Added Value of Different Approaches of Real Options in Transportation Infrastructure Projects Decision-Making

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Abstract
The importance of including flexibility into transportation infrastructure projects decision-making is widely recognised. Real-option analysis (ROA) is a technique for valuing flexibility to adapt to an uncertain future which can be included in the traditional Cost-Benefit Analysis. However, current practice of real options in transportation infrastructure decision-making is limited and therefore this research aims to investigate to what extent ROA can be a valuable addition. Based on the application of the Simplified Decision Tree Method and Binomial Option Pricing Method in two different case studies and on interviews conducted, it can be said that ROA is valuable as it can enrich the decision-making information for certain Dutch transportation infrastructure projects. Essentially, ROA leads to optimal decision-making, additional strategic insights and it supports adaptive decision-making. However, there are also practical limitations for the application of ROA in organizations such as the current standardized decision-making process, the additional time and effort and complexity of the application. Therefore, a trade-off between the added value and the additional effort has to be made. Further research into the methods and the effects of assumptions, applications on different types of infrastructure projects and dealing with projects influenced by many uncertainties is recommended.

Keywords: Real Options, transportation infrastructure projects, decision-making, flexibility, case-study, Cost-Benefit Analysis

1. Introduction
A transportation infrastructure network needs maintenance, replacements and construction of new elements to function according to society’s ever changing needs (Ministerie van I&M - EZ - BZK, 2014). These days, a contextual transition can be recognised where the need for adaptive policies is growing and the role of flexibility is increasing. Currently, investment decisions about large infrastructure projects are in many countries evaluated by means of the Net Present Value (NPV) in a Cost-Benefit Analysis (CBA), also in the Netherlands according to the recently revised version of the CBA guidelines (Eijgenraam, Koopmans, Tang, & Verster, 2000; Romijn & Renes, 2013). This traditional method captures the value of a project’s future cash flow, but excludes the possible value brought by future uncertainties and flexibility (Zhao & Tseng, 2003). However, uncertainties like climate change, economics and technological development may have a large impact on the future value of a specific decision. For this reason taking flexibility into account by evaluating infrastructure projects can be valuable for decision makers (Neufville & Scholtes, 2011; Stratelligence, 2012).

Real Option Analysis (ROA) is a valuation technique that assumes that flexibility has a value; increasing the flexibility of an investment project may increase its total value substantially (Neufville, Hodota, Sussman, & Scholtes, 2009; Trigeorgis, 2005). Flexibility is expressed in real options, and a real option can be defined as ‘the right, but not the obligation, to exercise an option that creates flexibility’ (Yeo & Qiu, 2003). ROA received more attention over the last decade and several studies were conducted to contribute to the understanding of the application of real options in infrastructure management (Garvin & Ford, 2012; Kashani, 2012; Martins et al., 2015; van Rhee, Pieters, & van der Voort, 2008). Despite the acknowledged potential, real options theory is not widely used within the discipline of infrastructure development. This also counts for
transportation infrastructure projects in the Netherlands (Herder, Joode, Ligtvoet, Schenk, & Taneja, 2010; Pol, Bos, & Zwaneveld, 2015; Romijn & Renes, 2013; Schenk & Veld, 2008). In the Netherlands, only a few public studies to investigate the potential and application of ROA in infrastructure project evaluation have been conducted (Bos & Zwaneveld, 2014; van der Pol et al., 2015; Reitsma, 2010). These studies demonstrate the relevance of ROA in these specific cases, but also mention some drawbacks in the application. This study focuses on increasing the experience regarding the use of ROA in infrastructure projects and on giving advice on future applications.

This paper aims to answer the following question: How and to what extent can real option analysis be a valuable addition to transportation infrastructure project decision-making?

In this research valuable implies that ROA may lead to better insights without losing transparency for the decision maker. This study is performed in a Dutch context, but can be useful for all transportation infrastructure decision-making.

