which focuses on supporting and improving managerial decision-making (Keen, 1980: Pervan & Arnott, 2005). Fur the same purpose, literature on PSS was used in the definition of requirements for the design. A PSS is defined as 'an infrastructure that systematically introduces relevant information to a specific process of related planning actions (Te Brömmelstroet & Schrijnen, 2010).
- Tools that are currently used for CBA and for decision-making were evaluated to gain insight in the development of these tools. In this way, tools that are of added value for decision-making and the current state of affairs in CBA tools were included in the design of the real option tool. Examples of these tools are 'MKBA Fiets' and 'TEEB-stad' (Appendix III).

Literature was found by using Google, Google Scholar, and Scopus (Table 2.1). The snowball principle, both forward and backward, was applied on some relevant articles. A drawback of the snowball principle is that only a limited number of perspectives on tools might be researched. Each article refers namely to another related article. However, as many different search indices were used, the risk of having limited perspectives was reduced. The search strategy and its most important results are shown in Table 2.1.

The research on needs, variables, and constraints led to a summary in a list of seven high level requirements. These seven requirements were also visualised in an objective tree, in which also measurable low level requirements were identified. With the visualisation in an objective tree and the identification of low level requirements, the high level requirements could be weighed against each other when they were conflicting due to the hierarchical representation in an objective tree (Appendix IV).

Table 2.1: search strategy in this research

Search engine	Search indices	Results (reference)	Principle	Results (reference)
Google scholar	Decision support systems	- Le Blanc & Tawfik Jelassi, 1989	Snowball principle	- Sprague & Watson, 1976
	Transparency & Decision support systems	- Halim & Seck, 2011	Snowball principle	- Fu, 2002
	User interface tool	- Sankar, Nelson Ford, & Bauer, 1995		
	Requirements for DSS	- Sprague, 1980 - Elm et al., 2005		
	Requirements of a tool	- Falessi, Shaw, Shull, Mullen, & Stein, 2013		
	Real option analysis	- Driouchi & Bennett, 2012 - Garvin & Ford, 2012 - Nembhard & Aktan, 2010	Snowball principle	- Mun, 2002 - Zhao et al., 2004
Scopus	User interface tool	- Dos Santos & Holsapple, 1989		
	Requirements for DSS	- Shim et al., 2002		
Google	'Transparantie besluitvormingsproces'	- Romijn & Renes, 2013	Snowball principle	- Ten Heuvelhof & Hobma, 2004
	Real option analysis	- Van Rhee et al., 2008 - Schoof, Derksen, Kandel, & Crooijmans, 2013		
	'Maatschappelijke kosten-baten analyse infrastructuur'	- Jonker, Vrij Peerdeman, & Van Veldhuizen, 2011 - Deviller & De Swart, 2012 - Hoefsloot, De Pater, Wijnen, & Rienstra, 2014a - Hoefsloot, De Pater, Wijnen, Holleman, & Knibbe, 2014b - Dusseldorp, Modijefsky, & Vervoort, 2012 - Van der Meij, Molemaker, Rienstra, & Vervoort, 2004 - Vervoort, Van der Ham, & Van Breemen, 2015 - Wageningen UR & MU Consult, 2013 - Decisio & 4Cast, 2006		
	'MKBA Tool'/ CBA Tool	- Fietsberaad CROW, n.d. - Platform 31, n.d. - Vereniging van Nederlandse Gemeenten, 2015 - RSSB, n.d. - State of Connecticut, n.d. - CBA builder, n.d. - Deltacommissaris, 2014 - Ministerie van Sociale Zaken en Werkgelegenheid, n.d.		
	Real option analysis tool	- 'No valuable results'		
	Effects of road widening projects/'Effecten wegverbreding'	- Van den Brink, Blom, & Annema, 2005 - Van Goeverden, 2009 - Elhorst, Heyma, Koopmans, & Oosterhaven, 2004		

2.2 Design of a tool

In the second phase of research, the tool was designed, based on the requirements that emerged from the first phase of research. The steps for development of the tool were: the determination of most relevant elements, the determination of the possibilities for design and the design decisions, modelling of the design decisions, and verification and validation (Sage, & Armstrong, 2000; Studio1Design, n.d.).

The tool was made iteratively, because many decisions on the design of the real option tool had to be made in this research (Figure 2.2). This design approach is also referred to as rapid iterative testing (Studio1Design, n.d.). First of all, the possibilities for design were researched. Then, the main decisions for design were made. Later on, these decisions were modelled followed by some degree of testing. Based on the results of these tests, possibilities for design were identified again and another decision was made or modelled (Figure 2.2). A clear example of this iterative approach is the determination of the travel time effects. The possibility and the decision to use a standard reduction in travel time of 5% in a road widening in the tool turned out to be invalid in the test. In this specific case, in a situation with no congestion, the travel time effects were relatively high compared to a situation with congestion. After this, the use of the ratio between the intensity and capacity (I/C ratio) was identified as a possibility for the design of the travel time effects and was modelled in the tool.

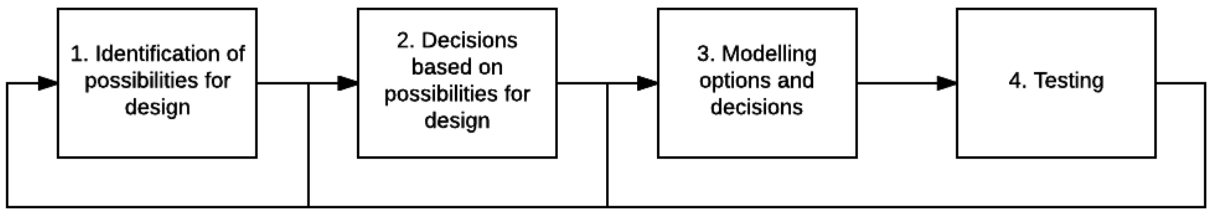


Figure 2.2: iterative design steps in this research (Based on Studio1Design, n.d.)

A drawback of the iterative design process is that the tool could not be fully improved during this research due to the available amount of time. The amount of time available in this research restricted the number of iterations for an optimal design. Therefore, recommendations for further research and recommendations for improvement of the real option tool were made.

The tool was modelled in a spreadsheet in Microsoft Excel, because adjustments in input and calculations could be made relatively easy by others than just the person that designed this tool. Comments and texts in the tool are in Dutch, because it was expected that this would lead to a higher added value of the tool in decision-making in the Netherlands. The internal structure of the tool is not described in this report, because this report focuses on the added value of the tool. But the main decisions in the design of the real option tool are described in detail in this report.

A case test was performed in this research. The outcomes of the tool with the input based on a real case were described. In this way, the behaviour of the tool becomes sufficiently clear for the purpose of this report. The extent to which practical application of the tool would be possible could be made clear. The tool could potentially also be used in other cases when the tool is able to assess a randomly chosen real case.

The assessment of the behaviour of this tool is important, because transparency for users might be low due to the complexity in calculations. Therefore, verification and validation was an important step in the design. The verification and validation of this tool was done by means of a black-box test and a sensitivity analysis. Black-box testing was used by changing the input in extreme values and by assessing the related output of the tool. This allowed for testing the tool on what it should do without having a look at the internal structure of the tool (Balci, 2003). Users will also be mainly interested in the input and output of the tool and not in its internal structure. This makes black-box testing valuable in this situation. Sensitivity analysis was performed, because assumptions were made on several topics in the tool, such as the assessment of the effects of road widening projects, the volatility, and the probability of scenarios. A low sensitivity on assumptions lead to a more robust tool (Balci, 2003). Both test also lead to conclusions on the applicability of the tool in practice, because when the tool scores well on both tests the tool does what is should do and represents reality.

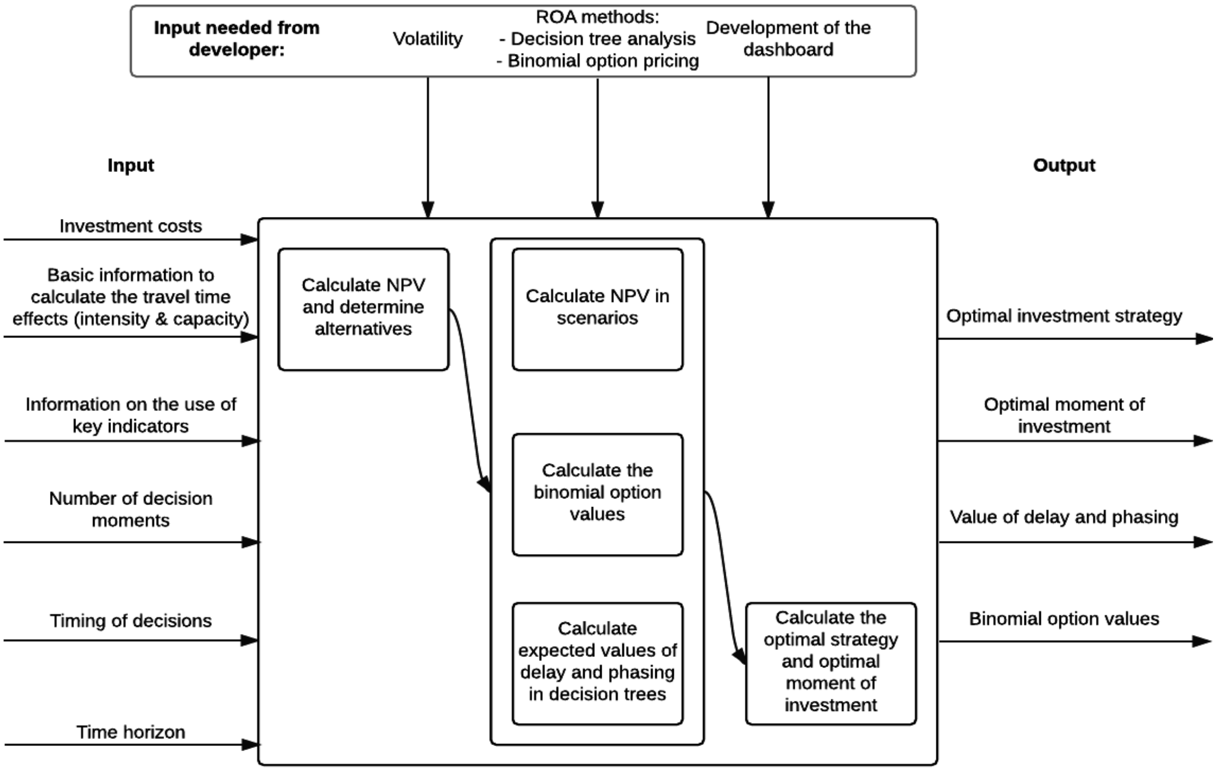


Figure 2.3: schematic visualisation of the real option tool

Figure 2.3 visualises a schematic overview of the real option tool. This Figure shows that basic input is needed from the user. The calculation of the NPV is based on key indicators that are known for many road infrastructure projects (Hoefsloot et al., 2014a). But, there are also some essential characteristics of a real option tool in which decisions were made that require further explanation on its methods.

- **ROA method**
  A decision on the use of a ROA method was made. All methods have specific characteristics and a qualitative evaluation of the ROA methods, based on ROA literature and an existing evaluation of methods, was used to make a decision on the incorporation of specific ROA

methods (Appendix II). Methods that were assessed in this qualitative evaluation are simplified decision trees, risk-adjusted decision trees, the Black-Scholes formula, binomial option pricing, dynamic programming, and Monte Carlo simulation (Van der Pol et al., 2016).

- **Volatility**
  Problematic is that the future is unknown and assumptions on the volatility in projects need to be made. The volatility is the representation of the uncertainty in binomial option pricing. The uncertainty around the actual cash flows is higher when the volatility is higher (Mun, 2002). Multiple methods for the assessment of the volatility exist, such as the use of historical values, regression analysis, and Monte Carlo simulation (Reitsma, 2010). Historical values were used in the assessment of the volatility, meaning that future volatility is based on the volatility in the past in this research. There is a large amount of data available within RWS on the intensities in road sections for motorways and some secondary roads of previous years (INWEVA) (Rijkswaterstaat, n.d.a). Assumptions on intensities of roads without available data were made by using data from roads in the same region, because intensities and expected traffic growth differ among regions (Rijkswaterstaat, n.d.a; CPB & PBL, 2015).
- **Dashboard**
  In the communication from the user with the tool, a dashboard was designed in the real option tool in which the most important input variables and the outcomes of the tool are shown. Dashboards from current tools in decision-making were used in the development of this dashboard (Appendix III).

2.3 Using the tool in practice

After the development of the tool, the current situation for decision makers in road widening projects was compared to the situation in which a tool is available to draw conclusions on the added value of the real option tool in decision-making. A drawback of doing interviews in answering part of the research question is that the added value is based on the perception of respondents and is not objectively measured.

First, respondents were selected for the interviews. All respondents were involved in decision-making in road widening projects to some extent, because the added value of the tool in decision-making had to be described. The criteria for the selection of respondents were fourfold. Meeting one of the four criteria is needed, and meeting all these criteria would have been best. Some of the respondents needed to have some expertise in the application of ROA. Others needed to have expertise in CBA. Thirdly, some respondents needed to have expertise in the use of tools and models in decision-making. Fourthly, some respondents needed to have expertise in transport or road widening projects. Respondents were also selected based on different roles in their relation to infrastructure projects and decision-making. Their expertise in ROA differed to make sure that multiple perspectives were included in the assessment of the tool.

For the assessment of the tool 7 potential users and experts from RWS, a consultant, TU Delft, and Centraal Planbureau (CPB) were selected for an interview on their opinion of the added value of this tool. In Table 2.2, the basic information of the selected respondents and their score on the criteria for selection is shown.

Table 2.2: selection of respondents and their score on the four criteria

Organisation	Job function	Most present expertise	Duration of the interview	
			hours &	minutes
CPB	Researcher	ROA/CBA	1	10
RWS	Senior advisor models and traffic forecasts	Models/transport	1	25
RWS	Senior advisor economy	CBA/ROA	1	25
RWS	Senior advisor economy	CBA/ROA	1	25
RWS	Senior advisor traffic and transport	Transport/road widening projects	1	5
Consultant	Director	ROA/tools/CBA	1	0
TU Delft	Researcher	CBA/transport	1	0

The selected respondents all met one or more of the identified criteria. However, not all respondents met all criteria in the selection of criteria. On the other hand, all criteria were represented by at least one of the respondents.

Qualitative interviews were held in this research (Yin, 2015). In the interviews, a fundamental framework of questions was made, but the verbalised questions differed among the interviews and the respondents' expertise or focus (Appendix X). All interviews were recorded and questions were prepared to improve the outcome of the interviews (Write, 2015). With this interview method, often two-way interactions evolved during the interviews. Face-to-face interviews were held, because the perception of the respondents was researched. Putting more questions is easier in face-to-face interviews and during these interviews the interviewer was able to present the tool in an interactive way (Opdenakker, 2006).

The interview protocol was the same for all respondents and consisted of three main phases (Appendix X). First, a short introduction on the topic was given and the respondents were asked on their role in the decision-making process, their expertise in using tools, and their knowledge of ROA. Secondly, a short presentation of ROA and the tool was given and the tool was presented to the respondents. The steps were held the same for each interview in the testing of the tool with experts to be able to draw conclusions on the usability of the tool by comparing the interviews (Jokela, Koiyumaa, Pirkola, Salminen, & Kantola, 2006). The limitation of this approach is that information may be lost, because the testing of the tool is limited (Jokela et al., 2006). Thirdly, the respondents were asked on their opinion of the tool, the strengths and weaknesses of the tool, and the potential use of this tool in practice. The topics that were assessed in the interviews were based on the seven requirements of the tool. The respondents were also asked to describe improvements for the tool. Reports on these interviews were made and sent to the respondents for their endorsement. The corrected reports are added to this report (Appendix XI).

The arguments of the respondents were analysed by structuring the insights from the interviews based on the requirements of design described in the first phase of research. A reflection on the outcomes of the interviews was made after the analysis of these interviews. This reflection was based on literature and on practical insights that were generated during the design of the tool. The perspectives of the different respondents were balanced in the reflection.

3. The requirements of design

In this chapter, the requirements of design are described. The research question that is the central focus in this section is: W*hat are the requirements of a real option tool for road widening projects?* The answer on this question is based on literature research on ROA, DSS, CBA of road widening projects, and decision-making in infrastructure projects. The requirements for the design focus on defining the problem: what should be developed and how should it be developed (Raventós, Garcia, Romero, Albelló & Viñas, 2015). For a tool to be of added value, it helps when there is transparency in the assumptions during design (Te Brömmelstroet & Schrijnen, 2010). The requirements help in the creation of this transparency.

Section 3.1 focuses on the needs from a user perspective. Section 3.2 describes the variables of the tool. These are the main choices that have to be made in the design of the tool. Section 3.3 provides insights into the constraints that limit the design of a tool. The needs and variables were combined in requirements and a hierarchical representation of the requirements in an objective tree is described in section 3.4. A conclusion and the answer on the research question are given in section 3.5.

3.1 Needs

Several needs for a tool in decision-making are elaborated in this section. Often, the development of tools for planning and the need for these tools is inconsistent (Te Brömmelstroet & Bertolini, 2009). The focus in this section is on the needs for potential users of a real option tool. Users are mostly concerned with what the tool can do and how it assists them in decision-making (Sprague, 1980). Six needs for tools are identified by Sprague (1980) and form the basis for further elaboration of the needs in this section: support in decision-making, support in decision-making for users at all levels in the organisation, support in all phases of the decision-making process, support in a variety of decision-making processes, and easiness in use. It should be noted that the sequence of description of the needs in this section is not based on importance of the requirements.

3.1.1 Support in decision-making

The tool is mainly developed for being of added value in the decision-making process in road widening projects and should therefore support decision-making in these projects (Sprague & Watson, 1976). Research on DSS shows that tools focus on improving the efficiency of decision-making and can improve the effectiveness of that decision (Shim et al., 2002). It is the problem-oriented interaction that ultimately determines the value of a tool (Dos Santos & Holsapple, 1989). The problem in road widening projects is usually congestion and an uncertain growth in intensity in the coming years.

In being supportive for the decision-making process, the tool should take several main aspects of decision-making and the use of tools in decision-making into account. One of these aspects is the application of the tool in the different phases of decision-making (Sprague, 1980). Each phase of decision-making has its own characteristics and therefore also the needs in different phases of decision-making potentially differ. For example, in a later phase of decision-making there is a need for tools on the evaluation of alternatives, or the analysis of trends (Te

Brömmelstroet & Bertolini, 2009). In the first phase of decision-making, there is a need for tools involved in scenario developments, story-telling, and the development of visions (Te Brömmelstroet & Bertolini, 2009).

The real type of decision should be represented in the tool to support in decision-making. A decision on a road widening project is in itself an unstructured decision, because of the complexity and the fact that multiple stakeholders are involved. Therefore, the emphasis in being supportive for decision-making should be on semi-structured and unstructured decisions (Sprague, 1980). The tool should be able to handle the wide range of problems that the user is interested in (Fu, 2002). For road widening projects, alternatives may be the construction of additional lanes, the construction of rush hour lanes, and the construction of 'shunting' lanes, a combination of acceleration lane and exit lane. The alternatives could differ in geographical location, as roads are divided in multiple road sections. Many road widening projects involve decisions on engineering constructions.

The use of a tool in the decision-making process is difficult, because the human behaviour is less predictable and regulated (Geertman, 2006). Therefore, an important aspect of decision support is that it allows for communication and coordination between decision makers across organisational levels (Sprague, 1980). In a real option tool that is used in decision-making, this may not only be across organisational levels, but also across different stakeholders: from experts within RWS to politicians. It is currently unclear how this can be done in a real option tool. It is assumed that a good user interface helps in the communication and coordination between decision makers. The tool must be readable for individuals in different levels of the organisation. Therefore, not only economic aspects, but also managerial aspects are important (Pervan & Arnott, 2005). Examples of managerial aspects are that the tool could visualise the optimal strategy or show how the objectives can be achieved (Prasad & Gulshan, 2001). Also, the tool must be able to satisfy the decision-making requirements of different types of managers (Sprague & Watson, 1976). It is important to understand the roles and perspectives of different stakeholders in the development of the tool: the user, the intermediary, and the builder (Sprague, 1980). In a real option tool, the user may be a person involved in or responsible for decision-making, e.g. a politician. The builder may be an external consultant that could also be, but not necessarily, the user of the tool. The intermediary may be RWS.

In the end, a tool can only be used by one person at a time within an organisation for a specific problem. Therefore, the tool should also be supportive for an individual decision maker. It is important that the tool generates support for the personal decision-making styles of individual managers (Sprague, 1980). Only calculating output in the tool does not always reflect the personal decision-making styles. Also, the quality of the computational capabilities in a tool does not always result in a tool that is of added value (Te Brömmelstroet, 2012). Therefore, the focus of the tool should be on giving insights instead of only calculating output. A broad range of mechanisms should be available to reflect the personal decision-making styles of users (Sprague & Watson, 1976). In a real option tool, this means that not only the value of flexibility should be given, but potentially also the decision trees or the optimal strategy and the comparison between standard calculation of the NPV and ROA should be given to the user.

Then, the user can use all system's capabilities to support the decision-making process (Sprague & Watson, 1976).

3.1.2 Transparency

For public decision-making processes, transparency is one of the most important needs (Ten Heuvelhof & Hobma, 2004). Therefore, a tool that stimulates in this process should be transparent for the user of the tool. Besides, transparency is also regarded as important by users of PSSs (Te Brömmelstroet & Bertolini, 2009). Low transparency of a tool is a bottleneck for the adoption of this tool (Vonk, Geertman, & Schot, 2005).

Fu (2002) proposes several measures to improve the transparency of the tool: shielding complications from the interface, providing graphical user interfaces, and using pull-down menus. However, Fu (2002) uses a very small definition of transparency (Halim & Seck, 2011). As the definition of transparency is unclear in DSS literature (Halim & Seck, 2011) and transparency in the decision-making process is most important, two types of transparency with a broader definition are identified.

Firstly, the tool should allow for transparency in its calculations and behaviour (Halim & Seck, 2011). This type of transparency is also referred to as observability (Elm et al., 2005). Observability is the ability to generate insights into a process: to see activities, contingencies, and patterns. Furthermore, the decision maker should be able to interact with all elements of the tool (Sprague & Watson, 1976). However, there is an important trade-off between the observability of this tool and the easiness in use. The application of ROA requires many relatively difficult calculations. This makes it uncertain whether the observability of this tool is high enough for a wide range of potential users.

Secondly, the use of data and information in the tool should be transparent. It should be clear where the data and information comes from and which data and information is used in the tool for which purposes. Therefore, the sources of information should be included in the tool. This leads to a higher directability of the tool: the ability to direct/redirect resources, activities, and priorities when situations change (Elm et al., 2005).

3.1.3 High usability

Another important need for users is that the tool is easy to use. The usability is important, because executive and operational sponsorship are critical success factors for information systems that support decision makers (Pervan & Arnott, 2005).

A poor quality of the user interface is one of the main reasons for not using a tool (Turban, 1990). A well designed user interface is important for managing a large number of different tasks in a tool (Kiviniemi & Fischer, 2005). The user interface can be divided into two aspects: the communication from the user to the system and the communication from the system to the user (Dos Santos & Holsapple, 1989). The communication from system to the user can be divided into two aspects again: helping the user communicate with the system via help and diagnostic facilities and presenting the output to the user (Dos Santos & Holsapple, 1989). For the communication from the system to the user, good dialog management is required. The dialog management is about the command language, the menu, the question/answer structure etc. (Le Blanc & Tawfik Jelassi, 1989). Therefore, a dashboard is of added value for the user. This dashboard fulfils most of the needs in the dialog management of the tool. It is known that what-if analysis as interpretation of possible distributions, sensitivity analysis and scenario analysis is of added value in tools (Falessi et al., 2013). Therefore, a sensitivity analysis needs to be included in the tool, so that the users are able to perform these analyses relatively easy.

Affecting communication from the user to the system and vice versa, there should be consistency in the internal commands and a high adaptability in the user interface results in a higher quality of the tool (Sankar et al., 1995). The support for users can be increased by using commands in the tool that correspond to their existing verbs and this improves the effectiveness of decision-making (Keen, 1980). Therefore, the tool is made in Dutch. For creating easiness in use, it is important to emphasise on quick response of the tool (Sprague, 1980; Fu, 2002).

3.1.4 Adaptability

In complex problems, such as the decision-making in road widening projects, there is uncertainty on how decisions and alternatives look like in the future. Future scenarios may be different, measures can be added or requirements in the economic assessment of road widening projects may differ. This uncertainty leads to the importance of designing an adaptable and flexible tool (Keen, 1980). In this way, the user is able to adapt the tool to its own needs. An adaptable tool improves the effectiveness of decision-making (Keen, 1980; Sprague, 1980). However, there seems to be a trade-off between the level of adaptability and the level of standardisation in a tool.

In order to be adaptable, the tool should take three issues into account. Firstly, there should be the ability to reorient the focus of the tool when there is a significant change (Elm et al., 2005). Changes in focus could be the alternatives or scenarios that are assessed in this tool. Secondly, there should be resilience in the tool: the ability to anticipate and adapt to surprises and errors (Elm et al., 2005). When errors or surprises occur in the use of the tool, it should be clear for the user what has to be done. A measure that increases the resilience of the tool is the availability of a back office or manual in the governance of the tool. Thirdly, the tool should be dynamic and up to date without major or frequent ad hoc revisions (Sprague & Watson, 1976). This does not necessarily mean that other projects than road widening projects should be able to include in this tool, but that the assessment of road widening projects is also sufficient over a longer time period. Changes in the assessment of road widening projects might be needed when electric vehicles or autonomous cars are used more often. This could affect the travel time benefits of road widenings.

An adaptable tool can be created by making a clear link between the user, the builder, and the system (Keen, 1980). It should be mentioned that in this case users do not differ much in expertise. All potential users have a background in economics or have expertise in decision-making in road widening projects, but their expertise in the application of ROA may differ. This limited difference in expertise among users makes the necessity for an adaptable tool lower in this research (Dos Santos & Holsapple, 1989). The tool can be designed without taking into account a complex diversity among respondents. This is beneficial, because in this way the standardisation of the tool can be increased. In this way, ROA can probably be applied in a relatively standardised way in road widening projects.

3.1.5 Use of data

The data and information that is used in the tool has an important effect on the added value of the tool. Project specific information is needed for calculations and the higher the quality of this information, the better the outcome of the tool. However, the quality of this data does not affect the added value of the tool itself, but this data should be assessed and used in the tool in a good way. Good data management is important. There must be a variety of logical data views, relational and hierarchical data handling functions, and a file management system that is able to use internal and external databases when needed (Le Blanc & Tawfik Jelassi, 1989). In this tool, the data on the intensities on road sections are used as an external database. Only the volatility is based on this data. Therefore, this external database will not be connected in this tool.

The tool should also be able to combine a variety of data sources (Sprague, 1980). For example, the capacity and the average road capacity is included in the tool. Both include a percentage of freight traffic. Intensity and capacity should be combined and therefore, the percentage of freight traffic should be equal in both cases. The user should also be able to change data sources, e.g. on the growth in intensity over the years quickly and easily (Sprague, 1980). The tool should also be able to handle unofficial data so that the user can experiment with the data (Sprague, 1980). For this reason, it is important that variables in the tool can be adjusted by the user without many limitations.

3.1.6 Documentation, training, and vendor information

Literature on DSS mentions that documentation of the tool, training for users, and information about the vendor is important is of added value for tools (Le Blanc & Tawfik Jelassi, 1989). Documentation and training should be detailed, complete, and easy to understand (Le Blanc & Tawfik Jelassi, 1989). This research does not focus on these aspects and are not explicitly considered in the development of this real option tool. But it needs to be borne in mind that the added value of the tool also depends on documentation, training, and vendor information when it comes to the description of the added value of the tool.

3.2 Variables

This section describes the six variables for the design of the tool. These variables are the main choices that have to be made for the design of a real option tool. With a change in the decisions on the variables, for example on alternatives, ROA method, or uncertainty, the tool will still be a real option tool, but the tool would be completely different. Within these main decisions on the variables for design more detailed decisions have to be made. These decisions are further described in chapter 4. The main variables for design are described next.

3.2.1 Uncertainty and scenario changes in road widening projects

The uncertainty in the assessment of costs and benefits of road widening projects is one of the most important characteristics in the application of ROA.

The travel time effects are usually the largest benefits in infrastructure projects (Appendix I). Therefore, uncertainty in travel time affects the outcome of a project to a large extent (Appendix I).

There is a wide range of options with respect to this uncertain factor. For instance, in a study from Zhao et al. (2004) a real option model was developed for highway system development that included three types of uncertainty: traffic demand, land price, and highway deterioration. The uncertainty that underlies the travel time effects most is the amount of traffic in the future (Appendix I). This uncertainty on the growth in intensity of the road in a real option tool is considered as most important. Much different uncertainties in the amount of traffic are underlying this uncertainty in travel time. The most important are the developments in the region, the economic welfare, and the construction of other roads (Romijn & Renes, 2013). Other uncertainties are the behaviour of individuals, affected by e.g. the popularity of cars, the oil price, and the price of cars. The uncertainty in intensity on roads is included in the tool by, depending on the ROA method, the volatility or the growth of traffic intensity in scenarios high and low.

3.2.2 Real options in road widening projects

When no flexibility in road widening projects can be included, the calculation of the NPV in CBA is a correct method (Mun, 2002). However, one can think of road widening projects as flexible in the context of strategic capital decision-making (Mun, 2002). One of the main strengths of ROA is that it recognises the ability of decision makers to create, execute, and abandon strategic and flexible decisions (Mun, 2002). There are multiple types of real options that increase the flexibility of projects: the option to switch, the option to grow or to expand, the option to accelerate or decelerate, the option to delay or defer (Van Rhee et al., 2008). For road widening projects, only a limited amount of options seem to be valuable. For example, changing the function of a road is not valuable, because the function of a road is very specific: transport.

Technically, phasing is possible in road widening projects (Schoof et al., 2013). It can be problematic to assess which section of the road should be widened first. The determination of the order of phasing should be included in the tool when it comes to the phasing of road widenings. Delay of the road widening is also possible (Schoof et al., 2013). Delay might be of added value for a project. Then, flexibility then has an added value compared to a go/no go decision.

Problematic in the delay and phasing of road widening projects is that multiple studies and processes are required during a longer period, such as the environmental impact report (MER). This increases the overall costs for projects when the project is phased (Schoof et al., 2013). This shows that there are also costs associated with delay and phasing. These costs are not included in the tool, because no key indicators on these effects are currently available. It is uncertain whether taking into account these costs associated with delay and phasing would affect the results of the application of ROA significantly.

3.2.3 Effects of road widening projects

Multiple effects of road widening projects can be included in a real option tool. Which effects should be included is a variable for design. The effects of road widening projects can be divided into costs, direct effects, indirect effects, and external effects (Eijgenraam et al., 2000b). Currently, all of these effects are assessed in CBA of road widening projects (Appendix I). Even though the real effects of road widenings on the economy and the environment are highly uncertain, these external and indirect effects are included in the design of the tool and therefore should be designed. In literature it is acknowledged that road widening projects have an effect on emissions (Van den Brink et al., 2005; Van Goeverden, 2009; Elhorst et al., 2004).

The costs of road widening projects are usually divided into implementation costs, operation costs and maintenance costs (Appendix I). The direct effects are usually divided into travel time savings, reliability benefits including benefits for robustness, and reductions in travel costs (Appendix I). In many road widening projects, static national and regional transport models are used for the assessment of the direct effects, such as the Netherlands regional modal (NRM) (Appendix I). In general, the benefits of the increase in reliability are equal to 25% of the travel time savings (Appendix I). The reduction in travel costs in road widening projects is based on a reduction in costs for passenger transport and freight transport (Appendix I). This reduction comes from a change in travel distance or speed for users, leading to lower costs for the user, such as fuel costs. This change is assumed to be limited in road widening projects, because the travel distance and speed will only change for new users, and will stay the same for current users. The indirect economic effects usually give rise to debate. Usually a bandwidth of 0-30 % of the benefits for car users is used (Appendix I). The benefits of excise duties for the government are based on the number vehicle kilometres.

The external effects consist of effects for third parties, not necessarily considered by the owner or operator. Most important indirect effects in road widening projects are: road safety, nuisance during construction, air quality, climate change, and noise (Appendix I).

3.2.4 Alternatives

In a road widening project, the main alternative is the construction of an additional lane. The alternative is a capacity-increasing alternative leading to a higher capacity of the road. In this sense, it does not matter whether the road widening is from 2x1 lanes to 2x2 or that another measure is used. In all situations the capacity on the road is increased. Also, a rush hour lane can be assessed in the tool. The effects of the development of a rush hour lane can be different from a normal lane, because there are different effects in e.g. traffic safety and traffic speed (Grontmij Nederland B.V., 2015).

Intensity-lowering alternatives are not included in the design of the tool, as these are not road widening measures. Only capacity increasing measures are considered, because this leads to a higher possibility of standardisation and it increases the transparency (Wortelboer-Van Donselaar & Rienstra, 2014). There should be mentioned that it would not be difficult to assess the effects of these measures in a real option tool that uses the intensity and capacity as main input.

3.2.5 Time horizon

A road widening project has an effect on the society for a longer period. Therefore, using an everlasting period in the assessment of the effects of road widenings would be appropriate (Devillers & De Swart, 2012). Because of the discount rate that is used in CBA, the effect of the project after 100 years hardly counts in the benefits. Therefore, in practice a time horizon of 100 years is used in infrastructure projects (Devillers & De Swart, 2012). This is also used as a maximum time horizon in this real option tool.

3.2.6 ROA method

It could be of added value to include multiple ROA methods in a real option tool, because this creates the ability to catalogue and maintain a wide range of models, supporting all levels of management (Sprague, 1980). On the other hand, it is currently uncertain whether including multiple real option methods in a real option tool is also of added value for the decision-making process. Therefore, different methods are included in this real option tool. The ROA methods that are considered for incorporation in the real option tool are based on a study from Van der Pol et al. (2016):

- simplified decision tree;
- Black-Scholes Formula;
- binomial option pricing;
- dynamic programming;
- Monte Carlo simulation.

It was decided to include the simplified decision trees and binomial option pricing in this tool. The advantages of the simplified decision tree is that it gives insights in the opportunities for including flexibility and that it can represent the problem geographically (Appendix II). Furthermore, this method is in agreement with current CBA: a fixed discount rate is used and the scenarios from CBA can be used (Appendix II). Multiple types of decision trees for the application of ROA exist (Van der Pol et al., 2016). In this research, the most extensive type of decision tree is chosen. The costs and benefits are determined for each scenario and a probability per scenario is assigned. In this way, the value of phasing and delay can be calculated. One of the disadvantages of the most extensive type of decision tree method is that it treats uncertainty in a rough way: the probabilities of scenarios are usually unknown and it is only possible to include a limited number of decision moments and scenarios (Appendix II). The extent to which this is a problem is further assessed in this research.

Another disadvantage of this method is that the optimal moment of investment cannot be described. This can be done in the binomial option pricing method (Appendix II). Therefore, this method is also included the design of the tool. The generality of this method is high and it uses relatively easy mathematical calculations (Appendix II). Disadvantages of this method are the communication of the method and its results, and the use of doubtful assumptions (Appendix II).

To limit the design tasks, the other ROA methods are not included in the tool. When an increase in the number of methods or a specific method is of added value for a real option tool this can be included in a later phase of the development of the real option tool.

3.3 Constraints

The main constraints for design are described in this section. Literature on DSS describes several constraints, but also ROA and decision-making in infrastructure projects as main characteristics of the tool results in constraints for design. The complete list of constraints is visualised in Table 3.1.

3.3.1 'Leidraad MKBA'

Calculations in the tool shall be in accordance with the 'Leidraad MKBA'. This document contains guidelines and was developed by Romijn & Renes (2013). It was commissioned by the Dutch government. The reasons for making and using this guide in the Netherlands were the recent problems with cost overruns in infrastructure projects in the Netherlands. This guide was set up to improve the quality of decision-making in infrastructure projects (Commissie Infrastructuurprojecten, 2004). Therefore, this guide shall be seen as a constraint for the real option tool and the assessment of the effects of road widenings. Some of these guidelines, such as the preference for using a fixed discount rate, should not be seen as a constraint, since its potential incompatibility with ROA methods. Besides, the discount rate can be adjusted in specific situations according to the guidelines (Romijn & Renes, 2013). One of the guidelines in the 'Leidraad MKBA' is that in the costs, the value added tax (VAT/BTW) is included (Appendix I). Normally a tax of 21% is used in current economic road widening evaluations (Appendix I). Besides, following the guidelines, the right price level for key indicators should be used. For this tool, this is the price level of 2015, as this is the most recent known price level in 2016.

