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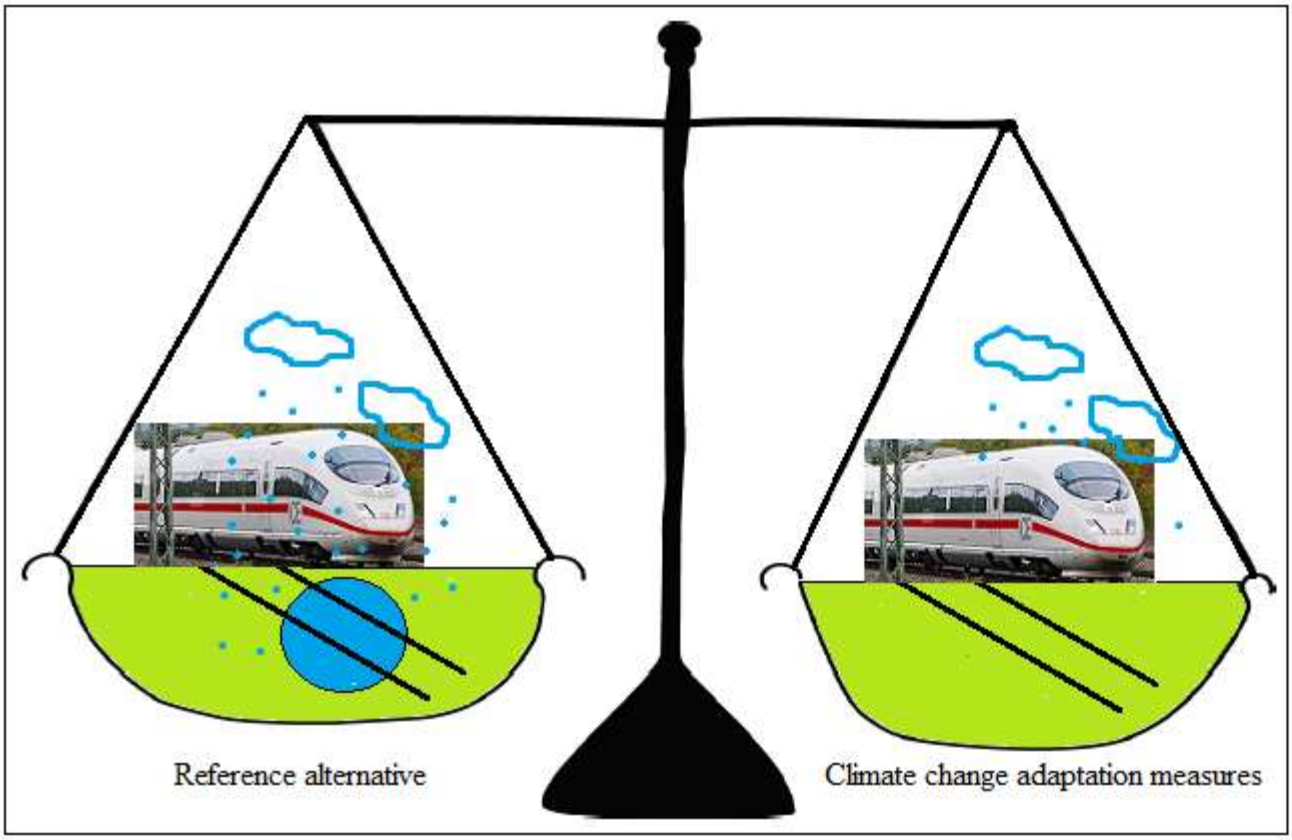

A Method for Cost-Benefit Analysis of Climate Change Adaptation Measures in Railway Projects

Master's Thesis in the Master's Programme Industrial Ecology

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Master's Thesis BOMX02-16-17
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"Cost-benefit analysis of different climate change adaptation measures for flooding in railway projects". Figure modified to fit this thesis from the front page of the Master's Thesis by (Karlsson & Larsson, 2014) and a picture of a high-speed train (Anon., 2016)

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ABSTRACT

The risks for flooding events in Sweden are expected to increase due to climate changes. Flooding events can cause damage on many parts of the society such as buildings, roads, sewage systems and railways and this contributes to high damage costs to the society. Climate change adaptation measures can be used to avoid many of the damage costs of a flooding event. Sweco Environment AB has developed a Microsoft Excel-based cost-benefit analysis (CBA) model to analyse the economic effects of different adaptation measures and this tool has been applied in several municipalities in Sweden. Even though this model can be applied well to urban areas in Sweden, it is not adapted to railway projects. The Swedish Transport Administration is planning to construct a high-speed railway between Gothenburg and Stockholm, called *Götalandsbanan*. Sweco is one of the consulting companies that is planning and designing a part of Götalandsbanan. What the damages will be if flooding occur on Götalandsbanan and what mitigation measures that are most cost efficient to use for each area of concern is not known. This thesis was initiated to investigate what the damages would be on the railway system if flooding occurs at railways and also evaluate what they will be if different measure alternatives is made.

The main objectives of this thesis have been to: (1) adapt Sweco's CBA-model to railway projects and (2) apply this CBA-model to Götalandsbanan. In order to adapt Sweco's CBA-model information about damages related to flooding on railway was collected partly from earlier railway accidents in Sweden and partly estimated by people working in areas such as flooding and railway. This study shows that there is limited information about damages on conventional railway systems in Sweden due to flooding. The adapted new CBA-model was applied on the area *Rävlandatunneln* at Götalandsbanan, where two alternative measures were evaluated. Alternative 1 was to pump the water from the beginning of the tunnel to a lake located nearby called *Rammsjön* and alternative 2 was to pump the water in a pipe through the tunnel. Alternative 2 had the highest NPV and based on this value it should thereby be the most preferable alternative to invest in. However, due to the difference between the alternatives being so small and high uncertainties, one cannot say that alternative 2 is most preferable to invest in. The values from the CBA-model should not be trusted in detail since many assumptions have been made, but the results could be used to give an indication of which measure alternative that is the best one to invest in from a perspective of social welfare.

Key words: Cost-benefit analysis, flood damages, high-speed railway, climate change adaptation measures, Götalandsbanan

Kostnads-nyttoanalys av klimatanpassningsåtgärder inom järnvägsprojekt

Examensarbete inom mastersprogrammet Industriell Ekologi

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SAMMANFATTNING

Risken för översvämningar i Sverige väntas öka på grund av klimatförändringar. Översvämningar kan orsaka skador på flera delar av samhället såsom byggnader, vägar, avloppssystem och järnväg vilket orsakar höga skadekostnader för samhället. Klimatanpassningsåtgärder kan användas för att minska påverkan på samhällen orsakat av en översvämning och därmed även minska skadekostnaderna för samhället. För att analysera hur klimatanpassningsåtgärderna kan minska kostnaderna som följer av en översvämning har Sweco Environment AB utvecklat en kostnads-nyttoanalysmodell i Microsoft Excel. Denna modell har applicerats på många kommuner i Sverige men modellen är inte anpassad för att användas på järnvägsprojekt. Trafikverket planerar att bygga en höghastighetsjärnväg mellan Göteborg och Stockholm som ska heta *Götalandsbanan*. Vilka skador som kommer uppstå om en översvämning sker på Götalandsbanan och vilka åtgärdsalternativ för översvämningar som är mest kostnadseffektiva vid olika delar av järnvägen är ännu inte känt. För att kunna utvärdera vilka skador som är relaterade till järnväg vid en översvämning och vilka åtgärdsalternativ som är mest kostnadseffektiva har detta examensarbete skapats.

De huvudsakliga målen med detta examensarbete är att (1) anpassa Sweco's KNA-modell så att den kan appliceras på järnvägsprojekt och (2) applicera KNA-modellen på Götalandsbanan. För att kunna anpassa modellen till järnväg samlades konsekvenser för järnväg orsakade av översvämning in genom att titta på tidigare händelser i Sverige men även genom att ta del av kunskaper från personer som arbetar med relaterade frågor såsom översvämningar eller järnväg. Studien visar att tillgänglig information gällande skador på järnväg orsakade av översvämningar i Sverige är begränsad. Den nya KNA-modellen för järnvägsprojekt applicerades på Götalandsbanan, mer bestämt Rävlandatunneln. Två klimatanpassningsåtgärder utvärderades i KNA-modellen. Alternativ 1 innebar att pumpa bort vattnet från tunnelmynningen till en närliggande sjö som heter Rammsjön och alternativ 2 innebar att dra en dagvattenledning genom tunneln för att på så vis leda bort vattnet. Alternativ 2 visade sig ha högst NPV och borde därför vara det mest fördelaktiga alternativet ur ett socio-ekonomiskt perspektiv. På grund av att skillnaden mellan alternativen är små och stora osäkerheter i resultaten finns det stora osäkerheter i denna slutsats. Resultaten från KNA-modellen skall ses som en indikation av vilket alternativ som är mest fördelaktigt och inte som slutgiltiga kostnader då många antaganden är gjorda och att enbart några få skador är inkluderade i modellen.

Nyckelord: Kostnads-nyttoanalys, översvämningsskador, höghastighetsjärnväg, klimatanpassningsåtgärder, Götalandsbanan

Contents

Preface

This Master's thesis was performed at Chalmers University of Technology at the department of Civil and Environmental Engineering in collaboration with the consulting company Sweco Environment AB in Gothenburg, in a group that partly works with risk assessment. Cost-benefit analysis is a tool that was used during my master studies in Industrial Ecology and this thesis concludes my knowledge in my master by developing a CBA-model for climate mitigation measures for railway projects. I hope that the work I have done in this study will contribute to that the economic costs for municipalities will be minimized in the future by the use of this tool. I will first of all thank my examiner and supervisor Lars Rosén for professional supervision and well-performed feed-back during my studies. I will also like to thank my other supervisor Lars Grahn for giving me the opportunity to perform my master thesis at Sweco Environment in an area that are direct connected to a real problem in society. I would also like to thank all other consultants at Sweco that has been helpful during my study.

Göteborg June 2016

Kristina Wetterhorn

1 Introduction

1.1 Background

The most common type of flooding event in Sweden, with about 70% of the total number of events, is flooding in lakes and streams, most commonly caused by rain fall during a long period of time or snow melting (MSB, 2012). In coastal areas, temporarily increased sea levels cause flooding. Heavy rain falls are also one common cause to flooding events, but this is more of a local problem since the precipitation tends to fall on limited areas. The risk for flooding due to increased water levels in streams lakes and the sea, as well as due to heavy rainfall, is expected to increase in Sweden because of climate changes (MSB, 2016a). Consequences related to flooding events are damages on e.g. buildings, drainage and sewage systems, recreational areas, people's health and infrastructure such as roads and railway (MSB, 2016a); (Blumenthal, et al., 2010). Landslides and landslip are other consequenses than flooding resulting from heavy rainfall (MSB, 2016a). Risks for flooding events are high today in many parts of Sweden, but the risk will be even higher if the physical planning, such as infrastructe projects, is not adapted to climate changes.

Since infrastructure is one of the parts in society that is affected by flooding events, flooding risks are important to take into account when designing new infrastructure projects. Conventional railway is the railway type present in Sweden today, but a high-speed railway that is planned to connect Sweden with the European railway network is currently being designed by technical consulting companies for the Swedish Transport Administration. *Götalandsbanan* is the name of the high-speed railway that is planned to be built between Gothenburg and Stockholm (Trafikverket, 2014). The part of Götalandsbanan between Gothenburg and Borås is divided into three different parts during planning and design: Almedal – Mölnlycke, Mölnlycke – Bollebygd and Bollebygd – Borås (Trafikverket, 2016). The consulting company Sweco has been given the responsibility for designing the high-speed railway between Mölnlycke and Bollebygd and one important basis for the design work is to investigate the risk for flooding and identify proper alternatives for climate change adaptation on this part of the line.

