Intelligent Transportation Systems

Capturing the socio-economic value of uncertain and flexible investments

David Andersson
Simon Robertsson
Abstract

**Intelligent Transportation Systems - Capturing the socio-economic value of uncertain and flexible investments**

*David Andersson, Simon Robertsson*

The aim of this study is to evaluate an alternative socio-economical valuation method (i.e., Hybrid Real Options, HRO) to the traditional benefit cost method (CBA) for the evaluation of investments within Intelligent Transportation Systems (ITS). The proposed alternative method will be evaluated by the use of a case study where it is applied and compared to the results of the traditional method. The case study evaluates the socio-economical effects of an investment in Variable Speed Limits along a section of the motorway E18. The results of the study shows that the choice of evaluation methods affects both the investment strategy and the estimated socio-economical benefits of the investment. Using the HRO method yields twice as high socio-economical benefits compared to the CBA method. The main reason for this being that HRO account for risk and uncertainties whereas CBA only accounts for the most probable outcome of the investment. The choice of method is a complex task that involves many stakeholders however a more critical approach to the choice of socio-economical evaluation method is advocated based on the results of this study.
SAMMANFATTNING

Antalet fordon i världen ökar snabbt, år 2035 antas världens totala fordonsflotta öka från dagens cirka 1.2 miljarder till 2 miljarder. Trots att fordonstransporter för många är nödvändighet ger detta upphov flera problem såsom trängsel, utsläpp av växthusgaser samt trafikolyckor. En ny typ av lösningar för att hantera dessa problem går under beteckningen ITS – ”Intelligent Transportation Systems”. ITS är lösningar sprunna ur dagens digitalisering vars strategi är att minska transportproblemen beskrivna ovan genom att integrera IT-lösningar i förvaltningen och den dagliga driften av transportsektorn.


I detta arbete genomförs en fallstudie, där både NNK och HRO används för att illustrera och belysa hur valet av utvärderingsmetod påverkar det estimerade värdet av en infrastrukturinvestering. I fallstudien utvärderas en utbyggnad utav variabla hastighetsskytlor längs E18 genom Västerås.

Resultatet visar på att valet av utvärderingsmetod påverkar den estimerade samhällsekonomiska nyttan av investeringen och även att investeringsstrategin påverkas. I fallet där HRO används blir den samhällsekonomiska nyttan mer än dubbelt så stor som i fallet med NNK främst genom att HRO tar osäkerheter i beaktande till skillnad mot NNK där endast det mest troliga scenariot ligger till grund för beräkningen.

Nya investeringar såsom många ITS-tekniker har en större grad av osäkerhet och är mer flexibla för att anpassas längre fram i tiden. Detta gör att HRO gynnar denna typ av investeringar och NNK gynnar mer säkra och konservativa investeringar. Valet av utvärdering metod bör inte ses som självlklart. En myndighet som vill gynna investeringar i nya tekniker såsom vägverket i Sverige bör se över om de socioekonomiska utvärderingsmetoder som används ligger i linje med den övergripande investeringsstrategin.
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1. Introduction and problem discussion

Transportation of people and goods is an integral part of what drives the economic growth. Before the introduction the automobile the fastest mode of road based land transportation was by horse. The mainstream introduction of the automobile with Ford’s assembly line started the age of the automobile and radically changed the way people lived, worked, and traveled. With an increasing number of vehicles on the roads space on the roads becomes more scares and building more roads is not a reasonable solution in most developed areas.

The number of vehicles on the world’s roads are still increasing rapidly. In 2014 the world's estimated car pool was 1.2 billion vehicles but this figure is expected to increase to 2 billion by year 2035 (Voelcker, 2014). Though transport is a necessity for many people as well as for society and businesses there are also problems associated with the road transportation of today.

The increasing number of vehicles is leading to congestion problems. The average urban commuter spends eight day per year stuck in traffic jams. Besides frustration among drivers and reduced leisure time it is estimated that time spent in traffic wastes 84 trillion SEK in worldwide; a number over three times larger than Sweden’s GDP (Cityscope, 2014 and World Bank, 2014).

Furthermore the transport sector accounts for one fourth of worldwide CO2 emissions, a figure expected to grow to one third by year 2050 (European Comission, 2016). Safety is also a major challenge. 1.3 million people die in road accidents each year, that is close to two people every minute, it is the most common cause of accidental death by people aged between 15 and 29 (ASRIT, 2015).

Emerging transportation technologies offer solutions to the continuing problems of traffic congestion, environmental impacts and health issues. One such type of solutions is, Intelligent Transportation Systems, ITS. ITS is a result of the increased digitization of services and is a set of strategies for relieving the problems of transport, by integrating, information and communication technology (ICT) applications into the management and operation of transportation systems (Maccubbin et al, 2005).

In decision making regarding investments in road transport there are a number of aspects commonly taken into account. One of them is the economic dimension of the investment from a societal point of view, referred to as a socio-economical evaluation. The predominant socio-economical evaluation method today is the Benefit-Cost method, although researchers argue that the method is by no means superior (Lee, 2000).

A cost benefit analysis (CBA) is a systematic approach, assessing the benefits and costs of one or several investment options to either (1) determine if it is a sound investment or more often (2) to compare several alternative investments from a socio-economical
point of view. CBA is the most commonly used socio economical evaluation method for stakeholders within the transport sector with over 80 % using it on a regular basis (Mans et al, 2011). Although being the most commonly used method CBA are criticized by researchers for a number of causes, one being the difficulty of forecasting and handling uncertainties of the future (Shapiro, 2011).

An alternative approach to the traditional CBA is the Hybrid Real Options (HRO) methodology. This approach originates from Massachusetts Institute of Technology and takes uncertainties and flexibility into account by using statistical methods from financial options theory (Neely & Neufville, 2001). According to Hodota (2008), CBA is useful for evaluating smaller low-risk projects while HRO is suitable for larger and more risk prone projects such as large infrastructure projects.

A hypothesis for this thesis is that; the method used for socio-economical evaluations will affect the estimated value of transport infrastructure investments, which may in turn affect the investment decisions made. By performing a case study as an illustrative example, similarities and differences between the traditional CBA and the alternative HRO approach can be highlighted and the implications of the choice of evaluation method can be discussed.

1.1 Aim

The aim of this study is to evaluate an alternative socio-economical valuation method to the traditional CBA method for the evaluation of ITS-investments. The proposed alternative method will be evaluated by a case study where it is applied and compared to the results of the traditional method.

1.2 Research questions

- What are the fundamental differences of the two methods CBA and HRO?
- What would the implications of implementing the alternative method in the decision making process from an ITS-perspective?

This thesis uses the implementation of a Variable Speed Limits system in a major swedish city as base for the case study. The decision analysis methodology “Hybrid Real Options” presented by Neely & Neufville (2001) will be used and compared to the traditional BC-Method in the case study.

1.3 Concepts

There is a confusion of concepts within the area of evaluating societal benefits of investments. A socio-economic analysis often refer to Cost Benefit-Analysis (CBA) or a Cost Benefit Analysis (CBA). They can and are often used interchangeably in the literature (SIKA, 2005).
In this thesis the methodology most commonly used in a CBA will be referred to as a traditional CBA. From the process of conducting a traditional CBA different Key Performance Indicators (KPI) can be derived such as Net Present Value (NPV) and Benefit-Cost Ratio (B/C).

The proposed alternative methodology Hybrid Real Options (HRO) will in this thesis also be used to perform a socio-economic analysis, calculating the estimated societal cost and benefits of an investment. From the HBR-process corresponding KPI:s can be calculated, they will be referred to as Expected Net Present Value (ENPV) and Expected Benefit-Cost Ratio EB/C.

A list of commonly used acronyms is presented below.

<table>
<thead>
<tr>
<th>ACRONYMS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADT</td>
<td>Average Daily Traffic</td>
</tr>
<tr>
<td>B/C</td>
<td>Benefit-Cost ratio</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost Benefit Analysis</td>
</tr>
<tr>
<td>ENPV</td>
<td>Expected Net Present Value</td>
</tr>
<tr>
<td>HRO</td>
<td>Hybrid Real Options</td>
</tr>
<tr>
<td>ISA</td>
<td>Intelligent Speed Adaption</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transportation Systems</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>RO</td>
<td>Real Options</td>
</tr>
<tr>
<td>VSL</td>
<td>Variable Speed Limits</td>
</tr>
</tbody>
</table>
2. Literature review

2.1 ITS

This part gives an overview of the ITS (Intelligent Transportation Systems) in general, how it is defined, its main benefits, and some common applications. There is also a chapter about the ITS-technology Variable Speed Limits (VSL) along with sub-chapters related to VSL. The information and results presented under the VSL-chapter is used in the case where a VSL implementation is studied.

ITS is a generic term referring to the use of communication, control and information processing technologies within the transportation sector. The term is broad and used differently between institutions. For example, the US Department of Transportation refers ITS to solutions within the transportation system across all modes of surface transport (US DOT, 2015) whereas the European Union only refers to road transport (EU, 2010). The main function of ITS is to improve decision making, often in real time, by all users and controllers within the transportation system, thus improving the operation of system as a whole. Data is the core of ITS and many applications is based on the collection, processing, integration and supply of information. The most predominant benefits that can be expected from ITS are related to traffic congestion, air quality and safety. An overview of these benefits and associated ITS solutions is presented below (World Road Association, 2015).

- Traffic management tools to ensure maximum efficiency of the road network, including:
  - Monitoring current traffic conditions and predicting what can be expected
  - Coordinating traffic signals to minimize delays and queues in a dynamic, traffic responsive way
  - Giving ‘green waves’ through traffic signals to give priority to bus/tram services and emergency vehicles thus improving punctuality and reliability
  - Detecting and managing incidents on the highway network
  - Video surveillance of congestion hot spots
- Electronic payment, access control and enforcement systems, such as:
  - Road pricing, including automatic tolling and congestion charging
  - Vehicle recognition and restriction
  - Camera systems for traffic signal and speed enforcement
  - Environmental benefits
- Air quality monitoring and management, such as:
  - Pollution detection and prediction
  - Implementation of strategies to ease air quality problems
  - Safety benefits
- Safety systems including:
- Adaptive speed control
- Collision detection and avoidance
- Enhanced vehicle safety systems
- Cooperative vehicle highway systems

As shown ITS offers a wide range of tools that can be integrated into the transportation system. A common argument is that it is only through integration of these components ITS will be able to achieve its full potential. Today, however, many ITS project use standalone solutions because it is often more cost-efficient in the short term. This standalone approach has been criticized and it is argued that, in order for ITS to reach its full potential system integration will play a vital role (World Road Association, 2015).

Movea is a Swedish traffic consultant company with a team of researchers with several years of experience doing studies about transport in Sweden. In 2011 Movea published an Investigation about the potential future use of different ITS technologies in Sweden. This study suggests that the best practice for dealing with congestion issues along motorways is homogenization by the use of Variable Speed Limits (VSL) (Movea, 2011). Other studies also make statements about congestion benefits and accident reductions by the use of VSL (Nissan, 2010; Hegyi, 2004). This case study will illustrate how the use of VSL could be implemented together with the potential associated benefits along the road section. Below, a presentation of VSL follows including a technical review and potential benefits of the technology.

2.2 Variable Speed Limits (VSL)

VSL are digital signs that are able to display different speed limits depending on input such as traffic conditions, weather conditions, and work zone activities. (Hatcher et.al, 2014) They can be implemented to show either a mandatory (enforced) or advisory (recommended) speed limits. Sometimes in the case of mandatory VSL an Automatic Speed Enforcement (ASE) system is installed to increase compliance (also allows for an income stream in form of tickets). VSL can be effective in conjunction with ramp metering (Nissan, 2010) and is often implemented with other Motorway Control Systems (MCS). VSL can be implemented for a multitude of reasons, the two major being to harmonize heavy traffic flows and to lower speed at dangerous conditions (e.g., weather or road work). When it comes to harmonizing heavy traffic flow there are two distinct approaches/strategies, homogenization and limitation. They can be implemented together but are used under different conditions (Hegyi, 2004).

Homogenizing is done by reducing speed in some lanes and along a controlled segment of the road, as this creates a more stable flow that also increases safety. The homogeneous flow is more stable since there will be less speed adaption and takeovers that can induce a breakdown in flow. Homogenization of the flow will not resolve shockwaves but instead increase the time until breakdown. Studies of homogenization using VSL show that its calibration is crucial for a successful implementation (Nissan,
If the VSL reduces the speed too early it will instead lead to higher travel times and might not increase overall capacity (Van den Hoogen & Smulders, 1994).

Limiting the flow is aimed at resolving jams and reducing shockwaves, usually around bottlenecks. When traffic has broken down at some point along the highway VSL is used to gradually decrease the speed limit upstream from the breakdown. This gives drivers time to adapt to the speed of the jam which will both decrease the risk of rear-end collision and help resolve the traffic jam. The risk of rear-end collision will decrease since the drivers will be less likely to be caught by surprise of a sudden drop of speed. The lower speed of traffic flowing into the jam will also increase the chance of the jam “solving” itself since the reduced inflow of traffic decrease the shock wave thus not build up the jam as fast. Papageorgiou, et al. (2008), showed that an implementation did move the flow-density curve, allowing a higher flow and increasing the time until breakdown.

VSL is turned on either automatically by an algorithm or manually by operators in a traffic control center. The algorithm requires input data of traffic flow and usually activates VSL at a certain threshold of average speed or flow rate. It is also possible to activate VSL at certain weather conditions such as heavy snowfall or rain to reduce speed at dangerous conditions. VSL can sometimes interact with Automatic Incident Detection (AID). In that case when an incident has occurred, a lane can automatically be turned off or have its speed reduced to alleviate the effect of the incident. A manual activation can be used when the operator for example wants to override the current automatic setting due to an incident or roadwork.