3.3.2 Software and data

There are also constraints related to the use of software and data. It is paramount that the data is of high quality to guarantee output with an added value for decision-making (Raventós et al., 2015). Garbage in is garbage out. First of all, this is a responsibility for the user of the tool. But, the tool shall be able to process heterogeneity in data sources (Raventós et al., 2015). Therefore, it is important to use the right software for the tool. The software shall be able to process data with heterogeneity. Also, the software shall be compatible with the organisation's hardware and software strategy, memory needs, and data communication capabilities (Le Blanc & Tawfik Jelassi, 1989). Microsoft Excel meets these software constraints. Therefore, this tool is developed in Excel.

3.3.3 Use of the tool

The user interface is well described in the previous section focusing on the needs of users. There are also constraints in the tool on the practical use of the tool. Performing well on run time is of added value for a tool, but the tool shall also be able to be used within a reasonable amount of time (Halim & Seck, 2011). As this tool is not designed for one specific type of road widening project, the tool shall have a high degree of standardisation in the assessment of road widening projects. The tool shall be designed problem-structure independent (Halim & Seck, 2011).

Table 3.1: list of constraints

Constraints
Shall include VAT of 21% in costs
Shall include the right price level for key indicators for monetisation
Shall be able to process heterogeneous data
The software shall be consistent with the organisation's hardware & software strategy
The software shall be consistent with the organisation's memory needs
The software shall be consistent with the organisation's data communication capabilities
Shall be able to be used in a reasonable amount of time
Shall have a high degree of standardisation in assessing road widening projects

3.4 Requirements

In the development of a tool, constraints with respect to time and budget of the development should be met (Falessi et al., 2013). This may lead to the necessity of making trade-offs between several requirements during design. An objective tree could help in comparing conflicting requirements. Therefore, all variables and needs are integrated in an objective tree in which hierarchy in requirements is included and measures are added. When two requirements are conflicting, the objective tree can be used in making trade-offs. The requirements in the highest and lowest levels of the objective tree are visualised in Table 3.2 and the objective tree is shown in Appendix IV.

The requirements from Table 3.2 were also identified in the review of other tools that are potentially of added value in decision-making (Appendix III). Trade-offs between requirements were found in these tools. Although it was difficult to describe the potential added value of these tools and the requirements of these tools, the requirements could be identified relatively easy in these tools (Appendix III). 'MKBA Fiets' is a tool that uses standardised calculations and has a web-designed user interface (Appendix III). However, this tool is not very transparent in its design as key indicators and calculations are not visible in this tool. The 'TEEB-stad' tool is very transparent (Appendix III). A lot of explanation on the effects is visible in the tool and the equations are also visualised. On the other hand, the tool does not provide much guidance in use: much information is needed from the user. The 'MKBA-tool Sociale Wijkteams' could be used in different stages of decision-making in which different levels of information is available to the user (Appendix III). Key indicators can be used in the first phase of decision-making, but the tool can be used without key indicators when more information is available. One of the other tools, the DAS/BEST Cost/Benefit Analysis Tool, did not provide any guidance and could be used in very many projects. Some of the tools also contained instruction videos and detailed manuals. Besides, the needed expertise of users differed among the tools. Some of the tools required much expertise of the user. Other tools were relatively simple.

Table 3.2: list of requirements

High level requirements	Low level requirements
Good implementation of ROA	High feasibility of real options
	Good method of applying ROA
	Good representation of uncertain variables
Good assessment of road widening projects	Good representation of uncertain variables
	Good calculation of costs
	Good calculation of direct effects
	Good calculation of indirect economic effects
	Good calculation of external effects
	High feasibility of road widening alternatives
Good use of data	High ability to combine a variety of data sources
	High ability to handle unofficial data
	High ability to add and delete data
High adaptability	High ability to anticipate and adapt to surprises
	High ability to anticipate and adapt to errors
	High ability to reorient focus
	Being up to date without major revisions
	Being up to date without frequent revisions
High transparency	Many insights in activities
	Many insights in patterns
	Many insights in contingencies
	High transparency in use of data and information
Good user interface	Good internal commands
	Good dialog management
	Good help- and diagnostic facilities
	Good presentation of the output to the user
	Good analysis of outcomes
	Quick response
High support in decision-making	High amount of new insights
	High degree of standardisation
	High amount of mechanisms
	High communicability

3.5 Conclusion

The research question that was central in this section was: *What are the requirements of a real option tool in road widening projects?*

The requirements were divided in needs, variables, and constraints. These three aspects resulted in a list of high level requirements in the development of the objective tree:

- good implementation of ROA;
- good assessment of road widening projects;
- good use of data;
- high adaptability;
- high transparency;
- good user interface;
- high support in decision-making.

The main constraints for a real option tool in road widening projects are:

- consistency with the 'Leidraad MKBA': effects should include a VAT and the right price level;
- the software should process heterogeneity in data and results in a tool without conflicts;
- the tool should be able to be used in a standardised way and within a reasonable amount of time.

In this section, multiple tools that are currently available were analysed. The analysis of the tools shows that, in these tools, there seems to be a trade-off between the requirements for the design of tools. This increases the difficulty in the design of tools when decisions between the incorporation of requirements have to be made. Decisions on the design of a real option tool have to be made and is further described in the next chapter.

4. Design of the real option tool

This chapter describes the design of the real option tool. The research question that is central in this chapter is: *How do the requirements lead to a real option tool for road widening projects?* Section 4.1 describes the output and the sensitivity analysis. Section 4.2 elaborates on the calculations that are needed for creating the output. In section 4.3, the input is described. The result of these steps is the real option tool developed in this research. A case test and the interpretation of the results that are generated by the tool is given in section 4.4. Section 4.5 describes the verification and validation of the tool. After that, section 4.6 provides conclusions on the research question from this chapter.

All different sections of the tool are shown in Figure 4.1.

Figure 4.1: visible and invisible sections of the tool (respectively blue and grey)

4.1 Output of the tool

In the output section of the tool, the expected value of phasing and delay and the binomial value are presented. Also, the optimal investment strategy over time is given, because it is expected that this gives the user insights for decision-making. A sensitivity analysis allows the user to assess the sensitivity of the results of the tool. The output section of the tool is specifically important, because the communicative value of this output is paramount to be of added value in planning issues (Te Brömmelstroet & Bertolini, 2009).

4.1.1 Expected values and binomial option values

The value of delay and phasing is the main output of the tool. Two types of option values need to be described: the value of delay and the value of phasing.

The expected value of phasing or delay is calculated in the decision trees. This is the expected NPV that can be obtained when the widening is delayed or phased over time. This expected NPV is shown to the user in the tool in a number and in the decision trees. The user is able to compare the expected value of delay and phasing and the expected value of the current investment, because also the NPV of the alternatives from standard CBA are presented. Also, the expected value after each decision moment can be assessed by the user by a visualisation in a decision tree. Multiple decision trees were made to be able to assess situations with different numbers of decision moments. The decision trees are made based on the amount of decision moments and the year in which the decisions are taken, which should be filled in by the user. The user is only able to see one tree for phasing and one tree for delay in the dashboard based on the input.

The binomial option values should be presented to the user. This is done for each alternative specific: from the widening of only one section to the widening of all sections. In this way, the option value of delay is described. For each option to phase, the binomial option value is also presented.

An important characteristic of the decision trees is the layout, because this should allow the user to interpret the results easily. The trees are made in a spreadsheet in Excel and no other software is used for visualisations, because the decision trees consist of both visualisations and calculations. Perhaps other software could make the decision trees look better, but the interface between different types of software, that are able to apply either calculations or visualisations, would make the design too complex. As the trees consist of many results, it is decided to visualise the results and to give a colour indication to the results to simplify the interpretation of the results (Figure 4.2). A visualisation of the trees is given in Appendix VI and Appendix VII.

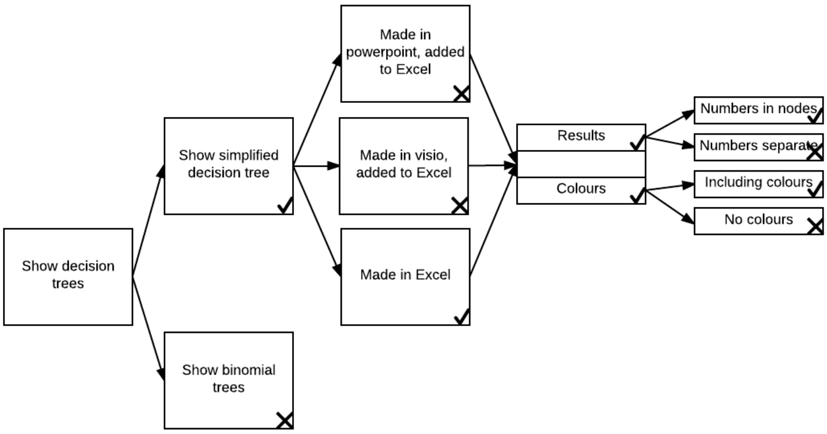


Figure 4.2: design decisions for the layout of the decision trees (the checkmarks show the options that were chosen; the crosses show the options that were dropped)

In the dashboard and the results, the binomial trees are not visualised, because it is expected that it would make the interpretation by users more difficult. The results from the binomial trees are shown in the optimal investment strategy and the binomial option values are presented in the dashboard.

4.1.2 Optimal investment strategy

Providing an optimal strategy will potentially help the user in analysing decisions. The optimal strategy is a strategy that consists of the optimal decisions and the optimal decision moment for both delay and phasing.

The optimal year of investment for each alternative or option to delay or phase is given, resulting from the binomial decision tree analysis. The optimal year of investment can be visualised in a number and in a timeline. There is decided to use a number per alternative and option (Figure 4.3).

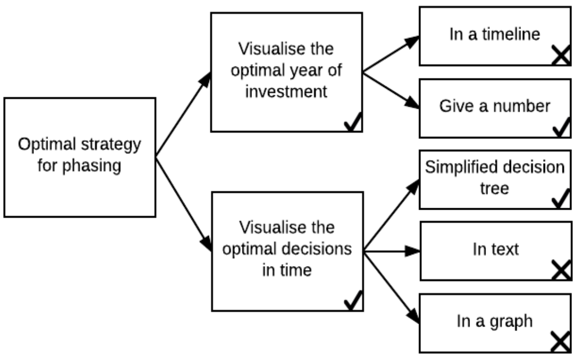


Figure 4.3: design decisions for the optimal investment strategy (the checkmarks show the options that were chosen; the crosses show the options that were dropped)

Alongside the optimal year of investment, the tool should be able to draw conclusions on which choice should be made in each decision node for each scenario. This is done in a simplified version of the decision tree in which just the alternatives with the highest expected values are shown in each decision node. Other options for design were text boxes and a graph in which, such as the costs and benefits were shown over the time. There was decided for the simplified decision tree, because the calculations in the tool are made in this format and the user will be accustomed to the use of decision trees instead of timelines in the tool.

4.1.3 Sensitivity analysis

In addition to the results of the binomial and simplified decision tree analysis, a sensitivity analysis could help in the interpretation of the results by the user. The sensitivity analysis assesses the effect of a small change in input variables on the outcome of the tool (Bots & Bouwmans, 2016). A change of +10% and -10% in the input variables is used (Bots & Bouwmans, 2016).

The sensitivity analysis is performed on five input variables and five output variables. As there are many input- and output variables in this tool, there is decided to model only most important variables (Figure 4.4). These variables are important, because they include many assumptions or have potentially a high effect on the outcomes. The probability of the high scenario, and therefore also the probability of the low scenario, is one of the uncertain variables. The key indicators, the growth in traffic, the additional traffic due to a road widening and the capacity of the lanes are also uncertain input variables. These input variables are mainly reflected in the cash flow, what results in the decision to use the cash flow per year as input variable in the sensitivity analysis. This also covers the uncertainty in the NPVs. The discount rate and the time horizon are included in the sensitivity analysis, because these input variables are intensively used in both ROA methods. The input that is needed from the users in the dashboard is not included in the sensitivity analysis, such as the amount and timing of the decision moments, because the effects of changes in these input variables can easily be assessed in the dashboard of the tool.

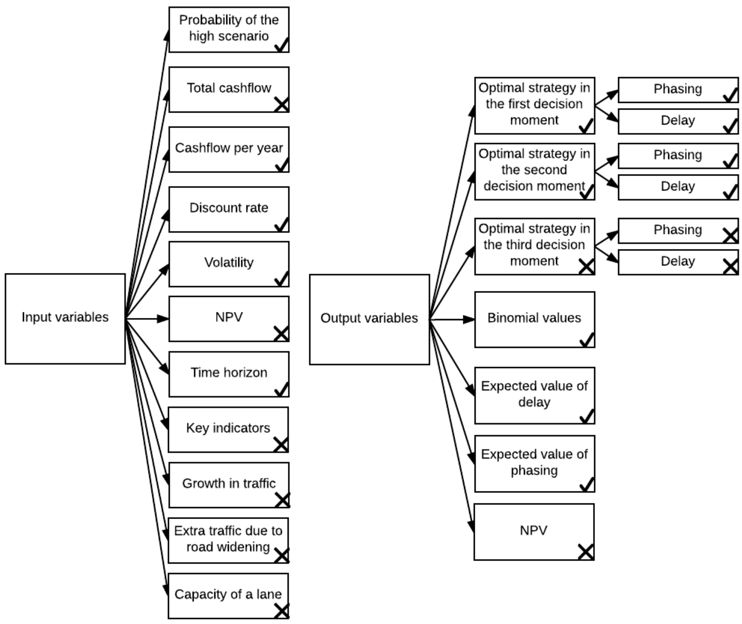


Figure 4.4: design decisions for the input and output variables implemented in the sensitivity analysis (the checkmarks show the options that were chosen; the crosses show the options that were dropped)

The output variables that are assessed in the sensitivity analysis are all important results in the dashboard section except for the optimal strategy. Only the optimal strategies in the first and second decision moments are included in the sensitivity analysis.

The tool gives a report on the sensitivity which is visible for the users. A visualisation of the results in a bar chart with the percentage change in output is used. In this way, the sensitivity of one input variable on multiple output variables can be shown easily. Other options were the visualisation of the sensitivity in a line chart in which the sensitivity of multiple input variables on one output variable can be shown. A third option was visualising the percentage change in a table. It is assumed that the first option will lead to the best and most easy interpretation of the results.

4.2 Calculations

The calculations are the connection between the input of the tool and the results of the tool. The tool consists of four types of analysis and calculations:

1. Calculate the NPV.
2. Calculate the simplified decision tree.
3. Calculate the binomial decision tree.
4. Apply the sensitivity analysis.

For these calculations and analyses, multiple design decisions were made. This section elaborates on these decisions. First, the yearly cash flow and the NPV should be calculated for each road section in the project situation. Secondly, the simplified decision trees is implemented and analysed to retrieve the expected value of phasing and delay and the optimal investment strategy. Also the allocation of the road sections among the different alternatives should be made. This influences the order of phasing. Thirdly, the binomial decision trees are implemented, and the binomial option values and the optimal moments of investment are calculated. Fourthly, the sensitivity analysis is applied.

4.2.1 NPV

There are three reasons for the calculation of the NPV in the tool. The binomial values are calculated based on the annual benefits of alternatives (Reitsma, 2010). Also in the decision tree method, this NPV is the basis for the calculation of the expected value. Thirdly, the effects of phasing and delay can be compared to current analysis in CBA. To give a good indication of the NPV and the cash flow, some assumptions were made and many key indicators were used. The assessment of the NPV in this tool is not a replacement of the often required CBA, because more research on the specific project is then necessary. Since often the CBA is not available in an early stage of decision-making, the NPV is assessed in this tool.

The alternatives that are assessed in the tool should be chosen to calculate the NPVs of these alternatives. In the tool, a road is split into four different sections, each representing one alternative. It is expected that in this way a wide range of projects can be assessed in the tool. Also when only three road sections are needed, the tool will be able to assess the NPVs of the other three sections. It is maybe problematic when five or more different road sections are questioned in the tool. Because ROA is very much dependent on the allocation of the alternatives in the calculation of the NPV and the change in cash flow over the year in this tool, there was decided to not allow the user to change this NPV or change the cash flow based on results from CBA. The tool potentially still gives a good indication of the value of phasing and delay when the analyses of the NPV in the tool and in CBA are inconsistent.

The assessment of the NPV consists of four effects of road widening projects: the costs of the project, the direct effects, the indirect effects, and the external effects and can be calculated with equation 1 (Appendix I).

$$NPV = \sum_{t=0}^{n=100} \frac{(Benefits - Costs)_t}{(1+D)^t} \tag{1}$$

In equation 1, n stands for the time horizon of the project and t stands for the year. D is the discount rate. The focus in the remaining part of this section is on the identification of the costs and benefits of the alternatives.

4.2.1.1 Costs

There are three types of costs assessed in the tool: implementation costs, operation costs, and maintenance costs (Figure 4.5). The implementation costs of a road widening are most specific to the project. Therefore, an estimate of the implementation costs is assumed to be known by the user. Besides, no key indicators for the implementation costs were found in literature. For the operation- and maintenance costs of road widening projects, a percentage of the implementation costs is often used. The operation- and maintenance costs of infrastructure projects are 1.5% of the implementation costs per year (Wageningen UR & MU Consult, 2013). The user is able to increase or decrease this percentage in the tool to allow for changes when more information is available. The operation- and maintenance costs are higher when a peak hour lane is used as alternative, because the lanes must be monitored with cameras and measurement systems (Rijkswaterstaat, 2016a). For rush hour lanes, 2% of the implementation costs per year for the operation- and maintenance costs is used. The overhead costs are not implemented in the tool, because this type of costs will be of little effect compared to the other costs.

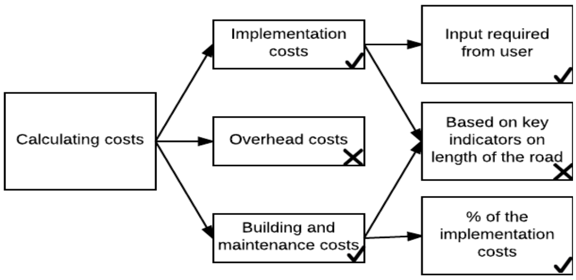


Figure 4.5: design decisions for the costs of alternatives (the checkmarks show the options that were chosen; the crosses show the options that were dropped)

4.2.1.2 Direct effects

There are four types of direct effects assessed: travel time effects, reliability effect, travel costs, and excise duties (Figure 4.6).

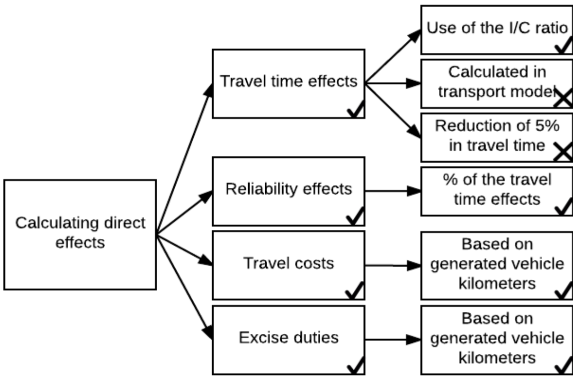


Figure 4.6: design decisions for the costs of the direct effects (the checkmarks show the options that were chosen; the crosses show the options that were dropped)

The travel time effects in CBA are usually assessed in NRM. This transport model usually provides good estimates of the travel time effects. However, the use of a transport model is time-consuming. Besides, NRM is not doing well in the calculation of the effects of many different scenarios which is needed in decision tree analysis. In the decision tree for phasing with three decision moments, already 257 outcomes have to be calculated. NRM is currently a static model in which an equilibrium is used (Van der Hoeven & Nijhout, 2013). There is a need for more dynamic models, because the situation differs in time. ROA is more in line with dynamic models, because the dynamic growth in traffic is important to determine whether phasing or delay is profitable.

For all these practical and theoretical reasons, an alternative had to be found for the assessment of travel time effects in this tool. Road widenings between 2008 and 2010 in the Netherlands resulted in a decrease in total travel time of 5% (Kennisinstituut voor Mobiliteitsbeleid, 2012). However, using this percentage does not make any sense in a situation with no congestion. A road widening does not necessarily result in 5 percent travel time reduction, e.g. in a situation when the intensity of the road is one car per hour. Furthermore, this percentage does not represent a difference in travel time effects between additional lanes and additional rush hour lanes. The method that was chosen to use for the calculation of the travel time effects in the tool is the ratio between the intensity on the road and the capacity of the road (I/C ratio) (Figure 4.6; Figure 4.7). Congestion arises on the road when this ratio is above 0.8 (Henkens & Tamminga, 2015).

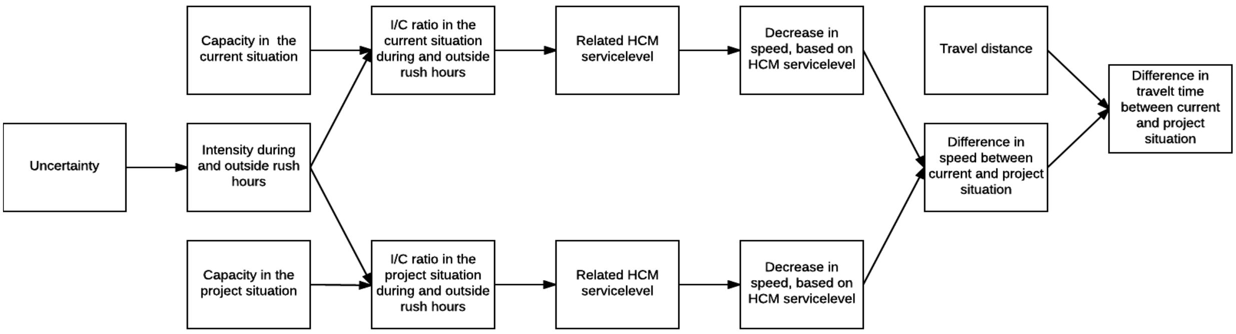


Figure 4.7: approach in the calculation of the direct effects in the tool

The uncertainty that is reflected in the two scenarios has an impact on the amount of cars on the road in a specific timeslot: the intensity, which is equal in the current situation and the project situation. Rush hours and the rest of the day are separately modelled in the tool, because there is a difference in I/C ratio between both. It is assumed that 15% of the total intensity consists of heavy goods vehicles, because this is the average in the Netherlands (Tromp, 1997). The capacity differs in the project situation compared to the current situation. Based on the intensity in each year in rush hours and other hours, the I/C ratio in each year for both rush hours and other hours can be determined in both the current and the project situation. Then, the lost hours of travel should be calculated, wherefore the average speed in the current and project situation should be calculated. The average speed decreases when the intensity increases. This can be calculated based on the Highway Capacity Manual (HCM) service levels, because a relation between the I/C ratio and the HCM service levels is given (Henkens & Tamminga, 2015). The HCM service levels are formulated by the Transportation Research Board (2000) and each of the service levels corresponds to an average speed. The relation between I/C ratio and average speed is assumed to be linear in the tool between the values given in Table 4.1. The difference in total travel time is the total benefit for the project alternative. This approach can easily handle the little effect of a road widening when there is not a problem in congestion. On the other hand, this method involves many assumptions in the calculation of the direct effect.

Table 4.1: relation between the I/C ratio, the HCM service level, and the average speed (Source: Transportation Research Board, 2000)

I/C ratio	HCM service level	Average speed (km/h)
0.8-1.0	E & F	64.4
1.0	E & F	48.3

The monetised value of the travel time effects is calculated based on key indicators that are often used (Table 4.2). All key indicators used in this section are in the price level of 2015 and include taxes (CPB, 2015). A percentage of 25% of the total travel time effects is used for the effects on the reliability (Romijn & Renes, 2013; Appendix I).

The amount of generated vehicle kilometres affects the direct effects of the project. The amount of generated vehicle kilometres generated is a controversial effect in road widening projects (Kennisinstituut voor Mobiliteitsbeleid, 2014). The road already exists and it is therefore uncertain what the effect of a road widening on the vehicle kilometres is. On the other hand, a wider road could lead to:

- a modal shift from train to car as the trip by car becomes shorter and more reliable compared to the trip by train;
- more travelling as the travel distance is higher in the project alternative in the same amount of travel time (Kennisinstituut voor Mobiliteitsbeleid, 2014).

The travel time effects increase when the number of users of the road increases. The rule of half is applied to the new users of the road in the tool. They are given the half of the benefits of the current users (Romijn & Renes, 2013). The amount of excise duties increases and the total travel costs decreases due to an increase in the vehicle kilometres. These values are monetised based on key indicators (Table 4.2).

Table 4.2: key indicators for the direct effects (Price level (2015) is calculated based on CBS, 2016)

Effects	Cars	Freight
Travel time effects (€/person/hour) (Kennisinstituut voor Mobiliteitsbeleid, 2013)	€9.35	€ 49.33
Excise duties (€/km) (Hoefsloot et al., 2014a)	€0.078	€0.236
Travel costs (€/km) (Ministerie van Infrastructuur en Milieu, 2010)	€0.042	€0.125

4.2.1.3 Indirect effects

In the guidelines for creating CBAs of road infrastructure projects, the indirect effects must be in a bandwidth from 0 to 30% from the effects for cars (Romijn & Renes, 2013). It seems to be logic to set 15% as default, because this is often done in CBA of road widening projects (Appendix I). This percentage was made adjustable to allow for change if more information is available for the user.

4.2.1.4 External effects

The external effects consist of several effects that do not affect the users of the road directly. Much information on the external effects usually comes from the environmental impact assessment (Appendix I). Based on this information, the effects can be quantified and monetised in the calculation of the NPV. However, it was decided to calculate the effects based on generated vehicle kilometres and key indicators, because this information is probably not available when the tool is used (Figure 4.8).

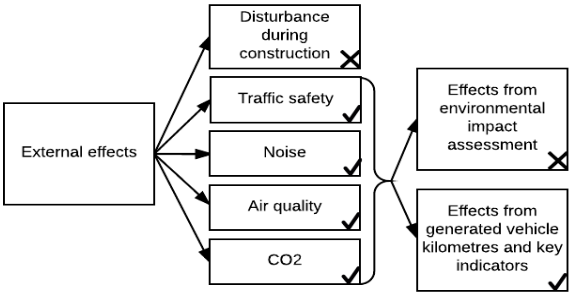


Figure 4.8: design decisions for the external effects (the checkmarks show the options that were chosen; the crosses show the options that were dropped)

In the generated vehicle kilometres, it is expected that a road widening will not lead to significant disturbance during construction. The roads usually remain open or are closed for only a limited amount of time, not leading to significant effects.

In reality, the development of the external effects over years is subject to uncertainty (Schroten, Van Essen, Aarnink, Verhoef, & Knockaert, 2014). Vehicles can become more fuel efficient or electric vehicles may be adopted. However, the effects on traffic safety, noise, air quality, and CO_2 can also be calculated based on the generated vehicle kilometres (Appendix I). A disadvantage of this approach is that the uncertain development of the external effects is not included, which are expected to decrease per vehicle in the future (Schroten et al., 2014). The external effects are often calculated based on the generated vehicle kilometres (Appendix I).

Compared to a location outside the urban area, a project that is located inside the urban area the effect of CO_2, air quality, and traffic safety is larger. For noise, the main difference in the effect is differentiated in primary roads and secondary roads. Especially the effect of freight transport on noise on secondary roads is larger than the effects on primary roads. One of the reasons is the short distance to residential areas. The key indicators in euro per kilometre differ on the location and the type of road inside or outside urban areas and on primary or secondary roads.

The key indicators that are used for the calculation of external effects in the tool are shown in Table 4.3.

Table 4.3: key indicators for external effects (Price level (2015) is calculated based on CBS, 2016) (Sources: Hoefsloot et al., 2014a; Hilbers, Van Meerkerk, Verrips, Weijschede-Van der Straaten, Zwaneveld, 2015)

Vehicle km	Effect	€/km in urban areas / on primary roads	€/km outside urban areas / on secondary roads
Car	CO_2	€ 0.00707	€ 0.00477
	Air quality (PM10, VOC, NO_x, SO_2)	€ 0.00582	€ 0.00312
	Traffic safety	€0.15	€0.017
	Noise	€ 0.00122	€ 0.01159
Freight	CO_2	€ 0.01723	€ 0.01184
	Air quality (PM10, VOC, NO_x, SO_2)	€ 0.05749	€ 0.02516
	Traffic safety	€0.239	€0.049
	Noise	€ 0.00724	€ 0.14818

4.2.2 Decision tree analysis

The decision tree analysis consists of two steps: the design of the decision tree and the calculation of the expected values (Figure 4.9).

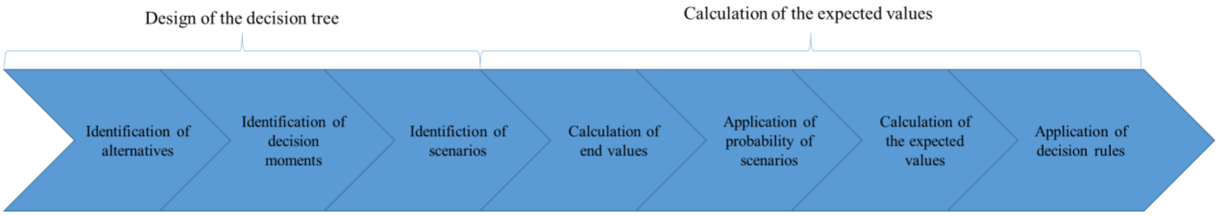


Figure 4.9: steps in decision tree analysis

For the design of the decision tree, alternatives for phasing and options were selected. As described above, it was decided to split the road into four different sections. The sections can be constructed in phases: from the construction of one section to the construction of all section. Besides, there is an option to do nothing than current policy: the reference alternative. Together this leads to 5 alternatives for phasing:

- reference alternative (no construction of additional lanes);
- construction of section 1;
- construction of section 1+2;
- construction of section 1+2+3;
- construction of section 1+2+3+4.

Two types of decision trees were made: one for phased construction and one for delayed construction. The design of the decision trees consists of three steps:

1. Identification of alternatives for phasing.

2. Identification of decision moments.

3. Identification of scenarios.

In the decision trees for phased construction, it was decided to only allow for a phased construction from not expanding to the construction of section 1 to the construction of section 1 and 2 to the construction of section 1, 2 and 3. In each phase, an additional section of the road is widened. Therefore, the alternatives need to be ordered in some way in the tool. There should be determined which section is number one, which section is number two and so on. The ordering should take place based on an indicator. There are multiple possibilities: total costs, total benefits, NPV, geographical location, or political preference. It had been decided to order the alternatives based on the NPV of the section, because this is the most rational and comprehensive indicator of all.

In the decision trees for delayed construction, it was decided to only assess the delay of the complete construction and not of each alternative separate, because the added value over a larger time period, compared to the decision trees for phasing, can be described in this way. More decision moments can be included due to a simpler design of the trees.

The number of decision moments for delay can be adjusted by the user, but there is a maximum of five decision moments. The complexity of calculations increases and there is a more difficult interpretation of visualisations when the number of decision moments increases. Therefore, two decision moments are used as default setting. The number of decision moments for phasing is more limited. There is a maximum of three decision moments. This is mainly due to the fact that the design of the decision tree for phased construction is much more complex, because more alternatives need to be assessed. If a too complex decision tree would be used, it is expected that this leads to a lower usability of the tool. Alongside the number of decision moments, the user should be able to adjust the year in which a decision can be made. The default settings are year 0, 10, 30, 40 & 50 for the five decision moments.

The third step is the inclusion of the uncertainty in the decision trees. Relevant scenarios were identified. The uncertainty affects the intensity on the road as already described above (Figure 4.7). The effect on the intensity of the road can be calculated based on the exploration of the future of mobility by CPB & PBL (2015). In this report, the growth in vehicle kilometres in two scenarios in three different regions is explored. For this tool, it is assumed that the growth in vehicle kilometres and intensity is equal. The three different regions are Randstad, intermediary zone, and other. Each of the 12 provinces belongs to one of these three regions (CPB & PBL, 2015). It is assumed that the growth is linear to 2050 and after 2050 (Table 4.4). This is different from current practice, but is done since prognoses of growth after 2050 are unavailable.

Table 4.4: scenarios and growth in intensity (Source: CPB & PBL, 2015)

Scenario	High			Low		
	Randstad	**Intermediary zone**	**Other**	**Randstad**	**Intermediary zone**	**Other**
Growth till 2050 (%)	57	44	42	26	19	15
Growth per year (%)	1.13	0.92	0.88	0.58	0.44	0.35

Scenarios high and low are used in the decision tree analysis in the tool, because the growths in intensity in these scenarios are known. Therefore, after each year and after each time period, the yearly cash flow can be calculated in both scenarios. Potentially, after each decision node the scenario can change from high to low. As a result, many combinations of scenarios are possible and are included in the tool. Another opportunity could have been the use of the older general economies (GE) and regional communities (RC) scenarios. Both scenarios high and low represent calm changes in the future and are therefore more realistic than the older GE and RC scenarios. Also, more specific uncertainty could have been included as scenarios in the decision trees, such as the opening of a store, a university or a residential area. These events are now included in the scenarios high and low and not separately included as one of the leaves in the decision tree, because these scenarios are difficult to standardise.

The next step in design is the calculation of the NPV in each scenario and at each decision node. The calculations in the decision trees consist of four steps:

1. Calculate end values.

2. Apply probability of the scenarios.

3. Calculate the expected value.

4. Apply decision rules.

First, the values at the end of the decision trees should be calculated. This can be done based on the cash flow and the discounted implementation costs in each year. The implementation costs should be discounted, because the value of money decreases and effects on a long term are of less value then the effects on a short term. The intensity in all combinations of scenarios can be calculated based on the timing and number of decision moments. When the intensity follows scenario high from decision moment one, the intensity can follow scenario low from the second scenario to the third decision moment and so on. The growth in the intensity of the road can be calculated for each alternative. The approach from Figure 4.7 creates the ability to calculate the different scenarios at each end of the decision tree for all possible scenarios over time relatively easy in this tool. With three decision moments, there are nine different combinations of scenarios for which the growth in intensity should be calculated.

Secondly, the probability that a certain scenario occurs is needed to calculate the expected value. Information on the probability that a scenario occurs is unknown. Therefore, it was decided to use a default setting of an equal distribution among the probability of scenarios high and low. This number can be adjusted in the tool when more information on the probability is available for the user.

Thirdly, the expected value should be calculated for each alternative for each scenario. The expected values in the decision tree analysis can be calculated by calculating the expected value in each node from right to left. Equation 2 describes how the expected value is calculated. The expected value in a node $E(V_t)$ is the sum of the value of the previous nodes V_{t-1} times the probability of the scenario P.

$$E(V_t) = \sum V_{t-1}P \quad (2)$$

Fourthly, decision rules should be applied for the calculation of the expected value for each decision node. The decision rule that is used is that a decision maker will always choose the option with the highest expected NPV. This decision rule holds for each decision moment. A decision maker will always choose the outcome with the highest expected benefits (Equation 3).

$$E(V_t) = MAX(V_{t-1}) \quad (3)$$

4.2.3 Binomial option pricing

The binomial option values can be calculated using binomial option pricing. This method consists of two steps: the calculation of the input for the analysis and the determination of the binomial option value (Figure 4.10).

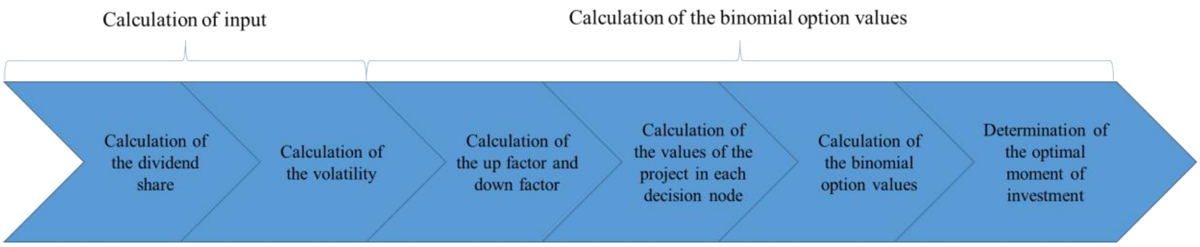


Figure 4.10: steps in binomial option pricing

The first two steps identify most important input for the application of the binomial option trees:

1. Calculate the dividend share.

2. Calculate the volatility.

First, the dividend share should be calculated. This is the current value of the project. This value of the underlying asset is equal to the annual benefits of the project in road widening projects (Reitsma, 2010). One benefit of the binomial decision trees compared to the simplified decision tree method is that the NPV does not have to be calculated for each scenario specific. To get a complete overview of the road widening project and its options, there was decided to use alternatives in a combination of delay and phasing in the determination of the binomial option value. The construction of the full additional lane can be delayed over time. Also, the project can be phased: from the development from least comprehensive alternative to most comprehensive alternative over time. This order of phasing is also based on the economical most optimal alternatives as already described in section 4.2.2. A fixed number of 25 time steps is used based on a minimum time step of 4 years and a time horizon of 100 years, because this potentially increases the transparency in calculations. This can be adjusted by a change in the time horizon when a larger time step is desired by the user.