In Sweden, there is a regulation called *Förordningen om konsekvensutredning vid regelgivning* (SFS 2007:1244) which requires responsible authorities to be the first to evaluate the consequences of their decisions (Kriström & Bonta Bergman, 2014). Several EU directives have also been implemented in Swedish laws and these require climate change adaptation alternatives to be evaluated with respect to costs and benefits. Such evaluations can be made using *cost-benefit analysis* (CBA) to identify which of several alternatives that is most profitable to invest in for the society. The results can then be used to support decision makers in decisions on which adaptation measure to implement. Sweco Environment AB has developed a tool for CBA that they apply in different projects when evaluating flood risks, mainly for Swedish municipalities (Rosén, et al., 2011). The CBA-model is however not developed to be used in railway projects, such as Götalandsbanan.

1.2 Direct and indirect flood damages

Flood risk management aims to reduce flooding damages (Messner, et al., 2007). Flood damages are all kinds of harm caused by flooding. Flooding can for example cause damages on humans and their belongings, to ecosystems and infrastructure. One common way of categorizing flood damages is according to its form of damage and the consequences of the damage. The form of damage can either be direct or indirect and the consequences can be divided into tangible and intangible damages. The direct flooding damages are immediate and are typically measured as damage to stock values. Examples of direct flooding damages are damage on buildings, economic assets, loss of standing crops and livestock in agriculture. Indirect flood damages are damages caused by disruption of the physical or economic environment and can for example be loss of production, traffic disruption or emergency costs. Tangible damages are the damages that easily can be expressed in monetary terms, e.g. Swedish kronor (SEK), such as damage on asset or loss of production. Intangible damages are typically negative effects on non-market goods and services and more difficult to express in monetary terms, e.g. loss of life or reduced provision of eco-system services. The categorization of the flooding damages according to Messner et al (2007) can be seen in Table 1.

Table 1 *Categorization of flooding damages with examples adapted from (Messner, et al., 2007).*

<table>
<tr><td></td><td colspan="3">Measurements</td></tr>
<tr><td rowspan="3">Form of damage</td><td></td><td>Tangible</td><td>Intangible</td></tr>
<tr><td>Direct</td><td>Physical damage to assets:
• buildings
• contents
• infrastructure</td><td>• Loss of life
• Health effects
• Loss of ecological goods</td></tr>
<tr><td>Indirect</td><td>• Loss of industrial production
• Traffic disruption
• Emergency costs</td><td>• Inconvenience of post-flood recovery
• Increased vulnerability of survivors
• Eco-system services, e.g. availability of clean water</td></tr>
</table>

1.3 Aim and objectives

The overall aim with this study is to investigate how the cost-benefit methodology developed by Sweco can be adapted and applied to high-speed railway projects. The expectation is that the adapted CBA-model should be possible to apply on Götalandsbanan and other similar infrastructure projects in order to evaluate if climate adaptations are profitable, and if so which adaptation alternative that is most profitable, to society. In order to fulfil the aim the following specific objectives were formulated:

- Identify possible damages on railway systems due to flooding. This will be made by a literature review of earlier damages on railway systems in Sweden and also collect knowledge within Sweco.
- Estimate the damage costs and probabilities that the damages will occur.
- Gather information from co-workers at Sweco about suitable climate change adaptation measures and the costs for these measures.
- Review and adapt the cost-benefit methodology developed by Sweco to railway systems by adapting the current CBA-model or create a new CBA-model.
- Apply the CBA-model to a case study area on Götalandsbanan.

1.4 Limitations

A limitation in the literature study is that only four search words were used when searching for information about damages on railway in MSB’s database. This was done in order to limit the time to find information in the text since it was very much information to sort from. The gathering of information about damages on railway systems due to flooding is limited to flooding events in Sweden. Assumptions are also made in this study in order to make the calculations, and this is also a limitation with this study, i.e. that the model is partly based on assumed damage costs and time for reparation of the damages on the railway. The study is limited to damages on the railway facility and standstill, as well as to one case study area and two climate change adaptation measures.

2 Cost-benefit analysis – the Sweco model

Sweco has developed a CBA-model to evaluate the economic profitability to society of investment alternatives to reduce flooding risks (Rosén, et al., 2011). Sweco has implemented the CBA-model in an Excel tool, which includes uncertainty analysis. Uncertainties may originate from imprecise and incomplete input data to the model, resulting in uncertainty of the economic profitability calculations. The model is divided into eight steps described below.

2.1 STEP 1: Modelling of flooding scenario

The first step in the CBA is to model and analyse different flooding scenarios. Different flooding scenarios are based on different water levels or rain events with specific return times, e.g. 10, 50, and 100 year return times. How the water levels expand over the area, can be assessed by the use of *geographical information systems* (GIS-systems). Once the flooding maps are made the number of different types of objects that are flooded, e.g. houses, can be calculated. By valuation of different categories of damage costs (see STEP 2), aggregated damage costs can be calculated for each flooding scenario. At least three flooding scenarios should be modelled to make a representative calculation of the total expected damage cost, i.e. the risk cost. To reduce the uncertainties when calculating the damage costs is it also recommended to do a field examination to make shore that the objects are really there and that no other objects have been missed.

2.2 STEP 2: Economic valuation of damage costs

The damage costs of a flooding can be divided into three different categories depending on when they occur: *direct*, *restoration* and *long-term effects*. Direct damage costs are the costs for keeping up functions in society and costs for reducing damages during the flooding event. Costs for restoration are the costs for repairing, restoring and replacing damaged buildings, infrastructure and residential areas. Example of costs due to long-term effects are costs due to deceased production of crops, restricted exploitation possibilities due to flooding risks and damage on water catchment areas. The damages that are included in each category are presented in a matrix of the damage costs in Table 2.

Standard values for the total costs of damaged objects are calculated, mainly based on insurance data and expert judgement, and available for some objects in the Sweco-model. There are no standard cost values present in the model for railway damages and it is therefore necessary to gather new information on such costs in order to adapt the CBA model to railway projects. The total expected damage cost (risk cost) is calculated by multiplying the standard value with the amount of objects identified by the GIS-analysis (see STEP 1). Damage costs are presented with uncertainty distributions in order to facilitate uncertainty and sensitivity analyses (see Section 2.9).

Table 2 *Direct, restoration and long-lasting and remaining costs (Rosén, et al., 2011).*

DIRECT	RESTORATION	LONG-TERM EFFECTS
ACUTE MEASURES	**RESIDENTIAL BUILDINGS**	Restrictions in landuse
COMMERCIAL	Villas and Townhouses	Mortality and physical damage on humans
Interruption in production of goods and services	Apartment buildings	Psychological stress on humans
Decreased sales of goods and services	**COMMERCIAL BUILDINGS**	OTHER
Loss of income (private persons)	Offices	
TRAFFIC DELAYS	Stores	
Road traffic -persons	Industrial	
Rail traffic -persons	**PUBLIC BUILDINGS**	
Road traffic -goods	Critical - e.g. fire station, police station, hospital	
Rail traffic -gods	Important - e.g. schools, library, nursing homes	
INTERRUPTION IN SUPPLY SYSTEMS	**OTHER BUILDINGS**	
Sanitary purification plants	Complementary – e.g garage, storage	
Water production plants	Cultural buildings	
Compensation for interruption in drinking water supply	Event buildings	
Compensation for interruption in electrical power supply	**INFRASTRUCTURE**	
ENVIRONMENTAL DAMAGES	Road (m^2)	
Discharge of pollutants from contaminated areas	Railroad (m)	
Forest damages	Water pipings (m)	
Damage on agricultural land	Central heating pipings (m)	
Damage on raw water supplies for drinking water	Electrical transformers	
OTHER	Electricity lines (m)	
	OTHER	

2.3 STEP 3: Calculation of risk cost (reference-alternative)

The third step in the CBA-model focuses on the reference-alternative, typically a 0-alternative where no climate adaptation measure is made. All costs and benefits of the CBA are estimated relative to the reference alternative. The total risk cost for a specific flooding scenario is approximated by summarizing the damage costs for e.g. three flooding scenarios, as shown in the left part of Figure 1, and by creating an approximate graph for the damage costs of all flooding scenarios over a specific time horizon. The total risk cost is usually underestimated in Sweco’s model since all damages cannot usually be monetized. Figure 1 presents the risk for three flood scenarios R1, R2 and R3 (left) as well as the approximated risk for all flooding scenarios (right) in the zero-alternative.

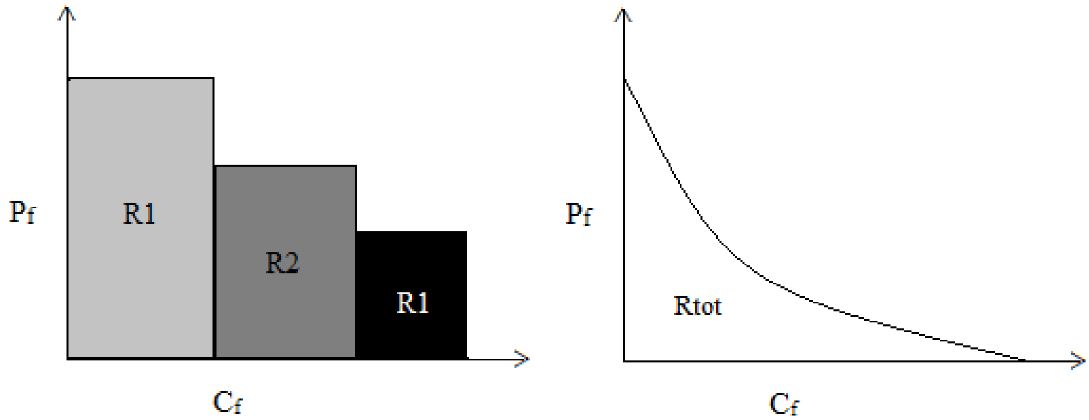

Figure 1 *Left: Risk for occurrences of flooding scenarios R1, R2 and R3. Right: Total approximate risk for all occurrences of all flooding scenarios.*

The parameters used in Figure 1 are:

P_f = Probability of flooding
C_f = Damage costs due to flooding (SEK)
R_{tot} = Total approximate risk for a flooding event (*R1*+*R2*+*R3*)
R1, *R2*, *R3* = Risk for flooding event 1, 2 and 3 respectively

The total approximate risk cost for a flooding event is described by Equation 1:

$$R_{tot} = E(C_f) = \int_0^1 C_f(P_f)dP \approx P_{f1}C_{f1} + \sum_{j=2}^{n} P_{fj}(C_{fj} - C_{f(j-1)}) \qquad (1)$$

The parameters used in Equation 1 are:

$j = 2, 3\ldots, m$
m = number of flooding events

2.4 STEP 4: Identification of climate change adaptation measures

To reduce damages and thereby the risk cost, different climate change adaptation measures are compared with the reference-alternative in the CBA-model. Functions critical to society, such as hospitals, infrastructure and schools, are often prioritized when choosing which objects to protect. Some industries and recreational areas are other examples of areas that often need to be prioritized. Storm water management, wastewater treatment derivation and risk for leachate from the sewage system needs to be taken into consideration when prioritizing the measures. It is of importance that the measures are described with a high level of details in order to facilitate accurate calculations of the profitability of the measure. Some examples of climate change adaption measures for flooding are wall constructions, draining of water, outer and inner protection of buildings, construction of dams, and regulation of stream flows based on weather forecasts. Flooding measures are often built so that they can be built on, if the flood levels will increase further in the future.

2.5 STEP 5: Cost-estimation of climate change adaptation measures

After identification of possible alternatives for climate change adaptation measures to evaluate, and during which time horizon, the costs of the alternatives are estimated. The costs can be divided into five categories as follows: investment costs for measure, operation costs, maintenance costs, costs for reinvestments of parts, and other costs such as limitations of the use of an area caused by the measures. It is important that the times when the investments are made are noted so that all costs can be transformed into *present values*, see STEP 7

2.6 STEP 6: Estimation of risk cost for the climate measure alternatives

To estimate the effects of the climate adaptation measures hydrodynamic modelling can be made. The modelling is made for all included flooding scenarios. Risk costs associated with each climate adaptation measure alternative can be calculated accordingly and compared to the zero-alternative in the CBA-model.