A summary of evaluations performed after the implementation of VSL are shown in Table 1. The evaluations shows results with high benefit cost ratios and positive effects on travel time and accidents. Travel time with reduction of ~ 7 % on average and accident reductions of ~ 20 % on average. Regarding emissions, both positive and negative effects has been recorded but the average is still a reduction of ~ 4 %. Thus the major benefits for VSL seems to be travel time and accident reductions.

Table 1 Summary of VSL project evaluations

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>B/C</th>
<th>Travel time</th>
<th>Accidents</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mölndal to Tingstadstunneln (12 km)</td>
<td>(Lind &amp; Lindkvist, 2009)</td>
<td>10</td>
<td>5 % (heavy traffic) 15 % (queuing situation)</td>
<td>20 % (per million vehicle kilometers)</td>
<td>increased 5 % (positive effects of homogeneous flow not included)</td>
</tr>
<tr>
<td>The implementation of dynamic speed control in Barcelona area</td>
<td>(Easyway 2010)</td>
<td></td>
<td>7 % (also fewer stops)</td>
<td>26 % (off all, higher reduction in serious and casualties)</td>
<td>3.7 % CO2 (similar for NOx, SS, fuel consumption)</td>
</tr>
<tr>
<td>Summary overall system</td>
<td>(Easyway 2010)</td>
<td>8.64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engelbertunnel – Mundelsheim (both directions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For VSL to get the maximum results driver compliance is important.

### 2.2.1 Driver Compliance

An important parameter to achieve the desired benefits associated with VSL is driver compliance i.e., how well drivers respond to and accept the speed limits (Messmer & Papageorgio, 1994). VSL will still have an effect without enforcement (Lind & Lindkvist, 2009; Rämä, 1999) however Nissan (2010) suggests that VSL should be implemented as mandatory.

How driver compliance effects the impacts of VSL solutions has been studied by a number of researchers.

A study by Hellinga and Mandelzys (2011) models four levels of driver compliance (low, medium, high and very high) based on previous research and calculates the expected benefits with the associated adherence. Figure 1 shows the free flow speed in response to the VSL posted speed for speed recommendations between 60 and 100 km/h.

![Figure 1 Speed compliance scenarios](image)

The study uses a simulation model to estimate the impact of VSL during morning peak hours. The results of this simulation are shown in Table 2. Safety refers to the reduction in accidents and travel time to the increase thereof. As previous results of VSL implementations have shown the major benefits are associated with enhanced safety.
Safety increases as compliance increases with highest increase in the lower levels (from low to moderate compliance). As compliance increases the travel time also increases, especially in the case of very high compliance. However Hellinga and Mandelzys find this vast increase in travel time unexpected and counterintuitive hypothesizing that this may be the effect of an inadequate model rather than VSL per se (Hellinga & Mandelzys, 2011).

<table>
<thead>
<tr>
<th>Driver Compliance</th>
<th>Safety</th>
<th>Travel Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>10%</td>
<td>~7%</td>
</tr>
<tr>
<td>Moderate</td>
<td>28%</td>
<td>~4%</td>
</tr>
<tr>
<td>High</td>
<td>38%</td>
<td>2%</td>
</tr>
<tr>
<td>Very High</td>
<td>39%</td>
<td>(36%)</td>
</tr>
</tbody>
</table>

Table 2 Benefits for different levels of driver compliance

An important parameter affecting the driver compliance is enforcement. Many researchers argue that enforcement increases compliance. Some consider enforcement a necessity when implementing VSL while some studies shows a positive effect but to lesser extent (Piao & McDonald, 2008).

Another way of increasing driver compliance may be to use in-vehicle systems instead or as a complement to the roadside signs. One type of such a system is Intelligent Speed Adaptation (ISA) systems and will be the topic of the next section.

### 2.2.2 Intelligent Speed Adaptation (ISA)

ISA systems are in-vehicle systems that vehicle speed reacting when the vehicle is exceeding the local speed regulation. The system can be “passive”, warning the driver in case of speeding, or “active”, where some degree of automated control is used to take action in reducing the speed. More sophisticated systems may include more advanced features e.g., speed reduction for steep turns and set up speed zones for accident and road work zones (Paine et al., 2007).

To function, an ISA system needs to have an accurate location of the vehicle. The location information is combined with a digital map containing information about local speed limits and location of variable speed zones e.g., schools, roadwork zones etc. More sophisticated systems may include information about areas where the speed limit should be reduced due to weather conditions or accidents. There are several methods that can be used for determining the location of a vehicle (Paine et al., 2007).

GPS is the most widely used system for location determination. It uses satellites continuously transmitting radio signals that can be used to determine location of the receiver. The main disadvantage of this system is the lack of coverage that can be experienced in areas such as underground or in tunnels (Paine et al., 2007).
Radio beacons are roadside equipment continuously transmitting information that can be picked up by receivers in the vehicle. This information may include variable speed limits or traffic warnings that can be picked up by vehicles as they pass each beacon. The main disadvantage of beacons is that the vehicle needs to be in the vicinity of the beacon to be able to pick up the information (Paine et al., 2007).

Dead reckoning uses a mechanical system on the vehicle with sensors to predict the path taken by the vehicle. These sensors may include rotation of the road wheels, speed sensors, accelerometers and gyroscopes. To work this system requires the vehicle to begin at a known geographical position. It is hard to make these systems accurate and error typically increases as time goes by. Some high-end GPS systems use dead reckoning as a backup in case the GPS signal is lost (ibid.).

Carsten and Tate (2005) have studied the effects of ISA effectiveness. In a simulation study they examine the effects of ISA in respect to crashes. Three levels of ISA are considered, Advisory (passive), Voluntary (i.e., active but the driver can disable), and Mandatory (i.e., always active). Also, three levels of speed limit types are considered i.e., Fixed, Variable, and Dynamic. The results are presented in Table 3.

\[\text{Table 3 Simulated injury reductions for different ISA types}\]

<table>
<thead>
<tr>
<th>System</th>
<th>Speed Limit</th>
<th>Injury</th>
<th>Fatal and serious</th>
<th>Fatal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advisory</td>
<td>Fixed</td>
<td>10</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>10</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>13</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Voluntary</td>
<td>Fixed</td>
<td>10</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>11</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>18</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>Mandatory</td>
<td>Fixed</td>
<td>20</td>
<td>29</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>22</td>
<td>31</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>36</td>
<td>48</td>
<td>59</td>
</tr>
</tbody>
</table>

The effectiveness of the system increases with voluntary and mandatory ISA systems and also increases with the level of dynamic speed limits. Also the system has higher impacts on serious injuries and fatal accidents than for more minor accidents. A sensitivity analysis for the case of injury accident reduction is presented in Table 4 (Carsten & Tate, 2005). The sensitivity analysis shows that there are some uncertainties in the model but even in the low level estimates the effects are positive. The high estimate shows that in the best case scenario there are major benefits to be achieved (Paine et al., 2007).
### Table 4 Sensitivity Analysis for Injury accidents

<table>
<thead>
<tr>
<th>System</th>
<th>Speed Limit</th>
<th>Low</th>
<th>Best</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advisory</td>
<td>Fixed</td>
<td>2</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>2</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>3</td>
<td>13</td>
<td>27</td>
</tr>
<tr>
<td>Voluntary</td>
<td>Fixed</td>
<td>5</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>6</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>10</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td>Mandatory</td>
<td>Fixed</td>
<td>11</td>
<td>20</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>12</td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Dynamic</td>
<td>19</td>
<td>36</td>
<td>50</td>
</tr>
</tbody>
</table>

Few studies has been made on in-vehicle speed information systems in relation to driver compliance. Whitmire (2011) examines the effect of an augmented in-vehicle speed warning on driver behavior in work zones. Three driver configurations was examined as the driver entered a traffic work zone; a base case i.e., traditional signage, a visual in vehicle warning, and a case with the addition of an auditory warning system. The number of speed violations for the respective groups are presented in Table 5 (Whitmire et al., 2011).

### Table 5 Speed compliance in work zones for different ISA technologies

<table>
<thead>
<tr>
<th></th>
<th>% of time in work zone spent in speed violation</th>
<th>Number of violations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>44 %</td>
<td>4.3</td>
</tr>
<tr>
<td>Audio</td>
<td>7%</td>
<td>3.2</td>
</tr>
<tr>
<td>Visual</td>
<td>18%</td>
<td>3.5</td>
</tr>
</tbody>
</table>

The control group spent 44 % of the time in the work zone violating the speed limit. In contrast, the audio warning group spent only 7% of the time in the work zone exceeding the speed limit. The Visual speed warning system also reduced the amount of time spent speeding at 18 % of the time in the work zone. As well as the time spent in speed violation the number of speed violations was studied across the work zone of 2.1 km. The reference group had an average of 4.3 violations i.e., times going from a speed at or under the speed limit to exceeding the speed limit. Both the audio and visual group had a lower average of violation at 3.2 and 3.5 respectively. Comparing the number of violations there was no significant differences between the groups (p>0.25) (Whitmire et al., 2011).
2.3 Evaluating investments

This part introduces methods for evaluating investments, as well as research on what is mostly used within ITS. The chapter gives a general introduction to Cost Benefit Analysis together with some CBA-results from ITS-investments. A large segment is used to present the different criticisms against CBA, both political and methodological. Finally, Real Options is presented as an alternative to CBA and the altered version Hybrid Real Options, used in the case.

2.3.1 Methods for evaluating investments

Governments have to deal with the selection process of transportation investments. The selection approaches can be divided into four major categories (Erel et al., 2000):

- Profile and Checklist methods
- Scoring methods
- Benefit-Cost methods
- Mathematical programming models

Out of the four categories Benefit-Cost Analysis is the dominating method used today although it is argued that it is not superior compared to the other approaches (Lee, 2000).

![Tools used by 250 stakeholders to take decisions regarding ITS investments](image)

Figure 2 Results from a survey regarding tools used as a basis for decisions.

2DECIDE was a project funded under the European Union’s 7th Framework Programme for Research and Development. The objective of 2DECIDE was to develop an “ITS Toolkit” to assist transport authorities in the deployment of Intelligent Transport Systems (Mans et al., 2011).
To find out what the intended users looked for in an “ITS Toolkit” a questionnaire was sent out to 573 stakeholders from 28 countries (24 from EU Member States). The survey resulted in 250 completed questionnaires giving a response rate of 44% of which the researchers were very satisfied. The results from the survey (in Figure 2 and Figure 3) showed that Cost-benefit analysis and National/international best practice was the most frequently used tool by the stakeholders. Benefit data, lessons learned, and cost data was also considered to be the most useful information that could be provided according to the stakeholders. The questionnaire also showed that information on political acceptance and technical or standardization data was described as most useful by the fewest respondents.

### 2.3.2 Cost Benefit Analysis

A CBA is a framework that allows a systematic comparison between the collected effects and costs of an investment over its entire lifecycle. One big advantage with a CBA is that it forces an explicit report of how different effects of the investment are valued, for example traffic safety vs. reduced travel time. Another advantage is that the same weights are used independent of what solution is studied. It enables an objective and systematic comparison between different solutions and provides a foundation for discussion about the prioritizations. It should allow for scarce resources to be used in the most effective way (Börjesson & Eliasson, 2015).

Jules Dupuit first mentioned CBA in 1848; it was later formalized by Alfred Marchall. The Corps of Engineers established the use of CBA in the US in the Federal Navigation Act of 1936 that required a CBA to be performed for proposed federal waterway investments. The use of CBA was expanded during the 60s to water quality, recreational travel, and land conservation. Subsequently the use of CBA has also been expanded into other areas such as mental illness, substance abuse, college education, and chemical waste policies (Hanley & Clive, 1993).
A major turning point when CBA started to gain influence over policymaking was when Ronald Reagan campaigned on a deregulatory platform where CBA was supposed to serve as an unbiased tool yielding the best policy. After this turn towards a higher reliance on CBA critique against it started to rise from both academic and institutional sources, the critique can be divided into three main types of arguments (Shapiro, 2011).

1) CBA is just a cover for political goals - CBA can be used to as a cover to give legitimacy for whatever goal the politicians have and won’t necessarily yield the investment that maximizes public profit (Shapiro, 2011).

2) CBA is inherently anti-regulatory and ethically wrong - CBA monetization of environmental goods and public health is critiqued since it would lead to policy choices that are not moral and ignores distributional impacts (Shapiro, 2011).

3) CBA delays the regulatory process - requiring a CBA will make rulemaking more burdensome which might delay the regulatory process and lead to agencies avoid rulemaking altogether (Shapiro, 2011).

**CBA in traffic assessment**

CBA in was first used in transport in 1960 for the UK motorway project M1. After this it spread and gained a dominant position as a tool for evaluation transport investments. HEATCO, a consortium of stakeholders within transport, found that there was a significant difference between transport appraisal methods within the EU. There is currently an effort to harmonize this within EU. (European Commission, 2008) CBA is used in the US and Canada within both federal and state transport departments (Transport Canada, 1994; US Federal Highway Administration, 2003).

In a CBA the citizens own valuations of different effects are weighed against each other, the value of a shorter travel time is weighed against lower travel costs or increased traffic safety. This is called internalizing external values, i.e. taking into account the values and costs that are not directly shown monetarily. The value of carbon dioxide emissions is usually based on current and future political decisions. The value receives legitimacy based on that the public has elected the officials that have passed the legislations that lead to these values, creating a form of implicit valuation (Börjesson & Eliasson, 2015).

A CBA is based on a careful description of what effects a measure will have in the in terms of for example shorter travel times, how many travelers that are affected, and how their behavior changes. These are calculated for the present situation and then forecasted for future years using a model for how traffic volumes etc. will change, giving a voice not only to the present but also the future citizens. Using the same traffic forecast allows for comparison between projects (Börjesson & Eliasson, 2015).