Secondly, the volatility of the main uncertain factor needs to be assessed. This main uncertain factor is the intensity of traffic in road widening projects. A Geometric Brownian Motion is used in the assessment of the volatility with a specific drift and a variance. This means that the uncertain factor follows the Geometric Brownian Motion, resulting in a more easy calculation of the volatility in the tool. A problem of the Geometric Brownian Motion is that a constant volatility is assumed which is not completely realistic in reality (Ollila, 2000).

The fact that the growth differs in different regions is used to calculate the volatility. The volatility is unknown for many road sections. Therefore, the volatility was calculated for the regions that RWS uses. In this way, the tool is able to calculate the binomial option value for every road in the Netherlands even when no information in the traffic intensity over a certain period of time of the road is available. RWS uses six regions. Traffic intensities from INWEVA from 1986 to 2015 were used (Rijkswaterstaat, n.d.a). For each road in which the intensity was known in multiple years, the volatility was determined. The instantaneous standard deviation of historic changes in asset value was used to determine the volatility (Ollila, 2000). Equation 4 determines the volatility of one road section σ_j.

$$\sigma_j = \frac{\sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}}{\bar{x}} \tag{4}$$

In equation 4, x_i is the traffic intensity in a specific year in one of the six regions and $\bar{x}$ is the average of the traffic intensities in all years of a specific road section. In this way, the volatility was determined in each of the sections of which information was available. After this, the average volatility in each of the six regions was determined. n is the total number of years of which the intensity of a road was known. This differed among the different road sections, because some intensities of road sections were missing in the data and it was sometimes unknown which section from a specific year corresponded to the same section from another year.

The diversification of the volatility in different regions seems to be fine. The growth rate in traffic from 2012 to 2015 differs substantively between these regions (Table 4.5). Only 'WNN' and 'ON' show an almost similar growth rate. There is no geographical explanation for these similar growths.

Table 4.5: growth in traffic intensity in the 6 regions used by RWS of known road sections (Source: Rijkswaterstaat, n.d.a)

Region	WNN (north of west NL)	WNZ (south of west NL)	MN (middle of NL)	ZN (south NL)	ON (east NL)	NN (north NL)
Total traffic in a number of specific road sections in 2012 (in m vehicles/year)	20.2	24.1	13.6	26.1	18.0	8.5
Total traffic in a number of specific road sections in 2015 (in m vehicles/year)	20.5	24.7	14.5	27.4	18.3	8.5
Growth (%)	1.41	2.68	6.79	4.86	1.79	0.37
Volatility (%)	0.44	0.39	0.31	0.63	0.47	0.35

After the calculation of the input that is needed for the application of binomial option pricing, the binomial option values should be calculated. There are several steps in the calculation of this binomial option values:

1. Calculate the up factor and down factor.

2. Calculate the values of the project in each decision node.

3. Calculate the binomial option values.

4. Determine the optimal moment of investment.

Firstly, for each decision node, the uncertainty in the value of a project is calculated with the up factor and the down factor. Both can be calculated by using the risk free rate rf and the time step t. The up factor u and down factor d are determined with equation 5, 6, and 7.

$$u = e^{\sigma\sqrt{t}} \tag{5}$$

$$d = e^{-\sigma\sqrt{t}} = \frac{1}{u} \tag{6}$$

Conditional on

$$u > (1 + rf) > d \tag{7}$$

Secondly, the value of the project in each decision node is calculated. The down factor and up factor are used to calculate the value of the project in each node of the binomial decision trees. The value of the project in each node is V_t and is calculated by two different equations: for an up node (equation 8) and for a down node (equation 9) at a specific time step t.

$$V_t = V_{t-1} \cdot u \tag{8}$$

$$V_t = V_{t-1} \cdot d \tag{9}$$

V_{t-1} represents the value of the project in the first decision moment. This is the dividend share, in this tool equal to the annual benefits of the project as already explained above. The result of this step is a value tree which takes into account the uncertainty of future cash flows. This value tree does not include the flexibility to adapt plans to these uncertain future cash flows (Reitsma, 2010). This is done by the determination of the option value which is described next.

Thirdly, the binomial option values should be calculated. Multiple methods for the determination of the option value exist (Figure 4.11). One of these methods is chosen in the design of this

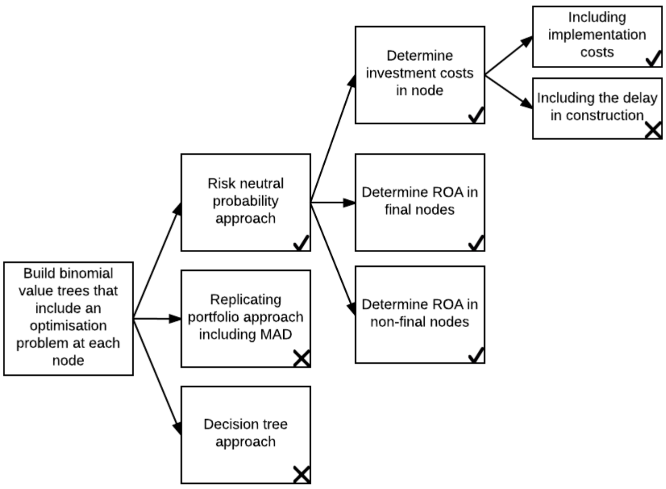


Figure 4.11: design decisions for the calculation of the binomial option value (the checkmarks show the options that were chosen; the crosses show the options that were dropped)

tool: the risk neutral probability approach. There are three steps in the calculation of the binomial option values: the determination of the investment costs, the calculation of the option value in the end notes, and the calculation of the option value in every other decision node (Figure 4.11).

The risk neutral probability approach is one of the most transparent ways of calculating the binomial option values (Cox, Ross, & Rubinstein, 1979). An assumption in this approach is that the portfolio of the underlying assets and options can be constructed such that it is riskless (Reitsma, 2010). Future values are therefore discounted against the discount rate. The risk free rate is usually used in binomial option pricing. It is however problematic that in infrastructure projects, the risk free rate is currently set at zero, because the interest rate is currently extremely low (Steunpunt Economische Expertise, 2016). A risk premium is added which results in the discount rate. As the risk that is involved in investments in infrastructure projects should be taken into account in binomial option pricing, the discount rate D of 3.5% is used in this tool instead of the risk free rate. It would not make much sense to use the risk free rate for the calculation of the binomial option value. This would mean that the rate of return on all public investments is zero.

- First, the investment costs should be calculated. The investments costs are discounted and are represented by I. The investment costs are assumed to be stable over time. The time for building, leading to a delay in benefits, is not included in the tool, because it is assumed that a road widening projects will not take much longer than one or two years (Rijkswaterstaat, n.d.b; Infrasite, n.d.). It is likely that including a short building time will not lead to different outcomes.
- Secondly, the binomial option value ROA_t in the end notes of the binomial decision tees should be calculated by applying equation 10. In these end notes, there is not a chance of going to another upstate or downstate.

$$ROA_t = MAX(V_t, V_{t-1}) \tag{10}$$

- Equation 10 is not sufficient for the determination of the option value in every other period. A probability of going to another upstate or downstate should be included. Furthermore, the investment costs of executing the project should be included. Therefore, the option value ROA_t in every other node is calculated with equation 11. CF_t represents the cash flow when the option is not exercised.

$$ROA_t = MAX\left(\frac{ROA_{u,t-1}p + ROA_{d,t-1}(1-p)}{1+D} + CF_t, V_t - I\right) \tag{11}$$

- In equation 11, p represents the risk neutral probability of being in an upstate the next period. That makes that logically $p - 1$ is the risk neutral probability of being in a downstate the next period. This probability should be calculated, based on the risk free rate, the down factor, and the up factor, with equation 12.

$$p = \frac{(1+D) - d}{u - d} \tag{12}$$

The value of flexibility is given by the binomial option value in the first decision node after all calculations are made.

Fourthly, the optimal moment of investment can be determined. How this optimal moment of investment stands out from the binomial option trees is visualised in Figure 4.12. An investment should be made when the binomial option value of a project is higher than the costs that are related to the project in this decision node. This included the costs of operation and maintenance.

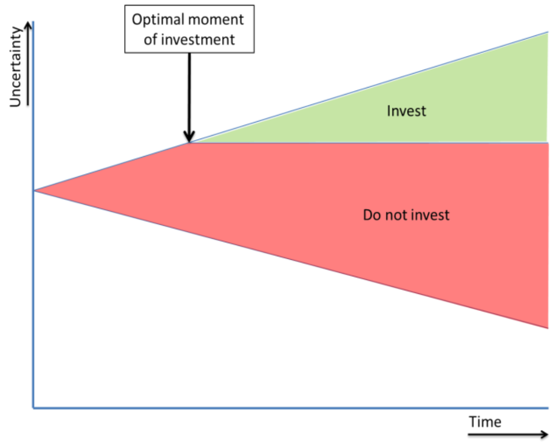


Figure 4.12: visualisation of the optimal moment of investment

4.2.4 Sensitivity analysis

In the sensitivity analysis, the calculations in the tool should run several times including percentage changes in the input variables. Furthermore, the percentage change in the outcomes should be calculated based on the absolute change in values. Therefore, three situations need to be calculated: a minus ten percent change in the input variable, a plus ten percent change in the input variable, and the base case. These percentages change in input variables are fixed and are minus ten percent and plus ten percent.

4.3 Input

In this section, all the input that is needed for using the tool is described. This section focuses on the input that is necessary from the user to run the tool, because the tool can also run without adaption of the adjustable input in the data that is used. It should be mentioned that these values are officially input for the calculations in the tool, but are too a large extend already described above, such as the key indicators. The input should be filled in by the user in the dashboard of the tool, in which also the results are visualised (Appendix V). Section 4.3.1 describes the input that is needed for calculations on the costs and benefits of the alternatives. Section 4.3.2 second section elaborates on the input that is needed for applying ROA.

4.3.1 Input for calculation of the costs and benefits

In the calculation of the NPV, there is input needed from the user on two subjects. Firstly, information for calculating the effects of the widening of different sections is required. Secondly, input on the characteristics of the project is needed to use the right key indicators for the monetisation of the effects and for the growth in traffic intensity. The effects of the project that should be calculated are twofold: the generated vehicle kilometres and the travel time savings.

The travel time savings should be diversified in different types of traffic, passenger and freight traffic, and should be given in time per person. The travel time savings are based on the I/C ratio. Therefore, the capacity and intensity should be filled in by the user. The capacity of roads is dependent on several aspects, but a basic key indicator for the capacity per lane can be found. An additional lane increases the capacity with approximately 2100 vehicles (Goemans, Daamen, & Heikoop, 2011). In this capacity, it is assumed that the total share of heave goods vehicles is 15%. The capacity of the rush hour lanes is 80% of the capacity of additional lanes, because usually the speed is lower and the lanes are narrower (Goemans et al., 2011). The capacity of 'shunting' lanes is too complex to involve in this tool, because the capacity is dependent on the length and the amount of shunting traffic flows (Goemans et al., 2011). Based on these key indicators, the user should fill in the current number of lanes and the additional number of lanes. The average intensity on the road during rush hours and during the day is needed from the user. Rush hours are defined as the hours between 7 and 9 am and between 4 and 6 pm in this tool. Basic information regarding this intensity on road sections during the day is publicly available (Rijkswaterstaat, n.d.a). The percentage of transport vehicles is also often available for road sections, but when this percentage is changed in the tool the user should check the key indicator for capacity again.

Alongside the intensity and the capacity, the total length of the different sections should be filled in. For visualisation purposes, also the name of the sections should be included, e.g. the starting location and the ending location. This enables the user to identify which specific sections corresponds to which alternative. Preferably, only short names are given to the sections, because this makes the interpretation of results easier.

Alongside the yearly growth in intensity, the user can adjust this intensity by describing events that might affect the growth in intensity. These could be local effects, such as the construction of a shopping mall, a campus, or a business park, positively or negatively affecting the growth in uncertainty. In this way, a step in the growth in traffic intensity for the different sections of the road can be included (Figure 4.13). This function of the tool is optional.

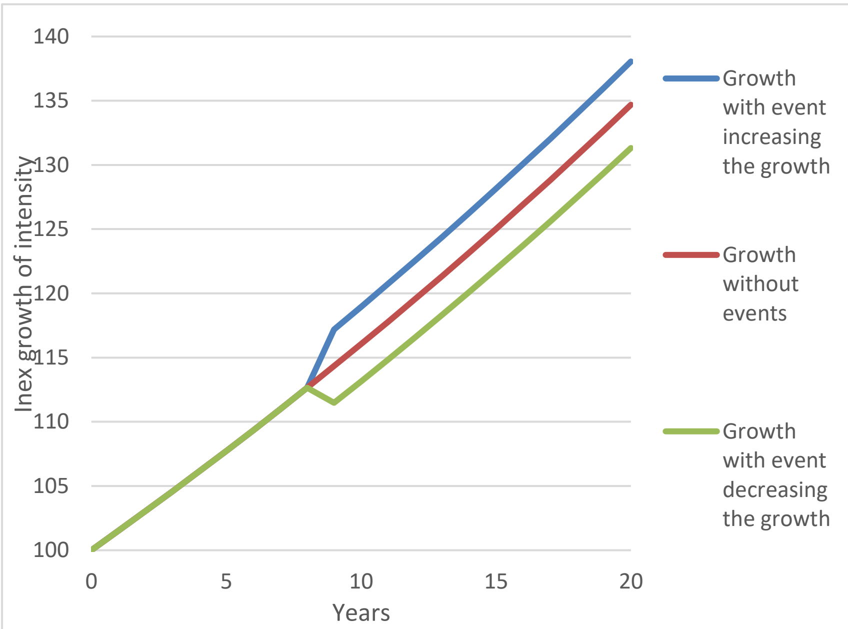


Figure 4.13: growth in intensity with events and without events as optional input in the tool

For the calculation of the travel time savings, the number of generated vehicle kilometres is needed and the rule of half should be applied. Many key indicators, on e.g. the external effects, are related to the generated vehicle kilometres (Table 4.3). The generated vehicle kilometres due to road widenings are assumed to be 4% of the total traffic kilometres at the start of the project (Kennisinstituut voor Mobiliteitsbeleid, 2014). This amount can be adjusted by the user, because in smaller projects the amount of generated traffic kilometres is often set to zero (Visser, 2016).

The implementation costs per section should be filled in by the user in the tool. Currently, no key indicators on the implementation costs are available (Appendix I). The implementation costs are probably dependent on many aspects of the widening and therefore project specific. The calculation of implementation costs usually becomes more accurate during the decision-making process.

Project specific information is needed for the use of the right key indicators for the monetisation of effects. There should be indicated by the user if the road widening is going to take place within or outside urban areas. Whether a specific region is urban or not is for discretion of the user, because a clear definition is missing (National Geographic, 2016). It should also be indicated whether the road is a primary or secondary road.

The discount rate is used in both the determination of the NPV as in the application of binomial option pricing. The discount rate is fixed in current CBA practice, but it might be beneficial for the user to adjust this number to assess the effects of an adjustment of the discount rate. The discount rate is set at 4.5%, including a risk free discount rate and a risk extension (Steunpunt Economische Expertise, 2016). As the benefits of road widening projects are travel time benefits, the relative upward movement of prices is 1% (Steunpunt Economische Expertise, 2016). Therefore the efficient discount rate that should be used is equal to 3.5%.

4.3.2 Input for applying ROA

The calculation of the volatility based on the growth in traffic intensity is already described in section 4.2.3. The volatility and the growth of traffic intensity in different regions in the Netherlands are given. The region, in which the road widening is going to take place, should be filled in by the user. Six different regions for the volatility and twelve provinces for the growth in intensity should be chosen.

Another important aspect for the application of ROA is the number of decision moments for phasing and delay and the years in which the decision moments take place. There was decided to not equally distribute the decision moments on the time horizon, but to make each decision moment individually adjustable. The time step in the binomial decision trees is set at 4 years with a time horizon of 100 years. When the time horizon is made smaller, the time step in the binomial decision trees is also decreased.

4.4 The practical application of the tool

The tool was used in a case to verify the potential practical applicability of the tool. When the tool is able to apply ROA in this case, conclusions can be drawn on the potential applicability of the tool in other projects. Besides, this case test shows the behaviour of the tool in this research and presents the results that were also presented in the interviews of the tool that are described in chapter 5.

The input parameters in this test are based on the input parameters of a real road widening project. The name and location of this case is however not given here, because the quality of the input variables has not been evaluated in this research. Therefore, the correctness of conclusions on this test cannot be guaranteed and should be treated with care. Input variables were slightly changed from the real case to guarantee that this case remains anonymous.

In this case, there is a question whether to widen a highway. No fixed alternatives were identified yet. Four different sections were identified. Five exits and ramps of the highway were chosen on which there is an intention to widen the road. The total distance between these exits is 8.8 kilometres. The letters A till E represent the exits and ramps of this motorway (Figure 4.14). The length of the sections could be found easily with an online measuring tool. All relevant widenings that are subject in this case could be included in the tool in these four sections.

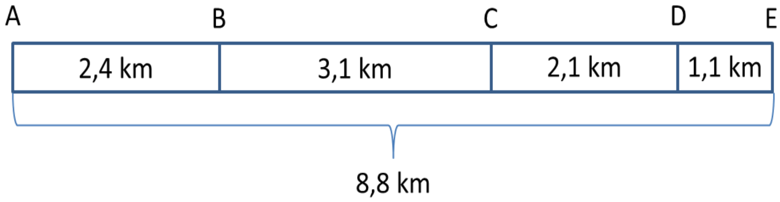


Figure 4.14: case example of a motorway divided in four sections

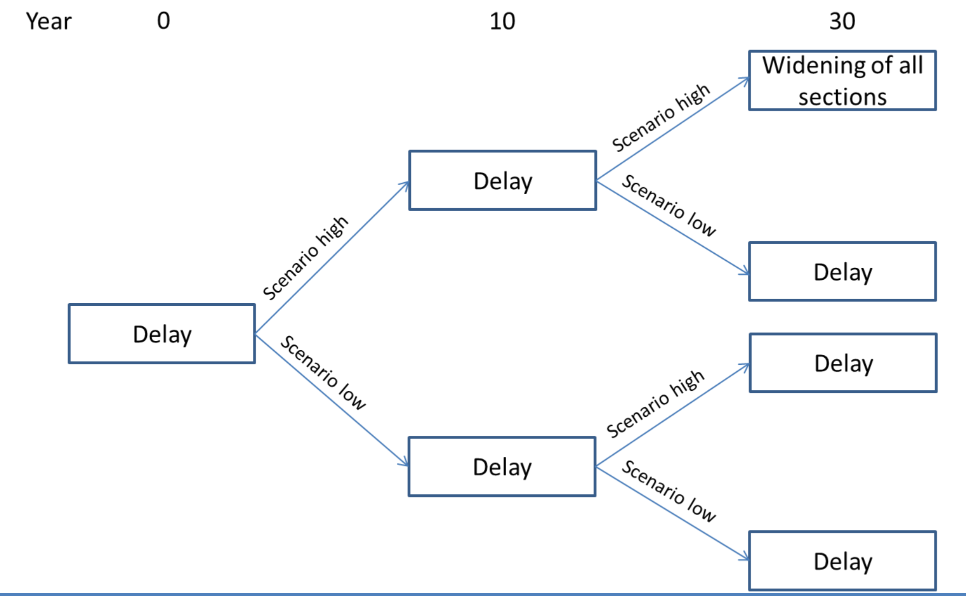
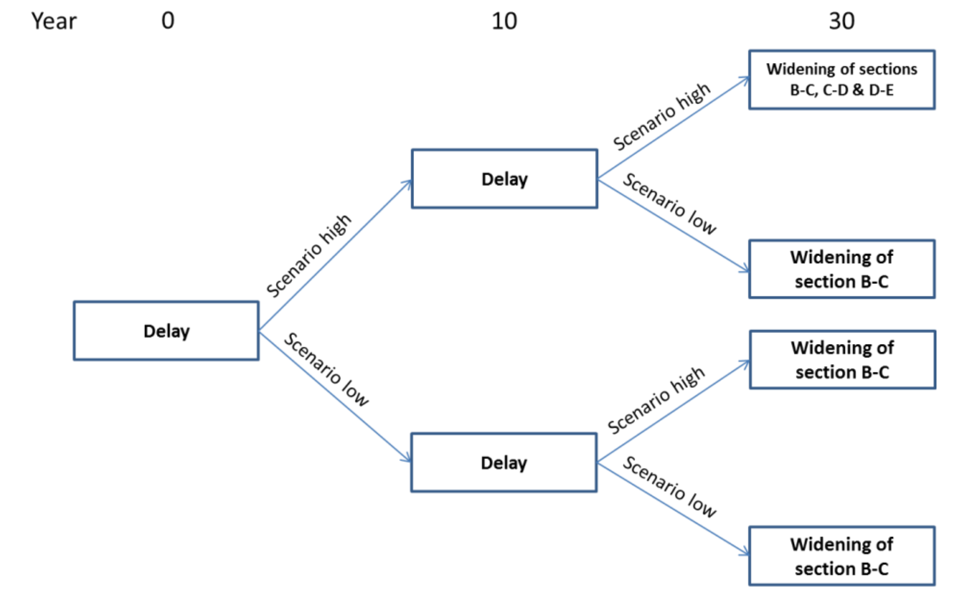
The input that was used from this case in the tool is shown in Table 4.6. The investment costs were described in a research on this case. In this non-public research, the investment costs also included other adjustments of the road besides the widening such as the construction of a curve in the road. However, assumptions could be made on the costs for only the widening of the roads. Besides, all directly related costs to the widening should be included, for example when two projects cannot be split. Other input that is needed in the tool is the region and the province: 'West Nederland Noord' and 'Noord-Holland'. Besides, the type of road, a motorway, and the location, outside urban areas were included in the dashboard. This is all basic information that could easily be found in this case.

Table 4.6: case input for the tool (Source intensity (Rijkswaterstaat, n.d.a (year 2012))

Name	Current situation	Project situation	Length (km)	Investment costs (m €)	Average intensity per hour in rush hours in two directions (cars/hour)	Average intensity per hour outside rush hours in two directions (cars/hour)
A-B	2*2 lanes	2*3 lanes	2.4	26	3300	1600
B-C	2*2 lanes	2*3 lanes	3.1	34	4200	2000
C-D	2*2 lanes	2*3 lanes	2.1	64	3700	2000
D-E	2*2 lanes	2*3 lanes	1.1	32	3800	2100

The number and timing of decision moments is randomly chosen, because information on the exact timing and number of decision moments in the decision-making process was not available. There was mentioned that it is expected that most problems on the capacity of the roads evolve after 30 years. Therefore, a decision-moment in year 0 and year 30 were chosen. Additionally, a third decision moment was included after 10 years. The NPV in scenarios high and low for four alternatives were generated (Table 4.7). Besides the order of phasing was determined (Table 4.7).

Table 4.7: most important output of the tool in the case test

<table>
<tr><th></th><th>Alternative 1</th><th>Alternative 2</th><th>Alternative 3</th><th>Alternative 4</th></tr>
<tr><td>Order of phasing</td><td>Widening of section B-C</td><td>Widening of section B-C and C-D</td><td>Widening of section B-C, C-D, and D-E</td><td>Widening of all sections</td></tr>
<tr><td>NPV in scenario low (in m €)</td><td>-20</td><td>-101</td><td>-140</td><td>-170</td></tr>
<tr><td>NPV in scenario high (in m €)</td><td>136</td><td>139</td><td>129</td><td>146</td></tr>
<tr><td>Expected value delay (in m €)</td><td colspan="4">30</td></tr>
<tr><td>Expected value phasing (in m €)</td><td colspan="4">63</td></tr>
<tr><td>Optimal strategy delay</td><td colspan="4">
</td></tr>
<tr><td>Optimal strategy phasing</td><td colspan="4">
</td></tr>
</table>

The expected value of delay of the widening of all sections is €30 million, which is higher than the NPV of scenarios high and low. The expected value of delay is also higher than the average value of the NPV of both scenarios, which is €-24 million. Delay is here of added value for decision-making. The added value of phasing is however much higher with €63 million. Phasing of the project is therefore recommended above delay of the widening of all sections, but only three decision moments were assessed in the delay of the widening of all sections. From the determination of the optimal strategy for delay it can be concluded that the road should only be widened in year 30 when the intensity has grown consistent with scenario high. In the optimal strategy of phasing the roads should also be widened in year 30. Only if the intensity has grown in consistency with scenario high, it is profitable to widen three of the sections. For every other scenario, widening of section B-C is the most profitable. It should be noted that a small reduction in implementation costs for section B-C shifts the widening of this section towards the second decision moment.

To sum up, this case test shows that the tool can relatively easy apply ROA in practice. Basic input is required and some assumptions have to be made on the input that is available. The test also shows that information is generated in the tool that would not be generated in a standard CBA of this road widening project. The effects of phasing in the widening of roads: from rush hour lane towards full additional lane are not assessed here, but this would also have been possible. A problem is that the tool divides the real case in two parts, and then afterwards the outcomes of these two different types of phasing should be calculated by hand. This test creates confidence that the tool can be used in a wide range of road widening projects, especially since this case was chosen randomly.

4.5 Verification and validation

The tool is verified and the validity of the tool is described in this section. The validity of the tool concerns the question whether the tool represents the reality. The verification of the tool is about the correctness of the behaviour of the tool. The results of the tests are presented and the conclusions on the validity and the verification of the tool are given in this section. In section 4.5.1 the results of the black-box test are presented. Section 4.5.2 elaborates on the sensitivity analysis of the tool.

4.5.1 Black-box test

A black-box test is a test in which the internal workings of the tool are not assessed. Only the input of the tool is changed and the change in output is described. There is reflected on the logic of outcomes based on these changes in input afterwards. Important input parameters are adjusted to zero and to a very high and unrealistic number in this black-box test. The output of these adjustments is assessed to verify the tool. All results of the black-box test are shown in Appendix VIII. The tested variables are briefly described here: the intensity, the capacity in the project situation, the length of the sections, the discount rate, and the time horizon.

The NPV of the alternatives approaches the investments costs of the alternatives when the intensity becomes zero. The order of phasing is then only based on the investment costs of the alternatives. This is correct, because the effects of a road widening are zero when the intensity on the roads is zero. The expected value of phasing and delay are the same when the intensity is very high. This seems to be correct behaviour of the tool, because the optimal strategy is to widen all sections in the beginning when the intensity is very high. Indeed, the effects of a road widening are very positive when the intensity on the road is very high.

When the capacity in the project situation is equal to the capacity in the current situation, there is no value in phasing or delay and the NPV of the alternatives is negative. This is correct behaviour of the tool, because an investment would not make sense when the capacity in both situations is equal. With a very high capacity in the project situation, the expected value of delay and phasing increased tremendously. This also seems logic, because there is a large difference in benefits when the I/C ratio is above 0.8 compared to the current situation due to the high capacity in the project situation. It should be noted that this is not very valid, because the investment costs would increase in reality when the capacity in the project situation is much higher. However, this should be adjusted manually in this tool.

When the length of the sections is equal to zero, the NPV of the alternatives approaches the investments costs of these alternatives. This is correct behaviour of the tool, because the benefits would be zero if the section of the road is also zero. Of course the investment costs would be zero as well with a road section of zero kilometres in reality. Also the expected value of phasing or delay would be zero, because the road would not be widened. The tool does also show this behaviour. With a very high length of the road sections, the benefits of the alternatives increase tremendously, making the widening of all sections optimal. Therefore, also the expected values of phasing and delay are equal to the NPV of the widening of all sections. This is correct behaviour of the tool.

When the discount rate is adjusted to zero in this tool, the average NPV and the expected value of delay and phasing increase. This is correct behaviour of the tool, because a lower discount rate always leads to higher values over time. It stands out that the order of phasing does not differ when the discount rate is adjusted to zero. However, this is correct, because the discount rate is equal for all alternatives in the tool. If the discount rate is very high, the expected values are equal to zero and none of the NPVs of the alternatives is positive. This is correct behaviour of the tool, because a high discount rate always leads to lower values over time. Besides, investing would not be profitable in this case and leads to expected values for phasing and delay of zero.

When the time horizon is zero, the expected value of phasing and delay is also zero. This is correct behaviour of the tool, because phasing or delay over time is impossible when there is no time horizon.

No strange behaviour of the tool can be identified for which no explanations can be found in the black-box test. Reasons for its behaviour can be found in the needed adjustment in input of the tool that has to be made manually by the user of the tool. For example, a higher capacity on the road logically leads to higher investment costs. The black-box test of this tool creates confidence that the tool behaves well in the assessment of road widening projects.

4.5.2 Sensitivity analysis

Alongside the sensitivity analysis that is available in the tool, the sensitivity of the tool is also assessed in this research. The input variables that are tested in the sensitivity analysis are uncertain variables on which no consensus exists in decision-making. The input variables mostly criticised are taken into account: the time horizon, the probability of scenario high, the discount rate, and the cash flow per year. The probability of scenarios is the input variable in ROA that is mostly criticised by experts (Van der Pol et al., 2016). Other input variables that were included in the sensitivity analysis are the variables on which assumptions are made in the design of this tool: the percentage of generated traffic due to road widening, the intensity, the capacity, and the yearly growth in intensity. The effects of small changes of these input variables, plus and minus ten percent, on several outcomes are assessed. The outcomes are the main outcomes of the real option tool: the expected value of delay, the expected value of phasing and whether there is a change in the choice for an alternative in decision moment one. The base case in the sensitivity analysis is the case that is used in section 4.4. The results of the sensitivity analysis are shown in Appendix IX and the most outstanding results are described below.

The sensitivity on the expected value of delay and phasing is relatively little compared to the sensitivity on the average NPV of all alternatives over all scenarios. This seems correct, because the expected values are based on many calculations in which many variables have a high impact. This makes that a small change in, e.g. the intensity has a limited effect on the total expected value.

The sensitivity of the average NPV of all alternatives over all scenarios is relatively high. Ten percent change in the intensity could lead to a change of the average NPV of more than 800%. This can be explained by the fact that the input variables affect both the NPV in scenarios high and low in the same direction. Besides, the heights of most effects of road widenings are dependent on the I/C ratio and the related travel time effects.

The input variables with the highest impact on the output of the tool are the intensity, the time horizon, and the capacity. This holds for each outcome that is assessed in this sensitivity analysis. The yearly growth in intensity also affects the outcomes of the tool to a large extent. This seems logic, as many benefits of road widenings are dependent on the intensity and capacity in the tool. The variables with the smallest impact on the output of the tool are the percentage of generated traffic due to road widening and the probability of scenario high. This holds for all outcomes of the tool that were analysed.

To sum up, the tool is relatively sensitive for changes in input variables. The expected values, the NPVs, and the optimal strategy change much when the input variables are slightly changed. This means that the input variables should be chosen with care by the user to get more robust outcomes. Mistakes in input variables in the tool could be problematic for the validity of the tool. Research on the height of input variables helps in achieving valid results. One of the most surprising results from this sensitivity analysis is that the most questionable input variable of ROA, the probability of scenarios, seems to affect the results of the tool relatively little compared to the other input variables. Another questionable input variable, the percentage of generated traffic, also affects the outcomes of the tool relatively little. The sensitivity analysis creates confidence that the tool behaves well in the assessment of road widening projects when input variables are deliberately chosen. One may wonder whether this is possible for users in the first phase of decision-making, because then usually only rough information is available.

4.6 Conclusion

The main result from this chapter is the developed real option tool. The following question was central in this chapter: *How do the requirements lead to a real option tool for road widening projects?* All requirements can be included in the design of a real option tool that is potentially of added value for decision-making. Even when assumptions have to be made and key indicators have to be used.

Two different ROA methods are included in the real option tool: the simplified decision tree analysis and binomial option pricing. The main outcomes of the tool are the expected values of phasing and delay, the optimal strategy in each decision moment, and the optimal moment of investment. Basic input on the characteristics of the project is needed in the tool to calculate the outcomes of the tool.

In the design of the tool, assumptions and trade-offs between requirements had to be made. This reduces the exactness of the assessment of effects of road widening projects. On the other hand, these key indicators were needed to implement ROA in a standardised real option tool. Furthermore, the adaptability and transparency of the tool could be indicated as difficult to include in a tool. For example, the assumptions can be made transparent, but how each cell is exactly calculated is difficult to make transparent for the user. Especially, because there also seems to be a trade-off between the transparency and adaptability of the tool and the quality and the simplicity of the user interface. The tool assesses the effects of road widenings based on key indicators and the I/C ratio. The NPV can be calculated for each section of the road in scenario high and low. With the use of the I/C ratio, the growth in intensity among each scenario from each decision moment can be calculated relatively easy. These calculations result in a number for the direct effects and the inclusion of indirect effects, external effects, and costs, the expected value in the decision trees for delay and phasing. Also the binomial value of delay and phasing are calculated. In this way, a relatively standard implementation of ROA for road widening projects is possible.

The implementation of a case leads to the conclusion that the real option tool could lead to additional insights for decision-making. There was a benefit for delay and phasing of the road widening compared to implementation of one of the alternatives based on the NPV in the case test. The case test also shows that an optimal strategy can be presented to the user in a relatively clear way. The sensitivity of the tool was tested in this research. The tool is relatively sensitive for changes in the output, but a small change in most questionable assumptions seem to affect the outcomes relatively little. The tests create confidence that the real option tool can be used in road widening projects in reality. However, it remains uncertain how and whether the tool creates added value for decision-making. This is assessed in the next chapter.

5. Assessment of the tool

This chapter describes the evaluation of the tool with experts and potential users. Seven respondents were asked on their opinion on the tool and the possibilities to use the tool in practice. This chapter answers the third research question: *What can be learned from comparing the current situation of decision-making in road widening projects and the situation in which a real option tool is available?* The evaluation of a DSS is important and can be done best with the involvement of users, because they are in the best position to evaluate the system (Sprague, 1980). In an iterative design approach, the evaluation of users could also help to improve the tool (Sprague, 1980). The seven respondents are indicated with a letter (Table 5.1).

Table 5.1: respondents and their organisation/functions

Respondent	Organisation	Function
A	CPB	Researcher
B	RWS	Senior advisor models and traffic forecasts
C	RWS	Senior advisor economy
D	RWS	Senior advisor economy
E	RWS	Senior advisor traffic and transport
F	Consultant	Director
G	TU Delft	Researcher

In section 5.1, the results of the interviews are described. Section 5.2 describes the reflection on the outcomes of the interviews based on literature and trade-offs that were made in the design of the tool. Section 5.3 gives a conclusion and answers the third research question.

5.1 Interviews with experts

Each respondent was asked to judge the seven high level requirements of the tool (section 3.4). Based on their opinion on the importance of these requirements and their expertise related questions to these aspects were questioned. Results from the interviews are described from section 5.1.1 to section 5.1.7 for each aspect. Each respondent was asked on their opinion about the added value in decision-making of this tool. Reports of the interviews are shown in Appendix IX.

In the interviews, only the simplified decision tree method was assessed. This was done to reduce the complexity in the task of testing by the users, because only a limited amount of time was available in the interviews. The need for another method instead of the simplified decision tree could be assessed indirectly in this way.

5.1.1 Connection with the user needs

Most of the respondents indicate the connection with the needs of the user as one of the most important requirements of a tool. Several related questions were asked to the respondents on how this tool would score in assessing the needs of potential users. The main subjects in the interview were the methodology and the use of scenarios high and low in the tool.

5.1.1.1 Additional methods to the simplified decision tree method

For all respondents, the need for another method alongside the simplified decision tree was limited or not present. Applying more methods in addition to simplified decision trees would not necessarily increase the added value of the tool. Respondents G and H state that the added value of multiple methods in a tool depends on how these methods are used in the tool.

Respondent F describes that the application of multiple methods could be of added value for the back office. However, for consultants and engineering firms that would apply the method, multiple methods would not be of added value. More ROA methods could create added value for the back office or a company that is engaged in knowledge development. The reason is that this company could give advice on the choice between methods. It might be possible to use different ROA methods for different types of problems. This identification of methods could also be done in one tool with e.g. a small survey in the beginning. A range of characteristics leads to the use of one method and a range of other characteristics leads to the use of another method. There might be an incentive for the routine user to use the method which creates the best results in their opinion when more than one method is used in the same tool. Then, the tool might be used strategically, which should be avoided.