2.7 STEP 7: Calculation of NPV and profitability

The benefit of an adaptation measure alternative is calculated as the reduced risk associated with the measure. The benefit is compared to the costs for implementing and maintaining the adaptation measure. A net present value (*NPV*) is calculated for each climate adaption measure alternative i =1, 2 … n. by using Equation 2.

$$\text{NPV}_i = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left[\left(R_{tot,0}(t) - R_{tot,i}(t) \right) - K_i(t) \right] \quad (2)$$

where

$R_{tot,0}$ = the total risk cost for the reference alternative
$R_{tot,i}$ = the total risk cost after the implementation of alternative i
r = discount rate
T = time horizon for years t=1…T
K = construction and maintenance costs of risk reduction alternatives

The calculated *NPV* indicates if the specific alternative is profitable or not. By comparing the NPVs for analysed alternatives, it can be estimated which alternative that is the most profitable. The discount rate recommended for socioeconomic projects are 3.5 % (Trafikverket, 2016) but for projects regarding climate change an often recommended discount rate is 1.4% (Stern, 2006).

2.8 STEP 8: Ranking of profitability of the alternatives

Which measure alternative that is preferable is presented in Sweco's CBA Excel-model as well as the probability that the NPV is positive for that alternative. These results make it easy to visualize which choice that is preferable to choose from a socio-economic perspective.

2.9 Uncertainty and sensitivity analysis

In all valuations of the risks and the costs of the measure alternatives there are uncertainties. The uncertainties for each variable in the CBA-model can be estimated by the use of Crystal Ball© which is an add-on to Excel, provided by Oracle. The uncertainty of the resulting variable can be calculated by means of Monte Carlo simulations. A simple drawing of the Monte Carlo methodology can be seen in Figure 2.

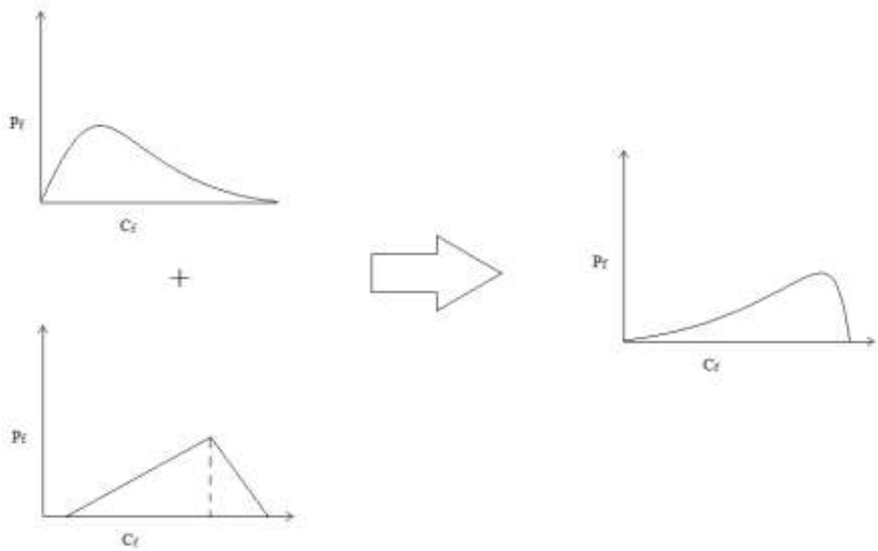

Figure 2 *Schematic illustration of Monte Carlo simulations.*

Some examples of values that can be obtained from the graphs are: the expected value (the mean value), the most probable value (the mode), the median value (50-percentile), a reasonably lowest probable value (e.g. the 5-percentile) and a reasonably highest probable value (e.g. 95-percentile). The range between the lowest and highest reasonable values is called the prediction interval. Sensitivity analyses can also been made in this step of the CBA. The sensitivity calculated for the NPV is dependent of the input data. In the sensitivity analysis, information can be presented about which input data that provides most uncertainty to the end result (e.g. the *NPV*). The input data that contributes most should be prioritized when collecting additional data to achieve a CBA with a higher degree of reliability.

2.10 Economic valuation of costs and benefits

Cost-benefit analysis is based on an economic valuation of costs and benefits. Costs and benefits in cost-benefit analysis are normally seen from a perspective of public welfare, but what a benefit is for the public welfare can be subjective. People perceive risks differently, depending on many different factors (Räddningsverket, 2003). Factors affecting people's risk perceptions are e.g. voluntariness, controllability and uncertainty. Some people might get anxious of the thought of a consequence and will thereby probably value the risk much higher than a person that is not as anxious. How people view risks can affect the real results of a cost-benefit analysis, but not that much in cases where peoples view are quite similar. This study focuses on limiting the economic consequences of flooding on railway systems, which most people probably have the similar view on, i.e. that mitigating the damages of flooding events is a worthwhile contribution to society.

3 Railway systems

Section 3.1 provides an overview of the compartments of a railway and the differences between a conventional railway and a high-speed railway. Detailed information about how the planned Swedish high-speed railway, Götalandsbanan, is going to be designed is described by Trafikverket (2015). Further information about Götalandsbanan is shown in Chapter 5.

3.1 Build-up of a railway line

The ideal railway should preferably be flat, horizontal, straight, have a stable substratum and not lose its shape and carrying capacity when frost occurs in the ground (Bårström, 2005). Also, it should preferably not permanently deform under the wheels, the rail should be properly even and controlling enough for the trains to stay on the rails. All these parameters are important to pursue when constructing a railway, even though all parameters cannot be constructed as perfectly as the ideal. A general overview of the compartments of a railway is presented in Figure 3.

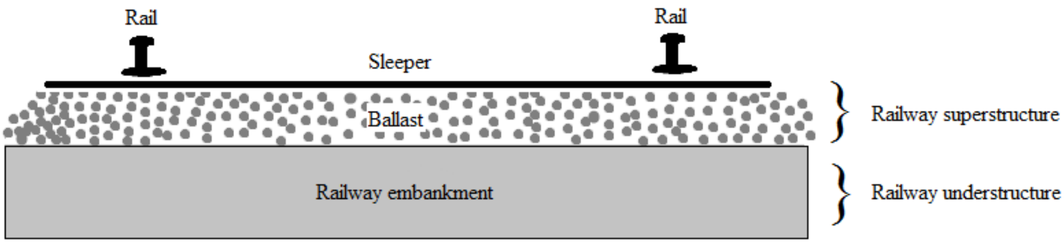

Figure 3 *A general overview of the compartments of a railway line: a track superstructure and track understructure. Adapted from: (Tellerup & Tellerup, 2016).*

3.1.1 Track superstructure

The track superstructure can either be built up by ballast tracks or ballast-free tracks. Ballast-free tracks are commonly used at high-speed railways around the world in for example Germany, Netherlands and China (Nyquist, 2010). Countries that use ballast tracks on their high-speed railway are for example France, Italy and Spain. Japan was the first country that built a high-speed railway in 1964 and in 1975 the first ballast-free tracks were used there to reduce the amount of maintenance. The maintenance on ballast track is for example made by using tamping machines and ballast cleaners (Ekberg & Paulsson, 2010). It can also be so that only parts of the railway are constructed with ballast-free tracks, as for example at bridges, underbridges and tunnels (Nyquist, 2010). Even though the ballast-free tracks require less maintenance than ballast tracks there are still some problems with settling and cracking in some countries.

Figure 4 *Conventional railway with ballast tracks.*

Figure 5 *Ballast-free tracks/Slab tracks (Terfloth, 2004).*

3.1.2 Track understructure

The track understructure can either be embankment, bisections, tunnels, bridges or culverts (Bårström, 2005). The understructure can be built directly on the ground but it is common that the ground is prepared to avoid slides and landslides, draining the soil or isolating from frost in the ground. How well the geotechnical conditions are considered in the construction of the railway influence the buoyancy, elasticity, the level of protection from slides, landslip and how much the frost affects the railway. Ground conditions are different in different areas and affect the construction of the railway.

3.2 Other parts in a railway system

Electric power supply is necessary for several parts of the railway system: for transportation of the trains, for the signal box, to control the gears and providing the heat system with electricity to keep the gears clean from snow, and to provide electricity to signals, telecommunication as well as lighting of the stations (Bårström, 2005). There are some systems that are commonly used within railway systems to secure safety and to control the steering of the trains. One such system is the ATC-system, *Automatic Train Control*.

Another system used in railway systems are the ERTMS/ETCS, *European Rail Traffic Management System/European Train Control System*, which makes it possible for international traffic to pass on Swedish rails even though that different countries uses different systems for train control, such as the ATC-system (Bårström, 2005). Telecommunication in the railway system is important since communication needs to be possible even though the mobile phones and internet are not working. The need for communication between traffic control head office and local technical devises is very important as well as between signal boxes and block system devises. These are only examples of what the telecommunication in the railway system are used for, but it shows that all these technical parts are important for a well-functioning railway system.

3.3 Differences between conventional railway and high-speed railway

The conventional railway lines have been present in the world for a very long time, but the high-speed railway lines were developed much later. The world's first high-speed train service was built in Japan between Tokyo and Osaka in 1964 (UIC, 2016).

Today 1600 million passengers are travelling annually with high-speed trains and 800 million of them travel in China, 355 millions in Japan, 130 millions in France and the rest travels in other parts of the world. Germany, France, Spain and Italy are some examples of countries in Europe that currently have high-speed trains in operation.

The definition of high-speed railway lines is not universal since different high-speed railway lines have different properties and the definitions are also stated differently in different countries (Forsberg et al, 2008). Since the definitions of a high-speed railway line differ worldwide it is quite difficult to express the differences between a conventional railway line and a high-speed railway line. However, the Swedish Transport Administration has listed some differences between the two types of railway systems, see Table 3.

Table 3 *Definition of conventional railway and high-speed railway (Forsberg et al, 2008)*

	Conventional railway	**High-speed railway**
Definition	Upgraded or newly constructed rail for passenger trains and cargo trains	Newly constructed rail designed for high speed trains for passengers
Maximum speed	200-250 km/h with or without tilting of the wagon	250-350 km/h without tilting of the wagon
Average speed (high speed train)	120-180 km/h	200-250 km/h
Type of train	High speed trains, local trains, regional trains, heavy- or light cargo trains	Real high speed trains, High speed regional trains, high speed cargo trains
Geometry of the tracks	Moderated curve radius, small gradients	Large curve radius, Large gradients
Level crossing between road and railway	Occur	None

High-speed railway lines are railways designed to be used for high-speed railway trains. High-speed railway lines are built to manage speeds for trains that have a maximum speed of 250 km/h or more without tilting of the wagon. Depending on if the high-speed railway line is adapted for cargo trains or not the tilting of the rail can differ in the construction of the railway. Cargo trains cannot be transported on high-speed railway lines with a tilting of as little as 35‰, but that is possible for passenger trains. The definition of high-speed railway used by the Swedish Transport Administration is a newly constructed line designed for real high speed train used for transportation of passengers.

4 Method

The methods used in this study were developed over time since the gathering of input information to the CBA-model became a more comprehensive part of this study than first thought. The study in this thesis was first started with a literature review with the aim of gathering information about damages and damage costs on Swedish railway systems due to flooding. Some information about damages was found in individual papers and reports on specific flooding events, but in order to make a larger collection of damages research was done for a database with flooding events that possibly could include information about damages. The most important finding of the literature review was a database with information about natural disasters. How the database was used to find information about damages and damage costs related to railway are described in Section 4.1.

4.1 Database of natural disasters in Sweden

The database is named "Swedish Natural Hazards Information System" and developed by MSB (The Swedish Authority for Safety and Emergency; In Swedish: *Myndigheten för samhällsskydd och beredskap*) (MSB, 2016b). This database makes it possible to search for information about railway in a much faster way than studying individual accidents. It includes information about some e.g. flooding events, landslips and landslides in Sweden from 1950 to 2016. The flooding event category was investigated in this study in order to find information about damages on railway systems in Sweden due to flooding.