This paper firstly provides general information about Real Option Analysis, relevant for this study. Secondly, the results of two case studies performed are presented to gain insights in the added value of ROA by conducting two different ROA methods. Thirdly, a reflection on these different methods and the main insights from the case study will be discussed. Moreover, the suitability of ROA within the current decision-making framework will be reflected upon. Finally, an overall conclusion and recommendations for further research will be presented.

2. Real Option Analysis
‘A real option approach shifts the decision-making process from simply choosing whether to invest in a transportation project to a management approach that considers a range of possible decisions, with the potential value of each decision measured in terms of its option creating value’ (Brand, Mehdiratta, & Parody, 2000, p. 57).

Compared to the general NPV method, ROA also includes the possible value brought by uncertainty and flexibility and balances this towards the additional costs of the option. This results into the following function that presents the total value of a project:

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

For transportation infrastructure projects different types of options are mentioned, such as the option to defer, the option to expand and the option to phase the investment, which are the most likely (Eijgenraam et al., 2000; van der Pol et al., 2015; van Rhee et al., 2008).

Methods
Various methods that enable the application of ROA based on different principles are acknowledged in the literature. Recently, CPB acknowledged the Simplified Decision Tree method as the most appropriate method within the Netherlands due to its transparency and applicability (Pol et al., 2015). However, some say that this method is too simplified and not a real application of Real Options. Also the Binomial Option Pricing Method is successfully applied for two Dutch cases (Reitsma, 2010). To compare these methods, they are both applied in this research.

Simplified Decision Tree
By using a graphical tree, decision moments and uncertainties are identified and structured. Per branch the NPV is calculated to get insights in the consequences of decisions under a certain scenario. Break-even analysis and sensitivity analysis can be used to select the preferred alternative.

Binomial Option Pricing Method
This method consists of a continuous decision tree that determines the value of an alternative based at each moment in time. The uncertainty is captured in the volatility finally the option value is derived from the tree. In this study the Binomial Option Pricing method was conducted based on the model developed by Cox, Ross and Rubinstein (1979) and the guidelines mentioned by
This model is based on the following principle:

Applicability of ROA
The real option approach is not a one-size-fits-all solution for project evaluation. ROA is only relevant for projects that are characterised by uncertainty, managerial flexibility, irreversibility, asymmetric pay-offs, limited importance of non-monetary costs and no no-regret alternative. To what extent these characteristics have to be present is still not explicit. Furthermore, ROA can be used in two current manners; as a way of thinking and as a calculation method. The applicability varies per project.

Expected added value of ROA
Based on the studies conducted, the following strengths of ROA are known (Blok et al., 2011; Garvin & Ford, 2012; Stratelligence, 2012):

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

Disadvantages of ROA
However, ROA is also expected to have some disadvantages (Block, 2007; Herder et al., 2010; Lander & Pinches, 1998; van der Pol et al., 2015):

- There are not a lot of examples to conduct ROA, which might result in confusion and a lack of transparency.
- Some input variables which are needed to make a proper calculation are unknown and have to be determined or estimated.
- Since ROA is relatively new, there are some implementation issues and decision makers prefer to continue with the current evaluation procedure. Moreover, this is also hindered by the standardised procedures described in the OEEI-guidelines. Note that this is not a disadvantage of the method itself, but an practical application barrier.

Current status within the Netherlands
Although there is the impression that ROA is barely applied in the current Dutch infrastructure decision-making, the idea to include flexibility in infrastructure investment evaluation is not new. In 2000, the OEEI-guidelines mention the value of including flexibility and suggest to use ROA (Eijgenraam et al., 2000). It mentioned that a flexible design and phasing of a project would lead to a better response to future developments and reduce the risks of inappropriate decisions.