Most often named additional method was binomial option pricing by respondents A, C, D & F. The binomial decision trees were identified as very complex for decision-making by respondents A, C & D and therefore potentially of a limited added value. Some drawbacks of binomial option pricing were mentioned by these three respondents. Especially the communication of the binomial decision tree could be troublesome. Furthermore, the use of a flexible discount rate in binomial option pricing is not suitable in the Dutch CBA context, because a fixed discount rate is often used according to the Dutch CBA guidelines. There are exceptions, but these exceptions are in practice not often applied. Thirdly, the binomial model assumes uncertain solutions in which at a certain moment the value is exactly known.

5.1.1.2 Use of scenarios high and low

There was no consensus on the need for more scenarios in the tool alongside scenarios high and low among the respondents.

Respondent E states that adding more scenarios to the decision trees is probably not necessary, because scenarios high and low do already represent much of the uncertainty. Decision makers are satisfied that currently only two scenarios are used. When this number of scenarios is increased, one may wonder if this still gives enough support for decision makers, because this results in a wider range of outcomes.

However, respondent C mentions that in practice a third scenario can be beneficial, especially for the assumptions that are made in the NRM model. An example of such an assumption is the construction of a regional road in a specific year. Respondent D mentions that adding a specific policy to the scenarios in the decision tree creates two additional scenarios, such as the implementation of road pricing. Sometimes, environmental conditions are included in CBA when these conditions are very relevant for a specific project. Respondent A states that it might be of added value to include scenarios that are related to the engineering constructions in road widening projects. A new engineering construction might lead to other results.

Including more scenarios than scenarios high and low could be of added value, but it is difficult to standardise policy scenarios or region specific scenarios in the tool. Respondent F described another opportunity: to include these aspects by running the tool multiple times and include the effects on the growth of the intensity in scenarios high and low. The outcomes of the runs could also be reflected in one expected value as how it is done now when the probabilities of these scenarios are known.

5.1.2 Assessment of road widening projects

The importance of the quality of the assessment of road widening projects differed among the respondents. The main subjects in the interviews were the complexity of road widening projects and the alternatives in this tool, the use of the I/C ratio, the assessment of external and indirect effects, and the order of phasing.

5.1.2.1 Complexity of road widening projects

Respondent A makes clear that road widening projects are especially complex and are not only about the decision of additional lanes or rush hour lanes, but also about engineering constructions, such as bridges and tunnels. In reality, many decisions have to be made in one project. This makes the CBA of these projects relatively complex. All these decision are not yet included in the tool. The more flexible the tool is in its design, the more added value there may be. Currently, the tool might not be flexible enough to incorporate all complexities that are present in infrastructure projects. Most of the costs in road widening projects have to do with the engineering constructions. It would be good to include more flexibility in these engineering constructions, because one can expect that the value of phasing and delay in the construction of these engineering constructions is high.

5.1.2.2 The I/C ratio

The I/C ratio is used in this tool. This characteristic of the tool was surprising for respondent B, C, D & E, because in practice NRM is used for the assessment of the effects of road widenings. The monetisation of the travel time effects is the same as how it is currently done, because the travel time losses are monetised in this tool. There are some deficiencies in the use of the I/C ratio for the calculation of the direct effects:

- Respondent B and D state that the relation between the I/C ratio and the speed is a complex relation. For example, also the design of the road has an impact on the average speed. In specific situations, the capacity could be high in theory, while speed is low caused by congestion on the next section.
- A linear relation between the I/C ratio and the speed is used in the tool. Often a negative exponential function is used for this relation. This assumption of a negative exponential function is however questionable. Respondent B mentions this linear assumption is not automatically wrong, but that this assumption should be clear for the user.
- Respondent E mentions that there could be a difference in the value of construction in two different types of phasing, because the situation also depends on the widening of one of the other sections. For example, the construction of the last section can give more benefits than the construction of previous sections and vice versa. It would be better to include this in the tool.

- Respondent E makes clear that with the use of the I/C ratio, the radiation effect of a road widening, the effect on e.g. other roads or other sections of the same road, is not included. These network effects could affect the strategic decision.
- There is also an effect on the travel time when the I/C ratio is low, explained by respondent D. The maximum speed on roads may increase when a road is widened or when the rush hour lane is upgraded to a full additional lane. In reality, the effect of an increase in the maximum speed seems to be high.

Respondent G states that all models are wrong, but some are useful. NRM does not reflect the reality in essence, but could still be useful. The same goes for this real option tool with the use of the I/C ratio. This tool can still be useful, also when it does not reflect the reality.

All respondents can accept that in the comparison between different scenarios, the current approach is probably not problematic. The outcomes should not be considered as absolute outcomes. This could be problematic in discussions when the outcomes are considered as absolute.

5.1.2.3 External and indirect effects & generated vehicle kilometres

Including indirect effects in analyses of road widening projects is arguable for all respondents. Respondent C makes clear that in the selection of the optimal alternatives, usually the effectiveness of the alternatives is the most important effect in the first phase of decision-making. Therefore, the indirect effects can be ignored when this tool is used in the first phase of decision-making. On the other hand, including these effects in this tool is illustrative to show that these effects also matter in road widening projects.

The external effects are calculated based on the generated vehicle kilometres and also the direct effects are affected by the generated vehicle kilometres. This makes the assessment of external effects in this tool more disputable as mentioned by respondent B and E. In practice, it seems that there is only a limited amount of new traffic as is mentioned by respondent E. However, all respondents acknowledge that there is an effect of road widenings on the number of vehicle kilometres on the road. Respondent E makes clear that three mechanisms in the generation of vehicle kilometres are included in NRM:

- Adjustments in departure times (the simplest);
- Adjustments in the route;
- Adjustments in modal split.

Respondent B describes that an equal distribution in the increase of traffic kilometres among the different sections is fine for analysis, but that the reality could be different. The different sections of the road are related in the effect on the amount of traffic kilometres. When a specific bottleneck is solved, the traffic kilometres on the road could increase more than when this bottleneck remains. This is not included in this tool and could be a wrong simplification of this tool as mentioned by respondent B.

The use of key indicators to assess the indirect effects or external effects includes many assumptions. As a result, the use of these key indicators is complicated for users as described by respondent F. There are two conditions for decreasing the complication of the use of key indicators. The key indicators that are currently used should be without any discussion or should be filled in very conscious by the user. In the current tool, too many key indicators are used to meet one of these conditions. Another option might be that the set of key indicators are also used in the current CBA tool. Making the use of these key indicators transparent in this tool is challenging.

The inclusion of the assessment of the direct effects and external effects could be of added value for politicians, because this assessment creates the feeling that all effects are at least taken into account as mentioned by respondent G. However, it still remains uncertain how well these effects are assessed. Respondent A states that it could be helpful for illustrative purposes to assess the indirect effects and external effects in this tool. Therefore it is important to present the numbers as to be used for illustrative purposes and not for decision-making in the tool.

5.1.2.4 Order of phasing

The ordering of the phased construction based on the most optimal economic alternative in this tool seems to be logic to all respondents. Including an ordering based on e.g. political preferences in a calculation tool would be strange. With a more flexible specification of the tool, it would be possible to design a tool more towards the problem. This is mentioned by respondent A. Then, this assumption for phasing would be less problematic.

5.1.3 Use of data

The good use of data is one of the least important requirements of the tool for many respondents. As part of the use of data, the sensitivity analysis is identified as important for all respondents. In this section, the evaluation of the key indicators and the sensitivity analysis in the tool is centre.

5.1.3.1 Key indicators

The use of many key indicators in this tool leads to many assumptions. It would be good to review the key indicators for each project specific. It is important to acknowledge the risks of the use of these key indicators as mentioned by respondent B, because the use of key indicators could lead to different results from reality.

5.1.3.2 Sensitivity analysis

There are two reasons for performing a sensitivity analysis in a tool. Firstly, one of the most important aspects to validate in the sensitivity analysis is the high sensitivity of the outcomes of ROA on the probability of scenario high and low. There is much discussion on this point as mentioned by respondent C. Secondly, respondent B makes clear that the sensitivity analysis could be beneficial in the communication between decision makers. A statement such as “that is due to the discount rate” can be rejected or approved. In CBA, only the robustness of the outcomes is assessed, but a sensitivity analysis is not performed on the assumptions in the NRM model or CBA tool as described by respondent E.

All respondents acknowledge that the current sensitivity analysis needs more explanation and context. Furthermore, a clear conclusion on the sensitivity in the tool is missing. The sensitivity analysis should be risk driven and customised. Which input variables or assumptions can affect the results most, and which assumptions or input variables are most uncertain?

Improvements in the sensitivity analysis can be made. It may be beneficial to test the robustness of the outcomes as mentioned by respondents B and F. In this analysis of the robustness, the question is how much the input variables should change to affect the outcomes of the optimal strategy. An example is to calculate the break-even points as mentioned by respondent F. It might be better to let the user themselves perform the sensitivity analysis by adjusting input variables. In this way, it is immediately clear for the user which and how input is changed and what the outcomes are.

5.1.4 Adaptability

The adaptability is not often mentioned as an important requirement of the tool in the interviews. The flexibility of the design is however mentioned as important by respondents A and F. The difference between these aspects is that the adaptability is about the question if the tool can be adapted to a diverse range of problems and the flexibility is about the question if the tool is able to handle a diverse range of problems. In this regard. the characteristic that a road should be divided in four sections is an important limitation of the model. Respondent A makes clear that in reality there could be many more decisions or restrictions within a section, making the alternatives used in the model less useful. Flexibility in the tool in the use of these four sections is useful for the use of the tool in reality.

In the case, a phasing in sections of the road is used. However in practice, there may be more flexible solutions besides phasing in different sections of the road. An example is phasing from ‘shunting’ lanes to rush hour lanes to full additional lane as mentioned by respondents C and F. It is valuable when also these effects could be assessed in this tool, because the result that the widening is needed also creates insights for decision makers.

Other projects, such as maintenance projects also affect the intensity and capacity of the road. Maybe, the tool could be used as well in these projects as mentioned by respondent E. However, the main variable is the growth of the traffic intensity over time. Respondent F states that this would maybe not be the main uncertainty in maintenance projects. Respondent F thinks that it is more logical to develop new tools based on this real option tool for such problems. With this real option tool, these tools do not have to be developed from scratch.

5.1.5 Transparency

The transparency is not identified as important by respondents A, B, E and G. However, respondents C, D and F identify transparency as one of the most important requirements. The tool is considered as transparent by respondents C and D compared to other tools. The tool is insightful in the steps that are taken. Most important assumptions are visible for the user.

5.1.6 User interface

The user interface was directly and indirectly assessed during the interviews. Questions were asked on the quality of the user interface, but there can also be reflected on how the users were able to follow the steps that were made while testing the tool in the interview. While testing, no large issues came up in the use of the interface of the tool. There were some important remarks on the visualisation of the decision trees and the intuitiveness of the user interface.

5.1.6.1 Visualisations of the decision trees

Respondents B and E did not indicate the complex decision trees as problematic for decision-making. This is mainly because these respondents state that not everyone in the decision-making process should be able to interpret these results. Respondent E mentions that it would be good to use the decision trees internal to evaluate alternatives, but external, the opportunities for phasing or delay would be already much information for decision makers.

5.1.6.2 Intuitiveness

Respondent F stated that the dashboard of the tool was not very intuitive in use. Some recommendations to improve the intuitiveness of the tool were made:

- Increase the font size in the dashboard;
- Include comments in the dashboard on what to fill in where;
- Create a manual for users including examples, functions, assumptions and guidance on how the results should be interpreted;
- Give more explanation on which conclusions can be drawn from the tool. Therefore, more context is needed. It is often difficult to use someone else’s spreadsheet;
- The height of the cells should be increased. The current tool looks too much researchish and with larger cell heights, the tool probably looks more like a webpage. This could especially be beneficial for decision makers;
- It could help to visualise input and output side by side instead of amongst each other. This would match more with the shape of many computer screens.

5.1.7 Support in decision-making

The supportiveness in decision-making of the tool was one of the most important requirements of the tool for all respondents. Several aspects of this supportiveness were assessed in the interview: potential road widening projects in which the tool could be used, the potential user of the tool, the phase of decision-making in which the tool could be used, and the insights that the tool can create.

5.1.7.1 Potential projects

Respondent E makes clear that in practice, the question on what to do with flexibility and delay in road widening projects often comes up. For these questions, this tool can be of added value. Respondent E showed some examples:

- In the project A6 between Almere and Lelystad the question what the optimal moment of investment was came up. In this project, the effects of delay were also calculated based on the I/C ratio.
- In the project Ring Utrecht, the need for phasing in different sections of the road came up frequently. This tool could help to determine this optimal moment of investment in a more sophisticated way than how it was done in these projects.

- The tool could be of added value in the composition of packages of measures especially in those situations that a road widening is not necessary yet.

Respondents C and D expressed that it would be good to include other alternatives in this tool, such as measures from the 'Beter Benutten' program. This is a program focusing on improvements in accessibility containing practical measures. The effects of these measures can be included by assessing the effects on the intensity or the capacity on the road. Then, one might be able to assess when and how which sections of the road should be widened. Respondent E describes that projects in large municipalities and provinces can also be assessed in this tool, because the capacity and intensity is also known for these projects.

Respondent G focused more on the political perspective of flexibility in which the tool should create support. The introduction of flexibility in decision-making is difficult from a political context. Politicians do not want flexibility, because they want to be able to make promises to the electorate. Making promises is difficult when solutions become flexible. Politicians think that it is difficult to explain the incorporation of flexibility to the electorate. Introducing flexibility does not match with the current way of budgeting and the current way of decision-making in projects.

5.1.7.2 Potential users

The potential users of these tools were also described in the interviews. The respondents from RWS make clear that the tool would probably be used by external consultants, because usually calculations are not made within RWS. Respondents C and D made clear how this tool can be used by external consultants. With a real option tool, flexibility could be included in a standardised way in the assessment of road widening projects. For CBA performers, the tool could be of added value, because with this tool, the potential possibilities to phase or delay could be identified relatively easy.

Respondent A and G gave another perspective. The tool needs to be used in discussions in decision-making to increase the added value of the tool. Then, also a very complex decision tree would be difficult in the interpretation by politicians and in the discussion between civil servants. When the tool is used in discussions, it is valuable to test whether the tool has added value for different actors in the decision-making. This could differ among different actors in decision-making. It would be interesting to test this tool in a discussion within the ministry of Infrastructure and Environment to assess whether and how they would use the tool in a discussion or meeting.

Respondents C, D and F make clear that the governance of the tool is important for its added value. A back office increases the added value of a real option tool. It is proposed that the governance of the tool is exercised by an external consultant. The back office should be available for other consultants when RWS requires them to use the tool.

5.1.7.3 Phase of decision-making

Respondent E makes clear that in practice, CBAs appear relatively late in the decision-making processes. Therefore, the added value of these analyses for decision-making is currently unclear. This gives the insight to respondent E that it could be good to apply this tool earlier in the process to get an overview of alternatives and options to delay or phase earlier.

Respondent B makes clear that especially in the first phases of the decision-making process there is a need for these tools. This is due to the fact that stakeholders often disagree about the methods and tools to be used. It is therefore beneficial to have multiple tools and models available. This tool could be one of them. All respondents agree on that in the beginning of the decision-making process the tool could be used without the use of NRM, because in this stage of decision-making simple tools help to get insight in the problem. This tool could lead to the selection of alternatives.

All respondents agree that this tool is not detailed enough in a later phase of the decision-making process. More detailed and project specific information should be added. It might also be possible to connect such a tool with the NRM model. Respondent E and F think that the dashboard of this real option tool still could be used. Respondent C explains the idea that in different stages of the decision-making process, different types of this tool could be needed that differ in the degree of complexity and differ in the costs for running the tool. In a later stage of the decision-making process, also input such as the cost estimates of alternatives become more accurate.

5.1.7.4 Insights of the tool for decision-making

For all respondents, the tool creates insights in the value of phasing and delay and insights in the identification of potential flexibility in road widening projects.

Respondent A remarks that it is good that the tool helps to identify the possibilities of flexibility when currently the decision of widening the road is a go/no go decision. Then, it could be helpful that also a rough indication of the value of flexibility is given in the tool. For respondents A, B, C, D, and E, the tool does not fully satisfy in exactness, but it creates the feeling and the power to identify the opportunities for delay or phasing. They identify two different aspects in the identification of the opportunities for delay and phasing: the outcomes could create input for a more thorough discussion and the tool could help in structuring the problem.

Respondent G states that this tool might create the feeling for politicians that the effects of delay and phasing are taken into account. Respondents G proposes that a paragraph can be added to the current CBA reports in which an advice on flexibility is given to the politicians. Then, this tool could help, but does not have to be included in the report. The content of this paragraph can be very generic to be of added value for politicians.

All respondents state that the tool could help to provide insights in how flexibility can be incorporated in road widening projects and which alternatives are potentially profitable in the first phase of decision-making. Respondent A explains that the use of five decision moments in delay and three decision moments in phasing is already much. The use of two decision moments could be enough in practice. Many decision moments over a long period is probably not needed in practice for decision makers. The summary on the optimal strategy for each decision moment and scenario in the tool helps the user to interpret the flexibility in projects.

Respondent A mentions that in the current tool the negative value of uncertainty is not assessed. This negative perception of uncertainty might be present in reality. Citizens prefer certainty above uncertainty. This corresponds to the way politicians make decisions: based on the recognition that civilians want clarity. It would be good to include this negative value of uncertainty to give a complete overview of the value of flexibility. Besides, uncertainty leads to costs, e.g. civil servants are occupied with handling procedures or information meetings. When these costs are higher than the benefits of incorporating flexibility, the value of flexibility is much lower. Respondent A makes clear that it would be good to perform more research on these topics.

Respondent B explains that they do believe in these kinds of strategic tools within RWS, because it takes time and effort to run more complex models. It helps when a tool is able to do calculations relatively fast. With these kinds of tools, the number of choices can be reduced, what could be beneficial. In this regard, it could also be beneficial to hear or see what does not work, e.g. a specific ordering of phased construction. Respondent B, C, D and F make clear that it would be good to implement a real life case in this tool to see what the tool does and how the added value of this tool can be optimised.

5.2 Reflection

This section reflects on the outcomes of the interviews. There is a reflection on the four main topics that came up in the interviews: the ROA method, the assessment of road widening projects, the flexibility of the tool, and the phase of decision-making in which the tool can be used. First, there is a reflection on the methodology that is used in this tool. Secondly, the discussion on the assessment of road widening projects is assessed. Thirdly, there is a reflection on the flexibility of the tool. Fourthly, there is a reflection on the usability of the tool. The added value of the tool is described in the last section.

5.2.1 ROA methods

All respondents believe that an additional ROA method in this tool would not necessarily increase the added value of this tool. There might be concluded that the exclusion of binomial option pricing in the tool results in the same added value compared to the tool in which binomial option pricing is included. However, binomial option pricing or the inclusion of another ROA method could also have an added value for decision-making.

It was mentioned that multiple methods could be beneficial for the back office to give advice on the use of a specific method or different methods can be applied in different cases based on specific characteristics of the project. It is uncertain whether it is possible to give recommendation on the application of a specific method in a specific situation. Furthermore, the tool could become less transparent when a specific method is assigned to a specific project. The degrees of freedom in the use of the tool are then more limited.

It remains to a large extent uncertain why the respondents do not value an additional ROA method as of added value in a real option tool. There should be mentioned that the simplified decision tree method and binomial option pricing do not necessarily exclude each other in a real option tool. The input is more or less equal. The design task becomes more complex, but is to a great extent overlapping. Two potential reasons for the limited added value of additional ROA methods in a tool were identified.

First, respondents might be afraid that an additional method could increase the incentive for strategic behaviour by users of the tool. Information can be communicated selectively and this information can be used strategically in decision-making (De Bruijn & Ten Heuvelhof, 2008). However, the relation between tools and strategic behaviour cannot be further substantiated for the application of different ROA methods and should be tested to draw conclusions on the relation between methods and the strategic behaviour in a tool. Furthermore, all information can be used strategically, also when only one method is included in the real option tool. Therefore, an additional method might also decrease the incentive for strategic behaviour, because more information becomes available. When results in different methods are almost the same, this creates confidence that the results are valid.

Another reason for the low valuation of an additional ROA method could be that binomial option pricing, one of the most used methods alongside the simplified decision tree, has some drawbacks for some of the respondents. The communication of this method could be troublesome, which can be recognised in the development of this tool. It was difficult to present the results of this method in the dashboard of the tool and the binomial trees were left out. The simplified decision tree gives the expected value, which probably connects with the perspective of the user. Another drawback that was mentioned is the use of a flexible discount rate in binomial option pricing. The discount rate is used to reflect the amount of uncertainty in a project (Rakers et al., 2010). The use of fixed discount rates is usually applied in the Dutch CBA practice, because the exemption regulations are limited (Romijn & Renes, 2013). However, a flexible discount rate could be better aligned with the uncertainty that is present in a specific project or with a specific strategy of phasing or delay, also when this is currently not prescribed in the Dutch CBA practice. Risk is namely not equal in projects in every period in time.

Some of the respondents stated that binomial option pricing is a too complex method to apply in public projects. This can be confirmed as already the application of ROA in projects is not very high. This was also recognised in earlier studies (Gijsen, 2016; Reitsma, 2010). One of the respondents also makes clear that it is best to start with the application of the simplest method in decision-making. Forcing the application of ROA is already really difficult.

However, binomial option pricing and the Black-Scholes formula, both more complex methods, are also very often used in private organisations (Copeland & Tufano, 2004). It remains uncertain whether a transparent ROA method is needed in decision-making processes. This may be the case for the use of a real option tool in discussions. A reduction in complexity might not be necessary in the use of the tool by consultants.

5.2.2 Effects of road widenings

The comments on the effects of road widening are assessed in this section. The importance of the quality of the assessment of road widening projects differed among the respondents. This could be due to the fact that the expertise in the assessment of road infrastructure projects in the tool differed among the respondents. Some respondents had their main expertise in transport and others had their main expertise in ROA or CBA.

NRM is usually used in tools and models that describe the effects of road widening projects. These tools and models are better able to assess the effects of road widening projects than this tool does. Not using NRM in this tool is a limitation of this real option tool for many respondents. The use of NRM in this tool is next to impossible, because the number of results that must be generated is too high. This was also recognised by all respondents. At least a standardised tool for road widening projects would be very difficult with the use of NRM.

With NRM, network effects of measures and effects on secondary roads or complexity in the I/C ratio in different road sections can be included in the assessment of road widening projects. One of the comments was that the allowed maximum speed might increase when a road is widened. However, making assumptions on the effects of road widening when the I/C ratio is low, based on a potential higher average speed or making assumptions on the general effect of road widenings on other sections of the road, is dubious. A general key indicator cannot be found. It is also uncertain how large these effects are (Kennisinstituut voor Mobiliteitsbeleid, 2010). An increase in maximum speed is often not present, e.g. when the maximum speed is already 130 km/h. Including this increase in maximum speed in a standardised way in the tool would not make much sense.

The use of NRM is not always better, because NRM is also subject to discussion and the results might not differ as much as might have been assumed by the respondents. Subjects of discussion in NRM are that the absolute outcomes of the models is attributed too much value to and that NRM does not include enough dynamic (Van der Hoeven & Nijhout, 2013). The use of dynamic travel models would increase the assessment of road widening projects (Van den Brink & Wismans, 2012). NRM is an economic equilibrium model. This is not in agreement with ROA which is a dynamic method that includes a time variable.

The results from the CBA of the project ‘Ruit Eindhoven’, in which NRM was used, were compared to the results from the tool are not that much different in this specific situation (Table 5.2). But no conclusions can be drawn on the similarity between methods. For this purpose, the underlying characteristics of both methods should be compared. Besides, the results of this tool are sensitivity for the accuracy of the intensity of this road. The validity of this input variable was not assessed here. The input in the CBA was probably better researched than the input that was used in the real option tool in this test.

Table 5.2: results from comparison between outcomes CBA and outcomes tool

Project ‘Ruit Eindhoven’	**Results from CBA Source: Hoefsloot et al., 2014b) (alternative NZ)**	**Results from tool Source for input: Hoefsloot et al., 2014b & Wegenwiki, 2016**
NPV in scenario high/GE (in m €)	599	620
NPV in scenario low/RC (in m €)	-256	-270
Ratio between scenarios high and low	-2.4	-2.3

Another point of criticism of respondents in the assessment of road widening projects was the use of the I/C ratio itself as an alternative for the NRM model. It is uncertain whether the relation between the I/C ratio and the average speed in both the project situation and the current situation is well assessed in this tool. A difficulty in the relation between the average speed and the I/C ratio is that there seems to be no consensus on when congestion occurs: with an I/C ratio of 0.7, 0.8, or 0.9 (Dijkstra & Hummel, 2004; Goemans et al., 2011). The relation between I/C ratio and average speed is more complex in reality than is currently assumed in this tool with a linear relation between both. However, a linear relation between I/C ratio and average speed is also often used in practice. A 1% increase of the intensity of a road leads to a 3% increase in the loss of travel time in busy areas. In the tool a 1% increase of the intensity of a road leads to a 1.5% increase of the speed in situations with an I/C ratio above 0.8. This difference cannot well be described here, because it is unclear what the definition of busy areas is in this definition. Also, the shape of the relation between speed and the I/C ratio is unclear. There is no other option than making an assumption for this relation for the design of this tool. A negative exponential function could be used as an alternative (Equation 10; Figure 5.1).

$$\bar{v} = 64.37 \cdot 0.946^{\frac{I}{C}} \tag{10}$$

$\bar{v} = average\ speed\ in\ a\ specific\ year$
$I = intensity\ in\ a\ specific\ year$
$C = capacity\ in\ a\ specific\ year$

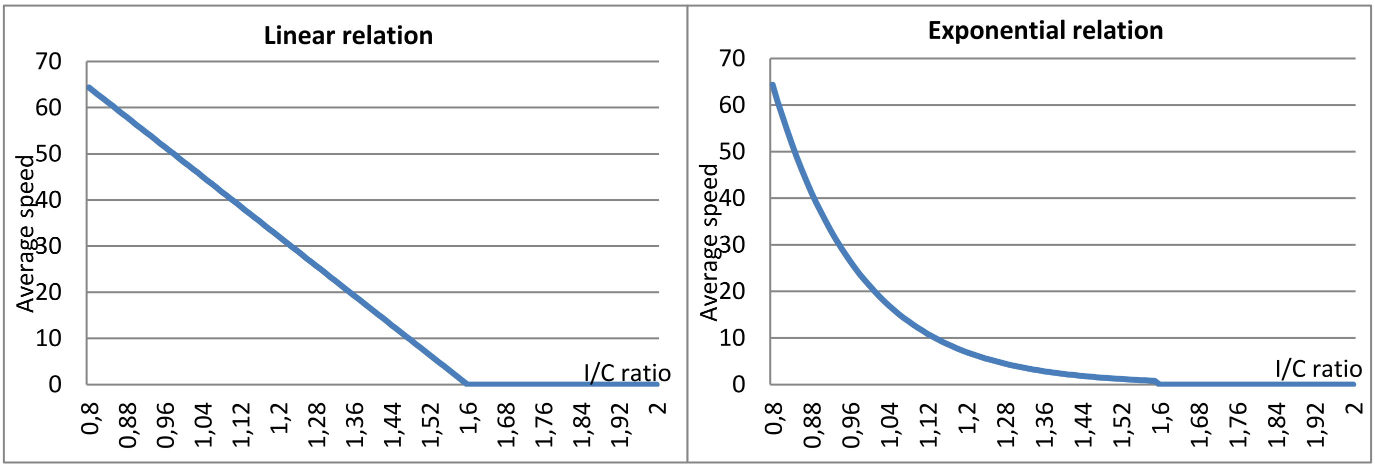


Figure 5.1: linear and exponential relation between the average speed and the I/C ratio

The outcomes of the tool differ much when this exponential relation is used in the tool (Table 5.3). The results of the tool are unrealistic when this exponential relation between I/C ratio and average speed is used. The NPVs in scenario high are too high compared to the NPVs in scenario low compared to outcomes of CBAs (Appendix I). This test could mean that a linear relation between the I/C ratio and the average speed is more appropriate for this tool, but it could also mean that another negative exponential function, e.g. with different input, would be more appropriate.

Table 5.3: the outcomes of the tool with an exponential relation between the average speed and the I/C ratio

	Widening of section B-C	Widening of section B-C and C-D	Widening of section B-C, C-D, and D-E	Widening of all sections
NPV in scenario low (in m €)	0	-80	-118	-147
NPV in scenario high (in m €)	1,462	1,337	1,141	849
Expected value delay (in m €)	657			
Expected value phasing (in m €)	714			

All respondents doubted whether the inclusion of the indirect effects and external effects creates added value or reduces the added value of the tool. However, these indirect and external effects are also currently included in CBA of road widening projects (Appendix I). Creating insights in these effects might be valuable for decision-making, for example when the effect on CO_2 of delay and phasing is subject to discussion in the process. In particular when there are differences between alternatives in the total external effects. For example, when a tunnel is constructed which permits capturing of CO_2. However, these effects cannot be adjusted per alternative in the current tool. Including this could be of added value when key indicators differ among alternatives.

Another reason for assessing the indirect and external effects in a real option tool is that road widenings do generate additional vehicle kilometres. Although the exact percentage is uncertain, this percentage should be somewhere between three and five percent (Kennisinsituut voor Mobiliteitsbeleid, 2014). This assessment could be improved by making this percentage flexible over all sections of the road in the tool to include the fact that the percentage of generated kilometres might differ in different types of phasing. On the other hand, it is uncertain how these percentages should be chosen. A fixed percentage for all sections could make more sense for a standardised real option tool.

The real option tool is marked as transparent by respondents C and D. For other respondents, the use of many key indicators in this tool is a point of criticism on this tool. However, all key indicators are also often used in CBA of road infrastructure projects (Appendix I). Some of these, e.g. the bandwidth of effects, are also prescribed in the application of CBA in the Netherlands (Romijn & Renes, 2013). Besides, the key indicators can be adjusted when there is a need to do so.

Respondent G explained that the negative effects of uncertainty should have been included in the tool and in ROA. This comment was made due to the fact that citizens might have a willingness to pay for certainty in policy decisions. More uncertainty is generated which might lead to a lower cost-benefit ratio with delay or phasing. However, it is currently unclear how large these effects are. Some costs of flexibility might be found by researching projects with a long delay and its associated costs, such as the project ‘A4 Delft-Schiedam’. The negative effects of uncertainty for society currently cannot be described in a standardised way. In the interpretation of the results by users of this tool, it would be good to describe that these effects should also be included in the value of flexibility.

However, one may wonder how problematic the negative value of uncertainty is and whether this may change the outcomes or optimal strategy when the measure is the widening of roads. The willingness to pay for more certainty might be relatively low for road widening projects, because people's behaviour probably does not differ much when there is uncertainty about the widening of a road.

It is important to mention that the current numbers resulting from the tool are only indicators of the effects of road widenings. It is important that these effects are interpreted by users as not precise values, as mentioned by some of the respondents. On the other hand, also in many CBAs the results are presented as numbers, but there is discussion on how these results should be interpreted. Numbers are always very specific and it is difficult to describe numbers in a non-specific way. In discussions, this can be especially hard, but it is important to mention that the tool's most valuable results are the relative values between the alternatives. The exact effects of phasing or delay can always be assessed with NRM in which more specific and valid results can be generated in a later phase of decision-making.

5.2.3 Flexibility of the tool

Some comments were made on the degree of flexibility of the real option tool in the interviews. The tool could be not flexible enough for use in practice. Flexibility was not included as a requirement for design in this research. Therefore, this section reflects on the degree of flexibility in this tool and reflect on the importance of a flexible design.

Flexibility of the tool is important, because road widening projects are complex and a wide range of characteristics of these projects are usually taken into account to describe the effects of these projects. Therefore, a wide range of programs and a wide range of measures are often used to improve the accessibility of regions. This wide range of measures and effects are currently not included, because only changes in the intensity and the capacity of the road are assessed. Only the construction of additional lanes and rush hour lanes are standardly included in the tool. On the other hand, all measures that have an effect on the capacity or intensity of the road can be assessed in such a real option tool. This includes all measures that increase the accessibility of regions, because these measures will mostly affect the intensity and capacity of roads. Therefore, the real option tool is also able to describe the effects of measures affecting the intensity, such as the 'Beter Benutten' program. For example, the tool can show the need for road widenings when other capacity-increasing or intensity-decreasing measures are implemented and it can show the resolving power of these measures. However, it can be problematic that the effects of these measures on the intensity on motorways are usually unknown and depend on multiple different characteristics of these measures (MuConsult B.V., 2013). Therefore, including these measures in a standardised way was very difficult in this research. This should be included in the tool when more information becomes available on the effects of these measures.

As described in section 5.1, some of the respondents did not judge the complex decision trees as problematic for decision-making. Others did judge the complexity of decision trees as problematic for decision-making, especially when the decision trees are available for everyone and are used in discussions among stakeholders in the decision-making process. For this reason, adding scenarios alongside scenarios high and low to the decision trees would for some respondents increase the added value of the tool. For others, this would definitely not be the case. Including more scenarios in the tool also increases the complexity of decision trees. Therefore, it is difficult to draw conclusions on the added value of the number of scenarios in this research. Probably, the added value of an increase in the number of scenarios also depends on how the tool is used.

Currently also only two scenarios are used in CBA. With the combination of scenarios in the decision trees, this tool already goes beyond, because the results of combinations of scenarios are assessed. Therefore, the criticism on the inclusion of more scenarios can be hesitated. There is also a practical problem in the inclusion of more scenarios. Adding scenarios on engineering constructions and on environmental conditions, such as the implementation of road pricing, is difficult to standardise in a tool. No key indicators are currently available for these scenarios. For scenarios high and low, key indicators on the growth in traffic are available (CPB & PBL, 2015). An easy solution for this problem is that the tool can run multiple times to assess the effects of these scenarios when this information is available. In the end, the expected value could be calculated based on multiple runs with different outcomes.

A trade-off was made between standardisation and flexibility in the tool. This friction between flexibility and standardisation in DSSs is regularly described in literature (Hanseth, Monteiro, & Hatling, 1996). The focus of the design of this real option tool was on standardisation as one of the main constraints. Therefore the flexibility of the tool may be limited. The more standardised the tool is in the application of road widening projects, the less flexible it gets in solving other types of problems. A both flexible and standardised tool of course creates most added value for decision-making, but is unrealistic. When a tool is very flexible, this would also increase the complexity of the task for the user. More input and knowledge of the tool interface is required.

5.2.4 Use of the tool

Some comments were made on the potential users and the usability of the tool in the interviews. Some difficulties came up on the usability of the tool. The difficulties in usability affect the added value of the tool. The extent to which this affects the added value of the tool depends on the user of the tool and their level of expertise. First, the potential user of the tool is described and after that the role of the tool in decision-making is assessed. Secondly, the usability of the sensitivity analysis is described.

It was suggested that the tool can be used by external consultants. There are two ways in which this can happen. A consultant may be obliged by RWS to use the real option tool when this consultant also performs the CBA of a project. A manual would be beneficial for the usability of the tool, but this manual falls beyond the scope of this research. In this way, also a phased alternative can be assessed in CBA of road widenings. Another opportunity is that a consultant might develop or use this real option tool to gain a competitive advantage. The results from the use of the tool can be presented in a report and this report can be used in the decision-making process. The use of the tool by an external consultant increases the level of expertise of the user, because a consultant can specialise in the use of this tool. On the other hand, it is uncertain if a consultant would use this tool for a competitive advantage, because the use of a real option tool should be profitable for the consultant. When there is no need for the application of the tool in decision-making projects, the consultants would also not use this tool to gain a competitive advantage.

There is a reason that external consultants should not use the tool. It could be problematic if the tool is used as a black box by external consultants. This could limit the transparency of the tool for decision-making. Therefore, it may be important that decision makers are also involved in the use of the tool. However, the use of the tool within RWS does not seem logical, because usually these kinds of tools that contain calculations are not used within RWS.

The governance of the tool was only briefly assessed in the interviews. However, governance is recognised as important by three of the respondents, because it can affect the added value of the tool. This is especially important when the tool is going to be used in practice. An external consultant may take the role of back office. All users of the tool should be able to obtain information on the use of the tool in the back office. When competitors of the back office company also use the tool, a competitive advantage for using this tool is no longer present. Therefore, the back office should be funded for this task. Feedback from users should be able to be given to the back office of the tool (Wright et al., 2011). It is of added value to have multiple types of communication available, for example a helpdesk, a telephone number, and an email address. Another role of the back office is keeping the tool up to date. Monitoring of the application of the tool is important for maintaining the quality of the tool (Wright et al., 2011). The acceptance and the effectiveness of the tool should be monitored. There could also be a role for RWS in the monitoring of the use of the tool.

RWS may have a supervising role in the governance of the tool. Another potential role is the role of financer of the tool, especially when RWS receives most added value in the use of the tool by external consultants. The back office can be assigned by RWS to an external consultant. It is important that the institutions are well established. Contracts between the main actors are mostly needed: the back office company and RWS. It is clear that bad or good governance of the tool has a large effect on the added value of the tool (Global Corporate Governance Forum & The International Center for Journalists, 2012). However, it remains unclear from this research how the governance affects the added value of the tool.