All flooding events in the database was investigated in this study. The database can be viewed in both Swedish and English but the Swedish version was chosen for research. The Swedish words for railway (Swedish: *Järnväg*) and train (Swedish: *tåg*) as well as the Swedish Transport Administration (Swedish: *Trafikverket*) and Swedish National Rail Administration (Swedish: *Banverket*) were used when searching information in the database. The Swedish National Rail Administration was the name used before changing to the Swedish Transport Administration and was thereby used in the texts for the disasters that occurred before the administration changed their name.

4.2 Questionnaire

There was a lot of information about damages in the database, but the information was not as specific as hoped for. To continue the gathering of information a questionnaire was made and sent out to persons working with related areas. The related areas were flooding events, geotechnics and railway respectively. The questionnaire was sent out to around 30 persons at both Sweco and the Swedish Transport Administration.

During a meeting with people at Sweco working with construction of Götalandsbanan from a flooding perspective it became clear that flooding in cuttings was an area that the CBA-model should be able to handle. Flooding events in tunnels have occurred in Sweden and tunnels are therefore an important part of the railway system when evaluating flooding. The questionnaire was thereby used to gather more information about flooding damages on these specific parts of the railway system.

The questionnaire was divided into two parts: the railway facility and railway traffic. The railway facility was divided into questions about the railway embankment, railroad bridges, railway tunnels and cuttings. There were illustrations of each of the four parts and for the railway embankment the flooding situation was sub-divided into three possible damage levels. The Figure used in the questionnaire for the railway embankment is presented in Figure 6.

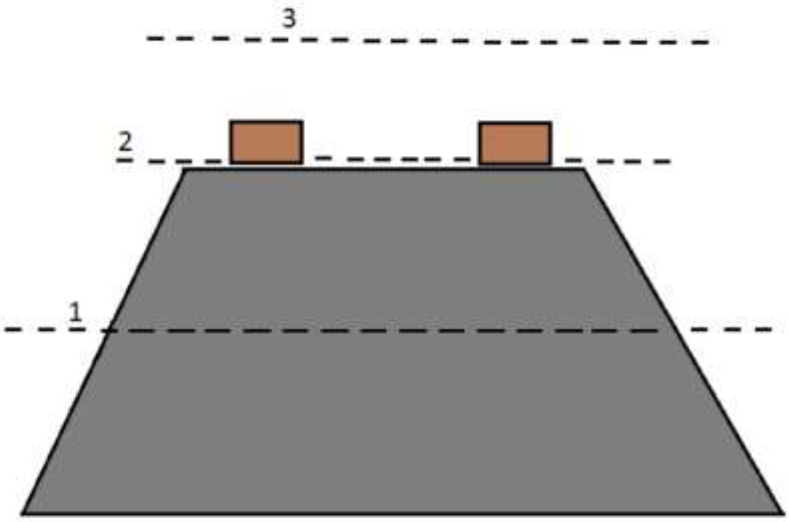

Figure 6 *A drawing of a railway embankment. The drawing was used in the questionnaire.*

The numbers in Figure 6 represent three possible flooding levels: water to the middle of the railway embankment (1), water to the lower edge of the rail (2), and water to a level higher than the rail with margin (3). The lines are dashed since it should be open for the ones doing the questionnaire to interpret if the water is on one side or on both sides of the railway embankment. Each part in the questionnaire generally began with an open text-space for the respondent to describe which damages that are of highest concern for that part. In the question about the railway embankment the respondent should answer about damages for the specific damage levels defined in Figure 6.

The second part of the questionnaire included questions about the railway traffic and how it can be affected by flooding, e.g. standstill and situations when the trains might have to be travelling with severely reduced speed, something that was found as a consequence in the literature review. The consequences asked for in the questionnaire were economic consequences. The consequences given by the respondent in the questionnaire were combined with follow-up questions about probability and monetary values for each consequence. The scales used in the questionnaire for probability and economic valuations are presented in Figure 7.

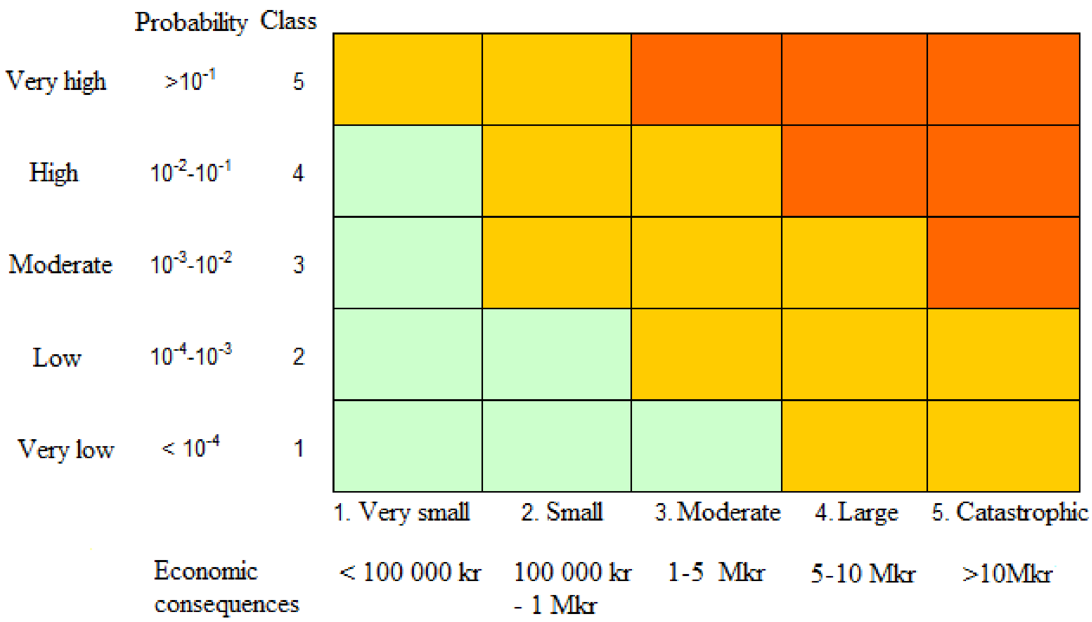

Figure 7 *Probability and economic consequences are combined for each flooding damage. The matrix has three different colors: green (low risk for damage), yellow (medium risk for damage) and red (high risk for damage).*

4.3 Meetings and questions by e-mails

A meeting was held with a consultant working with construction of bridges and tunnels at Sweco Civil AB. When starting to construct the CBA-model a problem was found: damage levels had to be defined for a railroad bridge as well as stating where damage would occur. This problem as well as damage levels for tunnels and cuttings was discussed with the consultant. Damage levels were also discussed, both at meetings and in e-mails with several other persons at Sweco.

4.4 Designing and evaluation of the CBA-model for railway projects

An evaluation was made of the current CBA-model by Sweco in order to see if it was possible to adapt to railway projects. The information that was required for railway projects were based on SEK/metre in the earlier CBA-model and thereby it was difficult to put any more details to that parameter in the model. It was decided that the best option was to develop a new CBA model, but with a structure resembling the Sweco CBA model. Damage levels were defined for the different parts of the railway in order to collect information about damages on railway due to flooding. The model is based on information about damages and damage costs from the literature review, questionnaire and meetings with consultants at Sweco. The new CBA-model was applied to Götalandsbanan and a sensitivity analysis was made in order to find the parameter that was most sensitive for the results.

5 Findings about damages on railway systems

5.1 Literature review

Section 5.1 describes consequences on the railway system that has occurred in Sweden due to flooding events; information that can be used as input to the new CBA-model.

5.1.1 Database on natural disasters

Between the years 1901 and 2010, 190 flooding events with substantial effect on health, environment, cultural heritage and economic business have been identified in Sweden. In addition to that, 500 minor flooding events have occurred (MSB, 2012). MSB has developed a database for some of these flooding events in Sweden where information from 40 flooding events from 1950 until today are gathered (MSB, 2016b). Of these flooding events, 19 events resulted in damages on railway. This means that almost half of the flooding events, with substantial effects on health, environment, cultural heritage and economic business in Sweden between 1950 and 2016, have led to damages related to the railway (under the assumption that information about railway is gathered in MSB's database if damages on railway occurred). The consequences of these flooding events on railway are presented in Table 4.

Table 4 *Consequences connected to railway due to flooding events in Sweden from 1950 to 2016 (MSB, 2016b).*

Flooding events in Sweden (area, date)	Consequences on railway
Kristinehamn, 2014	Railway closed 3-4 days.
Malmö, 2014	Train traffic affected and no trains could be driven for a few days.
Västra Götaland, 2014	Heavy rainfalls damaged the railway embankment on some parts of the railway line. Along 2 km there were damages on roads, contact line poles and the rail. 20 metres of the railway embankment were washed away. Train traffic worked again after four days.
Götaland, 2007	Train traffic was closed since risk for undermining of the railway embankment. 20 metres of the railway embankment were washed away. About 7000 train travellers were affected by this flooding event.
Västra Sverige, 2006	Erosion and landslip-damages on railway. Railway traffic stopped for some days. Västra stambanan had one track functioning with trains passing with lower speed. Commuter trains stopped.
Småland, 2004	Train traffic stopped since railway embankment was undermined.

Småland, 2003	Train traffic stopped since railway embankment undermined.
Södra Götaland, 2002	Railway traffic stopped for several months due to reconstruction of the whole railway.
Sundsvall, 2001	Train traffic stopped for several days due to damages on the railway embankment. 4000 train passengers were affected by the flooding event.
Skee, Strömstad, 2000	Railway traffic closed for 4 days.
Södra Norrland, 2000	Railway traffic stopped.
Arvika, 2000	Railway traffic stopped for several weeks. Increased demand for bus traffic.
Norra Sverige, 1995	A railroad bridge collapsed.
Västra Värmland, 1988	A railway embankment collapsed.
Dalarna & Gävleborg, 1985	A railroad bridge collapsed.
Noppikoski, 1985	A railroad bridge collapsed.
Bergslagen, 1977	Damages on railway.
Örebrotrakten, 1966	Railway embankment under water lead to stop in railway traffic.
Örebro & Kronoberg, 1951	Train traffic was totally closed in the region under a period of time. Cargo train traffic from Norrland had to be led trough Stockholm instead.

One of these events was the flooding event in Arvika and the consequences of this event have been investigated (Blumenthal, et al., 2010). Following this flooding event, the train traffic was first closed for three days and then the trains run for four days with a speed of 40 km/h and then the railway was totally closed again. After that, the trains had to travel with lower speed since the railway embankment was undermined. Other indirect consequences were compensation costs for late traffic, detour traffic and wear on the detour roads.

The overall consequences on transport systems caused by flooding were summarized in a document (MSB, 2012). The consequences described are that roads and railways have been cut or washed away, bridges and tunnels have been flooded and damages on harbour areas and airports have also occurred. There is also information stating that roads have been closed, thereby causing relocation of the traffic, and information about damages and disturbance on European roads, the main railway line and smaller roads. An additional consequence was that the reconstruction of the roads and railways took long time and had high costs. Further details about the damages are not present in the report. A summary of the consequences found in the database and other literature are presented in Table 5.

Table 5 *Direct and indirect effects of flooding events on railway in Sweden.*

Direct effects	Indirect effects
Traffic stopped	Passengers affected
Railway embankment damaged	Higher demand on bus traffic
Railway embankment washed away	Cargo trains has to go on other railway
Traffic stopped since risk for undermining of the railway embankment	Compensation costs for late traffic
Erosion damages	Detour traffic
Landslip damages	Wear on other roads due to detour traffic
Only one track of two can be used	
Train have to travel with lower speed	
Traffic stopped for months since total reconstruction of the railway	
Railroad bridge collapsed	
Railway embankment collapsed	
Damages on railway (not specified)	
Railway embankment under water	

5.1.2 Damage costs caused by flooding events

For three of the flooding events presented in Table 4, information about damage costs for railway was specified. The total damage cost for the Swedish Transport Administration for road and railway was 5 MSEK after the flooding event of Kristinehamn in 2014 (MSB, 2016b). The total damage cost for Banverket (part of the administration that today makes up the Swedish Transport Administration) in the region for the flooding event *Södra Norrland, 2000* was estimated to 35 MSEK, but no follow up has been made on the real damage costs. For the flooding event *Götaland, 2007* Banverket had an additional cost of 8.5 MSEK.