Increased availability is usually the biggest effect of a transport investment. The concept availability refers to: travel time, travel cost, punctuality and reliability, frequency, convenience and more or less all other aspects that affect how easy it is to reach different destinations can be included. Since reduced travel time usually is the
predominant effect of transport investments availability benefits are sometimes confused with time travel savings. The availability benefits are eventually translated into a combination of more leisure time, more hours at work, a higher salary and better living situation due to being able to reach more of the housing and work market in the same period of time. It is hard to know how these availability benefits are divided amongst different groups which might be a drawback (Börjesson & Eliasson, 2015).

To be able to aggregate all of the effects that an investment creates during its lifetime and compare these between different investments general parameters are needed, such as discount rate, economic lifespan, and tax factors. These parameters are hard to determine exactly, but they affect most investments similarly and usually don’t change the ranking of the investments. This has been studied by Eliasson, Börjesson and Lundberg (2014) in “Is ranking of transport investments robust?”. The study concludes that greatly altering (+100%) the valuation of travel time, emissions, and safety will not change the ranking for more than 30 of the top 250 investment alternatives.

The main benefit of CBA is that it facilitates prioritization between proposed infrastructure investments. If a single project is “profitable” or not is often less interesting since the value of the parameters will decide where the break-even point lies and since the total budget for infrastructure investments are not particularly affected by the profitability of single investments. As the CBA is performed in the same way for all proposed investments comparing their “profitability” still provides valuable information. Nevertheless the profitability of single investments is often cited in media for large infrastructure investments (Börjesson et al., 2014). However it should be noted that socioeconomic evaluations are better when they are used to compare between alternatives closer to each other. For example comparing two different types of fences will yield a better basis for decision than comparing a rail investment with an investment in traffic lights.\(^1\)

\(^1\) Gunnar Lind, Ph.D. and VP Movea Trafikkonsult AB, interview 2015-09-28 and email correspondence.
CBA results from ITS investments

US department of transportation provides a comprehensive database with ITS benefits. A statistical summary of 47 CBA from investments, evaluated with data generated from the actual investment, i.e. no simulations, are presented in Figure 4. It is noticeable that ~96% of the investments proved to be profitable (B/C>=1) and many (~47%) of the investments had a B/C between 1-5 and a significant proportion (~20%) had a B/C over 20 (US DOT, 2015).

CBA as a basis for decision

It is common for politicians to cite CBA when arguing for a certain solution, however studies suggest that CBA has little effect when it comes to which projects are actually funded. A study of transport investments in Norway and Sweden showed that CBA-analysis has little effect on which investments the government's decided on. The investment choices might as well have been done randomly. The Swedish government made investments for 70 BSEK that generated a socioeconomic profit of 77 BSEK. If they instead made all the investments with the highest socioeconomic profit first the 70 BSEK investments had generated 119 BSEK, an increase of 42 BSEK. Socioeconomic analysis did slightly affect the probability for smaller investments to be picked but had a very small effect for larger investments. What had the most effect for the probability of a project to be funded, in both Norway and Sweden, was the government's support in the region of the investment (Börjesson et al., 2014). Many studies such indicate that the support for the national government in a local region can affect the probability for public investments to be made in that region (Cadot et al., 2006; Bombardini & Trebbi, 2011; Hammes, 2013). This effect might not be attributed solely to vote buying since the elected governments had got elected on certain policies such as supporting rural region, policies they later fulfill. For example, the Swedish transport agency which, unlike the Swedish government, to a large degree did choose their investments based on socioeconomic analysis. This fact could be attributed to the Swedish government.

Figure 4 Histogram and cumulative distribution of B/C evaluations
campaigning that the steering of agencies investments should be based on socioeconomic value. Another possible explanation is that the agencies are made up of officials (experts) rather than politician, which might give a bias towards the most “effective” investments rather than the politically viable (Börjesson et al., 2014).

### 2.3.3 Aggravating circumstances of investment evaluations

There are several aggravating circumstances when dealing the uncertainty of the future and interaction between technology and society that has an impact on the result of an investment evaluation. In this chapter research findings and theory on four different problem areas are summarized.

**Challenge of forecasting**

The financial viability as well as the socio-economic and environmental potential of a transport investment is often heavily dependent on traffic demand forecasts. However, a traffic demand is complex to forecast (Flyvbjerg et al., 2005). Research from Flyvbjerg et al. suggests that forecasts are often both outside an acceptable error margin (+/-10%) but also tend to be biased. In their 2003 study they measured the forecasting inaccuracy of 210 transport projects. The main results were that: out of the the 183 road projects more than 50% of the forecasts had errors bigger or equal to 20% and that 25% of forecasts where more than 40% there was however no major (around 9% underestimation) biases. Rail projects had a large bias as 9/10 of the rail projects studied had a lower than forecasted traffic with an average overestimation of 105%. Flyvbjerg et al. argues that the tendency to overestimate rail projects might be explained by rail projects often having a more direct revenue stream in the form of tickets, why a higher traffic is needed to motivate the investment. From this Flyvbjerg poses the hypothesis that the sub-segment toll roads investment should have more overestimations than road investments in general. This has since been studied by Bain & Polakovic (2005) who showed the traffic demand on toll roads were on average overestimated by 20-30%, significantly higher than the 9% underestimation found by Flyvbjerg. Flyvbjerg continued to study the reason for the forecasts errors and found that trip generation, land use development, trip distribution, and forecasting model as the four causes for inaccuracies in road traffic forecasting. The study recommends reference class forecasting, developed by Daniel Kahneman to compensate for a type of cognitive bias in forecasting in human forecasting for which he was awarded the Nobel Memorial Prize in Economic Sciences. Reference forecasting argues that humans tend to take an inside view of a project focusing planned actions instead of comparing it to the outcome of similar ventures which is an outside view. This leads to an overestimation of the benefits. Reference forecasting can be explained in three steps (Flyvbjerg, 2005).

- Identify a reference class of past, similar projects.
- Establish a probability distribution for the selected reference class for the parameter that is being forecast.
- Compare the specific project with the reference class distribution, in order to establish the most likely outcome for the specific project.
**Flaw of averages**
The future is a distribution of outcomes and a single point estimate based on the average of these outcomes the NPV will not be correct. This is due to the “flaw of averages”, coined by Sam L Savage (2009). The flaw of averages stems from the nonlinear properties that most real systems will have. Neufville defines the flaw of averages as the “average of all the possible outcomes associated with uncertain parameters, does not equal (except if system is linear) the value obtained from using the average value of the parameters” (Neufville & Scholtes, 2011). The flaw of averages can be formally stated as in Equation 1.

\[ E(f(x)) \neq f(E(x)) \quad (1) \]

To illustrate this concept Savage uses an example of estimating the average profit for selling a product using its average demand. If the average demand for the product is 1000 units, the product costs 40 SEK to order and sells for 50 SEK the profit is 10 SEK for each product sold. Then the reasonable decision is to order 1000 units, this should yield a profit of 10000 SEK. This is wrong, for every product left in stock the profit is -40 SEK and for every demand that is not met the profit is 0 SEK. A better estimate of the expected profit is achieved by running multiple consecutive samples of demand from a distribution, then calculating the profit given the samples and averaging these profits. Running this model shows that the optimal decision is to order fewer than 1000 units even if that is the average demand (Savage, 2009).

**Trend breakers**
Neufville et al. (2008) argues that a major characteristic of any major infrastructure investment and why they are often deemed unsuccessful is the great uncertainty that comes with them. Major infrastructure investments often take a decade or more to design and develop. During that time, it is possible for major changes in technology, the economic situation, governmental regulation, the industry organization, and political structure. Greater changes in any of these dimensions may be trend breaking and regularly distrust long-term forecasts, see Table 6.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>Disruptive technologies have been seen to completely change markets throughout history.</td>
</tr>
<tr>
<td>Economic and financial</td>
<td>Major economic booms and busts can create trends that greatly affect the evaluation of projects.</td>
</tr>
<tr>
<td>Regulations</td>
<td>Regulations can reshape industries by dictating the market rules.</td>
</tr>
<tr>
<td>Industrial</td>
<td>New business models may quickly change the structure</td>
</tr>
</tbody>
</table>
Political Changes in political leadership may incur policy changes that greatly affect industries.

Other Greater events or changes stemming from rare natural occurrences and/or human error.

None of these trend breakers will occur in vacuum and there will be some level of interdependence between them. Neufville and Scholtes (2011) states that the best way to identify these trend breakers is through developing scenarios that implicitly identifies possible trend breakers. A scenario should be a narrative that convincingly demonstrates the dynamics and chain of events that lead to a certain scenario (ibid.).

For example, a possible scenario for the electric vehicle (EV) industry is that the cost of batteries will reduce at a much slower rate than anticipated while internal combustion engine vehicle (ICEV) continue to improve but at a higher rate than expected. This coupled with government subsidies for electrical vehicles reducing over time and failing to compensate for the higher cost of ownership for an EV leads to it remaining a niche product with a small market share. In another scenario the R&D of batteries will lead to both lower costs and longer lifetimes. The total cost of ownership of an EV closes in on an ICEV. The adoption of EV accelerates as government invests in charging infrastructure and subsidies of EV. The EV eventually overtakes the ICEV and its market share continues to increase (Kampman et al., 2011). It is common to also include the “business as usual” scenario where current trends continue and no major trend-breaks occur.

**Adoption of new technologies**

The market adoption of a new technology will have a significant effect on the economic evaluation of an investment. As stated above a scenario analysis can be performed to identify different trend breakers however the technology adoption rate is still difficult to predict.

Two examples of technologies with similar characteristics display this. The anti-lock brake (ABS) systems were first introduced by GM and Chrysler in 1971, Mercedes later introduced an all-electronic version in 1975. The growth of ABS had its peak in the early 1990 and by 1994 the growth rate had leveled off; the fleet adoption has remained around 60% since then. Airbags were introduced by Mercedes and Ford in the mid 1980's. In 1991 The U.S. Congress passed a mandate requiring all new passenger vehicles to be equipped with airbags by 1996. This had the effect that airbags went from 0% to 100% penetration of the newly produced vehicles (Hill & Garret, 2011).

This is an example of two technologies within the same problem domain that despite similar promise had different adoption rates due to external factors.
2.3.4 Hybrid Real Options

Hybrid real options is a relatively new valuation framework introduced in the early 2000s by joint research from Neufville, MIT Technology and Policy, and James E Neely III, Consultancy firm Booz-Allen & Hamilton Inc (Neely & Neufville, 2001). Hybrid Real Options aims to solve two problems with valuation of risky projects:

1) Traditional CBA is inadequate for many risky projects
2) Other available methods are often limited and impractical.

The first problem is discussed in the critique part of CBA. The second problem is related to the fact that the mathematical theory from real options is quite complicated to use and understand, why HRO aims to take parts of it and make it more accessible and understandable (Neely & Neufville, 2001).

An option is the right but not the obligation to buy or sell an asset at a certain price during a period of time. The price of the option depends on the current price of the underlying asset (spot price), how long the option is valid, and the estimated volatility of the underlying asset. Options are generally used to mitigate price risk of an asset, for both sellers and buyers. But can also be used to speculate without having to hold the actual asset (Schulmerich, 2010).

Real options is a concept that applies option theory to real investments, where real refers to a more tangible asset. For example, a real option would treat buying a mine while financial options treat contracts related to the price of ore. The value of the mine is closely related to the price of ore; the owner can choose to sell the mine or stop the development depending on the ore price. These options cannot be captured by a traditional CBA. Since there are some differences between a financial asset and a tangible asset, for example market liquidity, some alterations of the evaluation methodology needs to be done, while the general idea still stays the same (Schulmerich, 2010).

Real Options has been around for 25 years and is still a relatively new approach to valuation. It has been utilized a lot in academia but has not yet had a big spread within management. Marcus Schulmerich summarizes research on the spread of Real Options within management in his book “Real Options in Theory and Practice” from 2010. He finds that although academia is united in that Real Options is a theoretically superior method, not many within management know about it or use it. Schulmerich is still hopeful, since it took CBA 37 years to go from 9% to 90% of U.S. companies using the method.

In hybrid real options methods from real options are used to take external risks into account for the value of the investment while internal risks and decisions are treated using a decision three. The decision three is easier to use for management and thus greatly increases the chance of the tool actually being used. The decision three starts at
the first decision then branches out with different decisions and outcomes (Neely & Neufville, 2001).

Hodota (2008) states that many critics have pointed out that while CBA is appropriate for valuing low-risk projects it has limitations for projects with significant growth or strategic options. He also states that Real Options should be appropriate for valuing such investments.

Martha and Kulatilaka (1998) has developed a list of criteria that can be used to evaluate if Real Options is a good idea to use:

1) When there is a contingent investment decision. No other approach can correctly value this type of opportunity.
2) When uncertainty is large enough that it is sensible to wait for more information, avoiding regret for irreversible investment.
3) When the value seems to be captured in possibilities for future growth options rather than current cash flow.
4) When uncertainty is large enough to make flexibility a consideration. Only the real options approach can correctly value investments in flexibility.
5) When there will be project updates and mid-course strategy corrections.

Hybrid Real Options has been applied to different investments where uncertainty is a large component such as product platforms, risky R&D-projects, and large scale infrastructure investments (Jiao, 2012; Houge & Westlie, 2011).
3. Methodology

This chapter gives an overview of the research approach and methods used in the thesis. The research approach and study designed are described, explained and are discussed with regards to reliability and validity. The chapter also includes a methodological description of the two socio-economical evaluation methods that are used in the case study and how these two methods will be used together. It also introduces the traffic modelling and theory methods applied in the case.

3.1 Research approach

The thesis is qualitative in nature and takes an explanatory approach as the study will “evaluate an alternative socio-economical evaluation method”. This approach is useful for finding out insights in new light in areas of research which are to some extent under-developed (Saunders, 2009).

The term “qualitative research” is sometimes interpreted as an approach where quantitative data is not collected or generated. However, Bryman & Bell (2007) states that many writers on qualitative research argues that the distinctiveness of qualitative research does not reside in the absence of numbers. In this thesis, much of the data in the case study are of quantitative characters despite the fact that the research approach is qualitative.