Following different research, a first recommended step was to apply ROA during example studies. (Commissie risicowaardering, 2004) (Schenk & in ’t Veld, 2008) (Stratelligence, 2012). However, so far only a few case studies are publically available. Most recently, CPB researched when and how to apply ROA into Dutch infrastructure projects evaluation (Bos & Zwaneveld, 2014; van der Pol et al., 2015). This resulted in the recommendations to apply ROA on a case where a CBA is not yet conducted (1) and to compare different methods quantitatively (2). Therefore, this is done in this research.

3. Case studies

Case study approach in this research
ROA is applied on two case studies to illustrate the additional decision information derived from the application. Table 1 demonstrates that both methods have been applied on two different cases.
### 3a. Case study: ‘the widening of the A27 highway’

This first case study is about the ‘the widening of the A27 highway’. The aim of the project was to support the large traffic-flows on the A27 by widening the highway between Lunetten and Hooipolder. Studies based on the NPV method indicated that the estimated project cost would be too high to compensate for the travel time benefits. The ROA method offers the option to phase the project by widening the highway in four different phases. A phased investment could be beneficial because when the actual traffic growth deviates from the forecasts, the strategy can be adapted. This could make the project more beneficial as this flexibility to postpone or cancel the construction of certain elements may save costs. Both the Binomial Option Pricing Method and Simplified Decision Tree method are conducted on this case to be able to research the added value and compare the methods.

#### Alternatives

The following three alternatives are included:

- 0: No widening
- B3: Widening of the one track
- B: Widening the complete highway

#### Binomial Option Pricing Method

Based on this method, the real option value was calculated per alternative. This value represents the value of an alternative by integrating the value of uncertainties and includes a risk-correction.

By using the same assumptions the results can be compared with the CBA (see Table 2)

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Real Option Value</th>
<th>Net Present Value (CBA)</th>
<th>Difference (CBA – ROA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No widening</td>
<td>80</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>B3: 1 track</td>
<td>-38</td>
<td>-90</td>
<td>52</td>
</tr>
<tr>
<td>B2: 2 tracks</td>
<td>-156</td>
<td>-204</td>
<td>47</td>
</tr>
<tr>
<td>B1: 3 tracks</td>
<td>-169</td>
<td>-189</td>
<td>20</td>
</tr>
<tr>
<td>B: 4 tracks</td>
<td>-229</td>
<td>-229</td>
<td>0</td>
</tr>
</tbody>
</table>

Moreover, the moment optimal to invest was determined as depicted in Figure 2.

**Figure 2: Widening A27 – Optimal strategy**

The Binomial Option Pricing Method concluded on two main points; when widening the highway it would be the most optimal to do this in 2016 or later (1) and in once which means alternative B the complete highway (2). For this reason, performing this method resulted in less negative alternatives and demonstrated the value of deferring the investment to the moment the traffic flows are possibly high enough to compensate costs.

#### Simplified Decision Tree

The Simplified Decision Tree method was also conducted on this project to gain insights on the effects of a deferral and a direct or phased investment. Instead of a continuous variable taking into account the uncertainty as in the previous method, a high and a low traffic growth scenario were included.

This method showed that it is beneficial to defer the widening until 2018. This is mainly because the investment costs decreased considerably due to the discount rate and the growth of the traffic volume. Moreover, constructing the complete highway at once, alternative B, is also valued higher than a phased construction.

Table 3 and Figure 3 show the consequences of investing in 2018 in the complete highway (B), a partial investment (B3) or a phased investment (B3→B).
If the traffic growth turns out to be high, the phased investment results in a regret value of €28 which could have been gained by a direct investment in B. However, if the traffic growth would have turned out to be low, choosing for B3 instead of B could have saved €76 million and is for that reason less risky.

The Simplified Decision Tree also demonstrated that a phased investment would decrease the bandwidth of the expected NPV and consequently decrease the risk. This is a value flexibility has.

Comparison Methods
The Simplified Decision Tree presents that flexibility could have a value of €127 million when the widening of the complete highway (B) is deferred from 2013 to 2018. However, this value could vary between €149 million (low scenario) and €105 million (high scenario), dependent on the scenario chances. The option value of the Binomial Option Pricing Method is €80 million.