The flooding event in Arvika during the year 2000 caused direct costs for damages on railway of 4 MSEK (2006 years price) (Blumenthal, et al., 2010). No information was available about the costs for indirect damages for the flooding event in Arvika. Some flooding events in MSB's database contain information about total costs for the event but most often they do not contain information about the specific consequences on the damages and neither on the total costs for reparation of the railway.

5.2 Questionnaire

The questionnaire was sent out to people at Sweco that work with water systems, geotechnics and railway. The response was that the people working with water systems had trouble to state what the consequences due to flooding on the railway were. People working with maintenance of the railway had easier to state what damages on the railway facility could be. A summary of the answers on the questionnaire is given in the following sections.

5.2.1 Railway embankment

The damages that were stated when asking about the most important damage at each defined flooding level are shown in the Section 5.2.1. Table 6 presents damages at flooding levels 1, 2 and 3.

Table 6 *Answers from the questionnaire: damages on the railway embankment at flooding level 1, 2 and 3 according to the matrix in Figure 7.*

Railway embankment	Probability	Damage cost
Flood level 1		
Washout of the railway embankment (Person 1)	1	3
Impact on geotechnical conditions (Person 2)	3	3
Deepening of the railway embankment (Person 3)	3	2
Flood level 2		
The technical system will stop working since water shortcuts the different signals and electric systems (Person 1)	4	5
Impact on geotechnical conditions and effects on rail function (Person 2)	2	4
Deepening of the railway embankment (Person 3)	3	3
Flood level 3		
The technical system will stop working since water shortcuts the different signals and electric systems (Person 1)	5	5
Impact on geotechnical conditions and effects on rail function and thereby a risk when driving the train (Person 2)	1	5
Damage on electrical system (Person 3)	1	3

The characteristic answers for damage level 1 at the railway embankment are geotechnical problems. For damage level 2, the characteristic answer was damages on signals and electric systems and for the third damage level there was no additional damages that were not given for either damage level 1 or 2.

5.2.2 Railway tunnels

The most important damages in a railway tunnel that was gathered from the questionnaire are presented in Table 7.

Table 7 *Answers from questionnaire: damages on the railway tunnel according to the matrix in Figure 7.*

Railway tunnels	Probability	Damage cost
Drowning (Person 1)	1	3
Traffic system dysfunctional (Person 1)	5	5
Blocking of the emergency route (Person 1)	2	3
Train destroyed (Person 2)	4	4
Technical electric system failure (Person 2)	3	4
Geotechnical problems (Person 2)	3	4
Damage on technical installations (Person 3)	4	3
Damage on the railway line (Person 3)	3	2
Damage on the electricity/tele (Person 3)	4	3

The characteristics for damage level 1 in tunnels correspond to level 1 and 2 for the railway embankment i.e. damages on signals, electric system and telecommunications, standstill and geotechnical problems. The second damage level for the railway tunnel indicated that it could be problems with the emergency exits.

5.2.3 Railroad bridges

Damages on railroad bridges were also collected in the questionnaire and these are presented in Table 8.

Table 8 *Answers from questionnaire: damages on the railroad bridge at flooding according to the matrix in Figure 7.*

Railroad bridges	Probability	Damage cost
The bridge support will be washed away (Person 1)	3	5
Railroad bridge collapses (Person 1)	1	5
Water in technical equipment (Person 1)	1	5
Geotechnical problems (Person 2)	3	4
Rail technical problems (Person 2)	4	4
(Person 2)	3	4
Wash-out of the	3	3

foundation around the road cylinder (Person 3)		
Deepening of the bridge fundament (Person 3)	2	4
Damage on property down- or upstream (Person 3)	3	3

There were not that many relevant answers for the railroad bridge, but the characteristics are that the railway bridge has a risk for collapsing or being severely damaged if it is flooded.

5.2.4 Railway cuttings

Information about damages in railway cuttings from the questionnaire is presented in Table 9.

Table 9 *Answers from questionnaire: damages on the railway cuttings at flood according to the matrix in Figure 7.*

Railway cuttings	Probability	Damage cost
Washout of layer of gravel (Person 1)	2	4
Signal system and electric equipment dysfunctional (Person 1)	4	5
Stop in traffic (Person 1)	5	5
Geotechnical problems (Person 2)	3	3
Electrical errors (Person 2)	4	4
Damages on the trainset (Person 2)	4	4
Damage on technical installations (Person 3)	4	3
Damage on the railway line (Person 3)	2	3
Damage on electricity/tele	3	3

Some characteristics for the question about railway cutting were geotechnical problems for damage level 1 and damages on signal, electric system and tele for damage level 2.

5.2.5 Effects on the train traffic

5.2.5.1 Standstill

A question was asked about at which flooding level of the three given levels that would lead to stopping of the traffic. The answer to this question was flood level 2 and 3 from person 1 and flood level 2 for person 2 (note: flood level 3 will then also cause standstill). The third person did not respond to this question. This indicates that people believe that a standstill will occur if the bottom level of the rail is reached by water.

5.2.5.2 Lower speed

A question were also asked about at which flood level of the three given levels that would lead to significantly reduced train speed. This question was based on information from the literature review; that conventional trains often travel in low speeds such as 40 km/hour in cases of flooding events if there, for example, is a risk for undermining of the railway embankment. The answer to this question was flooding level 1 from one person and 2 and 3 from the other responding person. From the consequences that were stated for the question about lower speed for trains, it was concluded that it would lead to delays and stop in traffic. The consequences, together with the corresponding probabilities and damage costs from the questionnaire, are stated in the Table 10.

Table 10 *Results from the questionnaire from the questions about standstill and lower speed for the train.*

Effects on traffic when train has lower speed	Probability	Damage cost
Delay in train traffic	5	5
Stop in train traffic	5	5

5.3 Meetings and questions by e-mail

5.3.1 Flood damage levels for the railroad bridge

Some interviews were also made in order to gather information about flooding levels that would lead to damage on the railway embankment, railroad bridge, railway tunnels and cuttings. A meeting were held with a consultant at Sweco Civil AB that works with construction of bridges and tunnels. The question to the consultant was to state three flooding damage levels for the railroad bridge. The consultant assessed that defining three flooding damage levels was more difficult than to define two levels. One level was thus defined under the bearing (swe: lager) and the second damage level at the edge of the railroad bridge superstructure. The two defined damage levels are presented in Figure 11.

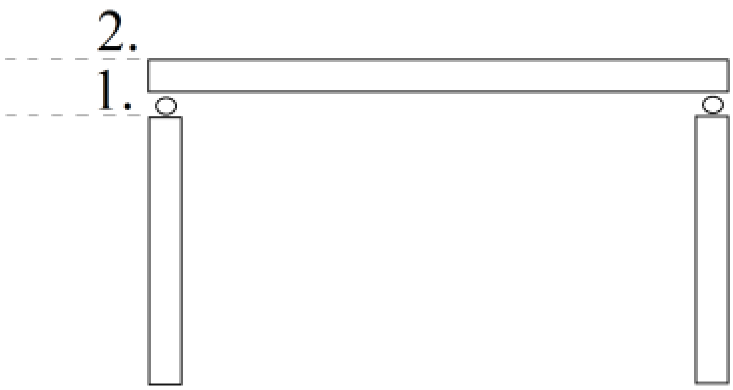

Figure 11. *Defined damages levels for a railroad bridge during discussed with a consultant at Sweco Civil AB.*

5.3.2 Flood damage levels for railway embankment, railway tunnel and cuttings

Damage levels for railway embankment, tunnels and cuttings were discussed with the consultant at Sweco Civil AB. The flood damage levels in the railway embankment were defined as previously and were presented in Figure 6. According to one consultant at Sweco Rail, the electrical equipment and telecommunication are placed at level 2. Another consultant at Sweco Rail stated that if the railway embankment is flooded to damage level 2, something called a baliser could be damaged. The baliser is placed in the ATC-system and sends information by radio signals to the train. One example of such signal can be that the speed should be turned down and if the driver does not adapt the speed fast enough, the ATC-system automatically reduces the speed of the train.

After a discussion with another consultant at Sweco Rail, it was stated that both small and large houses with electronic equipment could be destroyed if flooded with water. These are normally placed far above level 2, which means that the difference with respect to flooding consequences between flood level 2 and 3 in Figure 6 is the damage to electric houses. Damage level 2 for the railway embankment is assumed to be the same for damage level 1 for the tunnel, seen in Figure 12. Level 2 for the tunnel is blocking of the emergency route.

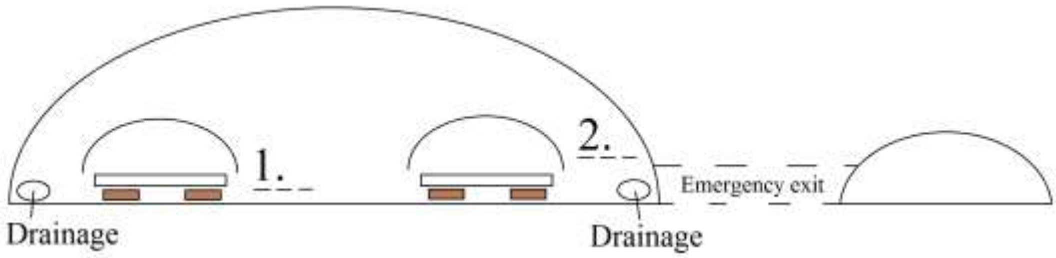

Figure 12. *Flooding damage levels for tunnel used in the CBA-model.*

Figure 13 presents the flooding damage levels for cuttings. Damage level 2 for the railway embankment is assumed to be the same as for damage level 1 for cuttings. The flooding damage levels for tunnels and cuttings were based on the information from one consultant at Sweco Rail.

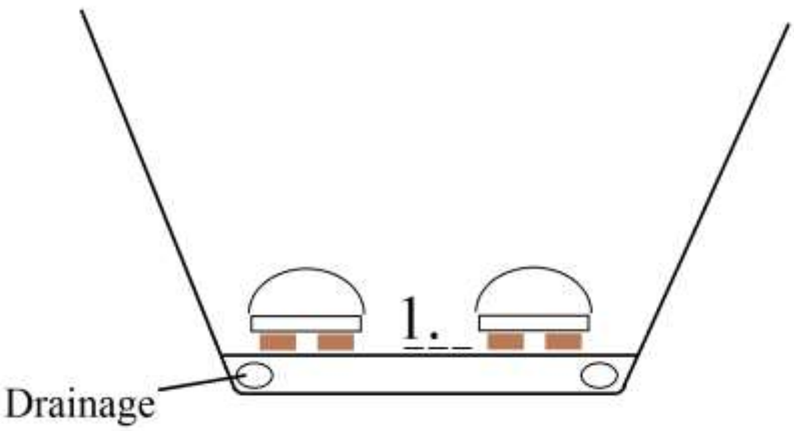

Figure 13. *Flooding damage levels for cuttings used in the CBA-model.*

6 Model for CBA of climate adaptation measures along railroads

Just as the earlier CBA-model made by Sweco the new CBA-model is developed in Microsoft Excel and uses the add-on-module Crystal Ball© for uncertainty and sensitivity analyses by means of Monte Carlo simulations. A flow chart of the new CBA-model is presented in Figure 14, which describes the general steps in the model.