Triangulation according to Bryman & Bell (2007) refers to the use of more than one approach to an investigation to enhance the confidence of the findings. In this study the use of both the use of secondary research findings together with the case study are used to increase the validity and reliability of the study. Triangulation has been subjected to criticism for its apparent subscription to a naively realist position that implies that there can be only one definite account of the world.

The following subsections further described in the literature study and case study of this thesis.

3.1.1 Literature Study

The first part of this study was to conduct a literature review. A literature review increases the credibility of the study and is performed with the purpose to find out, what is known in the research area, what concepts and theories that are relevant, and to find controversies within the area (Bryman & Bell, 2007). Parallel to the literature review, several interviews were performed with relevant people working in the area of this study, to discuss the aim of the study and get guidance in the choice of aim and data sources. The majority of these interviews were conducted with people at Ericsson AB, to make sure that the aim of the study are of interest for the team working with ITS.
3.1.2 Case Study

The thesis also contains a case study. Case studies are according to Johansson (2003) used to capture the complexity of a single case enabling for in-depth research. The methodology was chosen because of its ability to study (1) complex units, (2) in its natural context, especially when the studied object are a (3) contemporary phenomena.

Case studies are often criticized for its lack of generalizability. However, Yin (2012) argues the difference between statistical and analytical generalizations. In this thesis the generalizations of the results are of analytical nature emphasizing that the logic of the findings might be applicable in other situations. Or as Yin expresses it: “Case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes”.

3.1.3 Data Collection in the Case study

All traffic data, monetizing values and background information used in the case study is from governmental sources i.e., the Swedish Transport Authority. In the case study many uncertainties are considered e.g., Technological success and traffic demand. Accounting for these uncertainties required assumptions to be made, which are further described throughout the case study. Esaiasson et al. (2012) states that data from governmental sources are to be considered as reliable. The assumptions could have been made on other premises than used in this case which in turn could have yielded other results. However the focus of the case study is to highlight the characteristics of the valuation method rather than present results that could be used as base for decision making. A summary of the data collection resources are presented in Table 7.

<table>
<thead>
<tr>
<th>Data</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Volume</td>
<td>“Vägtrafikflödeskartan”, Swedish Transport Authority</td>
</tr>
<tr>
<td>Accidents</td>
<td>STRADA, Swedish Transport Authority</td>
</tr>
<tr>
<td>Monetizing values</td>
<td>ASEK, Swedish Transport Authority</td>
</tr>
<tr>
<td>Technical Effectiveness</td>
<td>Assumptions, Previous evaluations and simulations</td>
</tr>
<tr>
<td>Adoption Rate</td>
<td>Assumptions, Historical data on similiar technologies</td>
</tr>
<tr>
<td>Future Traffic Demand</td>
<td>Assumptions, Predictions from Swedish Transport Authority</td>
</tr>
</tbody>
</table>

In the case study, traffic modelling methods and socio economical valuation methods are used, the following sections contains an overview of these methods.

3.2 Case study methodology

The following section focuses on the methodology used in the case study. Since the case is used to illustrate the differences between the CBA and HRO methods a combination
of the two are used. Section 3.2 gives a practical overview of the two methods (Section 4.2.1 and 4.2.2) together with an explanation on how the two methods will be used together in the case study (Section 4.2.3). Finally the traffic modeling methods used are explained in section 4.2.4.

3.2.1 Cost benefit analysis

Typically a CBA analysis uses a microeconomic approach enabling an assessment of the projects impact on the society as a whole i.e., welfare changes. When doing a CBA only primary impacts should be assessed leaving out indirect (secondary markets) and wider effects (employment, regional growth). This is primarily due to complexity and the risk of double-counting this types of effects. However it is still feasible to provide a qualitative description of these indirect/wider effects (European Comission, 2012).

As the Traditional CBA is a method used in a wide variety of settings there are different ways of defining the process. The framework used in this thesis is from a publication from the EU Joint Research Program and is used among other to conduct a CBA on an ITS-investment. The framework devides the process into three main parts with a total of seven steps in the actual CBA. The process is illustrated in Figure 5. This section will shortly cover the different parts and steps.

![Diagram of CBA process](image)

**Figure 5 An overview of the parts and steps that make up a CBA.**

Define the boundary conditions and set parameters

In the first part of the process some of the main conditions and parameters that will affect the outcome of the evaluation. Setting the parameters initially can increase the
fairness of the evaluation since their level will affect the projects expected outcome. Some of the parameters that are set are the: discount rate to be used, time horizon of the CBA (15 years is common for ITS-investments), implemented technologies, and schedule of implementation. There are also assumptions regarding external factors such as the impact of the regulatory framework and macroeconomic factors as well as more direct factors such as the demand of the investment and how it will be distributed.

As mentioned the actual CBA part of the process is divided into seven steps that will be briefly explained below.

**STEP 1: REVIEW AND DESCRIBE TECHNOLOGIES, ELEMENTS AND GOALS OF THE PROJECT**

In the first step the technology and system components that is to be used are presented. The scale and local characteristics of the investment are presented as well as the most relevant stakeholders of the project. This step should also include a clear statement of the projects objectives.

**STEP 2: MAP ASSETS INTO FUNCTIONALITIES**

In this step the technological assets of the project are mapped into functionalities. For example, a game fence would be mapped to less game entering the road. The scope of this step will depend on the scope of the project and number of technologies used.

**STEP 3: MAP FUNCTIONALITIES INTO BENEFITS**

The functionalities are mapped into benefits using some model of the relationship. The type of model used can vary in complexity depending on the problem domain.

**STEP 4: ESTABLISH THE BASELINE**

When assessing a project with CBA the outcome is compared to a baseline scenario i.e., with-project compared to without-project. Therefore, one needs to define this baseline scenario without the project, define the scenario with the project and compare the difference between these two. Establishing a baseline requires some forecast of the future and a defined outcome as a baseline.

**STEP 5: MONETIZE THE BENEFITS AND IDENTIFY BENEFICIARIES**

Since many benefits doesn’t have market prices there is a need to use shadow prices to quantify the benefits. Shadow prices are the monetary value of a hard to calculate cost. The costs often stem from externalities, which is a term within economics that refers to a cost from a transaction that affects a third part.

**STEP 6: QUANTIFY COSTS**

Besides costs the negative effect a project can generate, quantified in the same way as Step 5 is added in this step. The costs related to a project is often measured directly in a monetary value, however estimating them is non trivial for large long term projects.
From the benefits and the costs different KPI:s can be derived such as B/C-ratio and NPV. Note from Table 8 that they both are needed to capture both the relative and absolute value created by an investment.

<table>
<thead>
<tr>
<th>Table 8 Example of KPI:s derived from Benefit and Cost outcomes.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Option</strong></td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

Perform Sensitivity Analysis

Sensitivity Analysis is not something that is specific to conducting a CBA. It will be covered in more detail in 4.5.

### 3.2.2 Hybrid Real Options

Hybrid Real Options is a hybrid version of the option valuation theory altered to better suit the needs and skills of project management. This is done by combining the elements of decision analysis and option analysis. HRO outlines three phases of the method outlined in Figure 6 with explanations below. This section will provide a high level introduction to the theoretical framework. A detailed example of a implementation on a simplified problem is available in Appendix B.

**Phase 1 Setup - Definition of the scope of assessment**

In the setup phase of the Hybrid Real Options method it is, just as in any project evaluation, necessary to identify the different uses of the project and the uncertainties that should be considered. Neely and Neufville uses the example of Ford looking into the development of fuel cells. In this case the fuel cell should not only be viewed as a replacement of the internal combustion engine, it could also be used as a portable or fixed power source in other applications. The project also carries market uncertainties such as new regulations for vehicle emissions and changes in oil supply, there are also many technological uncertainties with such a project and how it would affect the...
market. The project managers in charge of the evaluation also need to identify that there are benefits of a project that are not directly monetary, such as reduced emissions, in these cases the non-monetary should be monetized to accurately capture all value created. To properly value projects managers must also identify different decisions and flexibility that will be possible throughout the projects lifetime (Neely & Neufville, 2001).

**Phase 2 Analysis - Data collection and Analysis**

In the analysis phase the data for benefits, costs, and uncertainties needed for the project evaluation is gathered and structured. A model that quantifies the value associated with different outcomes is created. The model, benefits, costs, and uncertainties need to be combined into relevant decision analysis or options frameworks for the complete analysis.

The market risks and technical risks are usually treated separately since they require different perspectives and should preferably be performed by people with expertise in the different areas (Neely & Neufville, 2001).

**PROJECT RISK**
The project risk tries to quantify three different areas. The likelihood that the project will be successful, the risk of cost overruns, and the projects effect on the market.

**The Likelihood of Success**
The project will both have a risk of technology failure and in the case of success there are still uncertainties of what benefits it will yield. For an investment in a very novel project there is a risk that the endeavor will fail to yield any working solution at all, within the resource budget of the project. To model the risks in the decision analysis they need to be given discrete probabilities that are mutually exclusive and collectively exhaustive. These risks should be estimated by gathering data from previous projects with similar characteristics. In the case of ethical drug development there are statistics of thousands of previous projects that can be used to estimate the risk of failure (Neely & Neufville, 2001).

In case of a successful project there is still an uncertainty of how large benefits the project will create. The range of the uncertainty should depend on the novelty of the project. Something that has been done many times before should be easier to determine the outcome of than something very novel, with a middle ground of incremental improvements on previous projects. There are many factors that make it hard to determine benefits as they likely depend on the location and time. Just as the technology risk, both the spread of the benefits and their respective probabilities should be estimated based on previous similar projects (Neely & Neufville, 2001).

**The Possibility of Cost Overruns**
This can be modeled into the decision analysis in the same way as the benefit uncertainties. It is important to note that it is not sufficient to only take into account the
mean cost, instead the distribution of costs for similar projects should be studied (Neely & Neufville, 2001).

THE INFLUENCE ON THE AVAILABLE MARKET

This borders into market risks but managers also need to take into account how the project will affect the market. Some products such as a wireless phone will act as a substitute to a product currently available on the market, in the case of wireless phone the wired phone. This type of product should not have any greater effect on the size of the market. Others such as the cell phone expand the market into new areas. There are also examples where a product could reduce the market size, for example a vaccine could reduce the market for treating the particular disease (Neely & Neufville, 2001).

MARKET RISKS

TECHNOLOGY ADOPTION

The logistic distribution has been used to describe the diffusion of new ideas and technologies since Gabriel Tardes *The Laws of Imitation* 1890. Tardes identified three stages in the diffusion of an innovation. In the first stage the innovation struggles to get recognition, after the innovation starts to gain momentum there is a period of exponential growth, in the final period the momentum of the technology spread slows down as the final users adopt it at a logarithmic rate. Tardes model has been used to describe many major inventions such as: electrification, cars, and railroad (Grübler, 1990).

A logistic distribution has two parameters that can be adjusted to achieve the expected adoption rate. It is possible to define different scenarios for adoption that may be reached with certain probabilities, contingent on earlier outcomes such as technology success. The parameters that can be adjusted are scale (s) and location (my). Scale changes the shape of the curve while location shifts it (Grübler, 1990). The probability density function and cumulative distribution function are presented in Equation 2 and 3, with examples for two different parameter settings in Figure 7 and Figure 8. The probability density describes when in time the adoption occurs and the cumulative function shows the how the adoption grows over time.

\[
f(x; \mu, s) = \frac{e^{\frac{x-\mu}{s}}}{s \left(1 + e^{\frac{x-\mu}{s}}\right)^2}
\]

\[
F(x; \mu, s) = \frac{1}{\left(1 + e^{\frac{x-\mu}{s}}\right)}
\]
The Binomial Option Pricing model was introduced by Cox et al. (1979). It is a numerical method as opposed to analytical methods such as Black-Scholes introduced by Black and Scholes (1973). A benefit of a numerical method is that it can handle more complex functions (Kilic, 2005). The Binomial Option Pricing method is an iterative method where the price lattice is generated by starting from the valuation date and moving towards the expiration date. After that the option value is calculated at each of the final nodes. From the final nodes the process works backwards through the lattice until it reaches the first node, yielding the present day value of the option. The process is performed in the three steps presented below.

1. Generation of the lattice
2. Calculation of option value at each final node
3. Sequential calculation of the option value at each preceding node

**Figure 7** High: \( m=6, s=2 \); Low: \( m=15, s=1.5 \)

**Figure 8** High: \( m=6, s=2 \); Low: \( m=15, s=1.5 \)
The hybrid real options framework uses a modified version since the options are represented in the decision analysis tree, that is more suitable to incorporate “options thinking” in project management. The modified version uses the following three steps (Luenberger, 1998):

1. Outcome lattice generation
2. Evolving a probability lattice
3. Calculating cash flow at each node

NOTATION

t = time step
i = node index
S_{i,t} = underlying at time t and node i
p_{i,t} = probability of state i, t

THE METHOD NEEDS FIVE INPUT PARAMETERS
S_0 = the current asset value
\sigma = the estimated volatility of the asset
\nu = the expected asset trend
T = end time for the valuation
N = the number of steps from 0 to T

CALCULATED VALUES
\Delta T = T / N = step length
u = e^{\sigma \sqrt{\Delta T}}
d = e^{-\sigma \sqrt{\Delta T}}
p = 1/2(1 + \frac{\nu}{\sigma} \sqrt{\Delta T}) \quad (4)

1. As illustrated in Figure 9 the lattice tree starts at the first node with the initial value \( S_{1,0} \). From there the value can then move to either \( S_{1,1} \) or \( S_{2,1} \) with the respective probabilities \( p \) and \( p - 1 \). A transition to the higher value \( S_{1,1} \) is achieved by multiplying \( S_{1,0} \) with the factor \( u \), while a transition to the lower value \( S_{2,1} \) is achieved by multiplying with the factor \( d \). This process is then repeated from \( S_{1,1} \) to \( S_{1,2} \) and \( S_{2,2} \) and so on, growing the tree by \( t + 1 \) nodes for each time step. Noticeable is that both
$S_{1,1}$ and $S_{2,1}$ can reach the node $S_{2,2}$ and since $ud = 1$ then $S_{2,2} = S_{1,0}$. This is an example of a binomial lattice the same principle holds for higher dimensional lattices.