Although the values are not fully comparable by nature, it is remarkable that the differences between the alternative B3 and B are for both methods more or less the same (Table 4).

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Scen</th>
<th>NPV</th>
<th>Regret choosing B or B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Low</td>
<td>-138</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>B3</td>
<td>Low</td>
<td>-62</td>
<td>0</td>
</tr>
<tr>
<td>B3 → B</td>
<td>Low</td>
<td>-75</td>
<td>n/a</td>
</tr>
<tr>
<td>B3</td>
<td>High</td>
<td>-9</td>
<td>47</td>
</tr>
<tr>
<td>B3 → B</td>
<td>High</td>
<td>10</td>
<td>28</td>
</tr>
</tbody>
</table>

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

A major difference between both outcomes is that the most beneficial alternative calculated by the Simplified Decision Tree has a positive NPV while the Binomial Option Pricing Method only results into a less negative NPV. This could be due to the fact that the Simplified Decision Tree method is a strong simplification of the real situation, so the assumptions have a large influence.

Conclusion
The main conclusion from this study was that both methods led to approximately the same optimal alternative to defer the investment for a few years, but provide different decision-information. The Binomial Option Pricing Method is mainly relevant to gain more insights in the exact most optimal moment to invest, while the Simplified Decision Tree method supports real option thinking and generate insights in the value flexibility, in this case a phased construction, could have. The effort to perform the Simplified Decision Tree was relatively low, as all the information was already known. However, assumptions are made to make this project suitable to conduct this analysis. It is recommended to gain more insights by varying the decision moments and the scenario probabilities.

3b. Case study: ‘the replacement of the Kaagbrug A44’
The second case focused on the ‘replacement of the Kaagbrug’, a bridge part of the two road-lane highway A44. The technical life-end of the bridge is nearly finished, but the plans for the A44 highway are unsure. ROA was used to gain insights in the

![Figure 3: Widening A27 - Decision Tree](image)
most optimal replacement, by considering the following decision possibilities:

- Bridge or Aqueduct
- Width: Basic (2x2) or Plus (2x3)

Main uncertainties influencing the project are:

- Traffic growth A44 and;
- Decision regarding widening the A44 (in 2028).

It considered the following flexible options:

- Option to defer: Defer the investment and in this case the bridge replacement by maintaining the current bridge.
- Option to expand: Expand the bridge from 2x2 to 2x3 road lanes in a later phase.

**Simplified Decision Tree**

The CBA did not result in a clear preferred alternative. In a high traffic growth the bridge Plus (2x3) and for a low scenario the Bridge replacement Basic (2x2) was recommended. For this reason the Simplified Decision Tree was used to support decision-making in the case that the bridge had to be replaced before 2028, and the future plans are uncertain.

This resulted in the following values for the different scenarios. Accordingly, the NPV of a weighted average in situation A with the presented probabilities (P) on the results was calculated. In this situation A it is recommended to choose the phased investment alternative 4 with the lowest NPV. By adjusting P the preferred alternative for different situations can be determined. Overall, Alternative 4 has the highest NPV.

Based on the Simplified Decision Tree it can be concluded that in general it is recommended to defer the replacement as long as possible, because during this deferral more insights in the uncertainties can be generated and which decreases the risk and bandwidth of the results.

**Table 5: Results case Kaagbrug - NPV in million €, 2015-2100**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Situation A</th>
<th>NPV (€) weighted average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High 2x3</td>
<td>Low 2x2</td>
</tr>
<tr>
<td></td>
<td>P=0.4</td>
<td>P=0.1</td>
</tr>
<tr>
<td>1. Aqueduct Basic</td>
<td>-136</td>
<td>-72</td>
</tr>
<tr>
<td>2. Replacement Plus</td>
<td>-42</td>
<td>-70</td>
</tr>
<tr>
<td>4. Replacement Basic + expansion Plus in 2028</td>
<td>-42</td>
<td>-68</td>
</tr>
</tbody>
</table>

**Figure 4: Case Kaagbrug - SDT**

If the current bridge has to be replaced before 2028, as depicted in Figure 4 and Table 5, replacement by a bridge is always preferred over an aqueduct. This can be explained as the shipping is limited, therefore the benefits of an aqueduct are not much higher and an aqueduct eliminates the option to expand. However, if other criteria besides cost-effectiveness would play a larger role, the aqueduct could be favoured.