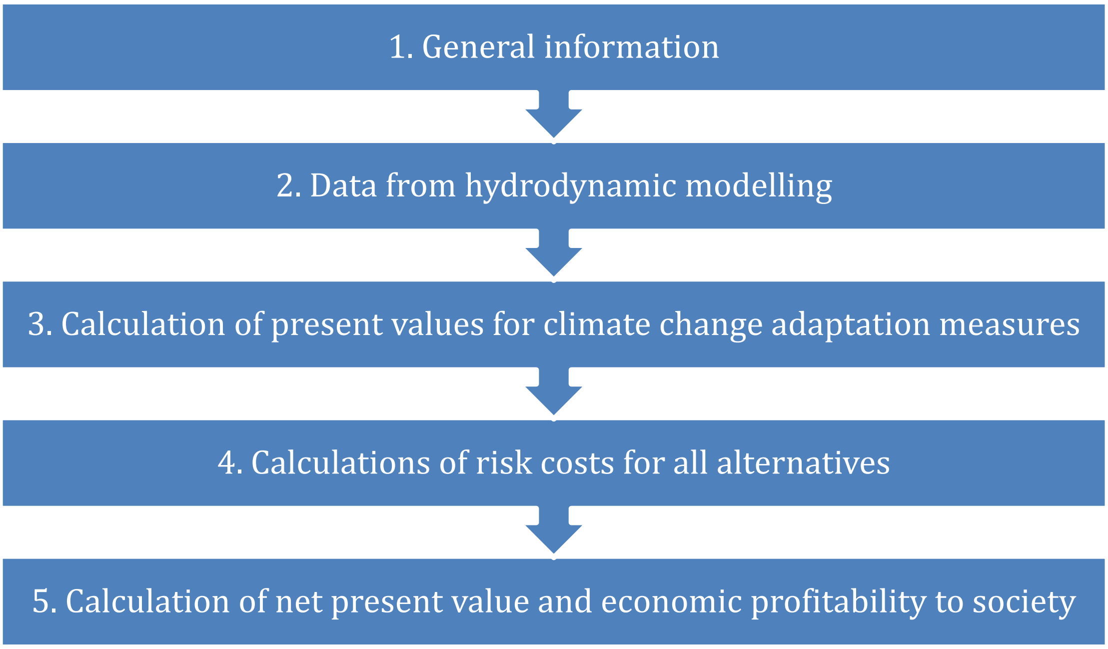

Figure 14. *A flow chart that represents the calculations in the CBA model for railway projects.*

6.1.1 General information

In step 1, called General information, presented in Figure 14, the information that is entered into the CBA-model is the name of the investigated railway and the specific investigated area at the railway. Time horizon, discount rate, investment- and maintenance costs of the measure alternatives are additional information that should be added to the CBA-model. The investment is assumed to occur during the first investigated year and the maintenance cost can be added to the model for each specific year during which maintenance is done. The maintenance costs are then recalculated into present values and are then summarized for each measure alternative. This information can later be used in step 3, where the present values for the climate change adaptation measures are summarized. In order to calculate the standstill costs in step 4, the probability of the return period that causes standstill is also entered to the model in step 1.

6.1.2 Data from hydrodynamic modelling

The second step in the new CBA-model is to insert data from the hydrodynamic model done for three different flooding scenarios (10-, 100- and 200- years return period) on the investigated area. The length of each railway type (embankment, tunnel, bridge and cutting) being flooded is assigned for each of the three rains with different return periods; this is done both for the reference alternative and for the measure alternatives. An illustration of the structure of this part of the CBA-model, where the above information is added, is presented in Figure 15 for a return period of 10 years.

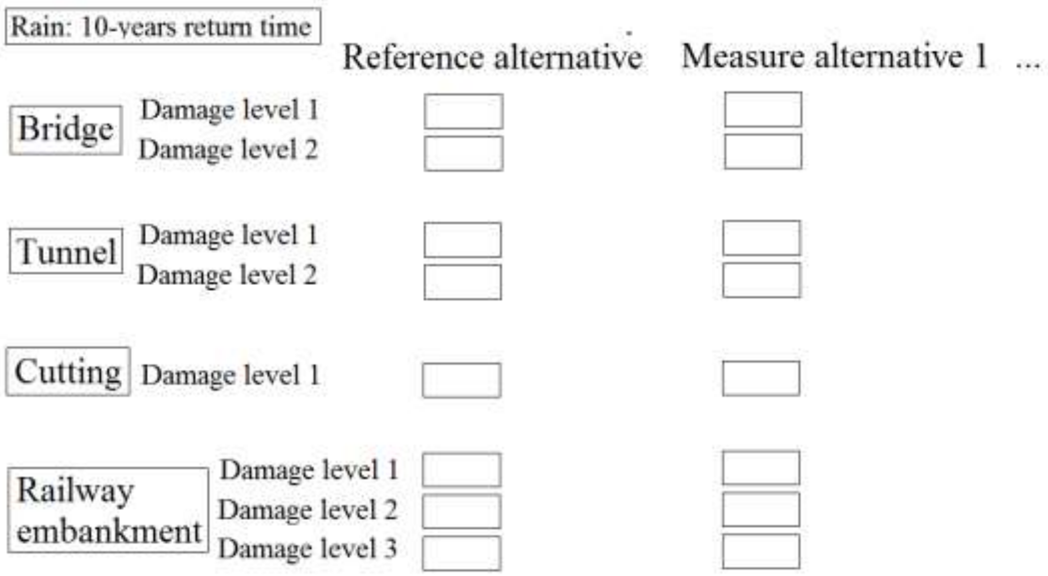

Figure 15. *An illustration of step 2 in the new CBA-model where data from the hydrodynamic model is added.*

6.1.3 Present values for climate change adaptation measures

In step 3, a summary of the costs for the climate change adaptation measure is made. The maintenance costs are recalculated to present values over the time horizon with the specific discount rate by the use of the built-in formula for net value in Excel. An example of how the calculation of the present value for a cost occurring the third year during the studied time horizon is presented in Equation 3.

$$Present\ value = \frac{maintainace\ cost\ for\ year\ 3}{(1+1.4)^3} \qquad (3)$$

Since the investment costs are assumed to occur during the first year, these values do not need to be discounted. The investment costs and the maintenance costs are then summarized into one present value for each climate change adaptation measure.

6.1.4 Calculations of risk costs for all alternatives

The fourth step of the CBA-model is to calculate the risk costs for the reference alternative and the climate change adaptation measures. The calculations are divided into different parts in the model and these are the railway embankment, the railway tunnel, the railway bridge and the railway cutting. The data from step 2, that includes information about how many metres at each damage level that are flooded for each rain return period at each type of area (railway embankment, tunnel, bridge and cutting), are collected for these calculations.

6.1.4.1 Damages on the railway facility

The calculations of the risk costs are made in several steps in accordance with Equation 1 in Chapter 2. Equation 4 describes the calculations of the risk cost for the damages on the facility (standstill not included) for the reference alternative in the

CBA-model. Equation 4 is used when calculating the risk cost for the damage levels individually.

$$R_{reference\ alternative:\ damage\ level\ 1} = P_{10\ years\ return\ time}(P_1C_1 + \sum_{i=2}^{n} P_i(C_i)) + P_{100\ years\ return\ time}(P_1C_1 + \sum_{i=2}^{n} P_i(C_i)) + P_{200\ years\ return\ time}(P_1C_1 + \sum_{i=2}^{n} P_i(C_i)) \quad (4)$$

The parameters used in Equation 4 are:

P_1 = Probability that damage will occur at facility part 1 (e.g. the rail) if flooded
C_1 = Damage cost for railway facility part 1 (SEK)
$i = 2, 3\ldots, n$
n = number of different types of consequences

The risk costs for each damage level are then summarized and this is illustrated in Equation 5. The calculations in Equation 5 represent the calculation for the railway embankment since three damage levels are defined in that case. The same type of calculations are also made for the other parts of the railway (tunnel, bridge and cutting) but adapted to their amount of damage levels, damages and probabilities.

$$R_{reference\ alternative:railway\ facility} = R_{reference\ alternative:damage\ level\ 1} + R_{reference\ alternative:damage\ level\ 2} + R_{reference\ alternative:damage\ level\ 3} \quad (5)$$

The same type of calculations is also made for the climate change adaptation alternatives, but for these, the calculations are instead made for the remaining flooded amount of metres after the adaptation is made. In order to calculate the present value of the total risk cost for the whole time horizon, Equation 3 is used. However, instead of maintenance cost, the risk cost for the railway embankment facility at year 1 ($e.g.\ R_{reference\ alternative:railway\ facility}$) is entered into the numerator. This is also made when calculating the risk cost for the climate change adaptation measures. A log-normal distribution was chosen for all times and costs in the calculations to represent uncertainties. The damages, damage costs and probabilities used in the calculations are presented in Section 6.5.

6.1.4.2 Calculation of standstill

Standstill at the railway lines does also cause costs to the society and this is also included in the new CBA-model. The risk cost for standstill is calculated with Equation 6.

$$R_{standstill} = P_{10.100\ or\ 200}C_{standstill} = P_{10.100\ or\ 200}T_{standstill}A_{trains/h}0.2 \cdot 10^6(SEK/train) \cdot 0.667 \quad (6)$$

The parameters in Equation 6 are:

$R_{standstill}$ = risk cost for the standstill during year 1
$P_{10,\ 100\ or\ 200}$ = probability of that the specific rain will occur
$C_{standstill}$ = total cost for the standstill
$T_{standstill}$ = duration of the standstill
$A_{trains/h}$ = amount of trains that passes per hour on the railway line

The probability that a specific rain will occur is chosen after looking at the hydrodynamic maps and identifying which rain (10-, 100- or 200- years return period) that causes flood in the railway line. If several of the return periods cause flooding on the same portion of the railway line, the shortest return period should be chosen. The number 0.2*10^6 in Equation 6 represents the cost for standstill of one train (Bedo, 2016). The number of trains was set to vary between four and eight trains per hour. The number 0.667 represent 2/3 which is the part of the day that the train will travel at the planned high-speed railway in Sweden, i.e. the train will not pass during night time (Grahn, 2016). When calculating the standstill time, a gamma-distribution was used for the parameters $T_{standstill}$ and $A_{trains/h}$.

The probability that a rain with T years return time will occur is given by 1/T. The standstill time is assumed to be the time it takes to repair the damages. The time range for reparation in the CBA-model varies between two hours and four weeks. The time range was set in order to fulfil the calculations in the model and it is highly recommended to update this time range in the future. By the formula for present value, a present value was calculated for the standstill risk cost with the formula in Equation 3. Later, the risk cost for the railway facility and the standstill are summarized.

6.1.5 Calculations of NPV’s

The last step in the CBA-model is to calculate the net present values. In this step, the remaining risk cost and the investment- and maintenance costs for each climate change adaptation measure are subtracted from the benefits. In this model three climate change adaptation measure can be investigated. The calculations are made by the use on Equation 2 from Section 2.7 using present values of costs and benefits:

$$\mathrm{NPV}_1 = \left(R_{reference\ alternative} - R_{remaining\ risk\ alt\ 1}\right) - K_{investment+maintenance} \quad (7)$$

Equation 7 is an example of the calculations for measure alternative 1. Equation 7 should be used in the same way for all climate adaptation measures. The NPV’s are presented in a diagram as 5-percentile, 50- percentile and 95-percentile; an example of how the results are presented can be seen in Figure 16. The CBA-tool facilitates a sensitivity analysis by the use of Crystal Ball©.