2. In the second step (seen in Figure 10) the probabilities for the system to reach the different nodes are generated. The probability for each node is calculated recursively by weighting the probability of the directly connected previous nodes with the transition probabilities $p$ and $p - 1$. $p$ is calculated to yield a risk neutral probability that takes the rate of increase and volatility of the underlying asset into account. If the underlying has an expected rate of increase $v$ this has to be taken into account since so that the average of the lattice tree has a trend that corresponds with $v$. As can be seen in Equation 4 a $v$ of 0 gives $p = 0.5$ thus an increase and decrease will be as likely.

3.
The next step (Figure 11) is to generate the cash flow for each node. This is done by applying the profit function $P$ to each node yielding a profit for each outcome in the lattice.

Finally, the profit each node is weighted by the probability for reaching it. The weighted profit each time step is then discounted to calculate the present value of future cash flows. The cash flows are then aggregated to yield the ENPV. The full expression can be seen in Equation 5.

$$ ENPV = \sum_{t=0}^{N} e^{-\gamma t} \sum_{l=1}^{t+1} p_{l,t}P(S_{l,t}) \tag{5} $$

**DECISION ANALYSIS**

Decision Analysis was first introduced by Ronald Howard in 1966. It builds on an event tree which is a sequential graph with contingent probabilities for different events leading to multiple different outcomes. Adding decision points creates the decision tree and in turn the option value of the evaluation. The expected outcome will be the weighted sum of all possible outcomes.

The decision tree is built up by three different types of nodes.

1. Decision nodes - representing the options and flexibility incorporated in the valuation.
2. Chance nodes - represents events with uncertain outcomes.
3. End value nodes - the end-points that represent the final value of each possible outcome in the valuation. The different end values will depend
on the previous event outcomes and decision leading up to the specific end nodes (Howard, 1988).

An example of a decision tree with different decision nodes and chance nodes leading up to end values can be seen in Figure 12. The options thinking is implemented by always choosing the decision that maximizes the expected outcome, as in the example in Figure 12 a R&D fail would lead to the decision of stopping the implementation to avoid the implementation costs. Since the decision analysis is based on always maximizing the expected profit the additional value created will always be higher or as high as the value from the event tree, even if the project is not expected to be profitable. The difference in value between the event tree and decision tree is the options value of the project (Neely, 2001).

![Figure 12 Decision Tree. Adopted from:](http://ardent.mit.edu/real_options/Real_opts_papers/delftpaperpublication.pdf)

**Phase 3 - Sensitivity Analysis - assessment of importance of key assumptions**

Since results from an evaluation of a real project will build on many assumptions it is good practice to test how they affect the result. Neely and Neufville (2001) argue that any evaluation process should incorporate a sensitivity analysis. There are many examples from the financial industry where over relying on assumptions have lead to terrible results that could have been avoided with a more critical view on speculative assumptions.

A sensitivity analysis can be performed in multiple ways. The most straightforward is to simply vary an assumption and study how it affects the outcome. This can be done visually by graphing the relationship as a line or a surface. There are also more advanced numerical and analytical methods for sensitivity analysis (Neely & Neufville, 2001).
3.2.3 Using Hybrid real options to perform a CBA

Both CBA and Hybrid Real Options are methods of for socio-economic evaluations by studying the associated benefits and costs of a project. In this thesis the Hybrid real options methodology is used in the case study, but using this method many of the same elements as the traditional CBA. The relationship between the two approaches is illustrated in Figure 13.

Figure 13 Relationship between HRO and CBA

As can be seen in the figure the two approaches have several similar elements. The major difference is that the HRO method incorporates the element of uncertainties and that the methods of analysis and Key Performance Indicators differ for the two methods.

In the case study the two methods will be combined to enable for comparison between the two methods and also highlight the calculated value of accounting for uncertainties and decisions. The case study will also be conducted using the three phases Setup, Analysis and Sensitivity Analysis, and will incorporate the elements shown in Figure 14.
3.2.4 Traffic Modelling methods

Traffic congestion is difficult concept to define as it encompasses both a physical and relative dimension. In physical terms a simple explanation is that vehicles interact in a way that hinders each other's progress. The interactions effect on the journey of the individual largely depends on the demand relative to the capacity of the road (how many cars are traveling on the road). There are also other external factors such as road work, accidents, and weather that have an impact on traffic congestion. The relative dimension is built up of the individual's perception of the state of traffic. An individual living in a rural area may for example perceive a situation where road work is causing a small cue, resulting in a slight delay of a few minutes, as traffic congestion. This small delay might not be considered as a congestion for an individual commuting in an urban area where congestion result in a trip taking as much as an hour more to complete.

Congestion is in other words not only the way vehicles interact and hinder each other’s progress but also the difference between the users expectations and perception of the road network performance (UK Department for Transport, 2015).
**Basic theory**

Traffic flow models have been used to understand and predict the flow of traffic since the beginning of the twentieth century. The two large classes are microscopic models that aim to explain the behavior of a single vehicle and macroscopic models that explain the flow of traffic on an aggregated level. This could be compared to either modeling gas by describing the behavior of a single particle or the entire gas (van Wageningen-Kessels, 2014).

A general macroscopic model of traffic flow aims to describe the relationship between flow \( Q \), density \( k \), and speed \( V \) on a 1 km long segment of road. The fundamental equation of traffic flow states that is the product of density and velocity (Immers & Logghe, 2002). Describing traffic flow using mathematics was pioneered by Bruce D. Greenshields in 1933 who based his theory on empirical data gathered using a rig that automatically photographed passing cars (Kuhne, 2008).

Equation 7 states the fundamental equation with the different states that follow from it.

\[
q = d \times v 
\]

\( q \) (cars/h)

\( k \) (cars/km)

\( v \) (km/h)

**OTHER CONCEPTS**

- \( V_f \) = free velocity
- \( V_c \) = critical velocity
- \( k_{jam} \) = density where a traffic jam occurs
- \( k_{max} \) = density that allows for the maximum flow
- \( q_{max} \) = maximum flow

**FLOW DENSITY**

The flow and density will vary with both time and location but for a given road segment the ideal case would behave. There are a few characteristics that can be noted.

- Zero density will correspond to zero flow, i.e. no cars on the road.
- A gradual increase in the number of cars will increase both density and flow.
- As more and more vehicles are added the flow starts to decrease and will eventually reach zero at \( k_{jam} \).
- There is a density \( k_{max} \) between zero and \( k_{jam} \) where the maximum flow \( Q_{max} \) is reached.
The true shape of the curve largely depends on local characteristics of the road. The first models proposed a simple parabola however empirical findings suggest that the relationship has more of a triangular shape, with $Q_{\text{max}}$ occurring faster than illustrated in Fel! Det går inte att hitta någon referenskälla. (Immers & Logghe, 2002).

**SPEED DENSITY**
The maximum speed, free flow speed, will be reached when the density is zero. After that speed will decrease as the density increases. It will eventually reach zero as density reaches $k_{\text{jam}}$. The simplest relationship is a linear decrease but, just as with flow-density empirical data indicates that the true curve is nonlinear (Immers & Logghe, 2002).

**SPEED FLOW**
The speed flow relationship is slightly more complex as it is not a function. The same speed can occur at two different levels of flow. This can be understood as the flow will be zero both when there are no cars and when the road is saturated. The maximum flow $Q_{\text{max}}$ will be reached at a certain critical velocity. Thereafter an increased number of cars will cause both the velocity and flow to decrease as congestion is induced (Immers & Logghe, 2002).

**COMBINED**
If all three diagram are combined as in Figure 15 it is possible to see how they relate to each other as the red lines indicate. This model is by no means an exact description of how traffic works. The true curves have more complex shapes that will differ depending on both the road segment studied and external factors such as weather. Nevertheless they provide a theoretical framework for transport planners (Immers & Logghe, 2002).

![Speed-density diagram](image1)

![Speed-flow diagram](image2)

![Flow-density diagram](image3)

*Figure 15 Combination of the three fundamental diagrams of traffic flow theory*
Three phase traffic theory

The fundamental equation treats traffic as a deterministic system, a more modern view of traffic theory views traffic as three different states with transition probabilities. The three states are free flow (F), synchronized flow (S), and wide moving jam (J) for which the traffic can transition as F<->S<->J depending on both micro factors (individual drivers actions) and macro factors (weather, bottlenecks). The three phase traffic theory does not displace the traditional view but rather adds another dimension (Kerner, 2009).

- Free flow (F) - traffic moves in a free flow the interactions of the vehicles does not hinder each other’s progress.
- Synchronized flow (S) - a traffic congestion is induced usually at a bottleneck due to drivers inability to cope with speed adaption.
- Wide moving jam (J) - wave propagation through space and time.

Akcelik Travel Function

A travel time function is used to predict the travel time on a road segment given degree of saturation, i.e. the level of traffic compared to the capacity maximum. Davidsson presented a function in 1966 that has been widely used in transport planning. It takes the minimum travel time, a level of service parameter, and degree of saturation to predict the average travel time (Davidson, 1966).

Akcelik’s Travel Time Function is based on Davidson work but expanded to better fit empirical observations. It uses a number of parameters presented in below, to derive the Equation 8. The different parameters are chosen to fit the characteristics of the type of road studied. Akcelik gives recommended parameters for different types of road. These can be found in Table 30, Appendix C, with their corresponding graphs seen here in Figure 16. It is noticeable that a road with higher capacity will take support a higher level of saturation before any major delays but instead have much higher delays for heavily saturated situations. The graph also shows three distinct phases. From: 0 to 0.7 when traffic moves in free flow, 0.7 to 1 when there is an onset of congestion, and >1 when breakdown occurs. The linear increase in travel time after breakdown is consistent with queuing theory (Akcelik, 1991).
Figure 16 Delay depending on DoS for different road types
4. Case Study

The chapter will provide a case study where an implementation of HRO is done using a ITS investment in Sweden that was earlier used in a trial. The chapter will be structured after the three phases of HRO. The analysis phase will constructing basic CBA and then expand that into an HRO by adding the methods for coping with uncertainty.

The case study will be performed for a road section along E18 through the town of Västerås, more specifically between the two intersections Hällamotet and Skälbymotet, see Figure 17.

![Figure 17 E18 from Hällamotet to Skälbymotet](image)

4.1 Phase 1 - Setup Phase

The first Phase of the case study is the setup phase. The overall aim of this phase is to establish the pre-conditions for project and includes the following topics described in Section 3.

- Define use of Project
- Estimate Demand
- Set Discount rate
- Set time Horizon
- Set schedule of implementation

In 2012 a study was performed regarding how the capacity of the intersections along the road section will be able to cope with the increasing predicted traffic along the section, on behalf of the Swedish Transport Authority. The analysis suggests that several of the intersections along the road section are expected to experience capacity issues in year 2026 if the city continues to grow while the travel patterns remain the same (Sweco, 2012).
This study was followed up by a response action study in 2013 where potential solutions to the expected future problems are examined. In the report the problems with road capacity are once again identified. If nothing is done the road section will suffer from queues and congestion problems in the future. Also, problems with accidents are mentioned. During the ten year period (2003-2012), 713 accidents involving personal injuries were recorded along the road section, most of which were secondary accidents. Six action plans are developed using different combinations of solutions ranging from increased public transport, building new road sections to the use ITS technologies (Trafikverket, 2013).

4.1.1 Investment Strategy

The case study is based on a combined roadside and in-vehicle system. This enables the variable speed limits to be mandatory which previous research suggests is more effective compared to a voluntary system. The roadside system will be of the same type as are already in use at some locations in Sweden, see Figure 18 (Sweco, 2012).

The solution also includes an in-vehicle system showing the same information as the roadside equipment but inside the vehicle. The investment strategy is to first make an initial investment in the two technologies. Five year into the project the results of the investment will be evaluated and action to continue with further investments can be taken. Decision for continuing development of the two subsystems (roadside and in-vehicle) can be made independently e.g., continue with both, just with one, or none. The investment process is shown in Figure 19.
The investment plan for the project includes an initial investment were 8 stations are installed and a secondary opportunity of an additional 8 units along the road section. Discount rate is used to discount costs and benefits from the future to a value of present time. The discount rate used in this case study is the discount rate recommended by the Swedish road authorities i.e., 3.5% per year (Trafikverket, 2015).

4.2 Phase 2 – Analysis and data collection

The second Phase of the Case study is the Analysis phase where data is gathered and analyzed to evaluate the Project. This analysis is divided into three sections; (1) a traditional CBA, (2) an evaluation with the added value of uncertainties and finally, (3) an evaluation with the value of decisions see Figure 20.

Before the analysis this chapter includes a section of Data Collection where all data used in the analysis are presented.
4.2.1 Data Collection

A base for this case study a section of E18 running through the city of Västerås is studied. The section is a total of 12.3 km long, see Figure 17. For the case calculations data about volume of traffic and number of accidents has been collected and will be presented.

TRAFFIC VOLUME
Data about traffic volume are used in the case study to estimate the cost of travel time and emissions. Traffic data for the section are collected from the Swedish Transport Authority’s “Vägtrafikflödeskartan”. Along the section seven measurement stations are in place measuring traffic volume, which is then converted into average daily traffic, there locations are shown in Figure 30 in Appendix A.

As can be seen subsection 1 and 3 only contains one station each while subsection 2 contains five. Thus, there is higher uncertainty in traffic volume for subsection 1 and 3 used in the case calculation. The traffic volumes for the corresponding subsections, during year 2014 are presented in Table 9. For more detailed data refer to Appendix A.