If it is likely that the A44 will be widened and the current bridge will be replaced by a new bridge, it does not matter whether a Basic or Plus variant is chosen as the additional costs to expand the bridge are very close (Arcadis, 2014). In general, the Simplified Decision Tree gained additional decision-information by illustrating the results and consequences of various decisions.

**Binomial Option Pricing Method**

This method can easily be applied on projects with one dominant continuous uncertainty and is therefore conducted on the decision to widen the A44 highway instead of the replacement of the bridge. The uncertainty is captured in the main input variable ‘volatility’, and is calculated based on the historic traffic intensity of the A44. For every node in time the cash-flow is determined which resulted into the following values (Table 6).

**Table 6: Results BOPM Widening A44 - NPV in million €, 2015-2100**

<table>
<thead>
<tr>
<th>#</th>
<th>PV Benefits ROA</th>
<th>PV Costs (€)</th>
<th>ROA (€)</th>
<th>CBA (€)</th>
<th>Option Value CBA – ROA</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASIC (2x2)</td>
<td>2.9</td>
<td>-38.8</td>
<td>-35.8</td>
<td>-37.3</td>
<td>1.5</td>
</tr>
<tr>
<td>PLUS (2x3)</td>
<td>41.6</td>
<td>-70.6</td>
<td>-29.0</td>
<td>-30.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Furthermore, based on a comparison per node in the tree between the current situation and widened highway, Figure 5 could be drawn.

![Figure 5: A44 – Optimal strategy](image)

This leads to the following conclusions:

- Uncertainty has a value and leads to less negative alternatives. This value is respectively €1.5 million for the Basic and €1.7 million for the Plus Alternative.
- Expanding to Plus is not recommended, but could be considered after 2018 if an high traffic growth is observed.

The Binomial Option Pricing Method includes, contrary to the commonly used CBA, the value of flexibility. This results into an optimal NPV per alternative, although this is a small difference. Furthermore it gives insights in the chance that the expansion to Plus could be considered, in this case only in a very high scenario. In addition, the model can be used to gain insights in the behaviour of the uncertainty by adjusting, for example, the volatility.

**Conclusion**

The main purpose of this application was to investigate the addition of the method to the decision-information. The Simplified Decision Tree was mainly useful to quantify the consequences of the different decision possibilities by calculating the value of each branch. The Binomial Option Pricing Method is valuable to see the impact of the uncertainty, in this case the traffic growth, on the decision-making and the total bandwidth.

### 4. Comparison Methods

One of the goals of this study was to compare both methods based on the application. This leads to the general results presented in Table 7.

Overall, it can be said that both methods have pros and cons, but are applicable on different types of projects.