There seems to be no need that everyone in the decision-making process should be able to interpret the results. The decision trees could be evaluated internally within the organisations of important stakeholders in the decision-making process. A report or paragraph additional to a report on CBA containing most important conclusions is one of the options. This may fit well with the use of the tool by an external consultant, especially when the results of the use of the tool are presented in a report.

Another insight was created in the use of the tool for politicians. When the tool also needs to be of added value for politicians, the tool should also be able to create support in discussions. Besides, the tool creates added value when the tool can be used in an interactive setting (Te

Brömmelstroet & Bertolini, 2009). The incorporation of flexibility might be difficult to explain to electorate. Therefore, for politicians, it might also be valuable to add a paragraph in CBA reports where the value of flexibility is described. The tool can help in the composition of this paragraph. When there is no real need for flexibility in decision-making by politicians, the added value of this tool also decreases.

There is mentioned that the sensitivity in this real option tool does not give much information to the user. However, the sensitivity is reviewed as important by all respondents. Some recommendations were made in the interviews. Currently, in ROA, it is assumed that the probability of scenario high and low is one of the most sensitive input variables. Among experts, there is much discussion whether a probability can be directed to scenarios. However, the sensitivity analysis that is performed in this research shows input variables that are much more sensitive than the probability of scenarios (Appendix IX). Therefore, one may wonder if the focus on the direction of probability to scenarios high and low is justified from an added value perspective.

With respect to the criticism on the sensitivity analysis in this tool, there should be mentioned that a sensitivity analysis of the input variables is also not included in the current CBA tool. Therefore, a sensitivity analysis on the input variables, such as assumptions in the travel time benefits or assumptions in the use of key indicators, is not required for CBA performers. However, a test of the robustness is currently included in CBA (Appendix I). It would be good to include this test in this tool as this would increase the usability of the tool. Especially since this might also increase the added value for politicians (Mouter, 2015). On the other hand, the test of robustness can also be performed by the user of the tool and should therefore not necessarily be included in the tool. This is probably also done in the CBA tool. When the users perform the sensitivity analysis themselves, the user might also be better able to reflect on the effects of changes in input, being one of the main criticisms on this sensitivity analysis. The transparency of the sensitivity analysis is increased when the users perform the sensitivity analysis themselves.

5.2.5 Phase of decision-making

Most of the respondents recommend using this tool in the first phase of decision-making. This is consistent with the perspective of applying ROA in the first phase of decision-making that is present among practitioners and experts. Strategic tools are already used in this first phases of decision-making of road infrastructure projects.

There are some other reasons for using the tool in the first phase of decision-making that are consistent with the recommendations of the respondents to use the tool in the beginning of solving a problem. In the first phases of decision-making, bottlenecks and possible measures should be identified (Eijgenraam et al., 2000b). This tool can help in doing that. Key indicators can be used in this stage of decision-making, because usually more detailed information is unavailable. It is also valuable that this real option tool needs limited input on characteristics of projects, because the availability of detailed input in these phases of decision-making is potentially low.

For politicians, there is a need for more information on the effects of infrastructure projects in the first phases of decision-making (IBO, 2016). When CBA or related information would appear earlier in decision-making for politicians, the politicians are able to consider the more fundamental aspects of alternatives (IBO, 2016). This can increase the flexibility in decision-making.

Using a real option tool in a later phase of decision-making could also be of added value for decision-making. A more complex and tailored tool might be valuable, especially when NRM is applied and more robust input is available. There seems to be a trade-off between the complexity of the tool and the phase of decision-making in which the tool could be used. The current tool seems to be consistent with the characteristics of the first phase of decision-making. However, there does not have to be a choice between a tool in the first phase of decision-making and a tool in a later phase of decision-making. Different types of this tool can be used in different phases of decision-making.

5.3 Conclusion

The next question was central in this section: *What can be learned from comparing the current situation of decision-making in road widening projects and the situation in which a real option tool is available?*

The respondents make clear that the most important requirements for a real option tool are the connection with the user needs and its support in decision-making. Additionally, important criticism on the assessment of the effects of road widening projects in the tool was given during the interviews. Another important aspect for the respondents of a real option tool for its added value in decision-making is the transparency and usability of the tool.

The real option tool scores well on its connection with the user needs. Tools that are able to describe the effects of measures are also currently used in the first phase of decision-making. There is a lack of information on potential flexible alternatives and the value of flexibility for decision makers and politicians in specific in the first phase of decision-making. Then, the tool creates added value in the identification of flexible alternatives and the value of flexibility. Governance of the tool can be arranged by contracts and by a consultant that is responsible for back office tasks. Additional ROA methods in a real option tool besides the simplified decision tree method are not necessarily of added value, because binomial option pricing may be too complex, not in consistency with current methods, or might create incentives for strategic behaviour. Besides, there seems to be a limited need for additional scenarios alongside scenarios high and low.

The tool does not score very well on its exactness in the assessment of the effects of road widening projects. Effects that play a role in road widening projects are not included in the I/C ratio that is used in the tool. Compared to the current situation in which NRM is used in tools, this real option tool assesses the effects of road widenings less accurate. However, calculating the effects in a standardised real option tool with NRM is next to impossible.

It can be concluded that the tool supports well in decision-making. Compared to the current situation, the availability of a real option tool is of added value in decision-making processes.

Such a real option tool is currently not available. The tool could create support in discussions between decision makers. The tool could be added to CBA. It is most likely that an external consultant would use the tool and discusses the results in a separate paragraph within the reports on CBAs. This creates competitive advantage for the consultant or is required by RWS.

6. Conclusion and recommendations

This last chapter elaborates on the conclusions and recommendations of this research, including the design of the tool and the assessment of the tool. Section 6.1 describes the conclusions. Section 6.2 discusses the limitations and implications of this research. In section 6.3, recommendations for further research and recommendations for the application of ROA in road widening projects are made. Section 6.4 describes a personal reflection in which the researcher reflects on his research, and on his own ability to design the real option tool. Performing this research resulted in several lessons learned for the researcher.

6.1 Conclusion

The main question in this research was: *What is the added value of a real option tool for decision-making in road widening projects?* It is currently unclear how a real option tool should look like to improve the adoption of ROA in decision-making and how ROA should be standardised in a real option tool. Therefore, the requirements of a real option tool were identified in this research. A real option tool was designed based on these requirements and this real option tool was assessed in interviews.

The seven most important requirements for a real option tool that were identified are good implementation of ROA, good assessment of road widening projects, good use of data, high adaptability, high transparency, good user interface, and high support in decision-making. Besides, three main constraints were identified that limit the design of a real option tool: the inclusion of the 'Leidraad MKBA', the use of software, and the standardisation of a real option tool.

The real option tool that was designed included two ROA methods: simplified decision tree analysis and binomial option pricing. The main outcomes of the tool are the expected values of delay and phasing, the optimal strategy in each decision moments, and the optimal moment of investment. Basic input on the characteristics of the project is needed in the tool. In the calculation of the output, assumptions and trade-offs had to be made. Most assumptions were made on the assessment of the effects of road widening projects: the I/C ratio is used for the description of the travel time effects and the generated vehicle kilometres are used for the indirect and external effects. A trade-off between the quality of the assessment of road widening projects and the implementation of ROA in a tool was made. Another trade-off was made between the adaptability and transparency of the tool and the quality and the simplicity of the user interface. The case test, the black-box test, and the sensitivity analysis create confidence that the tool can be applied in a relatively easy way in practice. The tool is sensitive for changes in the input, but a small change in most questionable assumptions, e.g. the probability of scenarios, seem to affect the outcomes relatively little.

In the interviews, the connection with the user needs, the assessment of road widening project, and the support in decision-making were identified as most important requirements for a real option tool. In the first phase of decision-making there is a lack of information on potential flexible alternatives and the value of flexibility. The most important governance aspect of the tool concerns an external consultant that can function as back office. Additional ROA methods are not necessarily of added value, because these methods may be too complex, not in consistency with current methods, or might create incentives for strategic behaviour. To sum up, the tool scores well on the connection with user needs. The tool does not fully satisfy in its exactness in the assessment of the effects of road widenings. The tool creates additional insights for decision-making compared to CBA of road widening projects, namely the optimal investment strategy and the value of delay and phasing. For use, the tool could be made mandatory or could be used for competitive advantage by external consultants. Conclusions on the use of this tool could be included in CBA reports or the tool could be used in discussions between decision makers. This means that the tool scores well on its support in decision-making.

A real option tool has added value for decision-making in road widening projects. The tool has added value, because:

- Seven experts mention that the tool could be of added value for decision-making;
- A real option tool could be designed that incorporates all relevant requirements and constraints, even when trade-offs between requirements had to be made;
- A standardised real option tool is currently not available in decision-making of road widening projects and can be used relatively easy in the first phase of decision-making;
- The tool gives additional insights compared CBA in the identification of possibilities for flexibility and the value of flexibility in decision-making;
- Standardisation of ROA in a real option tool is possible: the tool could potentially be used in a wide range of road widening projects.

6.2 Discussion

This research describes the added value of a real option tool for decision-making in road widening projects. This section elaborates on the extent to which this research answers this question. In section 6.2.1, four limitations of this research are identified: the tool, the identification of requirements for design, the assessment of the added value of binomial option pricing, and the assessment of a real option tool in this research. Next, the results of this research are described in the context of ROA in section 6.2.2. The theoretical and practical implications of this research are described in section 6.2.3.

6.2.1 Limitations

The first limitation concerns the real option tool. The tool could be improved on several aspects increasing its added value. Enhancement can be made on the user interface and the presentation of outcomes. The communication of the tool can be improved by creating a manual. The effects of training and the availability of a back office for the tool should be included. Another aspect that needs improvement is the incorporation of network effects. The designs of different sections of a motorway affect each other and the secondary road network in multiple ways. Incorporating these effects might lead to different outcomes of the tool. The relation between the intensity and capacity is complex. Currently, the tool deals with this relation in a simplified way, not representing the complexity in this relation. The added value of the tool on decision-making will increase when all limitations are solved. Another limitation is that the tool uses many key indicators. This significantly reduces the applicability of the tool in a later phase of decision-making. Key indicators should always be used carefully. But, it is also uncertain if it is possible to develop a standardised tool without the use of key indicators, e.g. on calculating the travel time effects for so many different scenarios and options. The limitations of the real option tool in this research ensure that the conclusions may not be generalised for real option tools in other projects. Even when there are improvements in the design of the tool, there is confidence that this tool was able to assess the added value of a real option tool in decision-making in the interviews. The behaviour of the tool represents the reality as assessed in this research. Almost all respondents were satisfied with the tool that was developed and valued the tool to be of added value for decision-making.

Secondly, this research is limited in the identification of requirements for design. The requirements were not evaluated by experts before the tool was designed. This could have been beneficial, for example in the identification of flexibility as an important requirement for design. It was expected that this evaluation by experts would be problematic, because respondents might have no clear idea on how a real option tool should look like before such a tool would be available. It is also important to mention that many respondents had no experience in the design of tools or the calculations in ROA. Also the researcher had no experience in this, but was able to research a wide range of literature in a larger amount of time.

Thirdly, this research only limitedly assessed the effects of different ROA methods. The use of multiple ROA methods in a real option tool does not seem to be of added value for this tool. However, the application of binomial option pricing in this tool was only indirectly assessed in the interviews. The main reason was the limited amount of time available in the interview. Besides, there seems to be a negative perception on binomial option pricing or complex methods for decision-making in general. The binomial decision trees were not assessed in the interviews. Therefore, no real conclusions on the added value of binomial option pricing in a tool can be drawn, because this method was not assessed in the interviews.

Fourthly, the description of the added value in this research is based on the perception of experts involved in decision-making. An extensive test of the tool was not possible in the interviews, because only a limited amount of time was available. Therefore, the conclusions on the added value of the tool should be treated with care. The added value in this research is only implicitly assessed by asking experts on their opinion without letting them apply the tool in practice. The added value could be researched more intensive to improve the conclusions on the added value of a real option tool. Besides, only a limited number of experts were asked to judge the added value of the tool. Better insights would have been created by interviewing more experts. Experts with different expertise were interviewed and multiple perspectives were taken into account. Furthermore, literature research on a wide range of topics was used to identify requirements for design.

6.2.2 Discussion of ROA

Triantis & Borison (2001) identified three approaches for the use of ROA in practice: as a way of thinking, as an analytical tool, and as an organisational process. This research focuses mostly on ROA as an analytical tool and in a limited way on the other approaches. The main conclusion from a recent study on ROA from Van der Pol et al. (2016) points out that the identification of options in itself is more important than the exact valuation of these options. This could be in agreement with ROA as a way of thinking or as an organisational process. In this regard, it is surprising that in the interviews the use of key indicators and assumptions in calculations were most subject to discussion in the interviews with experts. This research shows that ROA has added value for decision-making when it is applied as an analytical tool. Therefore, the focus in the adoption of ROA should not only be on ROA as a way of thinking, but also on ROA as analytical tool.

It is currently unclear and there is no consensus on when ROA should be applied in the decision-making process. ROA might be of more added value for decision-making in a specific phase of decision-making. Based on this research, conclusions can be drawn on the added value of ROA in two phases of decision-making: the start decision and the exploration phase (Figure 6.1). The inclusion of flexibility is still largely possible in the start decision. The identification of possibilities for flexibility, which this tool does, seems to create most added value in this phase. The application of ROA in this phase also creates added value for politicians. They have a need for information on the effects of projects in the beginning of the decision-making process. The inclusion of flexibility might already be more difficult in the exploration phase, because flexibility can only be limitedly available here. The valuation of flexibility might create most added value in this phase. Currently, also the results of CBA become available in the exploration phase. The results of ROA or this tool can be added to the results of CBA in a report. ROA could be applied and also might be of added value in all phases of decision-making. However, implementing ROA in two phases of decision-making is already a large step to start with.

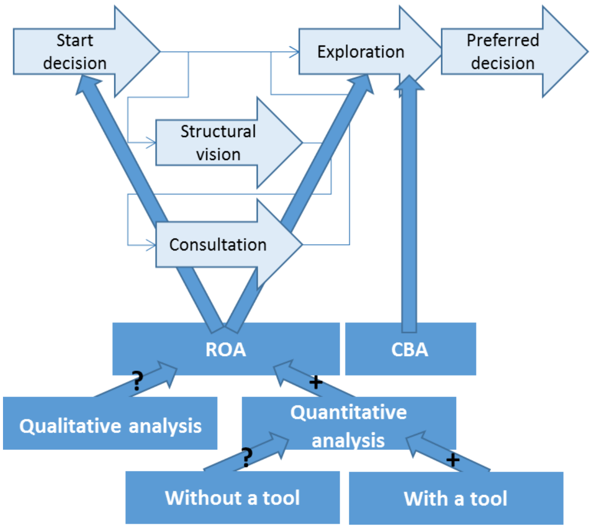


Figure 6.1: ROA and the phases of the decision-making process

A real option tool will not be the Holy Grail for the introduction of flexibility in decision-making, because decision-making is complex. Recommendations were made on the incorporation of flexibility in decision-making in a recent research (IBO, 2016). A political preference for a go/no go decision and the current budgeting strategy in infrastructure projects lead to difficulties in the incorporation of flexibility in decision-making. These difficulties cannot only be remedied by the application of ROA. However, ROA may play an important role in the incorporation of flexibility in decision-making. The potential added value of ROA is assessed e.g. by Van der Pol et al. (2016), but the practical application of ROA remains flawed. Besides, Annema, Frenken, Koopmans, & Kroesen (2016) state that ‘there is an increasing amount of evidence that CBA outcomes only have limited impact on political decision-making’. It is therefore highly uncertain that ROA will have large impact on political decision-making, because ROA is also an economic evaluation method.

6.2.3 Theoretical, practical, and policy implications

The theoretical implications of this research are threefold. First, the use of a DSS in decision-making might lead to adaption of a certain method, such as ROA, and improve the usability of this method. This tool could still be useful for decision-making when the numeric results of the tool are not as exact as desired. "All models are wrong, but some are useful" (Box, 1979). Secondly, this research supports the perspective that DSSs are valuable for decision-making. Thirdly, this research shows that ROA could be applied in a standardised way in a tool.

The practical implications of this research concern the adoption of ROA and a real option tool in practice. Rogers (1962) identified five stages in the adoption of tools: first, the generation of awareness of the existence of a tool, secondly, the formation of an attitude towards the tool, thirdly, a decision to adopt the tool, fourthly, the implementation of the tool, and fifthly the confirmation. This research focused on the first and second stage in the interviews on the tool. A focus on the decision to adopt the tool is the next stage for its adoption. For example, the tool could be made mandatory for external consultant in their assessment of the economic effects of road widening projects. In pilots, the tool can be further finalised and the added value of the use of the tool can become clear for decision makers. Positive experiences of the real option tool increase the aim of users to use the real option tool in a structural way (Vonk et al., 2005). Besides, it remains important to keep spreading the news of the existence of a real option tool and its added value (Vonk et al., 2005).

For policy, this research leads to the insight that a tool could lead to better understanding of the effects of road widenings with its insights in the value of delay and phasing. Potentially, better decisions on whether to widen a road, based on an economic evaluation, can be made with a real option tool. Besides, a real option tool could lead to the inclusion of flexibility in decision-making. This research creates confidence that standardisation of ROA, as how it is done in CBA, is possible, at least for road widening projects. This is potentially also the case for other types of projects on which decisions should be made and flexibility can be included. It remains unclear what the portion of added value of a real option tool is compared to the application of ROA in case-specific projects. It is difficult to describe the difference in the added value of a tool compared to case-specific projects, especially since ROA is not often applied ex-ante in decision-making in the Netherlands.

6.3 Recommendations

In this section, recommendations are elaborated for the application of ROA in road widening projects. Recommendations for further research are described afterwards.

6.3.1 Recommendations for the application of ROA in road widening projects

It is recommended to improve the current real option tool based on recommendations that were made in the interviews. The design of the tool is an iterative process that continues.

Although other methods than the simplified decision tree may be beneficial in specific projects, for road widening projects the application of ROA in by using the simplified decision tree may be fine. The two scenarios high and low can be incorporated relatively easy in the intensity of traffic. Besides, the limited number of decision moments was not a limitation of this tool for respondents. The absence of an optimal moment of investment was not mentioned as a shortcoming by respondents, although not specifically asked in the interview. Probably also since rough results are generated in the tool, an optimal moment of investments is not needed, because the validity of this number is then uncertain. In a later phase in the decision-making process there may be a need for an optimal moment of investment for which binomial option pricing should be applied. It is recommended to continue with the application of ROA in the simplified decision tree method and perform more research on the characteristics of projects when other methods are needed. For example, a framework can be developed with characteristics of projects and the ROA method that should be applied.

An alternative approach is to apply binomial option pricing to calculate the optimal moment of investment, and use this as input for the application of the simplified decision tree method. This could help in the identification of the right decision moments in the decision tree method. Another approach is to use different methods for applying ROA based on specific characteristics of the project in a tool. In this way, different methods cannot be used strategically by the user. A framework as described above can help in the development of this property of the tool.

Consensus on the ROA approach, as a way of thinking, as an analytical tool, or as an organisational process, should be reached to improve the application and adoption of ROA in practice. The approach for ROA as an analytical tool is beneficial for decision-making, because there is some added value of this tool for decision-making. Probably also the use of ROA as a way of thinking or as an organisational process is beneficial for decision-making. Which of them is best should become clear. It is also possible that consensus is reached among decision makers on the importance of all approaches together.

6.3.2 Recommendations for further research

The first recommendation for further research concerns the improvements that can be made in the real option tool. The current tool probably only fulfils the first phase iterations of an incremental systems engineering life cycle (Sage & Armstrong, 2000, p. 81). The tool can be improved based on the interviews with experts, but some improvements require more research.

- One of the perspectives that came up during the interviews was that politicians are looking for a reduction of uncertainty for electorate. Currently, the negative value of uncertainty for society is not assessed. The effects of this negative value of uncertainty are currently unknown. The willingness to pay for a reduction in uncertainty in road widening projects should be researched and included in the tool to improve the connectivity with the way of thinking of politicians.
- A standardised real option tool should be able to calculate many different outcomes for many scenarios. The I/C ratio seems to be a good approach to calculate many effects of different alternatives of road widenings in a relatively easy way. However, the effects of the use of the I/C ratio in this tool should be investigated more intensively to improve the validity of the tool. Here, it might also be valuable to compare the differences between the use of the I/C ratio and NRM that are most problematic in a real option tool. Furthermore,

standardised network effects and the specific characteristics of the road that matter should be researched. More research on the effects of the I/C ratio on the average speed is needed. Assessing the effects in a more dynamic way in the tool will improve the validity and practical applicability of the tool.

- Key indicators for flexible alternatives should be identified and included to improve the outcomes of the real option tool. The focus of research should be on key indicators on the costs of delay and phasing and key indicators on the effects of scenarios that include environmental conditions and the construction of engineering constructions. In this way, the tool is better able to describe the benefits of flexibility.

The added value of the tool for practical applications could be assessed in a better way in further research. Increasing the number and diversity of respondents could help to improve the conclusions on the added value of this tool. It would be good to test the tool in practice to assess what the real added value of the tool is and to test whether and how the real option tool should be applied in practice. The support for individual learning and its support in the communication and discussion should be researched specifically in this research (Pelzer, Geertman, Van der Heijden, & Rouwette, 2014; Te Brömmelstroet, Pelzer, Klerkx, & Schaminée, 2013). With these pilots, also the weaknesses of the tool can be described in a better way and therefore also the tool can be improved in a better way. Research on the added value of the real option tool can convince potential users to use the tool (Vonk et al., 2005). Furthermore, research can be performed on how governance should be exactly designed for the tool to create the most added value. It is currently unclear which actor should be engaged in the back office of a real option tool.

6.4 Personal reflection

In this section, I give a brief personal reflection on situations that appeared while doing this research. I give my reflection on the main issues, my actions in these situations, and the effects of my actions both positive and negative. The focus is on the reflection in the design of the tool, because my personal actions had the greatest effects in this research phase.

The standardised application of ROA in a tool appeared to be difficult. Especially calculating the travel time effects was difficult, because NRM could not be used and the use of a 5% travel time benefit seemed to work only in a situation with much congestion. The order of phasing would be depending mostly on the current speed and a difference between one or two additional lanes could not be made when I would have used this key indicator. Therefore, I decided to use the I/C ratio as an indicator for the travel time effects. This increased the complexity of the design task, because this made me calculating the effects for each combination of scenarios separately. Designing this model structure took some time and effort. My Excel and Visual Basic for Applications (VBA) skills improved during the design of this tool. I was able to improve my skills, because much information is available online. Of course, it was better if my skills were better in the beginning of this research. Then, probably also the quality of the real option tool might have been higher. Another effect of the standardisation of ROA was that I had to use many key indicators. This made me able to design the real option tool, but also reduced the exactness of the results of the tool compared to current analysis and models.

I had some problems in the design of the user interface of the tool. One of the reasons is that I did not have much experience in the design of a spreadsheet that needs to be used by others besides myself. One of the solutions was to design a dashboard with only input and output variables and to hide most of the sheets with calculations. I was wondering if this would not reduce the transparency of the tool to a too low level, but based on the interviews this is probably not the case.

The binomial decision trees were difficult to include in the tool for me. It was expected that it would be difficult to calculate the volatility, but based on the intensity of road sections in each region in the Netherlands, a scientific-based volatility could be calculated relatively easy. However, the communication of results turned out to be more difficult than expected. The availability of different outcomes would make the interpretation of the outcomes of the tool and therefore the added value of the tool more troublesome. I decided to leave out this method in the interviews. This made me less able to describe the added value of binomial option pricing in a real option tool for decision-making. This limitation of research is probably not problematic, because there does not seem to be a need for including binomial option pricing in a real option tool. It may be better to start with a relatively easy method for the adoption of ROA. When ROA is better adopted in decision-making processes, the complexity of methods can always be increased when needed.

I have learned that standardising a method is more difficult than expected. I improved my skills in Excel and VBA. I also learned much on decision-making processes, the role of different stakeholders, the effects of road widening projects, and the role of economic analysis in these processes. When I would do this research again, I would have focused only on the simplified decision tree method and would have included more flexibility in the design. I have certainly gained insight in the decision-making process in the Netherlands in this research.

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Appendix I. Analysis of CBAs of infrastructure projects

In this Appendix, the analysis of several CBAs of infrastructure projects is visualised. The CBAs were selected based on several characteristics that were assumed to be important for the design of the tool. Both regional and national projects were selected. The focus was on road widening projects. CBAs of different consultants and institutions were assessed.

CBA	Subject	Insights
Jonker et al., 2011	Type of project	Regional road widening project.
	Uncertainty	- In the implementation of other projects. - In the traffic density. - In the development of other roads. - In the regional development.
	Calculations	- The differences in morning rush and evening rush are assessed. - No CBA performed in this study.
Deviller & De Swart, 2012	Type of project	Regional infrastructure project.
	Uncertainty	- Amount of traffic in the future due to housing, road infrastructure and public transport. - The amount of traffic in freight transport
	Calculations	- Costs: investment costs and overhead costs (for both alternatives are overhead costs equal). - Travel time effects are calculated by the traffic model (NRM). - Reliability: 25% of the benefits for travel time. - Travel costs: both passenger traffic and freight traffic is included - Excise duties: based on vehicle kilometres. - Road widening leads to increase in reliability, because there is a parallel structure when emergencies occur. This effect is not monetised in this study. - Disturbance during construction is not monetised. - Indirect economic effects: a bandwidth of 5 – 15% is used depending on the location. - Phasing is of the road widening is calculated, not leading to significant improvements.
Hoefsloot et al., 2014a	Type of project	- National infrastructure project including road widening and construction of works - Conducted in the context of MIRT.
	Uncertainty	- Growth of the population leading to growth in traffic volume.

	Calculations	- In the calculations is VAT/BTW included - Overhead costs: different for the GE-scenario and the RC-scenario, because of differences in wages - Travel time effects are calculated by the traffic model (NRM). FOSIM is used to describe capacity for most complex parts of the road. The boundaries of the cordon in the model are to be determined. - Reliability: 25% of the benefits for travel time. - An increase in the use of motorways leads to a higher traffic safety. - An increase in traffic leads to a lower traffic safety, lower air quality and more climate change. This is calculated on the base of the MER (ideally), but can also be calculated with key indicators. - Indirect economic effects: bandwidth of 0-30% of the effects for cars is required. 15% is used here as this is usual. - Travel costs: based on costs per journey and the change in travel distance per journey. For new generated traffic, there is a cost reduction compared to the baseline, valued with the rule of half. - Excise duties: based on vehicle kilometres
Dusseldorp, et al., 2012	Type of project	Regional/national infrastructure project including road widening and construction of works
	Uncertainty	- Most significant uncertainty affecting the outcome is the amount of traffic in the future.
	Calculations	- Detailed traffic forecast were made, based on the methods proposed by Kennisinstituut voor Mobiliteitsbeleid. The outcomes are highly affecting the benefits of the project. - Only GE-scenario is calculated and sensitivity analysis is performed, based on the RC-scenario. - Reliability: 25% of the benefits for travel time. - Robustness: qualitatively included, because detailed information is missing. - The delay of the project leads to the same costs and benefits for project, but no different model calculations were performed.
Van der Meij et al., 2004	Type of project	Alternative 1 is about a road widening of the A50. A national road widening project.
	Uncertainty	- The amount of traffic (in this study, no GE scenario or RC scenario is assessed).
	Calculations	- In the calculations is VAT/BTW included. - CBA is performed based on already available information. - The travel time is adjusted, based on calculations from RWS. For each alternative, the change in traffic volume and travel time between alternative and reference alternative is calculated. - The road widening leads to a reduction in travel time and the amount of reduction is estimated independent of the traffic models.

		- The increase in the deliver reliability for freight transport: in accordance with similar studies this effect is 10% of the travel time savings for freight transport. - There is a decrease in traffic safety for wider roads.
Vervoort et al., 2015	Type of project	Regional infrastructure project
	Uncertainty	- The amount of traffic (instead of the GE-scenario and the RC-scenario, a middle scenario is used
	Calculations	- The regional traffic model 'Midden-Limburg' was used, what seems logic due to the regional character of the project. This model does not asses the generation of traffic. - In the calculations is VAT/BTW included with a percentage of 18.2%. Not all costs and benefits require a VAT/BTW. - The benefits of the construction of a park are included. - In the amount of traffic, the top of the bandwidth is between 168 and 112 less vehicle hours. - Reliability: 25% of the benefits for travel time. - Indirect economic effects: bandwidth of 0-30% of the effects for cars is required. - Traffic safety: decrease of injury victims of 2. - Noise: the threshold value of 48 dB for hindrance is used.
Wageningen UR & MU Consult, 2013	Type of project	Regional infrastructure project
	Uncertainty	The traffic growth is the most important uncertainty. The autonomous development is described.
	Calculations	- In the calculations is VAT/BTW included: 21%. - The positive outcome of the alternatives is due to the travel time savings. - Travel time effects are calculated by the traffic model (NRM). - A time period of 50 years is used. - Air quality: based on key indicators and the traffic kilometres per year from the traffic model. - The effect of CO_2: based on key indicators and the number of traffic kilometres. - Noise: the threshold value of 48 dB for hindrance is used. - The traffic models do not show significant changes in vibrations. - When roads are broadened, this can lead to higher traffic intensity, leading to a higher mortality of animals and more fragmentation of nature and disturbance. - The yearly costs of operation and maintenance are equal to 1.5% of the investment costs.

Decisio & 4Cast, 2006	Type of project	A large national infrastructure project, including road widening and the implementation of including the effects of a hard shoulder running including the construction of tunnels.
	Uncertainty	- The implementation of a national road pricing system. - The amount of traffic.
	Calculations	- The traffic intensities are based on different forms of road pricing and its effects. - The travel time savings are divided into freight, business, commuting, and other. - Reliability: 25% of the benefits for travel time. - The uncertainty in the implementation of a road pricing system affects the costs during construction, but this is not calculated here. - The indirect effects are either 7% or 9% for both alternatives, based on another study. - The external effects were not - The acquisition of land is distributed over a longer period, not completely realistic, because the accent of the acquisition will be on the first phase. - The differences in the uncertainty of the implementation of road pricing are assessed, based on another study. Probabilities of this uncertainty are not included. - Multiple discount rates are used, because the client asked to do so.

Appendix II. ROA methods

1. **Simplified decision tree**

Advantages	Disadvantages
Graphical representation of the problem (Van der Pol et al., 2016)	Inaccurate chances are usually unknown (Van der Pol et al., 2016)
Gives insights in the opportunities for including flexibility (Van der Pol et al., 2016)	A limited amount of choices and scenario's is possible (Van der Pol et al., 2016)
Can be made in addition to CBA (Eijgenraam et al., 2001)	There is not an opportunity to find the optimal moment of investment (Van der Pol et al., 2016)
Easy calculations (Van der Pol et al., 2016)	The assessment of the value of flexibility is relatively gargantuan (Van der Pol et al., 2016)
High transparency (understandable for a wide audience & easy to redraw and recalculate) (Van der Pol et al., 2016)	Real options are bound to assumptions (Van der Pol et al., 2016)
A fixed discount rate is used (Van der Pol et al., 2016)	A very complex decision tree leads automatically to dynamic programming (Van der Pol et al., 2016).
The scenarios from CBA can be used easily (GE scenario and RC scenario)	Is limited in handling new information becoming available (Van der Pol et al., 2016)
	A fixed discount rate is used (Van der Pol et al., 2016)

2. **Black-Scholes formula**

Advantages	Disadvantages
Can describe the value of expansion in a more expensive alternative (Van der Pol et al., 2016)	Just the delay of a project is assessable, the phasing of a project cannot be assessed (Van der Pol et al., 2016)
Only a limited number of assumptions need to be made (Van der Pol et al., 2016)	Uses doubtful assumptions: constant volatility, perfect markets, and a probability distribution of the benefits (Benaroch & Kauffman, 1999)
	Stapled options are not possible (Van der Pol et al., 2016)
	Low adaptability (Van der Pol et al., 2016)
	Difficult calculations for infrastructure projects (Van der Pol et al., 2016)

3. Binomial option pricing

Advantages	Disadvantages
Stapled options are possible (Copeland & Tufano, 2004)	Uses doubtful assumptions: constant volatility, perfect markets (Benaroch & Kauffman, 1999)
Less time steps are possible then in continues modelling, which could be valuable when investments are not possible on each moment in time (Van der Pol et al., 2016)	Difficult to integrate complex options, such as the construction of works. Usually this is necessary (Van der Pol et al., 2016)
Relatively easy mathematical calculations (Van der Pol et al., 2016)	The stochastics of benefits can be taken into account (Van der Pol et al., 2016)
If the change in climate is an uncertainty in the project, the application is less valuable (Van der Pol et al., 2016)	A sensitivity analysis should be performed to get robustness in the results (Van der Pol et al., 2016)
The generality is high (Van der Pol et al., 2016)	The assumptions have a technical character, leading to difficulties in communication (Van der Pol et al., 2016)
	Without many adjustments, the method can be used in different situations (Van der Pol et al., 2016)
	Communication with users is difficult: the verifiability of results could be low

4. Dynamic programming

Advantages	Disadvantages
The optimal investment strategy, for each scenario or situation, can be calculated (Van der pol et al., 2016)	No standard application available: implementation is specialised and time-consuming (Van der Pol et al., 2016)
Much freedom in design, leading to multiple types of application and the ability to implement multiple forms of uncertainty (Van der Pol et al., 2016)	Usually, a fixed discount rate is used (Van der Pol et al., 2016)
No assumptions on a perfect market (Van der Pol et al., 2016)	Functions in costs should be abstracted in the specific situation (Van der Pol et al., 2016)
Ability to produce a detailed economic analysis of flexible investment strategies (Van der Pol et al., 2016)	Relatively long calculation times (Van der Pol et al., 2016)
High adaptability: possible to respond to the future (Van der Pol et al., 2016)	Could result in a low transparency: checking the implementation by users is difficult and mathematical calculations are not especially open (Van der Pol et al., 2016)
Realistic assumptions can be made easily (Van der Pol et al., 2016)	
Usually, a fixed discount rate is used (Van der Pol et al., 2016)	
Can give insights in complex scenarios (Van der Pol et al., 2016)	

5. Monte Carlo simulation

Advantages	Disadvantages
Uses a probability distribution of one or multiple uncertain variables (Van der Pol et al., 2016)	Difficult to assess the probability distribution of variables: assumptions are needed (Van der Pol et al., 2016)
Highly suitable for complex decisions (Van der Pol et al., 2016)	The outcome is a probability distribution which is usually not sufficient for valuing flexibility (Van der Pol et al., 2016)
Options can be stapled (Van der Pol et al., 2016)	

Appendix III. Tools and requirements for design

1. Webtool MKBA Fiets: new infrastructure (Fietsberaad CROW, n.d.)

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• CBA for new cycle infrastructure. • Uncertainty is not taken into account: only the GE scenario is used.
Use of data	• The value of time is a 3-step variable: low, medium, and high. • For the reference alternative, number of bike trips and the average distance is needed. • For the project alternative, number of bike trips, the average distance, and the investment costs are needed.
Adaptability	• Possible to assess a wide range of bicycle infrastructure projects. • When more information is available, this cannot be adjusted in the tool.
Transparency	• Explanation of input and output is given. • A list of key indicators is available. • No transparency in data used for calculations. • No transparency in the calculations.
User interface	• Different settings can be adjusted: location, discount rate, operation and maintenance, modal shift from car and public transport, and the value of time. • Calculations are not visible. • Tool is online available in a webpage. • Dropdown boxes used for discount rate, operation and maintenance, and the value of time, resulting in a limited amount of options.
Support in decision-making	• Assesses two alternatives: a reference alternative and a project alternative • Only twelve variables are needed for calculation. • Few adjustments, based on specific situations, are possible. • Very limited methodological knowledge is needed for users. • All data should be adjusted: no bandwidths available.

2. Webtool MKBA Fiets: free guarded parking at the station (Fietsberaad CROW, n.d.)

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• CBA for the assessment of free guarded parking at stations. • Uncertainty is not taken into account: only the GE scenario is used.