Table 9 - Average Yearly Traffic Source: Vägtrafikflödeskartan

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Daily Average Cars</th>
<th>Daily Average Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Subsection 1</td>
<td>24270</td>
<td>2600</td>
</tr>
<tr>
<td>Average Subsection 2</td>
<td>46402</td>
<td>4360</td>
</tr>
<tr>
<td>Average Subsection 3</td>
<td>35580</td>
<td>4610</td>
</tr>
</tbody>
</table>

As shown in the table, subsection 1 (measure station 1) and 3 (measure station 7) has lower traffic volume of ~30 000 whereas subsection 2 has ~45 000 vehicles per day on average. Along the section ~10 % of the vehicles are trucks.

Today the road section has static speed limits of 100 km/h, for subsection 1 and 3, and 80 km/h subsection 2, see Figure 21.
Figure 21 Overview of the road section and subsections

For the case study the road section are divided into three subsections based on the speed limit. This since the speed limit is highly related to travel time and also since the subsection 2 has considerably higher daily traffic volume. The whole section is a four lane motorway and is considered to have the same capacity. Table 10 shows the amount of congested traffic and traffic breakdowns for a four lane motorway. As can be seen overload of the road is arising at ~ 60 000 vehicles per day. Congestion is defined as degree of saturation (DoS) between 1 and 0.7 while breakdown is defined as DoS exceeding 1 (Movea, 2011).

Table 10 Risk of traffic congestion and breakdown for different daily average traffic

<table>
<thead>
<tr>
<th>Daily Average Traffic</th>
<th>% of Traffic congestion</th>
<th>% of Traffic breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>15000</td>
<td>&lt; 1%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>30000</td>
<td>&lt; 1%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>45000</td>
<td>&lt; 1%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>60000</td>
<td>9%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>75000</td>
<td>28%</td>
<td>4%</td>
</tr>
<tr>
<td>90000</td>
<td>51%</td>
<td>14%</td>
</tr>
</tbody>
</table>

In the calculation the amounts of traffic congestion and breakdowns is considered to be linear between the points given by Table 10, a visualization of this can be found in Figure 34 in Appendix A.

For each subsection the travel time at different degrees of saturation are calculated using the Akcelik Travel Function presented in section 0. The travel time in minutes as a function of the degree of saturation for subsection 1 can ve found in Figure 31 in Appendix A. Note that after a saturation rate of ~ 0.9 the travel time rises quickly. For calculations the average travel time for three cases of DoS for each subsection has been used, these travel times are shown in Table 11.
Table 11 Average travel time for the subsections at different degrees of saturation

<table>
<thead>
<tr>
<th>Subsection 1</th>
<th>Subsection 2</th>
<th>Subsection 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt; DoS &lt; 0.7</td>
<td>2.41</td>
<td>3.24</td>
</tr>
<tr>
<td>0.7 &lt; DoS &lt; 1</td>
<td>2.56</td>
<td>3.38</td>
</tr>
<tr>
<td>1 &lt; DoS &lt; 1.5</td>
<td>10.80</td>
<td>11.63</td>
</tr>
</tbody>
</table>

Accident data for the road section are used in the case study to estimate the cost of accidents along the road. The data are collected from the Swedish transport authority's database STRADA. To get a reliable estimate of the number of accidents per year, the average of a ten year period 2005-2014 are used. The number of accidents per year divided by the severity of the accident are presented in Table 23 in Appendix.

For the case calculations the average of the 10 year period are used as the base case of accidents per year. This yields an average of 0.3 fatal accidents, 7.4 serious accidents, and 58.5 minor accidents per year.

The investment plan for the project includes an initial investment were 8 stations are installed and a secondary opportunity of an additional 8 units along the road section. The expected benefits from the investments are presented in Table 12.

Table 12 Expected benefits from Infrastructure Investments

<table>
<thead>
<tr>
<th></th>
<th>Travel Time Reduction</th>
<th>Emissions Reduction</th>
<th>Accidents Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Investment</td>
<td>6 %</td>
<td>2 %</td>
<td>13%</td>
</tr>
<tr>
<td>Extended roadside</td>
<td>9 %</td>
<td>4 %</td>
<td>21 %</td>
</tr>
</tbody>
</table>

The expected benefits from the Initial Investment have been chosen to be within the limits of the previous VSL investments, presented in Table 1. The extended roadside will have higher benefits since additional dynamic signs enables for higher compliance.

MONETIZING VALUES

The benefits of the project studied are the value of travel time savings, emission reductions, and accident reductions. To translate these reductions into monetary savings the ASEK framework is used. The ASEK framework is the framework developed by and used by the Swedish transport authority to make socio economical calculations. The framework includes methods, prognoses, shadow prices etc. to be used in socio-economic analyses within the transport sector (Trafikverket, 2015).

All the shadow prices used in this case study are taken from ASEK since this is the dominant framework for the country of the case study. The value of travel time used in the case is 188 SEK/vehicle hour. The value is a weighted average of the type of travel (e.g., private, business) and vehicle occupancy (Trafikverket, 2015).
For emissions figures for urban areas are used. For cars a value of 0.32 SEK/km is used (0.20 for CO2 and 0.09 for other emissions) and for trucks 2.84 SEK/km is used (1.35 for CO2 and 1.49 for other emissions) (Trafikverket, 2015).

Costs of accidents are divided into fatalities, serious accidents, and minor accidents. A serious accident refers to an accident with personal injuries requiring treatment at a hospital and a minor accident refers to treatment by healthcare centers. The costs used for fatalities, serious accidents and minor accidents are 23 739 000, 4 412 000, and 217 000 respectively (Trafikverket, 2015).

All of the monetizing equations (can be seen in Appendix A eq (9)-(11) will depend on ATDAs can be seen in equations (9)-(11) all benefits are dependent on ADT. The yearly benefits for different levels of ADT are presented in Figure 22. The Benefits are based on the case of the initial roadside technology. As shown in Figure 22, travel time savings are low at low levels of ADT but increases more rapidly with ADT than Accident and Emission reductions.

![Figure 22 Benefits for different ADT](image)

COST DATA
2DECIDE is a project funded under the European Union’s 7th Framework Programme for Research and Development. The objective of 2DECIDE was to develop an “ITS Toolkit” to assist transport authorities in the deployment of Intelligent Transport Systems (Mans et al., 2011).

The Toolkit incorporates a comprehensive cost database that has been used for the cost estimations in this case study. The cost data are calculated for year 2011 and are stated in Euros (EUR). The costs for this case are converted into values for year 2015 and Swedish Krona (SEK) using a conversion rate of 9.28 (EUR to SEK) and an inflation rate of 2 %.
The initial roadside technology investment cost was calculated for eight VSL signs, one for each intersection along the route. One sign per intersection is the minimum recommended number of units stated by Mans et al (2011).

The extended roadside investment includes an addition of eight additional VSL signs. This investment has significantly lower operating and maintenance cost because of synergies of the costs from the initial roadside investment.

Table 13 Investment and operating costs

<table>
<thead>
<tr>
<th>Cost calculation results (SEK)</th>
<th>Initial roadside investment</th>
<th>Extended roadside investment</th>
<th>In vehicle investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial investment</td>
<td>26,378,291.56</td>
<td>16,163,872.85</td>
<td>5,094,484.00</td>
</tr>
<tr>
<td>Operating and maintenance/year</td>
<td>9,111,346.73</td>
<td>1,980,062.84</td>
<td>720,981.97</td>
</tr>
</tbody>
</table>

UNCERTAINTIES
The uncertainties are divided into project risks and market risks. For this case the one project risk has been taken into account namely the technical success of the in vehicle system. This is a novel technology thus there is a degree of uncertainty in how effective the solution will be.

Two market risks are also taken into account, the adoption rate of the in-vehicle technology and the traffic demand over the time of the project. The adoption rate is influenced by the success of the technology. Political decisions can also affect the adoption rate e.g., the European Union is examining the possibilities of a union wide collaborative traffic database (EU, 2010). Such a collaboration would probably give incentives for third party providers e.g., car manufacturers and software providers to invest in in-vehicle technologies. The uncertainties together with the methods of modeling them are presented in Table 14.
PROJECT RISK: TECHNICAL EFFECTIVENESS OF IN-VEHICLE TECHNOLOGY
The technology success are divided into three scenarios i.e., High success, medium success, and failure. High success refers to the scenario that the in vehicle technology will get governmental support enabling the implementation of a mandatory in vehicle speed adoption system. The medium success refers to a scenario where the in vehicle system is voluntary thus may be de-activated by the driver. Technology failure refers to the case where the project fails and does not yield any benefits at all. Each of the three scenarios are given a probability based on the probabilities used by Hododa in his Hybrid Real Options study of a in-vehicle intersection collision avoidance system (Hododa, 2006).

Table 14 Uncertainties

<table>
<thead>
<tr>
<th>Risk Profile</th>
<th>Uncertainties</th>
<th>Quantification Methods</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Risks</td>
<td>Technical Effectiveness</td>
<td>Decision Tree, Discrete Prob</td>
<td>Previous evaluations and simulations</td>
</tr>
<tr>
<td>Market Risks</td>
<td>Adoption Rate</td>
<td>S shape Function, Discrete Prob</td>
<td>Transport agency predictions</td>
</tr>
<tr>
<td>Market Risks</td>
<td>Traffic Demand</td>
<td>Binomial Option Pricing lattice</td>
<td>Governmental predictions and historical data.</td>
</tr>
</tbody>
</table>

Table 15 Probability of technical success

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Probability</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Success</td>
<td>30 %</td>
<td>Mandatory</td>
</tr>
<tr>
<td>Medium Success</td>
<td>60 %</td>
<td>Voluntary</td>
</tr>
<tr>
<td>Failure</td>
<td>10 %</td>
<td>Failure</td>
</tr>
</tbody>
</table>

For each of the scenarios associated benefits are assigned. The Accident reduction are based on the scenarios in Table 3 Simulated injury reductions for different ISA types, were the values of High success was taken from the Dynamic mandatory case and Medium success assigned with the values from Voluntary Dynamic. Ertico suggests that in vehicle systems can yield emission reductions of between 10-15 %. The medium success was assigned with emission reduction of 10 % and high success 15 % respectively. Easyway suggests that travel time reductions of 15-40 % (Easyway Eval 2013) can be expected during peak traffic. As already mentioned, VSL shows greatest travel time reductions for peak traffic and based on the evaluations presented in Table 1, the assumption is made that the travel time reduction for DoS>1 is three times greater than for 0.7<DoS<1.0. The expected travel time reduction for peak (DoS > 1) is set to 40 % and 30 % for the high and medium success scenarios respectively. A summary of the expected benefits for the different technology success levels of the in-vehicle technology are presented in Table 16.
MARKET RISK: ADOPTION RATE
The American Association of State Highway and Transportation Officials (AASHTO) with support from United States Department of Transportation (US DOT, 2015) and Transport Canada undertook a comprehensive study of connected vehicles to provide information to decision-makers (Wright et al., 2014). As part of this study a number of different scenarios for the deployment of connected vehicles were created together with market growth projections by Hill and Garret 2011. Two of the four initially identified scenarios will be used as a basis to model the adoption of in-vehicle technology in the car population of this case. The parameters of the S-shaped curve where manually adjusted to create adoption rates that corresponded with the curves presented in (Hill and Garret, 2011). The two scenarios used are named Full Throttle and Proving Grounds. Parameters can be found in Appendix A under Table 24.

FAST ADOPTION
The so called "best case" scenario where things unfold in a way that provides the fastest possible spread of in-vehicle technology. In this scenario the government mandates that all new vehicles need to have in-vehicle capabilities. The scenario also assumes that the transport agencies all start to develop and implement deployment plans for in-vehicle signage that increases the willingness to retrofit older vehicles with in-vehicle technology or use an app based solution. It is also possible in this kind of scenario that different incentives such as tax breaks and/or reduced insurance premiums are used to speed up retrofitting. The scenario is more likely if research in the area is successful and the technology shows high benefits.

In Figure 23 it is visible that that ~30% of all will have in-vehicle capabilities by 2020, 80% by 2030 and >95% by 2040. Since the government will mandate all new vehicles to be equipped, adoption will start at a high pace. It will reach its maximum growth at 2024 when ~50% of the fleet will be equipped. After that the adoption loses momentum as the last adopters are acquired at a slower rate. A graph of this is found in Figure 33 in Appendix A.

SLOW ADOPTION
In this scenario there is no immediate mandate for new cars to be equipped with in-vehicle capabilities. There is no funding for major projects as the government takes a precarious role, relying on the private sector to lead the way. The car manufacturers will start implementing the in-vehicle technology in their new models but possibly using different standards. The equipped vehicles would come into the fleet through organic

---

**Table 16 Summary of in-vehicle VSL benefits**

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Travel time</th>
<th>Emissions</th>
<th>Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>High technology success</td>
<td>18 %</td>
<td>15 %</td>
<td>48 %</td>
</tr>
<tr>
<td>Medium technology success</td>
<td>14 %</td>
<td>10 %</td>
<td>25 %</td>
</tr>
<tr>
<td>Technology Failure</td>
<td>No benefits</td>
<td>No benefits</td>
<td>No benefits</td>
</tr>
</tbody>
</table>
sales based on marketing and cultural acceptance of the new technology. Retrofitting would also be possible through similar market mechanics.

In the proving grounds scenario it takes a while for the organic growth to reach its exponential phase. The growth will reach its maximum phase by 2032. At 2020, when the benefits would start showing in the investment less than 10% of fleet would be equipped and by 2030 ~40% of the fleet will have in-vehicle capabilities. A graph of this is found in Figure 33 in Appendix A.

![Adoption rate](image)

**Figure 23 Adoption rate**

**MARKET RISK: TRAFFIC DEMAND**

The market risk of the project is modeled using the average ADT on the three road segments as an underlying factor for the market for the project. A binomial lattice is used to generate potential future states with different traffic levels with the current average ADT 39274 as starting point. Since Trafikverket projects that there will be an annual increase in ADT of 2% on the studied road segments this was chosen as the baseline trend for the ADT in the lattice generation (Trafikverket, 2013).