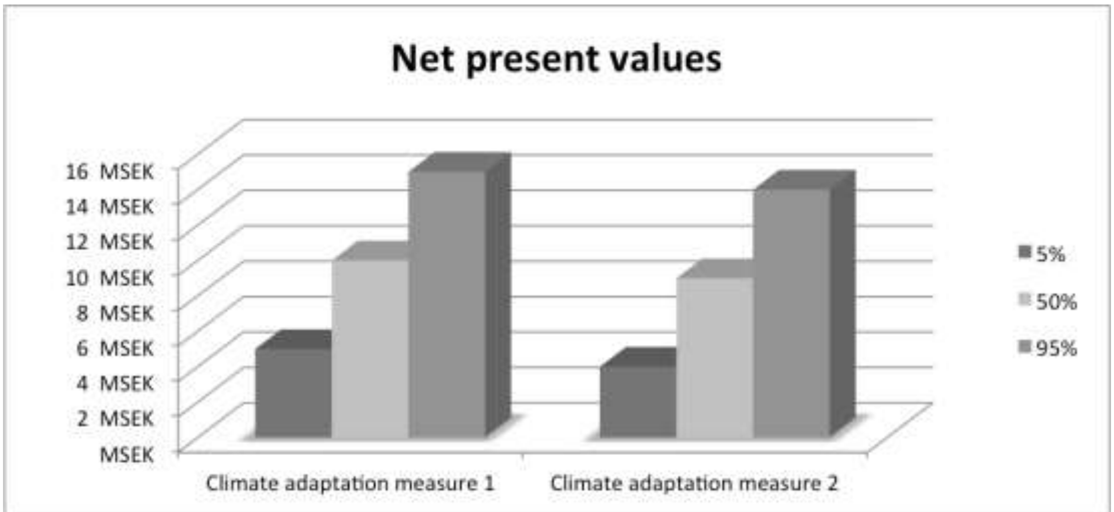

Figure 16 *An example of how the results are presented in the CBA-model.*

6.2 Damages and damage costs in the new CBA-model

In Table 11, a summary of the damages included in the new CBA-model is presented. The damages are categorized into different parts of the railway line i.e. to the railway embankment, tunnels, bridges and cuttings and at which damage level (level 1, 2 or 3) that the damage occur.

Table 11. *A summary of the damages included in the newly constructed CBA-model.*

Railway embankment	**Tunnels**	**Bridges**	**Cutting**
Damage level 1	*Damage level 1*	*Damage level 1*	*Damage level 1*
Geotechnical inspection	Baliser	Inspection of bearing	Baliser
Geotechnical reparation	Cables for electrics, signals and tele	Reparation of bearing	Cables for electrics, signals and tele
Damage level 2	*Damage level 2*	*Damage level 2*	
Baliser	Emergency exits	Discharge of the track superstructure	
Cables for electrics, signals and tele			
Damage level 3			
Technical house (small; includes only signals)			
Technical house (large; includes electrics, signals and tele)			

The damages and the damage costs used in the CBA-model originate from the literature review, the questionnaire and the meetings and emails with people at Sweco. The damage costs and probabilities used in the calculations in the CBA-model are presented in Table 12.

Table 12. *Damage costs for the damages in the new CBA-model.*

Damages	**Damage costs**	**Probabilities**
Geotechnical inspection	2-4 hours. 500 SEK/hour	1
Geotechnical reparation	2-4 days	0.5
Baliser	800 SEK	1
Cables for electrics, signals and tele (swe:	not found	1

spårledningar)		
Small electric house (swe: teknik-kiosk)	1 000 000 SEK	1
Large electric house (swe: teknik-hus)	2 000 000 SEK	1
Emergency exits	not found	not found
Inspection of the bearing	2-4 hours. 500 SEK/hour	1
Reparation of the bearing	not found	1
Discharge of the track superstructure railway bridge	30 000 – 35 000 SEK/m2	0.1

Experts at Sweco approximated all information about damage costs in this study. On the other hand, the probabilities in Figure 12 are arbitrary chosen and are thereby uncertain. The reason for why some of the probabilities are chosen to the value 1 is that it is assumed that the stated damage will occur all times if water floods that part of the railway facility. The geotechnical reparation is assumed to have a probability 0.5 since this measure is not as common as the geotechnical inspection that has the probability 1. The values are put like this in order to make a different between the two cases even though the real probabilities are unknown. The probability that a railway bridge collapses is put to 0.1 according to an expert interview. Both lognormal distributions and gamma distributions are used in the CBA-model for information that lack exact values. In the CBA-model, with the help of these distributions, the most probable values can be specified from data that range between different estimated values. An example of when distributions are used is for the case with geotechnical inspection that ranges between two and four hours.

7 Case study area - Götalandsbanan

7.1 Overview of location and design

The capacity demand on today's railway network between Stockholm and Göteborg, *Västra stambanan*, as well as between Stockholm and Malmö, *Södra stambanan*, is increasing since people tend to travel more and also because transportation of goods is increasing (Eriksson, 2014). Due to this increasing demand, the Swedish government has decided that a new double-tracked high-speed railway system should be built in Sweden[1]. The planned line for Götalandsbanan is presented in Figure 17 and the planned line for Göteborg – Borås is presented in Figure 18.

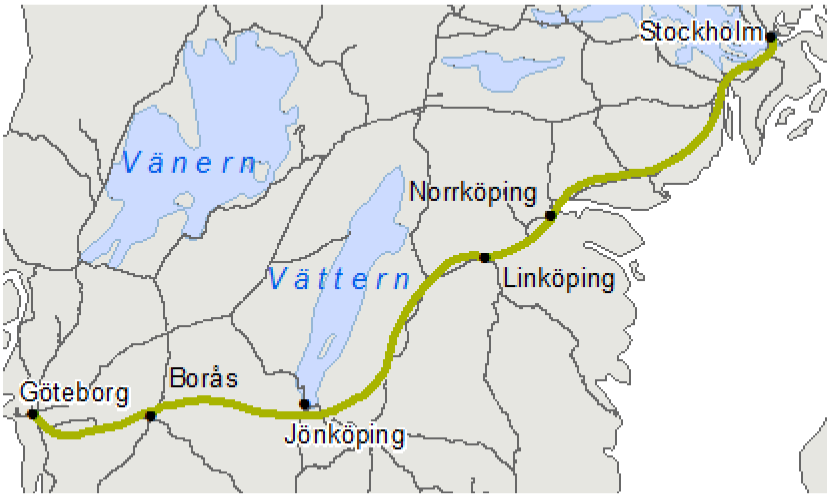

Figure 17 *The planned high speed highway, Götalandsbanan, between Göteborg and Stockholm (Trafikverket, 2014)*

Figure 18 *A map of the planned high-speed railway Götalandsbanan, lines between Mölnlycke and Bollebygd (Trafikverket, 2015a).*

The conventional railway between Göteborg and Stockholm is named *Västra stambanan* and the part between Göteborg and Alingsås is today near its maximum transport capacity (Trafikverket, 2015b). Since the new high-speed railway will have a maximum speed of 320 km/h (Trafikverket, 2016), instead of maximum 250 km/h as the trains on the current conventional railway (Forsberg et al, 2008), the travel time for passengers will be reduced and more trains can be used on the railway (Trafikverket, 2016). One example of the reduced travel time is that the time to travel between Borås and Göteborg will be reduced by 50% (Trafikverket, 2016).

[1] Proposition 2012/13:25, *Investeringar för ett starkt och hållbart transportsystem*

The demands on Götalandsbanan are stated in a document created by Trafikverket (2015c). In this document one can for example read that the tracks should be designed as fixed (ballast-free) at locations where the trains will be able to exceed 200 km/h and as ballast track at locations where the train speed are supposed to be below 200km/h. Other information presented in this document is that the gradient of the tracks should maximally be 35‰ (Trafikverket, 2015c). Cargo trains cannot be transported on rails with a gradient of 35‰ (Forsberg et al, 2008), which means that Götalandsbanan probably not will be used by cargo trains.

7.2 The tunnel in Rävlanda

7.2.1 Location

The area chosen to invest at Götalandsbanan is a tunnel in Rävlanda, called *Rävlandatunneln*. Rävlanda is a small municipality located between Mölnlycke and Bollebygd. The tunnel does not exist today but it is planned to be about 1050 metres long. The information about Rävlandatunneln can be changed later on in the designing progress. Sweco investigates two flood-mitigation alternatives for Rävlandatunneln, presented in Section 7.2.2, and these two are tested in the new CBA-model for railway projects. The location of Rävlandatunneln is presented in Figure 19 with the green line at the right in the figure. *Rammsjön* is the lake located (northwest) above the tunnel in the figure.

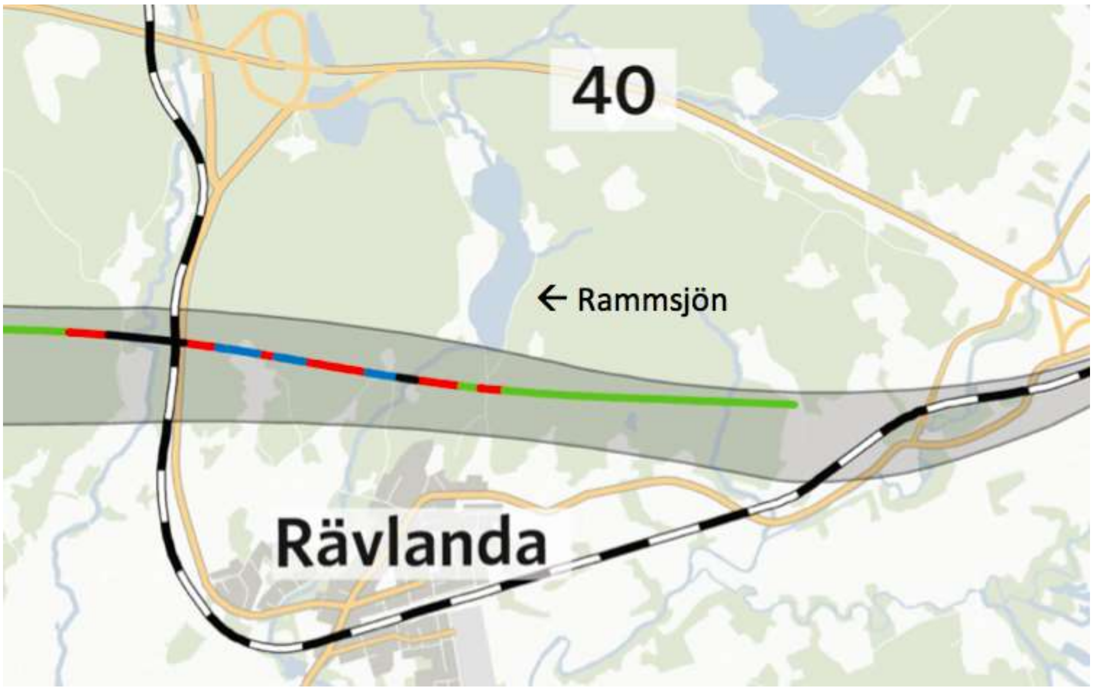

Figure 19 *The tunnel that is to be designed at Götalandsbanan in Rävlanda near Rammsjön. The tunnel is presented in green colour to the right in the figure.*

7.2.2 Two investigated climate change adaptation measures

The first investigated climate change adaptation measure, called Alternative 1, is to place one pump and a storm water retention dam to pump the storm water from the beginning of the tunnel to the lake Rammsjön. The second investigated climate change adaptation measure, called Alternative 2, is to build a pipe that transports the storm water from the beginning of the tunnel through the 1050 meters long tunnel. The CBA-model was designed to compare the two alternatives to a zero-alternative, i.e. to design the tunnel without any flood mitigation measures. The zero-alternative represents a situation where every time it rains, the tunnel will be flooded with water.

Alternative 1 includes a pipe with a capacity of 500 cubic meters, a pump station with a capacity of 600 litres per second and a storm water retention dam with a capacity of 500 cubic metres[2]. The total approximated cost for the investment of alternative 1 is 1.5 MSEK. Alternative 2 includes a storm water pipe with a diameter of 800 millimetres and a length of 1100 metres and a price per unit of 1050 SEK, which gives a total investment cost for alternative 2 of 1.2 MSEK. The maintenance costs for alternative 1 is approximated to 8800 SEK/week, which gives a yearly cost of about 0.5 MSEK/year. This maintenance cost is based on the assumption that two workers once a week will have to do an inspection with a service car for four hours. The electricity required for the pump station is not included in the approximation of the total yearly costs. The maintenance costs for alternative 2 are estimated to 72 000 SEK/year and this cost is based on the assumption that two workers will use a sewage lorry for six hours. Table 13 includes all input data applied to the CBA-model for both investigated climate measure alternatives at Rävlandatunneln.