Topic	Characteristics
Use of data	• There are 5 variables for input: investment costs parking, investment costs utilisation system, yearly costs for surveillance and enforcement, number of parking spots, and the expected average occupancy.
Adaptability	• Designed for a very specific decision: guarded bicycle parking at stations. • When more specific information on the project is available, this cannot be adjusted in the tool.
Transparency	• Explanation of input and output is given. • A list of key indicators is available. • No transparency in data used for calculations. • No transparency in the calculations.
User interface	• Different settings can be adjusted: replacement investments in percentage of the investment costs per 20 years (dropdown box), depreciation period, region (dropdown box), location (dropdown box) • Calculations are not visible. • Tool is online available in a webpage. • Dropdown boxes used for discount rate, operation and maintenance, and the value of time, resulting in a limited amount of options. • The visualisation of the outcomes is done in a bar chart.
Support in decision-making	• Assesses two alternatives: a reference alternative and a project alternative • Only twelve variables are needed for calculation. • Few adjustments, based on specific situations, are possible. • Very limited methodological knowledge is needed for users. • All data should be adjusted: no bandwidths available. • Three types of outcome are given: the social costs for the parking, social costs for taking the bus to the station, and the social costs for taking the car to the station. No benefits are available.

3. TEEB-stad (Platform 31, n.d.)

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• Describes effects of environmental projects. • There is an ability to assess multiple scenarios for the same project.
Use of data	• A lot of information should be adjusted by the user: little help is given: no bandwidths or averages mentioned. • All assumptions need to be done by the user itself. • References to data are described in the tool.
Adaptability	• There is a wide range of projects possible. • No adaption can be made when more information becomes available.

Topic	Characteristics
	• Adding effects when more specific information is available is not possible. • Changes in the tool cannot be made by the user. • The time horizon cannot be adjusted: 30 years is used.
Transparency	• A lot of explanation on effects available in the tool. Also references are used in the explanations. • Calculations of effects and value are directly visualised when a number is adjusted.
User interface	• A manual and an instruction video are available for users. • It is an online tool: a free account is needed for using the tool. • Effects must be walked through one by one.
Support in decision-making	• There is an option to immediately present the information to others. • In the output is only a number generated: the sum of all effects. • Only the benefits are described.

4. MKBA-tool Sociale Wijkteams (Vereniging van Nederlandse Gemeenten, 2015)

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• CBA in the social domain. • Uncertainty is not specifically mentioned.
Use of data	• The tool is made in Excel with three spreadsheets. • It presents key-indicators and, realistic input, and examples. Key-indicators can be adjusted. • Not able to use without manual. • If no information is available, a list of data from the manual is available, especially relevant for the first phase in the decision-making process.
Adaptability	• The tool can be adjusted manually, based on e.g. more information. • The tool can be adjusted relatively easy when more information becomes available, or adjustments in the design are needed, such as a change in key indicators or
Transparency	• No use of macros → all calculations are directly visible. • The calculations of the effects are not visible in the tool.
User interface	• Input and output spreadsheet. The input is divided into range, costs & effects. • No instruction in the tool itself, but in an additional manual. • In bar charts, the costs and benefits are visualised. • The costs, benefits, balance, and NPV are shown. • The costs and benefits for the coming years (9) are shown. • Numbers have to be adjusted manually, but recommendations on these numbers are visualised. • Yes/no options do use yes or no dropdown menus

Topic	Characteristics
Support in decision-making	• Can be used in three different stages of the decision-making: when little information is available and when detailed information is available. • The costs and benefits for multiple stakeholders are taken into account.

5. **Cost Benefit Analysis support tool for health interventions for rail companies (RSSB, n.d.)**

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• A business case of health interventions in rail companies.
Use of data	• There are no references to data. • There are some key indicators used. • Little data is used in the tool itself, although the problem is very specific. The data needed should be known for the user. • The costs are broken down in multiple pieces to make the assessment for users easier. • Descriptions on how to get information for the tool is provided.
Adaptability	• Key indicators can be adjusted if more information is available for the user. • Effects can be added or changed in the tool relatively easily.
Transparency	• Much information is provided in the help boxes. • Calculations are transparent.
User interface	• Tool is in Excel including the use of Macros. • Additional Support sections are available in the tool: in each effect a help box can be generated by clicking a question mark. • A spreadsheet with additional information is provided in the tool. • The length of the business case can be adjusted, and a bandwidth of 0 to 10 years is given; a longer business case is not possible and gives a warning. • Equations are shown in help boxes, but an implementation of these equations based on input is not given. • The macros are used for jumping between spreadsheets. • Examples of implementation are added to the tool.
Support in decision-making	• Costs and benefits of investments are assessed in multiple years and visualised in a graph with two lines: one for costs and one for benefits in different years. • Scenarios are not taken into account by the tool, but can be adjusted by the user.

6. **DAS/BEST Cost/Benefit Analysis Tools (State of Connecticut, n.d.)**

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• Cost-benefit analysis of IT projects.
Use of data	• No data is used at all.
Adaptability	• There is space for adding effects and adjusting. • The tool can be easily adapted, because it does not provide much guidance and just provides a design.
Transparency	• An enormous amount of information is available on aspects of the tool in different files.
User interface	• Only the layout of the tool is given. • No calculations in the tool. • A checklist of all potential costs and benefits is provided separately to the tool. • The tool is not easy to use at all.
Support in decision-making	• The tool is providing many insights in potential effects of IT projects. • Little structure and guidance is provided to the user.

7. **CBA Builder Advanced (CBA builder, n.d.)**

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• Cost-benefit analysis of multiple types of infrastructure projects • A sensitivity analysis is included to assess the effects of different account rates. • A sensitivity analysis is included to assess the effects of different time periods.
Use of data	• A time horizon of 20 years is used. • COBA method is used in the tool, including key indicators. • Multiple effects are taken into account: time-savings, environment and education, life and accident reduction and key indicators are used. • Multiple methods can be used for setting the horizon value.
Adaptability	• Alongside the effects with key indicators, multiple benefits can be included to assess other benefits than already in the tool. • Discount rate cannot be adjusted for every effect.
Transparency	• There is no transparency in the calculations of effects.
User interface	• The tool is available in Excel. • In the calculation of effects, cells in calculations are protected and not adjustable.

Topic	Characteristics
	• No project specific effects or costs are taken into account, but the focus is on calculations.
Support in decision-making	• The spreadsheet with results gives the NPV, the NPV including the horizon value, and the cost-benefit ratio. • The sensitivity analysis of the discount rate is presented in a chart giving the relation between the NPV and the discount rate. • The sensitivity analysis of the time period is shown in multiple NPVs, NPVs including the horizon value, and cost-benefit ratios.

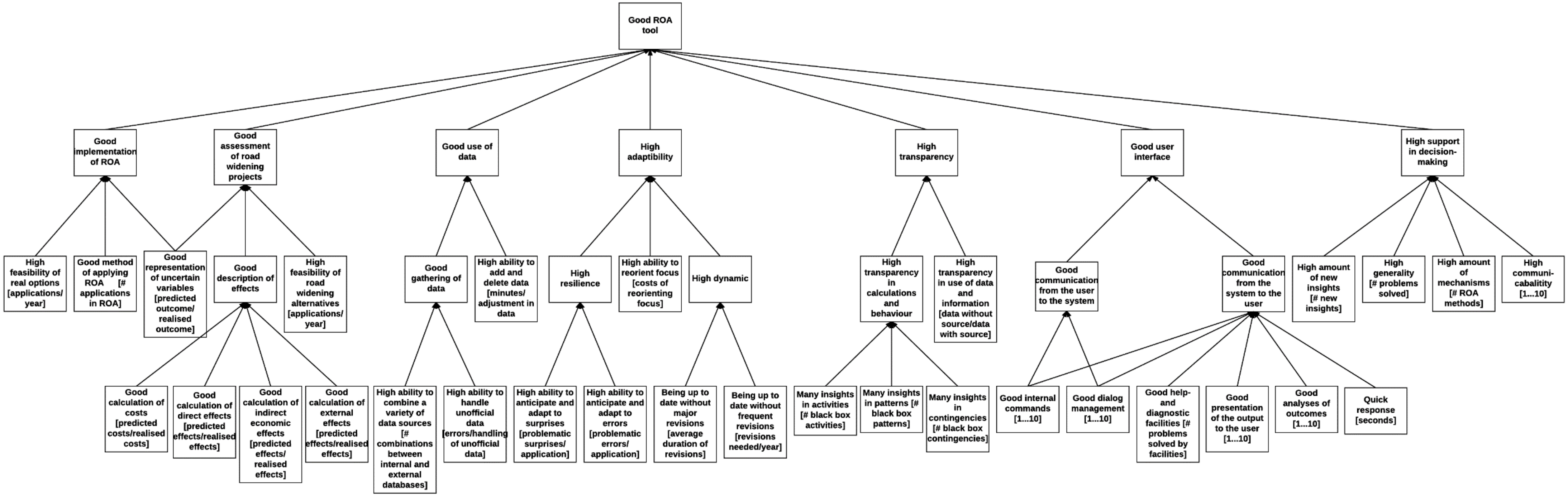
8. Deltaportaal (Deltacommissaris, 2014)

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• A web-based geographical presentation tool that provides information about the Delta model and Delta instruments.
Use of data	• Model based results on programs for fresh water and water safety can be combined with basic maps, such as infrastructure, boundaries, land use, functions, and values. • Data is divided into data from the Deltaprogram and data from other sources.
Adaptability	• It should be relatively easy to add information to the tool, but users are not able to do this by themselves. • A wide range of problems can be assessed, based on a large amount of data that is available.
Transparency	• All sources of data are accessible via the tool.
User interface	• The tool is mostly used by experts. • During the development, developers assumed that users were familiar with the terminology of the Deltaprogram. • A comprehensive legend is provided. • Maps can be added and deleted easily. • The real comparison should be made and interpreted by the user: comparisons are not made by the tool, only visualised.
Support in decision-making	• The information can be used to assess the combination of model results and other basic information on the Deltaprogram. • The tool creates insights in the effects of measures from the Deltaprogram. More specifically, in the national cohesion of the Deltaprogram.

9. Interventiecalculator (Ministerie van Sociale Zaken en Werkgelegenheid, n.d.)

Topic	Characteristics
Implementation of ROA	• No implementation of ROA.
Assessment of road widening projects	• CBA in the social domain.
Use of data	• It is unclear what kind of data is used. • It is unclear what and when data is used.
Adaptability	• The tool cannot be adjusted by the user and only specific problems can be assessed. • Additional calculations can be made after the first calculations are made when more information on specific aspects is available. This is mainly done for information where no results on research are available. This differs among different target groups.
Transparency	• Calculations and data are not transparent in the tool, but substance on these issues is given in separate files. References are given and there is an indication in the reliability of the factors: assumption or clear fact. • The effects taken into account are not clearly visible. • The effects among different organisations can be assessed.
User interface	• The tool is online available. • Examples of applications are available for users. • A manual is available for users. • One or two scenarios are used and can be manually inserted by the user via a dropdown box. • The costs need to be filled in by the user, with a dropdown box. • The tool does not correct for wrong input. • When not enough information is presented, the user is not able to let the tool calculate outcomes. • An instruction video is available.
Support in decision-making	• A breakeven point can be calculated. • A graphical representation of the breakeven point is shown.

Appendix IV. Objective tree



Appendix V. Dashboard of the tool

Dashboard

1. Invoer

Naam	**A-B**	**B-C**	**C-D**	**D-E**
Totale lengte (km)	2,4	3,1	2,1	1,1
Investeringskosten (in miljoenen)	26	34	64	32
Gemiddelde intensiteit in de spits per uur (personenauto's) in huidige situatie (voor 2 richtingen)	3300	4200	3700	3800
Gemiddelde intensiteit buiten de spits per uur (personenauto's) in huidige situatie (voor 2 richtingen)	1600	2000	2000	2100
Huidige situatie (voor 1 richting, waarbij beide richtingen gelijk zijn)	2 rijstroken	2 rijstroken	2 rijstroken	2 rijstroken
Maatregel (zelfde in beide richtingen)	Verbreding met 1 rijstrook	Verbreding met 1 rijstrook	Verbreding met 1 rijstrook	Verbreding met 1 rijstrook
Regio	West-Nederland Noord (WNN)			
Regio (provincie)	Noord-Holland			
Binnen/Buiten de bebouwde kom	Buiten de bebouwde kom			
Type weg	Snelweg			

Naar stap 3: resultaten

2. Aanpassingen door gebruiker

Verwachte toename in verkeersgroei (procent)				
Verwachte toename in verkeersgroei (jaar)				
Volatiliteit	0,43763%	Bereken volatiliteit		
Tijdshorizon (jaar)	100	Terug naar oorspronkelijke input		
Aantal beslismomenten voor uitstel	3			
Aantal beslismomenten voor fasering	2			
Beslismoment 1 (jaar)	0			
Beslismoment 2 (jaar)	10			
Beslismoment 3 (jaar)	30			
Beslismoment 4 (jaar)	50			
Beslismoment 5 (jaar)	70			
Kans op scenario hoog (procent)	50%			

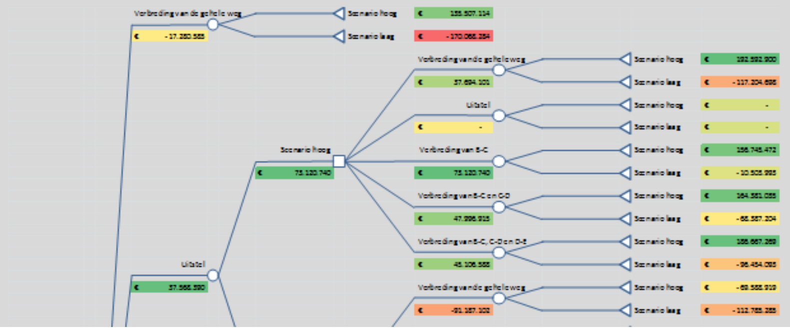
Visualiseer de beslisboom van uitstel | Visualiseer de beslisboom van fasering | Visualiseer de optimale strategie van uitstel | Visualiseer de optimale strategie van fasering

3. Resultaten

Alternatieven:	**Verbreding van B-C**	**Verbreding van B-C en C-D**	**Verbreding van B-C, C-D en D-E**	**Verbreding van de gehele weg**
NCW scenario laag (in miljoenen)	-20	-101	-140	-170
NCW senario hoog (in miljoenen)	136	139	129	146

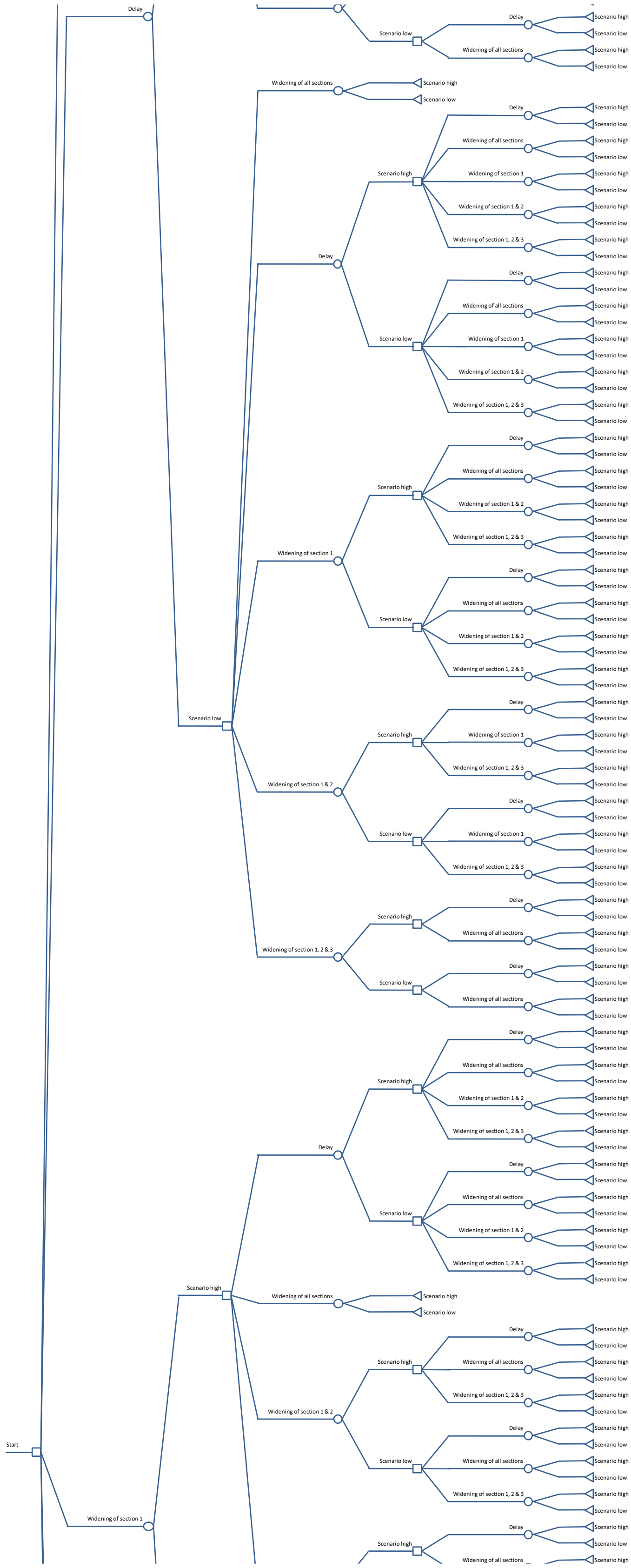
Verwachte waarde uitstel volledige constructie (in miljoenen)	30
Verwachte waarde fasering alternatieven met uitstel (in miljoenen)	39

4. Beslisbomen

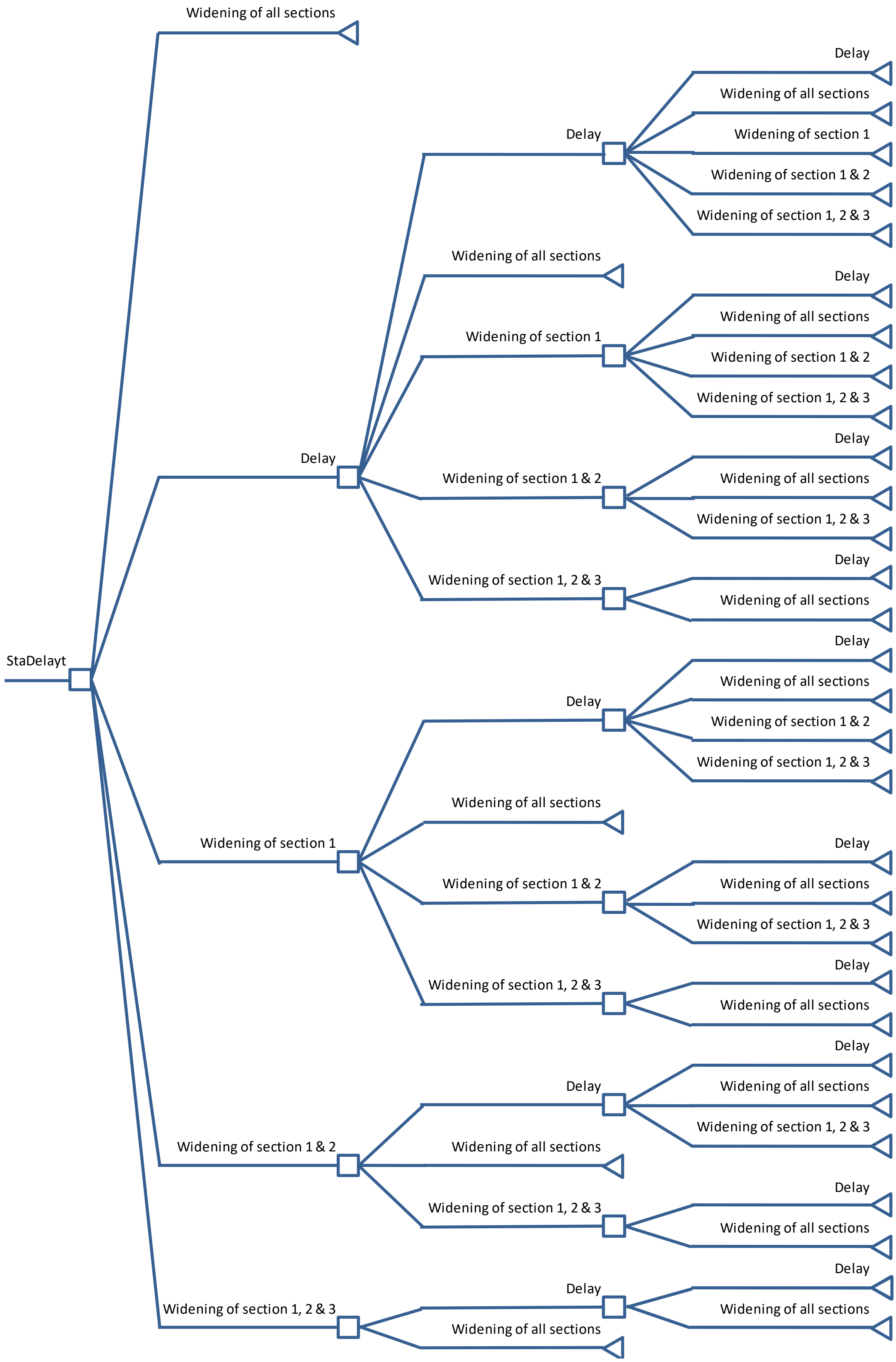


Appendix VI. Decision trees

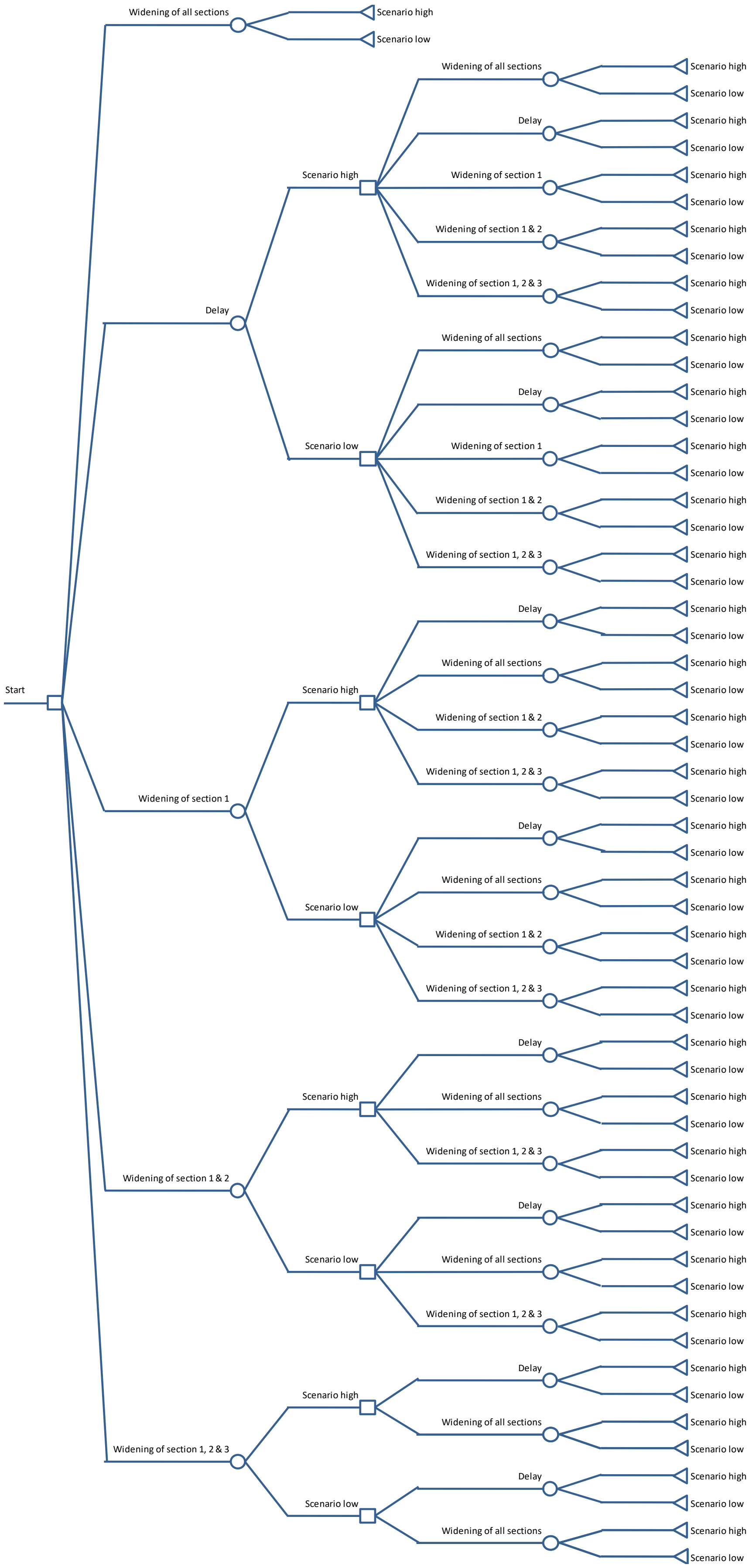
Decision tree phasing (3 decision moments, including scenarios) (partly)



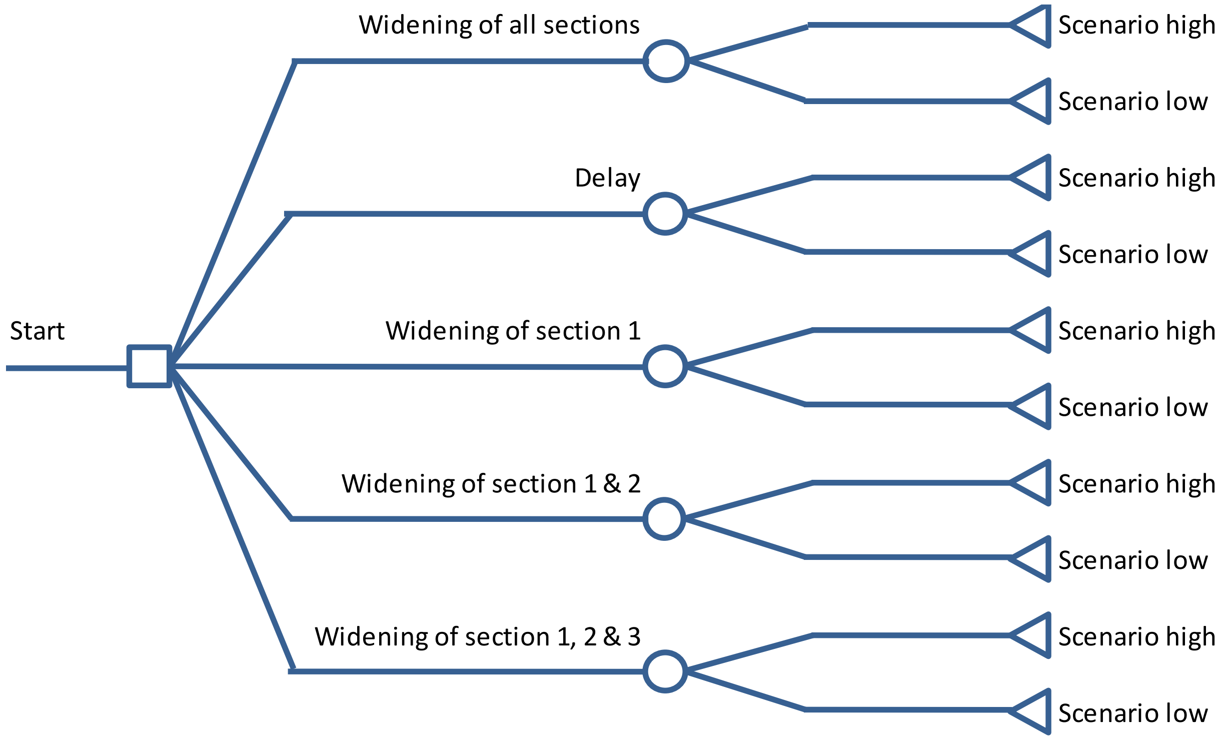
Decision tree phasing (3 decision moments, without scenarios)



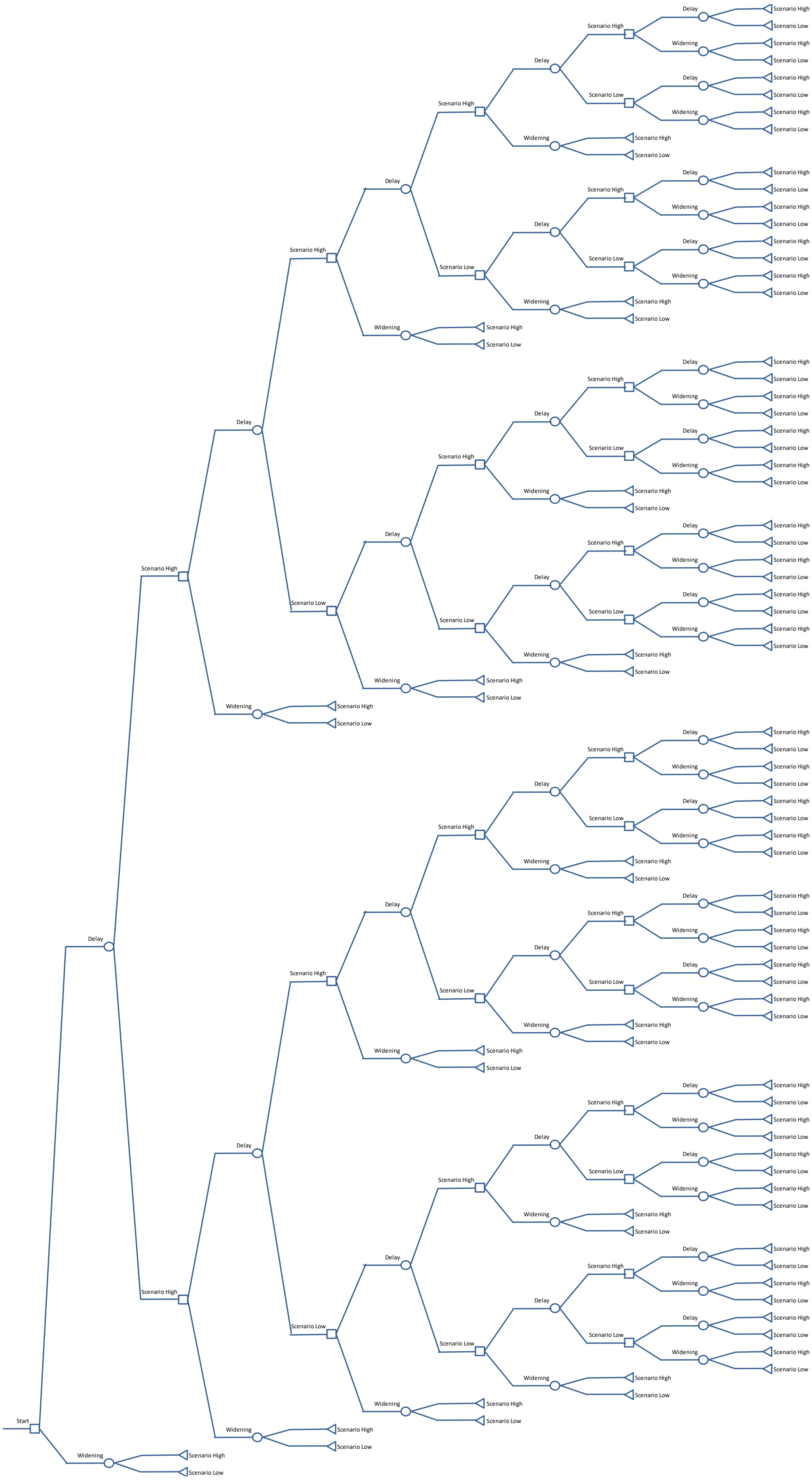
Decision tree phasing (2 decision moments, including scenarios)



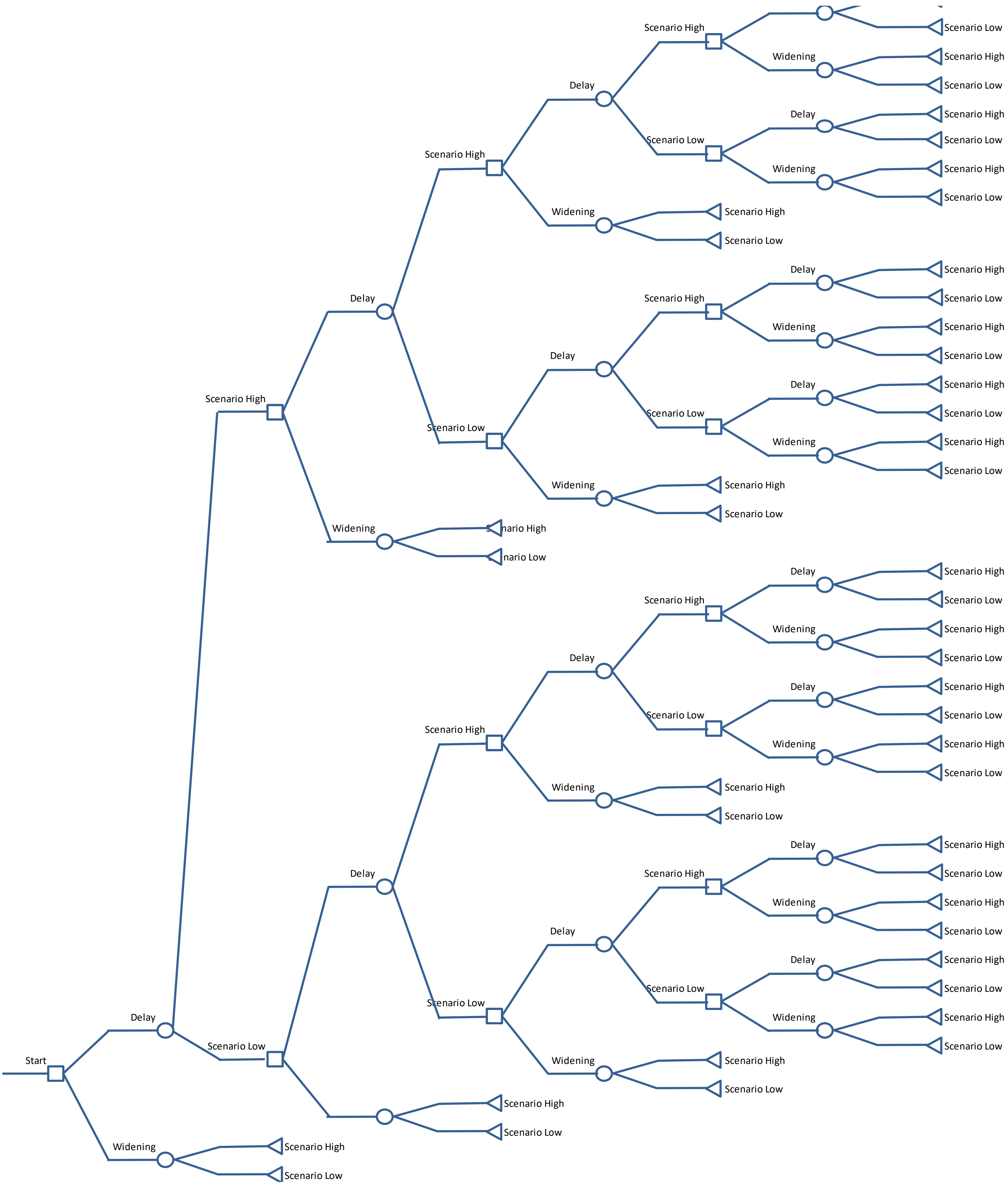
Decision tree phasing (1 decision moment, including scenarios)