It was difficult to obtain a multi-year time series of the ADT on the specific road segments studied to estimate volatility thus a proxy will had to be used. The proxy used was the inter-year change in number of registered passenger cars in Sweden. The timespan 2054-2014 was chosen since the number of registered passenger vehicles jumped dramatically during the Second World War when most passenger cars were deregistered. The volatility of the number of registered passenger vehicles during the selected period was 5.1% (SCB, 2015).
The end time of the lattice generation was set to 14 as that would yield the end time of the evaluation, 2030. The step length was set to 1 since it simplified the yearly value calculations. This gives the input parameters for lattice generation summarized in Table 17.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>#</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>14</td>
<td>Project length</td>
</tr>
<tr>
<td>deltaT</td>
<td>1</td>
<td>Giving sufficient granularity</td>
</tr>
<tr>
<td>S0</td>
<td>39274</td>
<td>Average ADT for the three road segments</td>
</tr>
<tr>
<td>v</td>
<td>2%</td>
<td>Estimated yearly growth by VV</td>
</tr>
<tr>
<td>sigma</td>
<td>5.1%</td>
<td>Based on volatility of registered passenger vehicles</td>
</tr>
</tbody>
</table>

The lattice generates the range of possible ADT states visible in Figure 24 together with the average ADT level, which coincides with Trafikverket’s prognosis. There is a large spread in the possible traffic levels and at the end of the evaluation period there is a probability that traffic will either half or double. These probabilities are however very small, Figure 24 illustrates the distribution of different ADT levels during the evaluation period. It shows that the most probable outcome is along the Trafikverket’s forecast and the extreme values have a very small probability (~0.5% for the highest and ~0.00000001% for the lowest).

![Figure 24 Distribution of different ADT levels over the project life time](image)

4.2.2 Analysis

The second part of phase 2 is the analysis. With the assumptions discussed above a spreadsheet has been constructed to calculate the value of the project. The analysis is divided into three stages to illustrate the value differential created by the layers of
uncertainties and decisions. The first phase is a traditional CBA model, the second phase adding the value of uncertainties, and a third phase with the addition of decisions.

**COST BENEFIT**
The traditional CBA-model is based on the most likely scenario. Hence, no uncertainties are accounted for. The most likely scenarios for the uncertainties are presented in Table 18. As shown the Cost Benefit scenario is based on a medium technological success and slow adoption rate. Traffic demand is assumed to be linear with an annual increase of 2 % per year.

**Table 18 Most likely scenario**

<table>
<thead>
<tr>
<th>Risk Profile</th>
<th>Uncertainties</th>
<th>Most likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Risks</td>
<td>Technical Effectiveness</td>
<td>Medium Success scenario</td>
</tr>
<tr>
<td>Market Risks</td>
<td>Adoption Rate</td>
<td>Slow adoption Rate</td>
</tr>
<tr>
<td>Market Risks</td>
<td>Traffic Demand</td>
<td>Linear traffic demand increase of 2 %</td>
</tr>
</tbody>
</table>

Based on the assumptions presented above, NPV for each of the decision scenarios are calculated and presented in Table 19. The decision yielding the highest value is to invest in both the road side and in-vehicle technology which gives a forecasted NPV of ~54 MSEK. The initial investment alone yields the lowest NPV of ~35.5 MSEK while adding only the in-vehicle technology results in a ~2.5 MSEK lower value then the scenario where the infrastructure also is expanded.

**Table 19 NPV for the different alternatives**

<table>
<thead>
<tr>
<th>Extended infrastructure</th>
<th>In vehicle</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>53,986,280.64</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>46,503,137.64</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>51,490,354.46</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>35,477,842.89</td>
</tr>
</tbody>
</table>

Based on a traditional BC the rational decision is to invest in both roadside and in-vehicle technology. This yields a NPV of ~54 MSEK, with a BC-ratio of 1.32. In the next section uncertainties will be taken into account to calculate new values for the scenarios.

**ACCOUNTING FOR UNCERTAINTIES**
In this section the methods presented in section 3.2.2 is applied to account for the uncertainties of the technology and market. This means that the NPV is not based only on the most probable scenarios but methods are used to account for these uncertainties. The methods used for handling the uncertainties are presented in section 3.2.2. The uncertainties of traffic demand are handled by the use of binomial lattice. The uncertainties related to technology effectiveness of the in-vehicle technology and the adoption rate is illustrated as nodes in Figure 25 together with the associated probabilities.
The table also shows all possible outcomes for the related outcome scenarios. Using weighted probabilities for all investment decisions results in the NPVs presented in Table 20. Again, investing in both roadside and in-vehicle technology yields the highest expected value.

**Table 20 NPV with the added value of uncertainties**

<table>
<thead>
<tr>
<th>Infra</th>
<th>NW</th>
<th>NPV</th>
<th>Increased Value due to uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>115,450,311</td>
<td>114%</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>76,133,838</td>
<td>64%</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>111,508,499</td>
<td>117%</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>56,622,508</td>
<td>60%</td>
</tr>
</tbody>
</table>

Compared to the traditional BC-valuation accounting for uncertainty scenarios increases the expected value by between 60 % and 117 %.

**DECISION VALUATION**

The investment process incorporates two decisions i.e., investing in roadside and/or in-vehicle technology or not. Adding the layer of decision options thinking means that the rational choice will be made after 5 years depending on the success of the in-vehicle technology. The expected NPV of the decisions for the three scenarios of in-vehicle technology are presented in Table 21.

**Table 21 NPV for different scenarios**
In case of high technological success the rational choice in to only invest in the in-vehicle technology yielding an expected 180.5 MSEK return. For medium success both roadside and in-vehicle technology gives the highest expected return of 93.2 MSEK. In the case of in-vehicle technology failure the rational decision is to invest in only roadside technology giving an expected benefit of 76.1 MSEK. Assuming the rational investment decision is taken in all cases makes it possible to ignore all outcomes but the highlighted in Figure 26.

Using the weighted probabilities gives a total expected value of 117,674,735 SEK.

Table 28 summarizes all three phases of the analysis. As can be seen accounting for uncertainties more than doubles the expected outcome of the technology and accounting for decisions increases NPV by more than 2 MSEK.
Table 22 Summary of NPV for the three different cases

<table>
<thead>
<tr>
<th>Method</th>
<th>Decision</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Benefit</td>
<td>Both roadside and in-vehicle</td>
<td>53,986,280.64</td>
</tr>
<tr>
<td>Uncertainties</td>
<td>Both roadside and in-vehicle</td>
<td>115,450,311.65</td>
</tr>
<tr>
<td>Option thinking</td>
<td>Decision depending on technological success</td>
<td>117,674,735</td>
</tr>
</tbody>
</table>

4.3 Phase 3 - Sensitivity Analysis

The third and last phase of the case study is the Sensitivity analysis. In this phase the sensitivity of the models used in Phase 2 are evaluated.

A sensitivity analysis was performed for three assumptions added in the Hybrid Real Options methodology. The assumptions analyzed were: probability of failure, sigma (volatility) in the lattice, and probability for the fast adoption scenario.

The ENPV had a linear relationship with regards to the assumption of failure probability with a range from 122 MSEK for 0% probability to 76 for a 100% probability. This gives a relationship where a change in failure probability by 1% changes the ENPV by ~460kSEK. Changing the failure probability did not affect the optimal decision given the different outcomes.

![Figure 27 ENPV for different probabilities of failure](image)

The next assumption tested are the volatility (σ) of the lattice generation. The volatility was changed between 0.02 and 0.052. The lower bound was given by the condition that σ ≥ v in the lattice generation, otherwise p > 1. The higher bound was due to limitations in the script Excel workbook used. The relationship shows a linearly increasing trend but with some areas providing most of the increase. This increase in
ENPV for higher volatility is the result of a higher volatility yielding a higher average ADT, and a higher ADT resulting in a nonlinear increase in benefits, as can be seen in Figure 28. The ENPV ranges from 82 MSEK to 117 MSEK. Noticeably a sigma of 0.02, which gives the same forecast as Trafikverkets 2% increase with no uncertainty, results in a the decision to only expand in-vehicle in the medium benefit scenario to be optimal.

![Figure 28 ENPV depending on choice of sigma](image)

The last assumption tested was the relative probability of fast adoption. Since the probability of fast adoption is contingent on the benefit uncertainty outcome the relative probability was defined as $x \cdot p_{fast\_high}$ and $x \cdot p_{fast\_medium}$ with $p_{fast\_high} = 0.8$ and $p_{fast\_medium} = 0.2$ from the case. The relative probability $x$ was altered from 0 when both probabilities were 0% to 5 where both reached 100%.

The relationship between ENPV and relative probability for fast adoption seems to have three different linear segments 0-1.2, 1.2-2.5, and 2.5-5, see Figure 29. The first, and fastest increasing segment, should be due to $p_{fast\_high}$ going from 0% to 100% thus no maximizing all benefits possible from the high benefit scenario. The second, less visible, segment is likely due to optimal decision changing at 2.75 from expanding infra and building in-vehicle in the medium benefit case to only building in-vehicle.

If the Hybrid Real Options analysis is used as a basis for decision given the different scenarios instead of a tool to find the ENPV of the investment the sensitivity analysis suggests that the model is relatively robust to assumptions. I.e. minor changes in assumptions would not change the optimal decision.
5. Discussion

As illustrated in the case study, the choice of socio economical valuation method impacts the estimated value of a project. Thus, the choice of method can impact the estimated value of a project. Since the socio-economic value of a project is an important variable for decision makers the valuation method can in turn impact the investment decisions for road infrastructure projects. During the work with the case study it has become clear that there is no obvious or perfect socio-economical valuation method however these calculations contain valuable information to be used in decision making. It is a complex task to calculate the societal value of a project and it is important to understand the underlying concepts of the methods used for these calculations. The choice of method determines the factors to be included in the valuation and not. Thus, no method should be taken for granted and it is important to be aware of the shortcomings of the method being used.

The Benefit-Cost and Real Options methodologies used in this thesis tries to solve the same problem; to calculate the societal value of an investment by calculating the NPV of a project by quantifying the expected costs and benefits over the project lifetime. The same key performance indicators can be derived for both methods e.g., NPV and B/C ratio. The fundamental difference is the methods view of the environment.

Using the Benefit-Cost method the environment and solution is considered to be static. It is possible to make sufficient approximations about the most likely scenarios of the
solution e.g., technical effectiveness, changes in traffic demand etc. Based on the scenario it is then possible to decide today what solution(s) to invest in for the future.

The Real Option methodology has a dynamic approach. Since it is not possible to make good enough approximations about the future, statistical methods are used to account for uncertainties. It is not feasible to determine today what decisions are best for the future. However it is possible to quantify the value of potential future decisions. Thus, the main difference is that RO accounts for uncertainties and decisions.

The case illustrates the differences between the handling of uncertainties between the HRO and CBA methods. CBA handles uncertainties by estimating the most probable outcomes. In real options the statistical methods presented in Table 14 are used to handle uncertainties. There are problems with the forecasting used in the CBA. The study performed by Flyvbjerg (2005) shows that predictions about future traffic volumes often are inaccurate. As illustrated in the case in Figure 35 Profit as a function of number of units sold the expected benefits are highly affected by the estimated traffic volume. In the HRO analysis a binomial lattice is used to account for variations in estimated traffic volume. This method takes into account for example that the final year may have traffic volumes of between 18 000 and 84 000 ADT. Since the scenarios with higher traffic greatly increases the expected benefits, the binomial lattice method increases the NPV in the HRO compared to CBA. Thus the HRO method values more “what if”-scenarios. HRO also accounts for different technological success and adoption rate scenarios other that the most probable medium success case as is the in the CBA. This increases NPV further since the probabilities of higher adoption rates and technological success are taken into account.

Accounting for uncertainties increases the expected NPV from 54 MSEK to 115 MSEK corresponding to an increase of 114%. However, the same investment decision i.e., investing in both roadside and in-vehicle technology yields the highest NPV. Accounting for uncertainties requires more assumptions to be made hence has an increased complexity compared to the BC method. As can be seen in the sensitivity analysis, changing the assumptions has a significant impact on the expected NPV of the project. This is one of the experienced downsides of the RO methodology. Many of the assumptions, e.g. probability of high or low penetration, are uncertain and hard to quantify. A reasonable question to ask is - “Is it better to make these assumptions (even if inaccurate) than to ignore them?”.

The other fundamental difference in HRO is the addition of decisions. This is a fundamental difference since the investment strategy changes. With the addition of decisions, there is no need to decide in the beginning of a project exactly how the solution will be designed at the end of the project. The addition of decision further increases the expected NPV in the cases study by 2 MSEK. The decision layer also emphasizes that there is a real value in the option of making a future decision, independently of whether the decision is made or not. The decision approach also requires continuous evaluations over the project lifetime to be able to make the rational
decisions during the project lifetime. This is also a complicating factor in the HRO analysis.

If investment decisions are made based on expected socio-economic value, the method of this evaluation will affect what type of projects are favored. The HRO methodology values other characteristics than the BCA analysis. The HRO analysis favors flexible solutions that are designed to be able to cope with an uncertain future. A small chance of a future scenario where the solution will have great impact should be considered as valuable. A flexible solution enabling future extensions/alterations is premiered by the use of HRO. The BCA analysis on the other hand does not emphasize flexibility. The BC analysis favour solutions with certain outcomes and cash flows. A risk with the BCA approach is that novel technologies with uncertain cash flows will be disregarded.

The advantages of the CBA method compared to the HRO method is the simplicity of the model. HRO requires sophisticated statistical calculations and many assumptions to be made hence is more sensitive than the CBA method. If HRO is to be used on a large scale comprehensive research has to be made to design procedures and best practices. However, if the future of transport investment are to make use of novel technologies, as many stakeholders advocates, it is important to use socio economical evaluation methods that support these investment philosophies.