<table>
<thead>
<tr>
<th>Table 7: Comparison ROA Methods</th>
<th>Simplified Decision Tree</th>
<th>Binomial Option Pricing Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Method</strong></td>
<td>By using a graphical tree, decision-moments and uncertainties are identified and structured. Per branch the NPV is calculated to get insights in the consequences of decisions under a certain scenario.</td>
<td>A continuous Decision Tree that determines the value of an alternative based at each moment in time while taking into account the volatility, where the option value is derived from the tree.</td>
</tr>
</tbody>
</table>
| **Advantages**                   | - Supports structuring the uncertainty and possibilities of flexibility and thus real option thinking.  
- Generates insights in the regret, choosing the wrong alternative, by calculating the regret value in a relatively simple manner.  
- Method is transparent, intelligible and easily conductible after performing a CBA. | - Generate insights in optimal investment strategy and the value of flexibility.  
- Accurate: determines the value for each moment in time.  
- Input variables can easily be adjusted to calculate the value of a different decision situation. |
| **Disadvantages**                | - Only able to include a limited amount of uncertainties or flexibility into one tree. Continuous uncertainties have to be captured in yes or no scenarios.  
- The results strongly depend on the simplifications made and probabilities chosen during the analysis.  
- The tree has to be constructed manually, for each other decision this requires a new effort. | - Includes uncertainty and yearly benefits in a continuous way. If this does not match with the real life situation, manually adjustment is required.  
- Calculations are less transparent due to extensive spreadsheet.  
- Determining a correct volatility is a challenge while this variable dominates the results of the tree. |
| **Results**                      | - Structure of the decisions and uncertainty  
- Value per branch  
- Regret value per alternative under certain scenario | - Optimal investment strategy  
- Real option value, value of flexibility |

**Figure 5:** A44 – Optimal strategy
5. Main insights from the Case study

In this section the case studies are linked to the main research question.

To what extent can ROA be valuable?
The extent to which ROA can be valuable depends on the characteristics of a project. For each project a trade-off between the potential added value of ROA and the additional efforts has to be made. In case the option costs are significant, it could certainly be beneficial to research the optimal investment decision with ROA. During the case study on the ‘widening of the A27 highway’ it became clear that a phased investment by deferring the investment of some tracks was valuable.

This research demonstrated with two case studies, the additional decision information ROA could have. With the case study on ‘widening the A27 highway’ it became clear that deferring the investment was valuable. The Binomial Option Pricing Method showed the most optimal moment to invest based on the uncertainty and the bandwidth of the possible values. The Simplified Decision Tree was mainly relevant to generate insights in the value of flexibility, in this case a phased investment, and consequences of a certain decision.

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

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

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

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

The Binomial Option Pricing Method is helpful to calculate the possible value brought by flexibility and uncertainties accurately for each moment in time. It can determine the optimal investment, for example, widening the A44 in case 2 could be beneficial from 2018. This method is especially applicable for projects that are influenced by one dominant continuous uncertainty that can be captured in the volatility.

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

Interviews with people responsible for decision-information were conducted to gain insights in the suitability of ROA in the Dutch decision-making process. Based on these interviews, it can be concluded that ROA is not considered as something crucial. Currently, the rigid and time-consuming infrastructure project decision-making process holds back the breakthrough of this method. Furthermore, it must be considered that the decision-making process includes plenty of factors other than the investment policy. There are many application barriers mentioned, for example, the additional time and effort, the need for prompt decision-making and the political will and political pressure to deliver.

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

7. Conclusion and further research

To conclude, based on the case studies performed and interviews held it can be said that, ROA can be valuable as it can enrich the decision-making information for transportation infrastructure projects. However, it comes at the cost of additional effort. Therefore, ROA has to be applied at the right moments, with the right method, on the right projects in order to be valuable.

Further research

Real Option Analysis is relatively new, thus there are still a lot of knowledge gaps that lead to recommendations for further research.

➢ Firstly, it could be beneficial to gain insights in the effects of assumptions per methodology. For the Simplified Decision Tree method, it could be interesting to research the effects of using an adjusted discount rate and probabilities, to then once compare with the Binomial Option Pricing Method. The Binomial Option Pricing method could benefit from additional research into the input variable volatility.

➢ Secondly, as both included methods are not able to include unlimited types of uncertainties, it would be interesting to make a comparison with a method which is able to, such as the Monte Carlo simulation.

➢ Thirdly, this research only tested the methods with the option to defer, the option to phase and the option to expand. It would be interesting to research the suitability of the methodologies for other type of options.

➢ Lastly, it is recommended to investigate the applicability of ROA on all types of projects such as decisions on construction, maintenance, replacement and procurement.

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