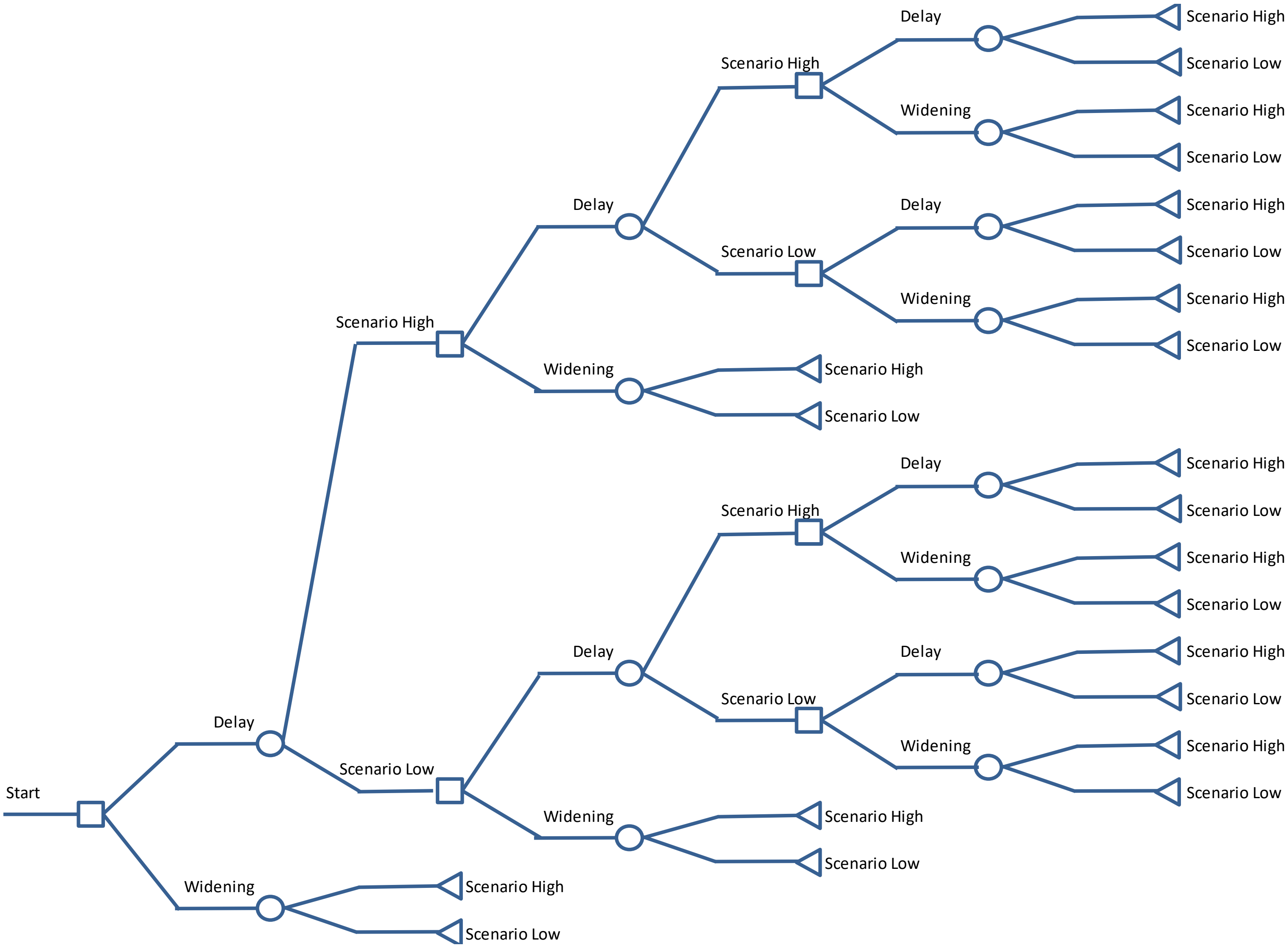
Decision tree delay (5 decision moments)



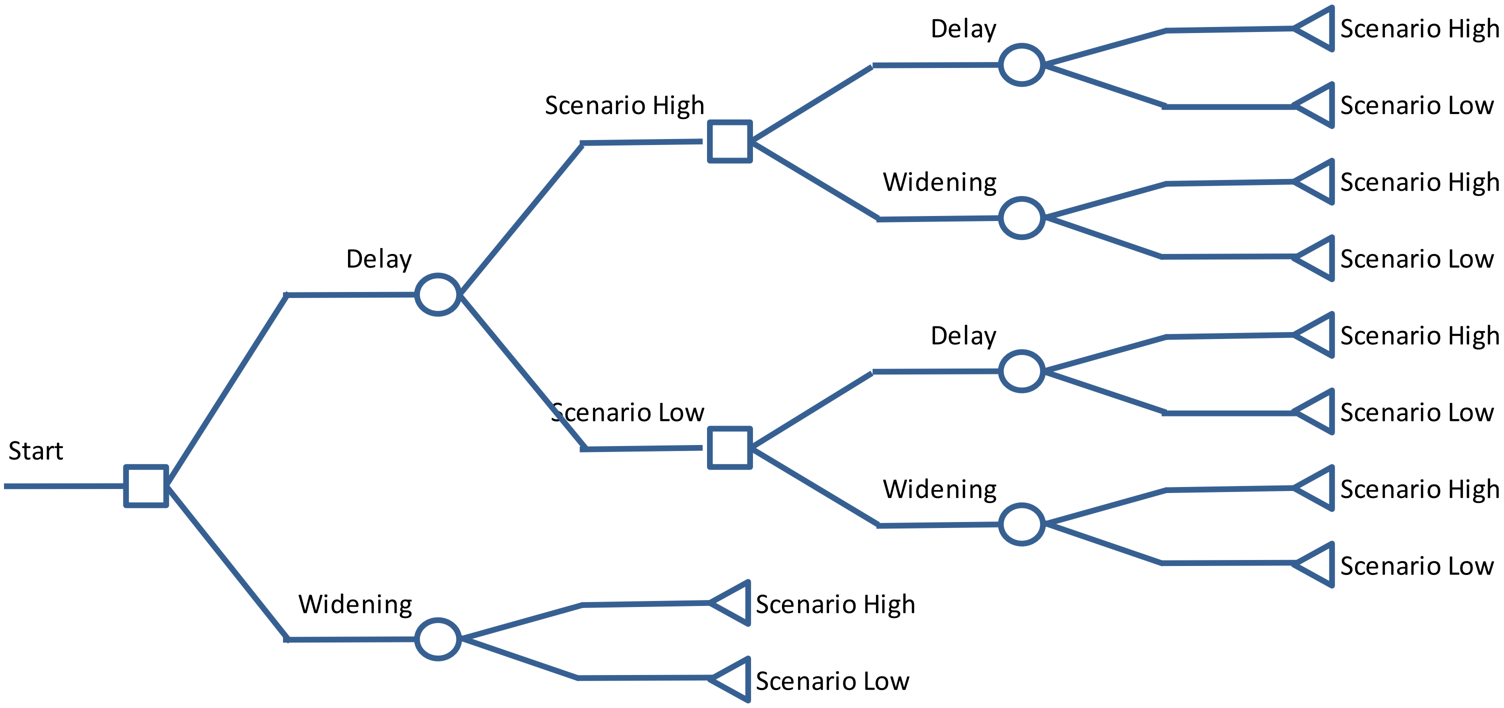
Decision tree delay (4 decision moments)



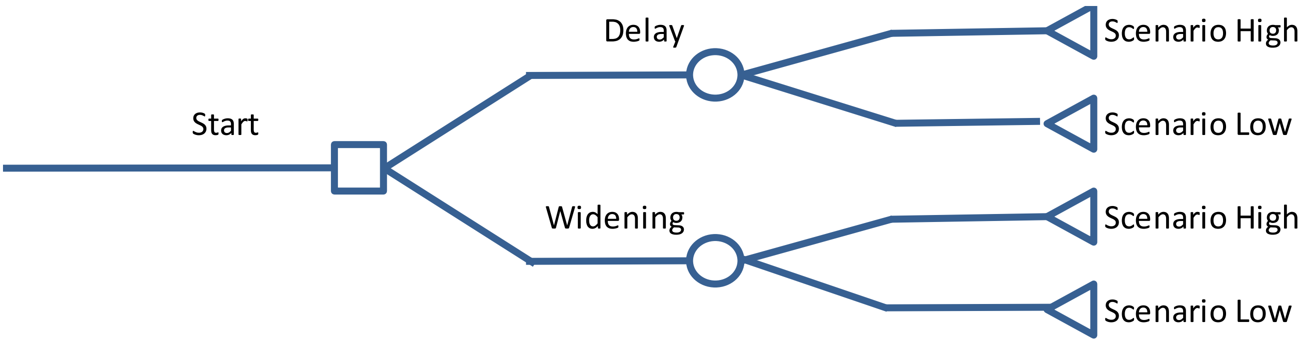
Decision tree delay (3 decision moments)



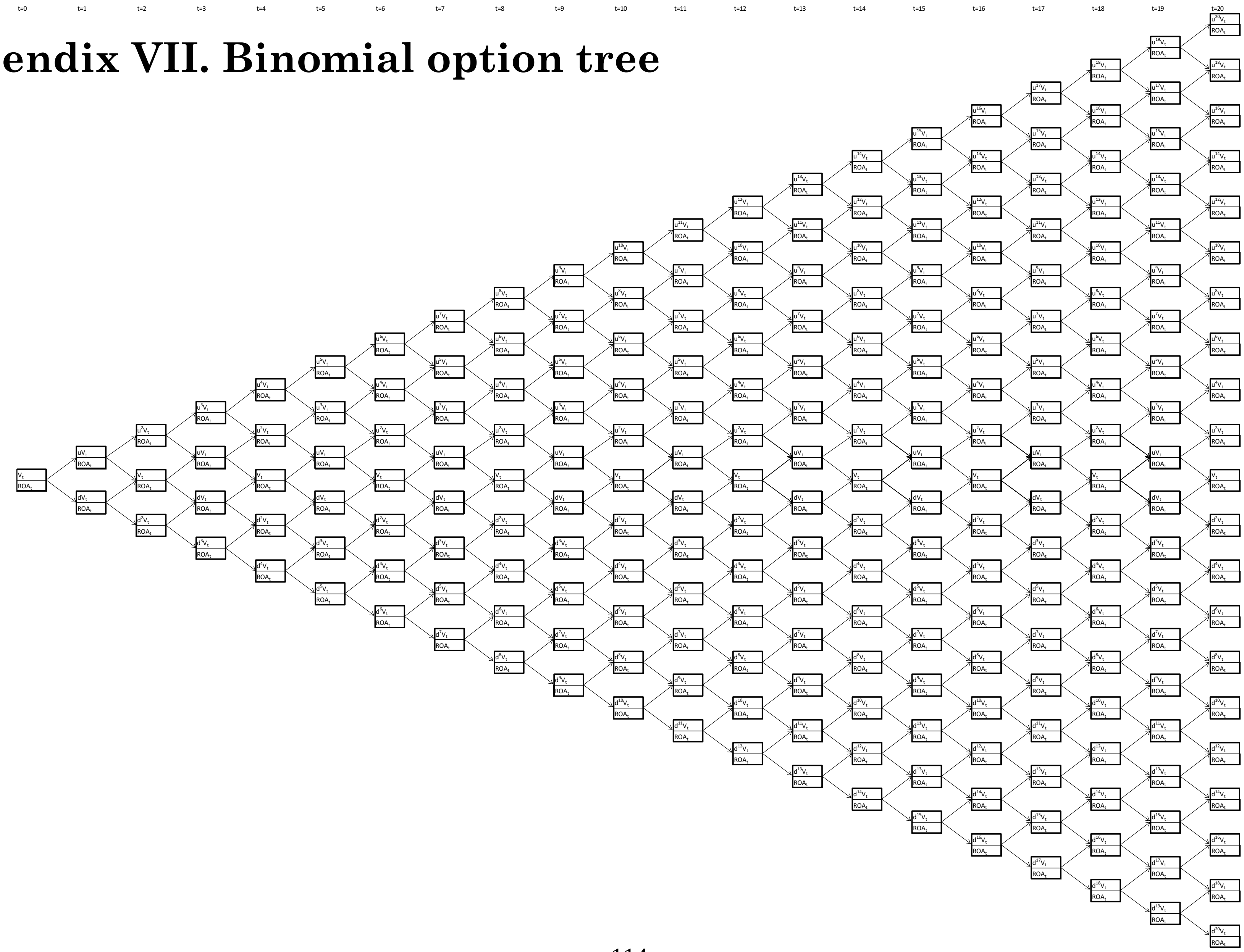
Decision tree delay (2 decision moments)



Decision tree delay (1 decision moment)



Appendix VII. Binomial option tree



Appendix VIII. Results black-box test

This Appendix describes the results of the black-box test. The input variables on which the effects were assessed are shown in the first column. A maximum time horizon of 100 years was used in the tool. Therefore, it was not possible to describe the behaviour of the tool of a very high time horizon. The second column shows the output variables of the tool. Several output variables were assessed in this test: 1) the expected value of delay and phasing, 2) the average NPV over all alternatives in scenarios high and low 3) the order of phasing of the sections of the road. The average NPV over all alternatives and scenarios was used to limit the number of tasks in this test. Besides, it was expected that taking this average would not result in different conclusions of the test.

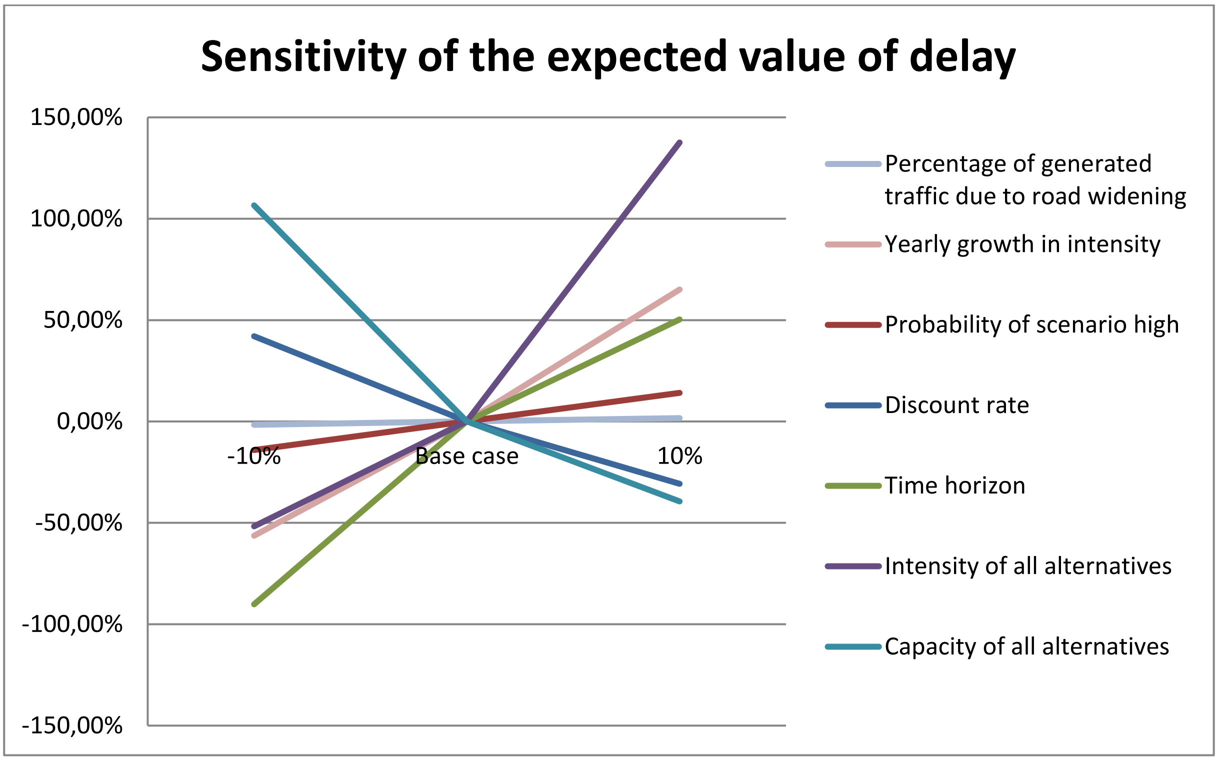
The third column describes the outcomes of the tool with the case input from section 4.4. The fourth column describes the outcomes when the input variable is adjusted to zero. The fifth column describes the outcomes when the input variable is adjusted towards a very high number. The height of the input variables is given in the first column.

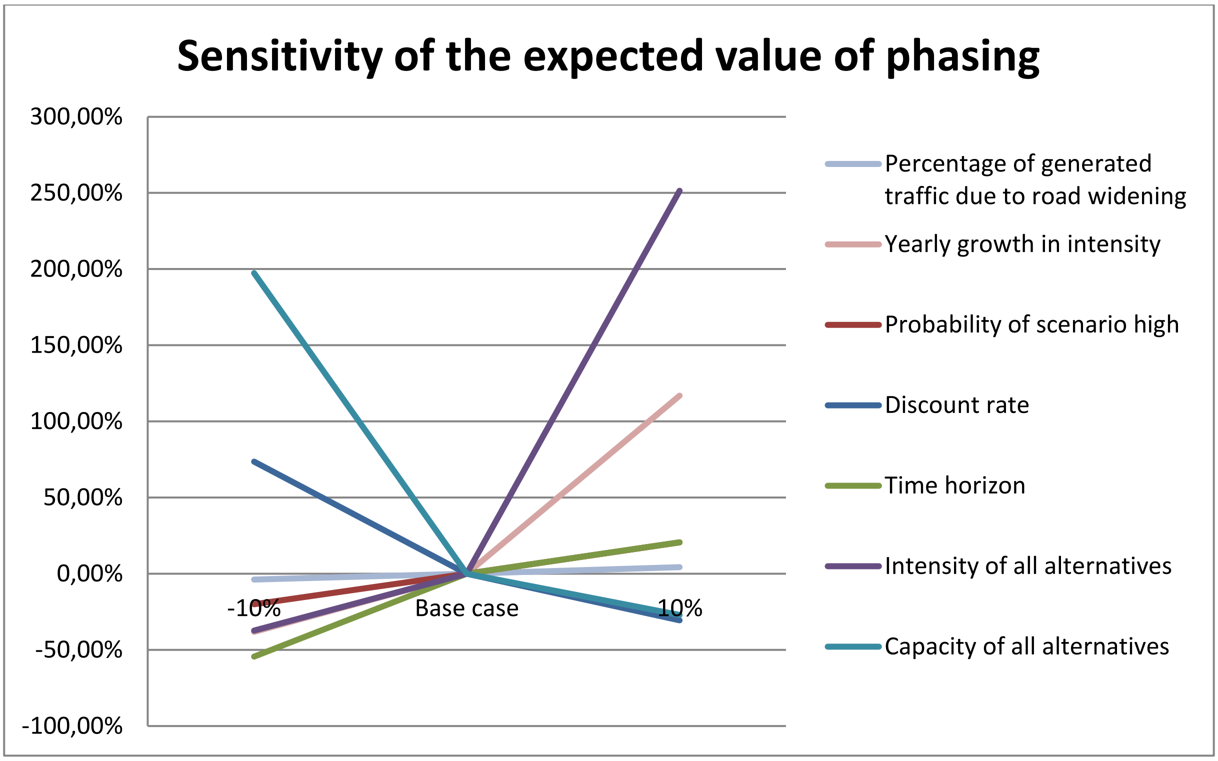
Input variable	Output variable	Outcomes with case input	Outcomes input variable towards 0	Outcomes input variable towards ∞
Intensity of all sections (0 and 100,000)	Expected value delay (in m €)	30	0	1,320
	Expected value phasing (in m €)	63	0	1,320
	The average over all alternatives of the average NPV of scenarios high and low (in m €)	15	-119	975
	Order of phasing	B-C → C-D → D-E → A-B	A-B → D-E → B-C → C-D	B-C → A-B → C-D → D-E
Capacity in the project situation (0 and 21,000)	Expected value delay (in m €)	30	0	41
	Expected value phasing (in m €)	63	0	81
	The average over all alternatives of the average NPV of scenarios high and low (in m €)	15	-99	49
	Order of phasing	B-C → C-D → D-E → A-B	B-C → A-B → D-E → C-D	B-C → C-D → D-E → A-B
Length of all sections (0 and 1,000)	Expected value delay (in m €)	30	0	92,842
	Expected value phasing (in m €)	63	0	92,842

Input variable	Output variable	Outcomes with case input	Outcomes input variable towards 0	Outcomes input variable towards ∞
	The average over all alternatives of the average NPV of scenarios high and low (in m €)	15	-119	69,207
	Order of phasing	B-C → C-D → D-E → A-B	A-B → D-E → B-C → C-D	B-C → D-E → C-D → A-B
Discount rate (0% and 50%)	Expected value delay (in m €)	30	2,757	0
	Expected value phasing (in m €)	63	2,771	0
	The average over all alternatives of the average NPV of scenarios high and low (in m €)	15	2,226	-87
	Order of phasing	B-C → C-D → D-E → A-B	B-C → C-D → D-E → A-B	B-C → A-B → D-E → C-D
Time horizon (0)	Expected value delay (in m €)	30	0	?
	Expected value phasing (in m €)	63	0	?
	The average over all alternatives of the average NPV of scenarios high and low (in m €)	15	-86	?
	Order of phasing	B-C → C-D → D-E → A-B	B-C → A-B → D-E → C-D	?

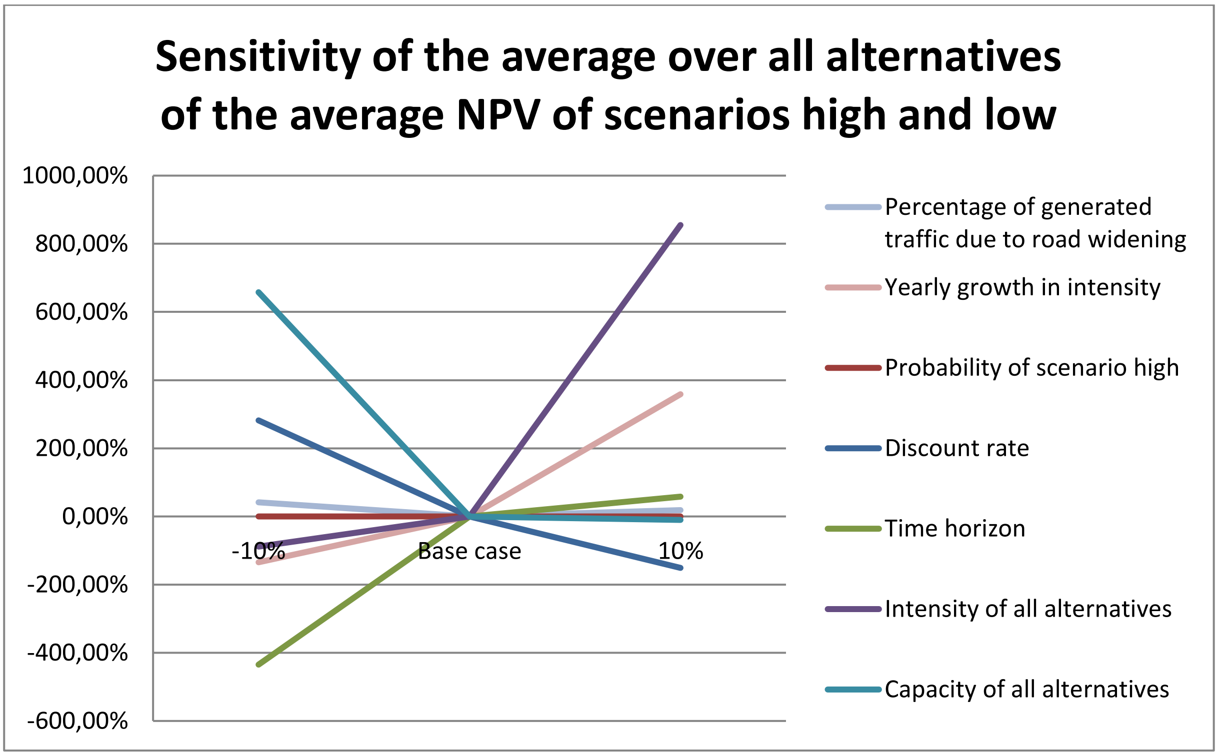
Appendix IX. Results sensitivity analysis

This Appendix describes the sensitivity analysis. In the sensitivity analysis, the outcomes of the tool were described, based on small changes in the input variables. The results of this sensitivity analysis are shown in the graphs below. In each graph, the proportional change in the output variable is shown, based on a -10% and +10% change in the input variables. For the sensitivity of the decision moments, a more difficult interpretation of the graph was needed. This is due to the fact that a percentage change is unavailable here. The optimal strategy is either changed or not changed. Therefore, for each change in optimal strategy a percentage from 1% to 4% was assigned. No value should be assigned to the height of these percentages.

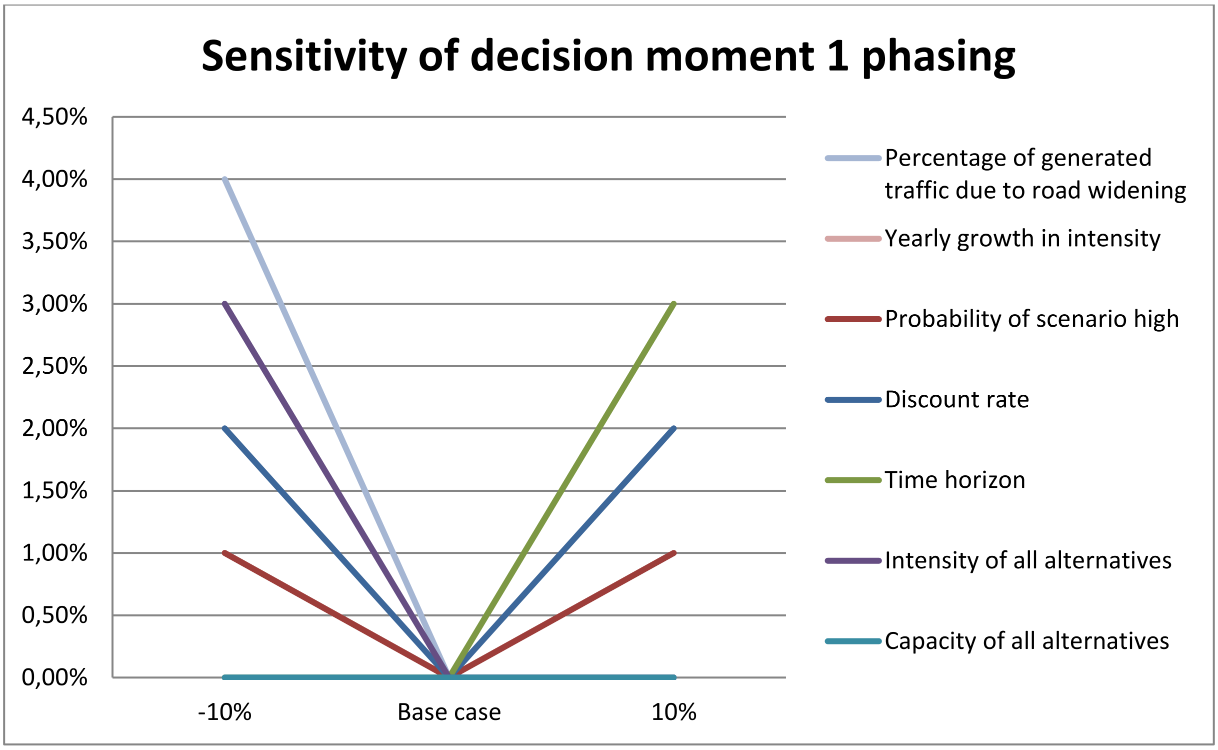


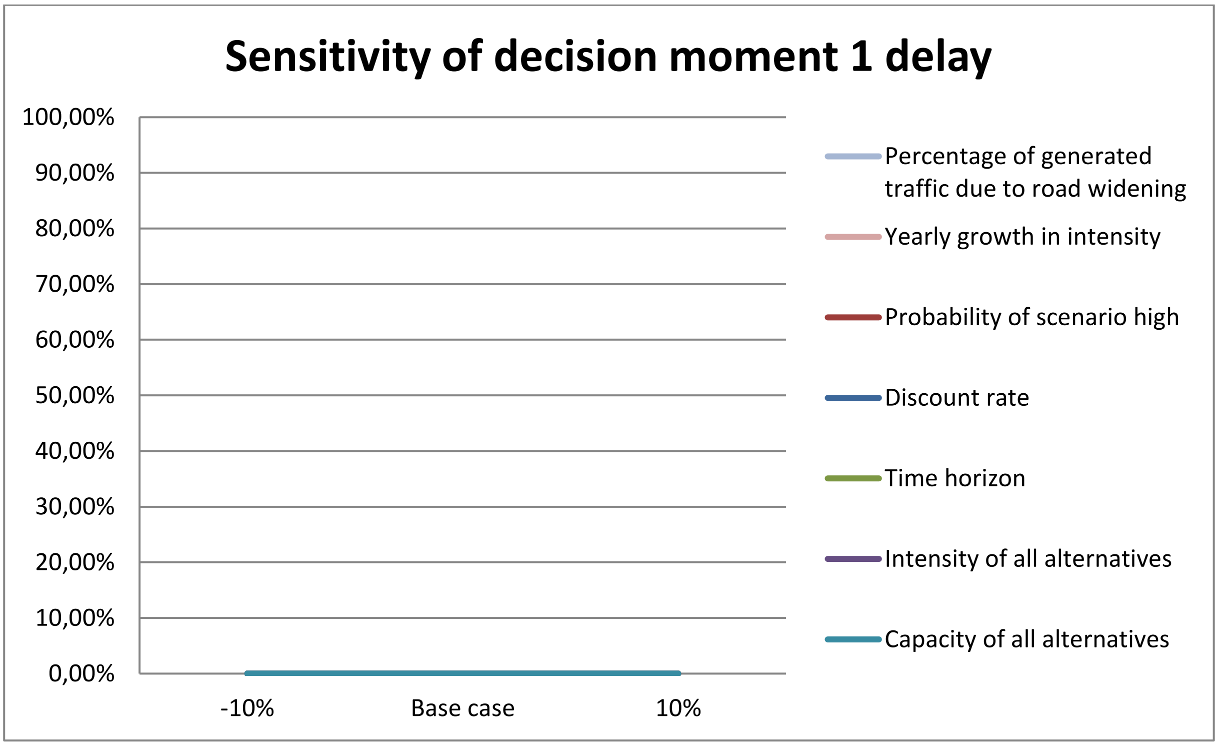


Sensitivity of the expected value of phasing
300,00%
250,00%
200,00%
150,00%
100,00%
50,00%
0,00%
-50,00%
-100,00%
-10%
Base case
10%
Percentage of generated traffic due to road widening
Yearly growth in intensity
Probability of scenario high
Discount rate
Time horizon
Intensity of all alternatives
Capacity of all alternatives



Sensitivity of the average over all alternatives of the average NPV of scenarios high and low
1000,00%
800,00%
600,00%
400,00%
200,00%
0,00%
-200,00%
-400,00%
-600,00%
-10%
Base case
10%
Percentage of generated traffic due to road widening
Yearly growth in intensity
Probability of scenario high
Discount rate
Time horizon
Intensity of all alternatives
Capacity of all alternatives


Sensitivity of decision moment 1 phasing
4,50%
4,00%
3,50%
3,00%
2,50%
2,00%
1,50%
1,00%
0,50%
0,00%
-10%
Base case
10%
Percentage of generated traffic due to road widening
Yearly growth in intensity
Probability of scenario high
Discount rate
Time horizon
Intensity of all alternatives
Capacity of all alternatives


Sensitivity of decision moment 1 delay
100,00%
90,00%
80,00%
70,00%
60,00%
50,00%
40,00%
30,00%
20,00%
10,00%
0,00%
-10%
Base case
10%
Percentage of generated traffic due to road widening
Yearly growth in intensity
Probability of scenario high
Discount rate
Time horizon
Intensity of all alternatives
Capacity of all alternatives

Appendix X. Interview protocol

Part 1: introduction and context

Introduction (5 minutes)

1. Thanking for participation.
2. Tailoring time use.
3. Introducing myself
4. Background and purpose of this research:
    - ROA is a method that can theoretically be of added value in decisions concerning public investments. In this way, it is a complement to adaptive programming.
    - However, the practical application of the method can be problematic. Therefore, I have been working on a real option tool that can simplify the application of this method.
    - The question rose whether a real option tool could be of added value for decision-making in road widening projects.
5. The purpose of this interview is to test and judge the real option tool to describe the added value of this tool.
6. Recording and elaboration of this conversation:
    • approval?
    • Report (No transcript) return?
    • Anonymizing?

Context (10 minutes)

7. Can you briefly introduce yourself and briefly describe your current job?
8. To what extent are you familiar with ROA or adaptive programming?
9. Do you use in your current work tools or methods to make choices / support alternatives?
10. If yes, please give an example and can you explain how this tool helps you?
11. Could you allocate 100 points across the following aspects in a tool, how much would you give every aspect? The aspect with the most points is the most important aspect:
    1. Connection to user needs
    2. Assessment of road widening projects
    3. Use of data
    4. Adaptability
    5. Transparency
    6. User interface
    7. Support in decision-making

→ Determine the order of interview.

Part 2: explanation ROA and tool (20 minutes)

Step 1: Show a general presentation and introduction on ROA.

Step 2: Show the tool to the user and show a (relevant) case.

Part 3: Questions concerning the added value of the tool

Connection to the user needs (10 minutes)

The following questions concern the choices made in the tool in the application of ROA and whether these choices reflect the wishes of the user. This refers to the method, the way options and alternatives are considered and the way uncertainty is included.

12. In this tool, ROA is applied in one way: by simple decision trees. Other ROA methods are possible, such as binomial decision trees, dynamic programming or Monte Carlo simulation. Is the use of one method sufficient? What methods would you like to see added? (This mainly concerns the added value of the number of methods).
13. The alternatives road widening and construction of additional lanes are included. Is this sufficient for practical problems?
14. It seems to be logical to first choose the most economically optimal alternative for phasing and then gradually the less optimal economic alternatives. This form of phasing is applied in the current tool. Separately, the postponement of the expansion of all parts used in the tool.

    Another possibility is to determine the sequence in phasing on the political most optimal alternative. Is this type of phasing also of added value or is economic staging better?
15. Uncertainty is captured in two scenarios: scenarios high and low with an impact on the traffic intensity in the tool. When an additional uncertainty besides scenarios high and low is added, a more complex decision tree will be shown. What would you prefer?
16. In addition, it is possible to include step-wise increases in the traffic intensity. This is taken into account at a specific time in the intensity in both scenarios. What do you think of this property and is it a useful feature in practice? Are there improvements?
17. Can you understand from the tool which investments would be (for example, the purchase of land) of added value for the project?

Assessment of road widening projects (7.5 minutes)

The NPV consists of the investment costs, operation and maintenance costs, direct effects, such as excise duties, indirect effects and externalities in this tool. The following questions concern the quality of the assessment of road widening projects in this tool.

18. The effects of road widening projects are based on a number of characteristics estimated in the dashboard: location (within urban / outside urban areas), the current situation, the number of additional lanes, the geographical location, the length, the

intensity and the investment costs. Do more types of inputs matter that are not included here?

19. The intensity/capacity ratio is used for the calculation of the travel time effects. The advantage of this approach is that we are able to calculate in a relatively simple way what the intensity does over time. In this way, many different results can be calculated. What do you think of this approach? Another possibility is the computation of the effects in a traffic model. A disadvantage is that for many different alternatives and in many scenarios, the effects should be calculated. What do you think of this approach?
20. Which improvement do you see in the assessment of road widening projects in the tool?

Use of data (7.5 minutes)

The following questions concern the data that used in the tool and its quality.

21. Is it clear for you what data is used as input for the model?
22. Multiple types of data is used:
    - Percentage operation- and maintenance costs for additional lanes and rush hour lanes per year (% of investment costs)
    - Reliability effects (in % of travel time savings)
    - Indirect effects (in % of travel time savings)
    - Additional car use due to road widenings (%)
    - Portion of freight traffic in traffic (%)
    - Capacity of an additional lane
    - Capacity of a rush hour lane
    - Key indicators for passenger traffic and freight traffic:
        - Travel time savings (€/hour)
        - Excise duties (€/kilometre)
        - Travel costs (€/kilometre)
        - CO_2 pollution inside and outside urban areas (€/kilometre)
        - Air quality inside and outside urban areas (€/kilometre)
        - Traffic safety inside and outside urban areas (€/kilometre)
        - Noise on primary and secondary roads (€/kilometre)
        - Traffic growth of passenger traffic and freight traffic in scenarios high and low (%)
23. Would you like to have the possibility to adapt this data?
24. How could the reliability of this data be improved?
25. In order to assess the sensitivity of the data, a sensitivity analysis is applied in the model. The results of this analysis are shown in graphs with the effects per sensitive variable. Do you have a preference for the visualisation of the sensitivity analysis and what is the importance of this sensitivity analysis?

Adaptability (5 minutes)

26. Is it important that a tool is easy to customise to users' own insights?
27. What would you like to adapt?
28. Would it be possible to assess other projects, no road widening projects, with this tool? How much time would it take you to do this?
29. Which improvement do you see in the adaptability of the tool?

Transparency (5 minutes)

The following questions concern the importance of transparency in a tool and to what extent this tool is transparent in use.

30. How do you consider the importance of transparency in a tool?
31. Is the use of formulas transparent?
32. Is the use of data and information in this tool transparent?
33. To what extent does Excel support transparency in a tool?
34. Which improvements do you see in the transparency of the tool?

User interface (10 minutes)

The interface guides the communication between the user and the tool. In this tool, the dashboard support mostly in this communication. The following questions concern the quality of the user interface of this tool and its importance.

35. How important is a good user interface?
36. Is it easy to interpret the various components of the tool?
- The dashboard?
- Data that is used?
- The results?
- The sensitivity analysis?

37. Is it in the current design clear what the key information and outcomes are?
38. What do you think about the use of Excel in this tool, concerning the user interface?
39. Does the model run fast enough?
- Runtime of the sensitivity analysis?
- Speed in obtaining results after opening?

40. Which improvements do you see in the user interface of the tool?

Support in decision-making (15 minutes)

Because of the possible practical application of this tool in decision-making processes, the following questions concern the extent to which the tool can support the decision- making process.