5.1 Conclusion

Few studies have been made on the usability of HRO as an evaluation approach for ITS-investments. This study illustrates how HRO can be used in the context of ITS as basis for decision making, contributing to a rather unexplored scientific field.

There are different methods used as basis for decision making within road transportation investments, two of which (i.e., CBA and HRO) has been studied in this thesis. By comparing these two methods in a case study it is clear that the two methods empathize different aspects of the investments. In the case study, the choice of method directly affected what investment and strategy of investment turning out most profitable from a societal point of view.

HRO emphasizes values of uncertainties and flexibility of design, which in the case study favored the more novel in-vehicle technology. Uncertainties and flexible design are typically associated with new technology and software heavy projects hence using HRO would be favorable if the strategy is to make use of these types of technology. The choice of socio economical evaluation method should reflect the overall strategy e.g., if the strategy is to do more flexible, technologically advanced investments the evaluation method needs to reflect this. Institutions that want to invest in ITS-technology should not take the CBA for granted. The risk of an uncritical choice of method is that important aspects do not get emphasized.
The CBA being the by far most popular evaluation method needs to be further studied and compared to other methods especially with regard to more technologically advanced solutions. The results of this thesis call for more research on this topic. The choice of method is a complex task that involves many stakeholders however a more critical approach to the choice of socio-economical evaluation method is advocated based on the results of this study.
6. References


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Appendix A

NUMBER OF ACCIDENTS AND FATALITIES OVER TIME FOR THE STRETCH OF ROAD USED IN CASE. DATA USED TO ASSESS BASELINE

Table 23 Number of people injured per degree of injury and year

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatalities</th>
<th>Serious Accidents</th>
<th>Minor Accidents</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>1</td>
<td>4</td>
<td>46</td>
<td>51</td>
</tr>
<tr>
<td>2006</td>
<td>1</td>
<td>9</td>
<td>51</td>
<td>61</td>
</tr>
<tr>
<td>2007</td>
<td>0</td>
<td>2</td>
<td>47</td>
<td>49</td>
</tr>
<tr>
<td>2008</td>
<td>0</td>
<td>11</td>
<td>79</td>
<td>90</td>
</tr>
<tr>
<td>2009</td>
<td>0</td>
<td>4</td>
<td>49</td>
<td>53</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
<td>9</td>
<td>76</td>
<td>85</td>
</tr>
<tr>
<td>2011</td>
<td>0</td>
<td>7</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>2012</td>
<td>1</td>
<td>5</td>
<td>53</td>
<td>59</td>
</tr>
<tr>
<td>2013</td>
<td>0</td>
<td>13</td>
<td>82</td>
<td>95</td>
</tr>
<tr>
<td>2014</td>
<td>0</td>
<td>10</td>
<td>74</td>
<td>84</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>64</td>
<td>585</td>
<td>662</td>
</tr>
<tr>
<td>Average/Year</td>
<td>0.3</td>
<td>7.4</td>
<td>58.5</td>
<td>66.2</td>
</tr>
</tbody>
</table>

MAP INCLUDING THE PLACEMENT OF THE DIFFERENT TRAFFIC MEASUREMENT STATIONS

Figure 30 Placements of measurement stations

DETAILED BREAKDOWN OF HISTORIC ADT FOR THE DIFFERENT SUBSECTIONS OF THE ROAD STRETCH USED IN THE CASE

<table>
<thead>
<tr>
<th>Subsection</th>
<th>Station</th>
<th>Year</th>
<th>Direction of Traffic</th>
<th>Daily Average Cars</th>
<th>Daily Average Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2014</td>
<td>1</td>
<td>13350</td>
<td>1280</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>2014</td>
<td>2</td>
<td>10920</td>
<td>1320</td>
</tr>
<tr>
<td>Tot Station</td>
<td>1</td>
<td>2014</td>
<td>1</td>
<td>24270</td>
<td>2600</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>24270</td>
<td>2600</td>
</tr>
<tr>
<td>Subsection 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2014</td>
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<td>26800</td>
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<td>1</td>
<td>17160</td>
<td>2590</td>
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<tr>
<td>3</td>
<td>7</td>
<td>2014</td>
<td>2</td>
<td>18420</td>
<td>2020</td>
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<td>Total Station 7</td>
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<td></td>
<td></td>
<td>35580</td>
<td>4610</td>
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<tr>
<td>Average</td>
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<td>35580</td>
<td>4610</td>
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Subsection 3

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<tbody>
<tr>
<td>THE FULL EQUATIONS USE TO MONETIZE BENEFITS FROM THE THREE DIFFERENT TYPES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Traveltime Benefits**

\[
= \text{Value of TT} \times (\text{Daily average Traffic} \\
\times (\% \text{DoS}_{0.7} \times \text{Reduction}_{0.7} + \% \text{DoS}_{0.71} \\
\times \text{Reduction}_{0.71} + \% \text{DoS}_1 \times \text{Reduction}_1))
\] (9)
Accident reduction benefits 
\[ = \%\text{Increased Traffic} \times (\text{Values Fatalities} \times \text{No Fatalities} + \text{Values Serious} \times \text{No Serious} + \text{Reduction}\%\text{Serious} + \text{Value Minor} \times \text{No Minor} \times \text{Reduction}\%\text{Minor}) \]  

Emissions reduction Benefits
\[ = \text{Emissions reduction } \% \times (\text{DAT Cars} \times \text{Value Cars} + \text{DAT Trucks} \times \text{Value Trucks}) \]

GRAPH OF TRAVEL TIME FOR SECTION 1 AS A FUNCTION OF TRAFFIC SATURATION. BASED ON THE MODEL USED.

**Travel Time Minutes Subsection 1**

![Graph showing travel time minutes for subsection 1 as a function of traffic saturation]

*Figure 31 Average travel time for the subsections at different degrees of saturation*
GRAPH OF THE NUMBER OF CARS REGISTERED IN SWEDEN. THIS DATA WAS USED TO ESTIMATE VARIABILITY IN CARS ON THE ROAD.

*Figure 32 Number of registered personal cars in Sweden (1923-2014)*

DISTRIBUTION OF THE ADOPTION RATES FOR THE DIFFERENT SCENARIOS USED IN CASE

*Figure 33 Distribution of adoption*

GRAPH OF INTERPOLATED CONGESTION BREAKDOWN AS A FUNCTION OF TRAFFIC
Figure 34 Congestion and Breakdown as a function of traffic

PARAMETERS USED FOR ADOPTION RATE

Table 24 Parameters used for adoption rate approximation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>my - location</th>
<th>s - scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast (Full Throttle)</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Slow (Proving Ground)</td>
<td>17</td>
<td>5</td>
</tr>
</tbody>
</table>
Appendix B

Example of a HRO analysis

The Hybrid Real Options method will be illustrated by a fictive example of a company producing umbrellas, facing a decision of investing in developing a technology that could increase production efficiency, reducing costs. The company's traditional procedure is to conduct a BC-analysis calculating the NPV with an investment write-off of four years. Their experience has been that the expected NPV of investments has differed greatly from the actual outcome why they have decided to try a Hybrid Real Options evaluation.

PHASE 1 SETUP PHASE
There are multiple parameters that the company needs to take into account when evaluating the investment. Firstly the yearly demand of their product is highly correlated with the amount of rainfall. The last few years has seen a trend where the amount of rainfall has increased, likely due to global warming. However, rainfall fluctuates between years increasing the uncertainty of the umbrella demand. Secondly there is a risk that the resources put into R&D efforts fail to yield a solution and in the case of a successful R&D the technology benefits are still uncertain.

PHASE 2 DATA COLLECTION AND ANALYSIS
The company has found through previous experience that revenue increases exponentially with the demand of umbrellas, the production cost of the umbrella is linear with a cost per umbrella and a fixed overhead cost. Combining the revenue and costs each year from Table 25 yields Equation 6 graphed in Figure 35.

<table>
<thead>
<tr>
<th>Table 25 Data for calculating profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
</tr>
<tr>
<td>e^(0.001S-1)</td>
</tr>
</tbody>
</table>
The project risks associated with the investment are a risk of R&D failure and uncertainty in project benefits. Previous similar R&D endeavors shows that R&D has a success rate of 80% resulting in a 20% risk of failure. The benefit of the proposed technology is estimated to vary between cost reductions of 20-50%, with 20% being more likely. The probability of a 20% cost reduction is estimated to be 65% resulting in a 35% probability of a 50% cost reduction. The project risks are summarized in Table 26.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Probability</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D (Success/Failure)</td>
<td>Success 80%</td>
<td>Failure 20%</td>
</tr>
<tr>
<td>Benefits (High/Med)</td>
<td>High 35%</td>
<td>Med 65%</td>
</tr>
<tr>
<td>Project benefits</td>
<td>Reduction</td>
<td>Resulting production cost/unit</td>
</tr>
<tr>
<td>High</td>
<td>50%</td>
<td>0.25</td>
</tr>
<tr>
<td>Medium</td>
<td>20%</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Analyzing historic market data shows an expected demand of 10000 umbrellas with a 2% per year increasing trend. The demand has had a volatility of 5%. This gives the following input parameters for the lattice generation.
\[ N = 3 \]
\[ T = 3 \]
\[ \Delta T = 1 \]
\[ S_0 = 10000 \]
\[ \sigma = 0.05 \]
\[ v = 0.02 \]
\[ u = 1.05 \]
\[ d = 0.95 \]
\[ p = 0.7 \]
\[ P(S_{i,t}) = e^{0.001 S_{i,t-1} - 0.01 S_{i,t} - 7000} \quad (6) \]

The generated lattice for demand the following 3 years and the profit lattice can be seen in Figure 36, in Figure 37 the probability lattice is shown.
The ENPV calculation as well as a traditional NPV, with expected demand and growth, can be seen in the calculation above, the ENPV yield a 75% higher expected. This since the profit function is non-linear with revenues increasing exponentially with increasing demand.

The investment in R&D efforts is made initially after that there is a risk of project failure before the implementation decision. The investment and implementation costs as well as their timing can be seen in Table 28.

Table 28 Cost and timeline of investment

<table>
<thead>
<tr>
<th>Decision</th>
<th>Cost</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invest</td>
<td>250</td>
<td>t=0</td>
</tr>
<tr>
<td>Implement</td>
<td>2250</td>
<td>t=1</td>
</tr>
</tbody>
</table>

The standard DCF-analysis is produced by multiplying the outcomes with their respective probabilities not taking into account that there is a possibility of stopping the implementation. In options thinking the implementation decision (illustrated in Figure 37 Probability lattice for the example)
38) that maximizes the expected net outcome is taken instead. For this project a successful R&D should lead to an implementation decision since the expected benefit of that decision is higher. If the project however fails the decision to stop the investment should be made instead.

![Decision tree from investment in example](image)

**Figure 38 Decision tree from investment in example**

**RESULTS**

<table>
<thead>
<tr>
<th>No investment</th>
<th>24438</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DFC</strong></td>
<td>$0.8\times(0.35\times28966+0.65\times24632)+0.2\times22026$</td>
</tr>
<tr>
<td><strong>Options thinking</strong></td>
<td>$0.8\times(0.35\times28966+0.65\times24632)+0.2\times24188$</td>
</tr>
<tr>
<td><strong>Option value</strong></td>
<td>25756-25325</td>
</tr>
</tbody>
</table>

The results indicate that the company should invest in the development of the new production technology since it will increase the ENPV by 1319 (25756-24438). The decision yields an option value of 431 that can be seen together with the calculations in Table 29. However this decision will depend on the probability for R&D success why the company will conduct a sensitivity analysis.

**PHASE 3 - SENSITIVITY ANALYSIS**
A sensitivity analysis is conducted where the R&D probability is varied and its effect on ENPV studied. From Figure 39 Sensitivity analysis of probability of R&D the company can conclude that as long as the R&D failure probability is lower than 80% the investment will yield a positive outcome.
Appendix C

PARAMETERS IN AKCELIK TRAVEL TIME FUNCTION

\[ t = \text{average travel time per unit distance (e.g. in seconds per km)} \]

\[ \tau = \text{minimum travel time per unit distance (e.g. in seconds per km)} \]

\[ JD = \text{a delay parameter} \]

\[ z = x - 1 \]

\[ x = q / Q = \text{degree of saturation} \]

\[ q = \text{demand (arrival) flow rate (in veh/h)} \]

\[ Q = \text{capacity (in veh/h)} \]

\[ rf = \frac{Tf}{\tau} = \text{ratio of flow period to minimum travel time} \]

\[ t = \tau(1 + JA x / (Q \tau(1 - x))) \]
\[ = \tau + 0.25Tf (z + (z 2 + 8JA x / (Q Tf))0.5) \quad \text{(15)} \]
\[ = \tau\{1 + 0.25 rf (z + (z 2 + 8JA x / (Q \tau rf)) 0.5)\} \quad \text{(8)} \]

<table>
<thead>
<tr>
<th>Description</th>
<th>( v_0 ) (km/h)</th>
<th>( Q ) (veh/h/lane)</th>
<th>JA</th>
<th>( \frac{vm}{v_0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway</td>
<td>120</td>
<td>2000</td>
<td>0.1</td>
<td>0.63</td>
</tr>
<tr>
<td>Arterial (uninterrupted)</td>
<td>100</td>
<td>1800</td>
<td>0.2</td>
<td>0.57</td>
</tr>
<tr>
<td>Arterial (interrupted)</td>
<td>80</td>
<td>1200</td>
<td>0.4</td>
<td>0.49</td>
</tr>
<tr>
<td>Secondary (interrupted)</td>
<td>60</td>
<td>900</td>
<td>0.8</td>
<td>0.44</td>
</tr>
<tr>
<td>Secondary (high friction)</td>
<td>40</td>
<td>600</td>
<td>1.6</td>
<td>0.41</td>
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</table>