41. Does the tool generate new insights?
42. Which insights does the tool generate?
43. Would you make a special effort for these new insights through the use of this tool?
44. At which stage of decision-making does the tool create most added value?
45. Do you see added value in the application of this tool?
46. Which sections of the tool generate the most added value/the least added value?
47. Would you use the tool?
48. Which improvements do you see in the support in decision-making for this tool?

Part 4: End

Closure (5 minutes)

49. Do you have questions or comments?
50. Thanking for the interview.
51. Make an appointment about sending a summary to make corrections.
52. Do you want to receive my thesis when it is finished?

Appendix XI. Reports interviews

1. Report interview with a researcher from CPB

Organisation	CPB (He gives his opinion on his own behalf)
Position	Researcher
Date	19 October 2016
Time	16.00
Duration	1 hour and 10 minutes

Part 1: Introduction

The respondent is researcher at CPB and is involved in research projects on CBA and methods related to CBA. He has a background in environmental economics and some operations research methods, including dynamic programming. He did research on real options analysis and was involved in applications of the simplified decision tree with a limited amount of decision moments. He made clear that the interview represents his own opinion and not the opinion of the CPB. In his work, the respondent does not use much pre-designed tools himself.

In the beginning of the interview, he explains the current issues in the application of ROA. These issues are twofold: both practical and theoretical. Most important theoretical issue is the difference between risk and uncertainty. In infrastructure projects and in CBAs, uncertainty is used wherein no probabilities can be given to different scenarios. In this way, it is difficult from a theoretical perspective to apply ROA as well as CBA in public projects.

All aspects of a tool that are mentioned in the interview are important for him. The connection with the needs of the user is specifically described as important. To test this connection, it could be helpful to assess a current CBA and the complexities within this CBA to see how the tool should behave.

Road widening projects are especially complex and are not only about the decision of additional lanes or rush hour lanes, but also about engineering constructions, such as bridges and tunnels. Therefore, many decisions have to be made in one project making the CBAs of these projects relatively complex. Giving transparency in how flexibility can be included in these projects could help.

The good use of data is important in a tool, but the data that is used in the tool should just be correct. Compared to data, the outcomes create most of the added value of the tool. ROA should be used in the beginning of the decision-making process to get an early overview of the decision problem and to identify flexibility in projects.

Part 2: Presentation of ROA and the tool

Much of the information in the second part was already known for him. During the short presentation and the presentation of the tool, the following comments were made:

- How are the travel time benefits determined?
- It is important that a fixed discount rate is used, because this is currently prescribed in the Dutch CBA guidelines.
- The length of the time horizon should be depending on the decision moments, especially when the decision moment is close to hundred years from now. However, this is a small detail.

Part 3: Questions related to the tool

Assessment of road widening projects

The approach for determination of the travel time benefits seems fine for him, but only for illustrative purposes. Ultimately, the effects are available from a transport model and these more reliable effects are used in this tool.

The focus of this tool is on the decision whether to widen the road itself, but most of the costs in these projects have to do with the engineering constructions. It would be good to include more flexibility in these engineering constructions, because one can expect that the value of flexibility in these constructions is high.

The use of key indicators in the assessment of indirect and external effects reduces the relation with the reality. On the other hand, these effects could affect the strategy when the option could affect the amount of CO_2 or particulates, e.g. with tunnels. It could be helpful for illustrative purposes to assess the indirect effects and external effects. Therefore it is important to present the numbers as to be used for illustrative purposes and not for decision-making. The key indicators are not accurate enough for use in practice in the decision-making process. The use of transport models and assessing the effects based on the transport model is better. However, the key indicators that are used in this tool are a good starting point.

Connection with the needs of the user

The characteristic that a road can be divided in four sections is an important limitation of the model. In reality, there could e.g. be many more decisions or restrictions within a section, making the alternatives used in the model less useful. Flexibility in the tool in the use of these four sections is useful for the use of the tool in reality. In practice, the choices are often limited due to environmental and political limitations. On the other hand, there could potentially be much more than just four alternatives. The more flexible the model is, the better it gets. The disadvantage of this tool is that the specification of the problem is already imposed by the tool. It could be better to first draw the decision tree for a specific project and then change the model to connect the specification with the practice. Designing a more flexible tool could be possible, but could take much time and effort.

The economic phasing of alternatives as discussed seems logical for him. However, in reality this could be different. With a more flexible specification of the tool it is possible to design a tool more towards the problem. Then, this assumption for phasing would be less problematic. Usually, there is an urgent problem when a CBA is made making this assumption different from reality. The identification of flexibility is most important what ROA and such a tool could do as this identification of flexibility seems difficult in practice. When there is too much specification, the identification of flexibility becomes difficult.

Applying more methods in addition to simplified decision trees would not be necessarily better. The use of the binomial method has some drawbacks. Especially the communication of the binomial decision tree could be troublesome. Furthermore, the use of a flexible discount rate in the binomial model is not suitable in the Dutch CBA context. Thirdly, the binomial model assumes uncertain solution in which at a certain moment the value is exactly known. The added value of the binomial model could be low.

He reflects on the use of scenario high and low with the comment that additional scenarios could be beneficial in certain projects. He also recognises that there is a trade-off between scenarios and the complexity of the decision trees. Adding more scenarios, especially for engineering constructions, could be beneficial in specific projects.

Effect on decision-making

The tool could help to provide insights in how flexibility can be incorporated in road widening projects. Then, there is already much gained. The use of five decision moments in delay is already much. The use of two decision moments could be already enough in practice. This results in the statement that the amount of decision moments is not the most important parameter in the tool. The summary on the optimal strategy for each decision moment and scenario in the tool is easier to interpret then the complete decision trees.

When currently the decision of widening the road is a go/no go decision, it is good that the tool helps to identify the possibilities of flexibility. Then, it could be helpful that also a rough indication of the value of flexibility is given.

Recommendations

The respondent would first start the ROA with the drawing of the decision tree. Modelling and adapting the tool after this step would be helpful. Then, the design of the tool would be more demand driven. Embedding the tool in the decision-making process might be possible when the tool would come near reality. When the tool is not flexible enough and too many choices were made in the design, the tool is forcing the problem into a frame which may not be the good frame.

2. Report interview senior advisor models and traffic forecast from RWS

Organisation	RWS
Position	Senior advisor models and traffic forecasts
Date	20 October 2016
Time	10.00
Duration	1 hour and 25 minutes

Part 1: Introduction

The respondent is senior advisor models and traffic forecasts. In the interview, he wants to limit the discussion to the topics in which he has expertise: the data input required and the outcomes of the tool. In his job, he has several responsibilities that are related to the use of transport models (NRM & LMS) in which long term forecasts are used. NRM is used in many phases of the decision-making process: from MIRT exploration till record of decision. He is functional manager of specific parts of these models. He is also manager of the data that is used for the forecasts in these models, e.g. socioeconomic data. For one-third of his time, He is coordinator of the support of the use of NRM and LMS in records of decisions and plan elaborations. He is familiar with ROA.

The use of NRM models is more protocolled when the decision-making heads towards the record of decision. In this stage, concrete solutions already exist. In the MIRT exploration, there are more degrees of freedom in the use of NRM and LMS. Currently, RWS is well able to supply the data that is needed for CBAs.

The respondent states that the connection with the user in the tool can be twofold: it can be about the user interface and about the economic perspective. Then, also the needs for the user should be known. In this regard, road widening projects are complex. He wants to focus in this interview on the technical aspects of the tool.

Part 2: Presentation of ROA and the tool

During the short presentation of ROA and the presentation of the tool, the following comments were made by him:

- He thought that input from transport models, such as travel times and time losses were used as input for this tool. He is surprised.
- The tool only focuses on the potential increase in capacity on the road and not on other types of policies in road widening projects. This is a limitation.
- In current MIRT explorations, usually a total amount of money and a date in which a project should be finished is given. In this stage of decision-making, the goal of the project is usually increasing the road capacity. If there are possibilities to phase or delay the construction, there is not a strong incentive to do so when only an amount of money and a date is given to the executors.

- The tool is in line with explorations and is more a design tool. It should be mentioned that design of roads usually happens when the strategic decisions are already made. The design of the roads should then be brought forward for this tool to be off added value.
- RWS only has a directing role in the construction of roads. Therefore, RWS mostly supplies information. The contractor now does not have an incentive to return money when the delay or phasing of the construction of roads is more beneficial. Then, it could help for this method to be beneficial to change this structure: a program approach for RWS could be helpful. Then, such a tool could be needed.

Part 3: Questions related to the tool

Assessment of road widening projects

The I/C ratio is used in this tool. He explains some difficulties in the use of this ratio as an indicator for the travel time benefits.

- The relation between the I/C ratio and the speed is a complex relation. For example, the design of the road has an impact on the average speed. In specific situations, the capacity could be high in theory, while speed is low caused by congestion on the next link.
- A linear relation between the I/C ratio and the speed is used in the tool. Often a negative exponential function is used for this relation. This assumption of a negative exponential function is questionable. Therefore, this linear assumption is not automatically wrong.
- He makes clear that there could be a difference in the value of construction in two different types of phasing, because the situation also depends on the widening of one of the other sections. For example, the construction of the last section can give more benefits than the construction of previous sections and vice versa. It would be better to include this in the tool.
- Optimally, the travel time benefits are calculated based on changes in the whole region and not only on the link of the project. Especially since including this could affect the strategic decision.

Concluding: for the comparison between different scenarios, the current approach is probably not a problem. The outcomes should not be considered as absolute outcomes. In reality, this could be problematic in discussions when the outcomes may be considered as absolute. However, calculating every input that is needed in this tool in LMS/NRM is unrealistic.

He recommends designing a two-step tool. The first one could be a quick scan in which the options are calculated. After that, the second one can calculate the results more exact and could be used in practice. The results from LMS/NRM should be used in this second tool.

There is an effect of road widening projects on the amount of traffic kilometres. Therefore, road widening projects increase the efficiency of travelling. This affects the economy. An equal distribution of the increase of traffic kilometres among the different sections is fine for analysis, but the reality could be different. The different sections of the road are related in the effect on the amount of traffic kilometres. When a specific bottleneck is solved, the traffic kilometres on the road could increase more than when this bottleneck remains. This is not included in this tool and could be a wrong simplification of this tool.

Use of data

The use of key indicators in this tool could be dangerous. The key indicators should be reviewed for each specific project. The use of key indicators between intensity and the congestion is done more often. For example, in busy areas, an increase of 1% in the intensity results in 3% increase in the loss of travel time. As the use of key indicators is dangerous, it is important to acknowledge the risks of the use of these key indicators.

The sensitivity analysis increases the added value of the tool, but the sensitivity analysis as it is now needs some more explanation. The sensitivity analysis could be beneficial in the communication between strategists: a statement such as “that is due to the discount rate” can be disproved. A clear conclusion on the sensitivity is missing. Only a picture does not say much in this regard.

The complex decision trees in this tool do not have to be problematic. Not everyone in the decision-making process should be able to interpret these results. The identification of opportunities for phasing or delay is already much information for the decision maker.

Support in decision-making

The method and tool could be beneficial as this method and tool are currently not used. This tool could have benefits in the exploration phase of decision-making. A condition is that there is acknowledged that this tool does not give absolute values. When a decision is more complex and other input is used, this dashboard could still be used.

The tool helps to limit the further application of ROA. With such a tool, one is able to make strategic decisions relatively easy. Within RWS, they do believe in these kinds of strategic tools, because it takes time and effort to run more complex models. Then, it helps when a tool is able to do calculations relatively fast. With these kinds of tools, the number of choices can be reduced, what could be beneficial. In this regard, it could also be beneficial to hear or see what does not work, e.g. an example a specific ordering of phased construction. The tool does not fully satisfy in exactness, but it creates the feeling and the power to identify the opportunities for delay or phasing. The outcomes could create input for a more thorough discussion.

Especially in the first phases of the decision-making process, there is a need for these tools. Because stakeholders often disagree about the methods and tools to be used, it is beneficial to have multiple tools and models available.

3. Report interview with economic experts from RWS

Organisation	RWS
Position	Senior advisors economy
Date	24 October 2016
Time	13.00
Duration	1 hour and 25 minutes

Part 1: Introduction

The senior advisors economy of RWS have several roles in decision-making processes. They help consultants and other external parties with the application of CBA in projects. The economic experts also evaluate the CBAs that are made for RWS. Another role is the creation of a framework for CBAs and the actualisation of this framework. Both are familiar with ROA and were involved in several projects in which ROA was applied. They would like to indicate that they speak on their own behalf and not on behalf of RWS.

Both have a lot of expertise in ROA and how it can be used in practice. Their theoretical knowledge of ROA is more limited than their practical knowledge. In their opinion, the largest challenge of ROA is to make it practically applicable. In this regard, the value of the binomial method is limited in their opinion. Their main interest in ROA is: how much should I understand to apply this method in practice?

They both are familiar with tools that are currently used in the evaluation of alternatives. For example, the CBA tool, which is included in the NRM model and is used default by consultants and is supplied to them by RWS. The outcomes of the CBA tool can be used in the CBA. The analyses are performed by consultants. The senior advisors economy are not involved in the application of tools and do not do calculations themselves.

Some aspects of the tool are especially important in tools for them. Transparency is important, because it is important that the decision maker or user is able to follow the steps that are taken in the tool. This aspect of transparency is more important than the presentation of the exact formulas in the tool. An example of a transparent tool is the CBA tool, because it does exactly what should be done. Based on research, the requirements of this tool were drawn. Another important aspect of transparency in a tool is to be able to see what input and which assumptions are used.

Alongside transparency, the support in the decision-making process and the connection with the needs of the user are named as important aspects of the tool. These aspects are especially important for decision makers.

A back office for the tool can be helpful when adjustments in the tool have to be made. These adjustments may be needed when there are new developments in the use of key indicators or methodology. Then, it is important that someone is the manager of the tool.

Part 2: Presentation of ROA and the tool

During the presentation and the presentation of the tool, the following comments were made:

- In NRM, also freight traffic is assessed.
- In NRM, a distinction between morning and evening rush hours and the rest of the day is made, because the intensities and directions on a road differ. In the tool the distinction between morning and evening rush hours is not made.
- The input that is used in the tool is too simple to draw conclusions based on these numbers, e.g. in the use of the value of time or the amount of freight traffic.
- The question arises how far we should go in the degree of accuracy? The input should be consistent with the exactness of the outcomes. On the other hand, you may regard this tool as first identification of options and alternatives.

Part 3: Questions related to the tool

Connection with the needs of the user

The challenge is how to use this tool in relation to current transport models? An interactive tool in the plan development phase could be used without the use of the NRM. Then the results are rough, but can create a selection of alternatives. This tool can be used as a preselection of alternatives in which later more detailed and project specific information can be added. Then, it might also be possible to connect such a tool with the NRM model. In this way, the tool connects with the user need for an overview of flexible alternatives and how these should look like.

Adding more scenarios in the decision tree could be useful. In practice, a third scenario can be beneficial, especially for the assumptions that are made in the NRM model. An example of such an assumption is the construction of a regional road in a specific year. Besides, adding a specific policy to the scenarios in the decision tree create two additional scenarios, such as the implementation of road pricing. This is another dimension that could reflect environmental conditions. These environmental conditions could be included and this might be beneficial. Sometimes, there environmental conditions are included in CBAs when these conditions are very relevant for a specific project.

Assessment of road widening projects

The I/C ratio in road widening projects assesses the effects when the intensity approaches the maximum capacity. There is also an effect on the travel time when the I/C ratio is low, because the maximum speed could increase when a road is widened or the rush hour lane is upgraded to a full additional lane. In practice, the effect of an increase in the maximum speed seems to be high.

In practice, there may be more flexible solutions then phasing in different sections of the road. For example, phasing from ‘shunting’ lanes to rush hour lanes to full additional lanes. It is valuable when also these effects could be assessed in this tool, because the result that the widening is needed also creates insights for decision makers.

The ordering of the phased construction based on the most optimal economic alternative seems to be logic to them. Including an ordering based on political preferences in a calculation tool would be strange.

Including indirect effects in analyses of road widening projects are disputable. It is unclear how far you should go with the inclusion of these effects in such a tool. The 5% extra vehicle kilometres due to a road widening is disputable, because it is unclear whether road widening projects create new traffic or translocate the traffic flows. In practice, it seems that there is only a limited amount of new traffic. To select the most optimal alternatives, usually the effectiveness of the alternatives is most important effect in the first phase of decision-making. Therefore, the indirect effects can be ignored here. The bottom-line is that these effects do matter. On the other hand, including these effects in this tool is illustrative to show that these effects also matter in road widening projects. It should be clear for users that these effects can be adjusted downwards in the tool.

Use of data

Performing a sensitivity analysis is important, but it should be very clear what is done in this analysis and what the effects on the outcomes are. Currently, it is unclear what an increase of the cash flow means in the sensitivity analysis. The sensitivity analysis should be risk driven: which input variables or assumptions can affect the results most? The sensitivity analysis should be customised: which assumptions or input variables are most uncertain? In this regard, it may also be beneficial to test the robustness of the outcomes. In this analysis of the robustness, the question is how much the input variables should change to affect the outcomes of the optimal strategy.

Currently, a sensitivity analysis is probably not performed in the NRM model or the CBA tool. Only the robustness of the outcomes is assessed in the CBA, but the assumptions in the model are not tested with a sensitivity analysis.

ROA has a high sensitivity on the probability of scenario high and low. A solution for this assumption and the discussion about this assumption may be to determine the regret of choosing an alternative and to choose the alternative with the minimum regret. This is another method that could be valuable in this tool.

Transparency

The tool is considered as transparent by the senior advisors economy compared to other tools. The tool is insightful in the steps that are taken. Most important assumptions are visible for the user. The value of excel in the transparency of the tool is difficult to interpret for them. Especially since the transparency in the software is important for external parties. The tool would probably be used by external consultants, because usually calculations are not made within RWS. It is not the task of these senior advisors economy to do calculations themselves: their roles are to advice and evaluate CBAs. This tool could be helpful for external consultants.

Support in decision-making

The tool could support the decision-making process, because such a tool is not available yet. Therefore, the tool could be of added value in the decision-making process.

This tool could be given to consultants or could be included in the CBA tool. Then, flexibility could be included standard in the assessment of road widening projects. Therefore it is important to test if a real project case can be applied in this tool. The applicability of the tool depends on the flexibility that is possible in this real project case. When this flexibility is delay, the tool could maybe be applied immediately. When this tool is applied in a real project case, a reflection on where the tool should be applied in the decision-making process can be made.

In the beginning of the decision-making process, the tool could be used without the use of transport models, because in this stage of decision-making simple tools help to get insight in the problem. It would be good to include other alternatives in this tool, such as measures from the ‘Beter Benutten’ program. The effects of these measures can be included by assessing the effects on the intensity or the capacity on the road. Then, one might be able to assess when and how which sections of the road should be widened. In a later phase of the decision-making process, this tool is not detailed enough. When decision makers think in packages of measures, this tool could be able to assess the infrastructure part of these packages.

In this tool, there is a difficult balance between the complexity of the tool and the simplicity of the tool. A simple tool has advantages and disadvantages, but a more complex tool also has advantages and disadvantages. This result in the insight that in different stages of the decision-making process, different forms of this tool could be needed that differ in the degree of complexity and differ in the costs for running the tool. In a later stage of the decision-making process, also input such as the cost estimates of alternatives become more accurate.

4. Report interview with senior advisor traffic and transport from RWS

Organisation	RWS
Position	Senior advisor traffic and transport
Date	24 October 2016
Time	15.15
Duration	1 hour and 5 minutes

Part 1: Introduction

The respondent is senior advisor traffic for RWS 'Midden Nederland' and advisor explorations and plan development. In this role, he is involved in the plan development of large road infrastructure projects. He also supports and judges outsourced work from consultants that perform traffic engineering or economic research.

In his work, the respondent uses static and dynamic transport models and tools for long term forecasts. He is also involved in the coordination between models and different public authorities. In this coordination, there is often discussion on input and the use of models.

Most important aspects of this tool are for him that it is connected with the needs of the user and that it supports decision-making processes. In this tool, these two aspects are probably very much related. Besides, transparency in formulas, assumptions, parameters and input is important in a tool. A good user interface helps to increase the added value of the tool.

Part 2: Presentation of ROA and the tool

During the short presentation of ROA and the presentation of the tool, the following comment was made by the respondent:

- The tool looks like an exploration before the decision-making starts, because it uses key indicators and is therefore not specific to a specific project.

Part 3: Questions related to the tool

Assessment of road widening projects

The use of the I/C ratio in this tool is different from current practice. The monetisation is the same, because the travel time losses are monetised in this tool. With the use of the I/C ratio, the radiation effect of a road widening, the effect on e.g. other roads or other sections of the same road, is not included. This is a limitation of this tool. Currently, these effects are included in the NRM model.

The effects of a road widening on the vehicle kilometres is more complex than assumed in this tool. There are currently three mechanisms that affect the amount of vehicle kilometres included in the NRM models:

- Adjustments in departure times (the simplest)
- Adjustments in the route
- Adjustments in modal split

Enrichment of the input in the current tool would be beneficial and make the tool more interesting. On the other hand, he agrees that it is unrealistic to calculate all different scenarios that are needed in the decision trees in NRM. As for as he knows, in NRM models not more than one methodology is used. Therefore, it is not necessarily wrong that this tool uses only one method for the application of ROA.

The use of four different sections as alternatives is sometimes used in practice, but usually among these four large alternatives many variants are assessed. It would be beneficial to include the phasing and delay of engineering constructions in this tool, because these represent a large amount of the total costs.

In practice, the CBAs appear relatively late in the decision-making processes. Therefore, the added value of these analyses may be uncertain. It could be good to apply this tool earlier in the process to get an overview of alternatives and options to delay or to phase. Especially to get an overview of how urgent the road widening is.

The order of phasing, currently based on the economic most optimal alternative, could also be determined project specific.

Adding more scenarios to the decision trees is probably not necessary, because scenarios high and low do already represent much of the uncertainty. Decision makers are satisfied that currently only two scenarios are used. When this number of scenarios is increased, one may wonder if this still gives enough support for decision makers, because this results in a wide range of outcomes.

User interface

He does not think that the visualisation of decision trees is problematic for interpretation in decision-making. He thinks that it would be good to use this decision tree internal to evaluate alternatives. The colour indication could help to interpret the results relatively easy. The decision trees can be of added value in the communication in the decision-making process. The use of such a tool could be done by an external party and is usually not done within RWS.

The sensitivity analysis in this tool could be beneficial, especially in the assessment of the relatively new scenario high and low. Then, the sensitivity analysis can create insight in the robustness of a decision. It might be difficult to present the sensitivity analysis and the results in a good and clear way.

Support in decision-making

Currently, the flexibility that is included in road widening projects is often limited. In this regard, this tool can lead to new insight for decision-making.

It might be problematic to determine in which phase of decision-making this tool should be used. Currently, the plan development already takes about 6 years. Therefore, it can be difficult to ensure progress and include flexibility at the same time. In the beginning of the decision-making process of an area-specific approach, the 'mobiliteitsscan' gives geographical representations of the current bottlenecks on the roads. A geographical model could create probably more insights in the earliest stage of the decision-making process. This tool could be of added value when a shortlist of alternatives is made. Such a calculation tool can help in bringing ideas that were not there yet. In practice, steps back sometimes have to be made. With such a tool, this maybe can be done more intelligent. Many decision moments over a long period is probably not needed in these projects. He is mostly interested in the monitoring of being on the right track after e.g. each 2 years.

The use of the I/C ratio could include more alternatives and orders of phasing than only the phasing in sections of the road:

- Programs, such as the program 'Beter Benutten', can be included in the tool when the effectivity of these measures is known. In theory, the effects of these measures on intensity and capacity can be determined. Assessing the effect of these measures on the intensity and the capacity in practice might be difficult, because monitoring these measures is difficult.
- Large maintenance projects do also have an impact on the I/C ratio: the capacity is temporarily decreased.
- Projects in large municipalities and provinces can also be assessed in this tool, because the capacity and intensity is also known for these projects.

In practice, the question on what to do when often comes up. For these questions, this tool can be of added value. Some decision makers are not convinced on making the decision now when the project involves large investments, but would like to delay the decision. In the project A6 between Almere and Lelystad, the question what the optimal moment of investment was came up. In this project, the effects of delay were calculated based on the I/C ratio. In the project Ring Utrecht, the need for phasing in different sections of the road came up frequently. This tool could help to determine this optimal moment of investment in a more sophisticated way. In practice, there is a need for these kinds of methods.

5. Report interview with director of a consultancy company

Organisation	Consultant
Position	Director
Date	28 October 2016
Time	14.45
Duration	1 hour

Part 1: Introduction

The interviewee is director of a consulting company and was involved in several projects in the Netherlands in which ROA was applied. Within this company calculations on ROA were done and different methods of ROA were applied in recent projects. The current application of ROA in infrastructure projects in the Netherlands can to a large extent be attributed to this company and the interviewee.

The director has developed several tools for decision-making in her work and these tools are currently also used in decision-making processes. Many of these were implemented in Microsoft Excel. The interviewee has not used standardised tools, such as the CBA tool, herself, because the consultancy company does not perform standard analyses. Knowing that a standardised tool is available could also be handy in not standardised project, such as the CBA tool. These tools could provide guidelines for the application of a certain method. She could imagine that such a tool is developed by one party, but handed over to e.g. RWS, because this enables other external parties to use the tool. This is often done in practice.

Most important aspect of a tool is that the tool is connected with the needs of the user, because all other aspects of tools are related to this aspect. The second most important aspects are: transparency, user interface, and support in the decision-making process. The third most important aspects are: the assessment of road widening projects, use of data, and the adaptability of the tool. It is important that the tool is flexible, but adaptability is less important in practice.

Part 2: Presentation of ROA and the tool

During the presentation and the presentation of the tool, the following comments were made:

- The font of the dashboard is too small. Especially the letters in the dropdown menus are too small. It is not difficult to adjust the size of these menus.
- In the current tool, the user should first identify the most logical widening: a rush hour lane or one or more additional lanes. The tool does not make a recommendation on the most logical widening, based on the intensity.
- It is currently unclear how the outcomes should be interpreted. What do the expected value of phasing and delay exactly mean? Therefore, it could be beneficial to include the average value between scenarios high and low when a decision would be made now. Then, the user is able to identify the reference alternative of CBA and can see the added value of phasing and delay. In this way, the added value of using this tool is immediately visible. In practice this could be different, because it is uncertain whether the decision

in CBAs is based on the average value between scenarios high and low or based on one of the scenarios alone.

Part 3: Questions related to the tool

Connection with the user needs

Applying more methods in one tool would not necessarily increase the added value of the tool. The added value of multiple methods is dependent on the use of the tool.

For consultants and engineering firms, multiple methods would not be of added value. When more than one method is used in the same tool, there might be an incentive for the routine user to use the method which creates the best results. This strategic behaviour should be avoided.

For the back office or a company that is engaged in knowledge development, more methods could create added value, because this company could give advice on the choice between methods. It might be possible to identify for different types of problems different related methods. This identification of methods could also be done in one tool with e.g. a small survey in the beginning. A range of characteristics leads to the use of one method and a range of other characteristics leads to the use of another method.

Assessment of road widening projects

The use of 4 sections of the road should be enough in many cases. If more sections need to be calculated the tool could be used multiple times, because network effects of the widening of one of sections on the other sections are not included in the current tool.

Including more scenarios than scenarios high and low could be of added value, but it is difficult to standardise policy scenarios or region specific scenarios. Another opportunity can be to include these aspects by running the tool multiple times and include the effects on the growth of the intensity in scenarios high and low. When the probabilities of these scenarios are known, the outcomes of the runs could also be reflected in one expected value as how it is done now.

The use of key indicators to assess the indirect effects or external effects includes many assumptions. As a result, the use of these key indicators is complicated for users. There are two conditions to decrease the complication of the use of key indicators. The key indicators that are currently used should be without any discussion or should be filled in very conscious by the user. In the current tool, too many key indicators are used to meet one of these conditions. Another option might be that the set of key indicators are also used in the current CBA tool. To make the use of these key indicators transparent is challenging.

She recognises that the use of NRM does not work for this real option tool, because too many results in different scenarios are needed. The use of the HCM service levels is new for her. Also, the exact relation between the I/C ratio and the average speed is not completely clear in this tool. Especially when the use of the I/C ratio approaches 1 and is above 1: are the current situation and the project situation then still comparable? The assumption that the average speed decreases linear between the I/C ratio of 0.8 and 1 and remains the same after the I/C ratio of 1 should reflect how it is currently done in CBAs and should correspond with the results of a calculation in the NRM.

Probably, this approach does not matter for the ratio between different alternatives and therefore does not affect the order of phasing. This approach does matter for the output in numbers such as the expected value. It might be good to identify with which I/C ratio the NPV of current road widening projects become positive and compare this to the results of the real option tool. In theory, the NPV that is calculated in this tool and the NPV that is calculated in the CBA should be the same.

Use of data

It is important to perform a sensitivity analysis, but including a sensitivity analysis in a tool in the way as it is done now is not always needed. Especially because the graphs that are currently shown do not always give enough insights in what is done and what the outcomes are. For further research, it might be better to let the user themselves perform the sensitivity analysis by adjusting input variables. In this way, it is immediately clear for the user which and how input is changed and what the outcomes are. The results of this analysis can be input in another tool to visualise the results of the sensitivity analysis. It could help to describe which input variables have the largest impact on the outcomes. An example of the effects of changes in these input variables can be given to the user.

Another opportunity is to allow for calculating the break-even point. This would allow the user to test the robustness of the outcomes of the tool. An example of a conclusion could be: with this change in the input, the phasing of alternatives would be the same.

Adaptability

Using this tool in other projects than road widening projects would not be recommended by the interviewee. The main variable is the growth of the traffic intensity over time. In other projects, such as maintenance projects, this would maybe not be the main uncertainty. It is more logical to develop new tools based on this real option tool for other problems. Then, these tools do not have to be developed from scratch.

User interface

The tool is not very intuitive in use. There are some recommendations to improve the intuitiveness:

- Increase the font size in the dashboard.
- Include comments in the dashboard on what to fill in where.
- Create a manual for users including examples, functions, assumptions and guidance on how the results should be interpreted.
- Give more explanation on which conclusions can be drawn from the tool. Therefore, more context is needed. It is often difficult to use someone else's spreadsheet.

- The height of the cells should be increased. The current tool looks too much researchish and with larger cell heights, the tool probably looks more like a webpage. This could especially be beneficial for decision makers.
- It could help to visualise input and output side by side instead of amongst each other. This would match more with the shape of many computer screens. A heading should then be added.

Support in decision-making

She expects that the tool creates new insight for decision makers, but it would be good to implement a real life case in this tool to see what the tool does.

For CBA performers, the tool could be of added value, because with this tool, the potential possibilities to phase or delay could be identified relatively easy. Also in the composition of packages of measures, the tool could be of added value, because it might become clear that a road widening is not necessary yet. This tool would be most profitable in the beginning of the decision-making process.

This tool could help in structuring the problem. After the problem is structured, a CBA is still required in which NRM is included. For many projects, the CBA including NRM is required.

6. Report interview with postdoctoral research from Delft University of Technology

Organisation	Delft University of Technology
Position	Postdoctoral researcher
Date	4 November 2016
Time	12.40
Duration	1 hour

Part 1: Introduction

The respondent is researcher at the Delft University of Technology. His research focuses on how CBAs can become more usable in politics and focuses on the ideological principles of CBAs and their consistency with the perspectives of Dutch citizens.

He is familiar with ROA and has seen the application of ROA in the CBA of the Olympic Games which was performed by the Rebel Group. In this study of the Olympic Games, multiple decision moments were included towards the bid. He does not apply many CBAs himself. He was the co-developer of the tool 'Wikken en Wegen'. This is a relatively simple CBA tool.

Most important aspect of a tool is that the tool fulfils the needs of the user, because all other aspects of tools are related to this aspect. When the tool is not connected with the needs of the user, the added value of the tool is much lower. All other aspects that are mentioned here are subordinate to this aspect. The support on decision-making is indicated by the respondent as the second most important aspect. The quality of the user interface is named as thirdly most important aspect, because a good user interface could definitely help in increasing the usability of the tool. Increasing the transparency of a tool does not seem to increase the added value of the tool, especially when the tool is already transparent in some way.

It turns out to be very difficult to make CBAs usable in decision-making of infrastructure projects. With a real option tool, the complexity of the economic analysis is increased. In essence, with an increase in the complexity, the method becomes less useful for decision-making. In this way, the tool should generate many valuable new insights to be of added value.

Part 2: Presentation of ROA and the tool

During the presentation of the tool, the following comments were made by him:

- The visualisation of the decision tree is very complex in the results of the tool. He is wondering who is going to read this decision tree? This might be too difficult for civil servants from the ministry of Infrastructure and Environment. However, for specialists from RWS, reading and interpreting these decision trees is not so difficult.

Part 3: Questions related to the tool

Connection with the user needs

It would be good to implement different methods for applying ROA in a flexible way. When a specific method is needed, the tool could apply this method. It is more risky to give users more complex methods for the application of ROA, because revolutions in the application of methods are incremental. Therefore, it does not make much sense to start with the most complex method.

Currently, the ministry of Finance is looking for flexibility in decision-making. But it seems to be difficult to incorporate this in the current decision-making process. Politicians do not want flexibility, because they want to be able to make promises to the electorate. Making promises is difficult when solutions become flexible. Politicians think that it is difficult to explain the incorporation of flexibility to the electorate. Introducing flexibility does not match with the current way of budgeting and the current way of decision-making. The Dutch government was/is working on an incentive for reversing decisions when profitable.

A very complex decision tree is probably too difficult to interpret for many users. The use of two scenarios would be fine for practical use. Besides, increasing the complexity of decision trees with more scenarios would probably not be beneficial. Introducing policy decisions in different scenarios in the tool would be difficult, because there are actors against doing this and it is uncertain if this would suit the opinion of politicians. A very complex decision tree would be difficult in the interpretation by politicians and in the discussion between civil servants. When the tool would not be used in discussions, a complex decision tree would not necessarily be problematic.

Assessment of road widening projects

Although the political aspect is important in decision-making in road widenings projects, it would not be valuable to base the order of phasing on a political perspective. However, during design there should be kept in mind that the political aspect is important in decision-making.

All models are wrong, but some are useful. NRM does not reflect the reality in essence, but could still be useful. The same goes for this real option tool with the use of the I/C ratio: this tool can still be useful, also when it does not reflect the reality. For this usefulness, it is important that the tool could facilitate the discussion in the decision-making process.

The inclusion of the assessment of the direct effects and external effects could be of added value, because this assessment creates the feeling that all effects are at least taken into account. As key indicators are used in this tool, it still remains uncertain how well these effects are assessed.

For valuing flexibility in a tool, this can also be the case: it creates the feeling that the effects of delay and phasing are taken into account. For politicians, this could be of added value. Maybe, a paragraph can be added to the current CBA reports in which an advice on flexibility is given to the politicians. Then, this tool could help, but does not have to be included in the report. The content of this paragraph can be very generic to be of added value for politicians.

In the current tool, the negative value of uncertainty is not assessed. However the negative perception of uncertainty might be present in reality. Citizens prefer certainty above uncertainty. This corresponds to the way politicians make decisions: based on the recognition that civilians want clarity. It would be good to include this negative value of uncertainty to give a complete overview of the value of flexibility. Besides, uncertainty leads to costs, e.g. civil servants are occupied with handling procedures or information meetings. When these costs are higher than the benefits of incorporating flexibility, the value of flexibility is much lower. However, it is currently unclear how large these negative values of uncertainty for citizens are.

Support in decision-making

It is most important that the tool is a building block for discussion. If the tool does not make the discussion better, the added value of the tool is limited.

It is valuable to assess whether the tool has added value for different actors in the decision-making. This could differ among different actors in decision-making. For decision makers, it would be most important that the tool is a building block for decision-making. For RWS, the added value of the tool could already be that calculations can be made in the tool.

To support in decision-making, the reality should be taken into account. Especially when the tool does not reflect the reality. Increasing the complexity and flexibility of the tool is not necessarily needed. Rough results are not always problematic. It is more important to investigate the more critical weaknesses of the method and the tool, such as the negative value of uncertainty for society. Then, the tool could also be of added value in discussions as it then reflects how politicians consider uncertainty.

It would be interesting to test this tool in a discussion within the ministry of Infrastructure and Environment to assess whether they would use the tool in a discussion or meeting. Then, the added value of this tool in decision-making can be assessed better. The tool can also be used as input for CBA, however currently a phased alternative is not included by default in CBA. A change in the characteristics of CBA usually goes very slow.

Source:
https://beeldbank.rws.nl, Rijkswaterstaat / Joop van Houdt