***Table 13**. Input data to the new CBA-model for Rävlandatunneln.*

Input data	**Alternative 1**	**Alternative 2**
Investment cost	1.5 MSEK	1.2 MSEK
Maintenance cost	0.5 MSEK/year	72 000 SEK/year
Amount of meters flooded (Rävlandatunneln)	1050 meters (for reference alternative) and 0 meters for alternative 1 and 2 respectively; for 10-, 100- and 200- years return period.	
Time horizon	60 years	
Discount rate	1.4%	
Probability of return period that causes that Rävlandatunneln gets flooded	0.1 (for the reference-alternative)	

7.3 Results of cost-benefit analysis for Rävlandatunneln

The model was applied to Götalandsbanan, to a tunnel that is being designed for a part of the railway in Rävlanda. A water engineer at Sweco Environment AB estimated how much of the area that would be flooded if no measure was made, i.e. the reference alternative. He estimated that the total length of the tunnel would be flooded but no surrounding areas, so 1050 metres were added to the CBA-model. Hydrodynamic models could have been made, but since the model is not a part of any project at Sweco, no specific maps for this area were made for this comparison of the measure alternatives. It was estimated that there was no remaining risk for the evaluated measure alternatives, as can be seen in Table 14.

[2] The data in Section 7.2.2 is given from consultants at Sweco Environment and Sweco Management.

Two climate change adaptation measures were evaluated, called alternative 1 (pump) and alternative 2 (pipe through tunnel). By using the input data presented in Table 13 and the new CBA-model presented in Chapter 6, the NPV values for the two different climate adaptation measures were calculated and presented in Table 14. The results are that the NPV for alternative 1 is 1 193 MSEK and for alternative 2 the NPV is 1 210 MSEK over the 60-year time horizon, presented in Table 14. The risk cost for the reference alternative is also presented in Table 14.

Table 14. *The risk costs and NPV values from the calculations made by the CBA-model for Rävlandatunneln. Red color indicates the cost and green color indicates the NPV values.*

Investigated alternatives	**Risk costs**	**NPV values[3]**
Reference alternative	1 213 MSEK	---
Climate adaptation measures 1	0 MSEK (Remaining risk cost)	1 193 MSEK
Climate adaptation measures 2	0 MSEK (Remaining risk cost)	1 210 MSEK

The results show that the benefits by far increase the costs for both alternatives, which indicates that all studied climate adaption measures are economically well-motivated. The risk cost for damages on the facility are 338 MSEK and for the standstill 875 MSEK. This indicates that about 40% of the risk cost originates from damages on the railway facility and that about 60% of the risk cost originates from the standstill.

Crystal Ball© was used to present the values of the 5, 50 and 95 percentile and these values was then presented in a graph, see Figure 20. The percentiles correspond to the reasonably lowest probable value (the 5-percentile), the median value (50-percentile) and the reasonably highest probable value (95-percentile) as presented in section 2.9 Due to the large uncertainties of the calculations and the low costs in relation to the substantial benefits, it is rather uncertain which of the two alternatives being the most beneficial.

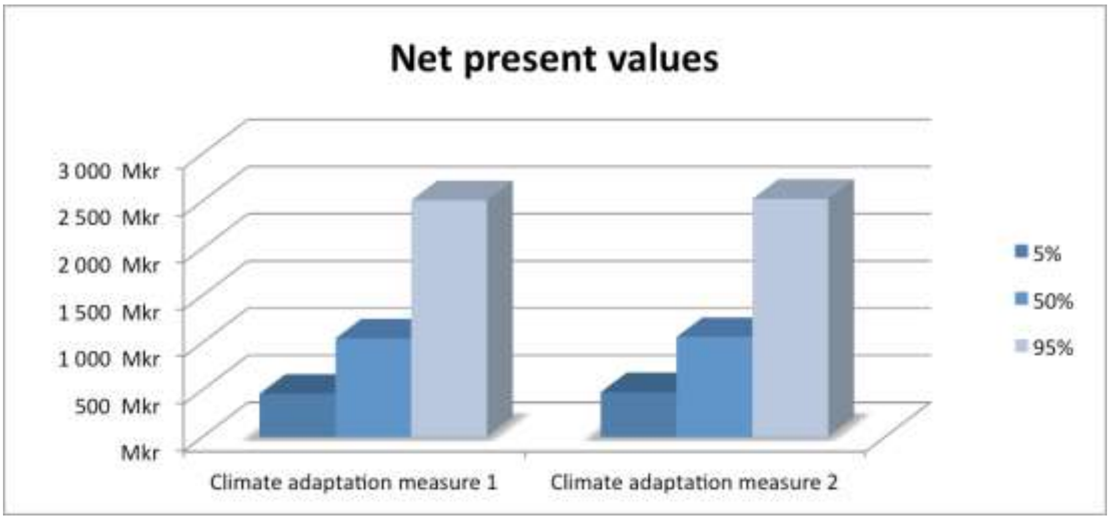

Figure 20 *Net present values presented in the CBA-model.*

[3] NPV = Risk cost (reference alternative) – Remaining risk cost – Cost of alternative in net value (investment and maintenance)

However, the uncertainty analysis made by Crystal Ball© provides important information on which of the parameters that were most uncertain. The two most uncertain parameters, presented in Table 15, are the time for standstill and the amount of trains that passes per hour. The percentages in Table 15 are contribution to variances, which present how large part of the total uncertainty that is caused by that specific assumed parameter. Contributions to variances are calculated from rank correlation coefficients. A rank correlation coefficient in Crystal Ball© is a parameter that correlated every assumption and every forecast (ORACLE, 2013).

Table 15 *The most uncertain parameters from the uncertainty analysis in the calculations made in the CBA-model for Rävlandatunneln.*

Most uncertain parameters	Percentage
Time for standstill	93.4%
Amount of trains/hour	3.8%

In the sensitivity analysis in Crystal Ball©, all parameters were presented but all parameters, except for the two parameters in Table 15, had lower percentage than 3.8% and are thereby regarded as certain parameters. The value 3.8% is also low and the amount of trains that vary per hour is thereby also certain compared to the parameter time for standstill that has a significantly higher percentage.

The most uncertain parameter is the time for standstill; that had an uncertainty contribution of 93.4%, which is a very high value. A specific sensitivity analysis was therefore made for this parameter to see how the total NPV changed while changing the time for the standstill. The time used in the CBA-model vary between two days and four weeks. This is a large time range and the uncertainty thereby has a very large percentage in Table 15. The time for the standstill was changed in order to see how the results changed. The tested time range was reduced to vary between two and four days and this changed the results from 875 MSEK to 219 MSEK. The total change in NPV for alternative 1 went from 1 193 MSEK to 537 MSEK. The risk cost is about half the value when changing the time for standstill to the shorter time range (two to four days) and this indicates the importance of the parameter standstill in the calculations.

Table 16 *A change in the parameter standstill from 4 weeks to 4 days resulted in that the total NPV reduced with about 50%.*

Time for standstill	Risk cost for standstill	Total NPV
Two days – Four weeks	875 MSEK	1193 MSEK
Two days – Four days	219 MSEK	537 MSEK

8 Discussion

8.1 Evaluation of method for gathering damages

The aim of this master thesis was partly to gather information about consequences that could be used in the CBA-model. The gathering of consequences began with a literature review of flooding events in Sweden. Some information was found about individual accidents in Sweden but the consequences were often stated as “damages on railway” and thus regarded as insufficient. To find more detailed information about damages due to flooding, research was made to find a database that included several flooding events. A database was found with information from many flooding events from the 1960’s to 2016, but the information was undefined and thereby difficult to include in the new CBA-model.

Due to time limitations, when searching for information in the database, some key search words were chosen. More information might be found if one searches more specifically, using additional or other search words, in the future. However, it is assumed that this would probably affect the results significantly, since the information found overall was not that detailed. A meeting was held with a representative from the Swedish Transport Administration. Interesting information that was obtained from this meeting was that there is no system for gathering information about damages on the railway due to flooding in Sweden. It was thereby very difficult to find information about the damages on the railway system in this study.

After the literature review, a questionnaire was made in order to gather more detailed information. Here it was focus on making the questions more detailed in order to get the required information that would be useful in the CBA-model. Since the model should include information not only about the damages, but also about the damage cost and the probability that the damage will occur, questions were asked about that as well. The response to the questionnaire was very sparse. One explanation of why the response frequency was low is that the questions were too detailed and thereby difficult to answer.

The questions were sent out to three groups of people; people working mainly with water, people working mainly with geotechnics and people working mainly with railway. Another reason to the low response rate could be that they only can provide answers on some of the questions and thereby it was not fair to answer without any knowledge about the other questions. It would have been good to have a possibility to say “I don’t know” as an alternative answer to the questions. But on the other hand this might instead have resulted in people responding that they do not know since it all “depends on”. This was something that was found difficult when gathering information; how to ask the questions so that the questions concerning information that was wanted would provide useful response and not only answers such as “it depends”. Even though the information was vague, sometimes in the gathering of damages this is a result that shows the need for a better system for the gathering of information on damages due to flooding events in Sweden. The gathered information is used as a basis in the model and, if more information is gathered, the CBA-model can be made even better in the future.

8.2 Evaluation of the new CBA-model

The second part of the aim in this study was to create a CBA-model for railway systems. From the beginning of this study it was thought that the CBA-model designed by Sweco should be adapted so that it would work for railway projects. During this study it was however found that it was better to create a new CBA-model than adapting the current CBA-model to railway projects. This decision was based on the fact that the earlier CBA-model included many parts and that these were different from the ones preferred for railway projects. Damage levels were an important factor when constructing the new CBA-model. These damage levels can be used as a tool in the future when collecting information about damages on the railway. Damages are much easier to define if specific damage levels are defined instead of asking about damages related to different rain return periods. The damages in a specific area depend on how high up on the railway that the water reaches, which in turn depends on if the railway is on a hill or in a valley. This can easily be seen on maps from hydrodynamic models but when general damages should be defined for the CBA-model is it very helpful with defined damage levels to relate the damages to. The new CBA-model is constructed and can be used, but further updates about damages, damage costs and probabilities would make the CBA-model even better.

8.3 Evaluation of the case study Rävlandatunneln

The two investigated climate change adaptation measures both resulted in NPV values of about 1200 MSEK and the difference between them was only 1.4%. There are large uncertainties of the NPV for the measure alternatives, as seen in Figure 12. The NPV differ in amounts of MSEK and this, in combination with the small difference between them indicates that there is no significant difference between the alternatives. The result indicates therefore that it is profitable to do an investment in one of the alternatives, but not in which of them.

The case study gives results that could have been known in forehand since the remaining risk of the alternatives where zero. However, the CBA-model provides important information of the total benefits and costs over the studied time horizon (60 years in the present case study) and the uncertainty contributions of input parameters to the model. The full potential of the CBA-model is when applied on climate change adaptation measures that reduce the flood risk, but that still have a residual risk of flooding parts of an area. Otherwise, the use of CBA will not come to its full use, since the least costly alternative then will be the most preferable alternative (something that could be seen without performing an CBA on that case study). The CBA performed for Rävlandatunneln was made in order to see how the newly created CBA model worked and what parameters in the model that was most important to update when the model is continuously developed. The standstill time contributes to 60% of the risk cost and has an uncertainty contribution of 93.4% in the CBA-model. Thereby this case study indicates that this is the most important parameter to update in the future.

8.4 Recommendations

8.4.1 How to gather more information about consequences

The first recommendation when collecting information about damages is to use the pre-defined damage levels when asking people to define the damages. Another recommendation for the one asking questions about damages on railway is to ask for the least probable value and the most probable value. This is easier for people to answer since it could be too difficult to get a specific point value, which might result in that no answer is given. Another positive thing is that, if one get the least and the most probable value, one could use these values and make an uncertainty distribution in Crystal Ball© or similar tools. Probabilities could be asked for in terms of if it is likely or unlikely that the damage will occur. The probability could it be put to near 1 in the model if the damage is likely and to values near 0 if the probability of the damage is unlikely.

8.4.2 Recommended updates of the CBA-model and case study

Further updates of the damages, damage costs and probabilities should be made to improve the CBA-model. Some of the assumptions are more critical to update, as for example the assumption that the standstill time represents a situation where damage will take between two days and four weeks to repair. The standstill time should be further investigated by updating the specific times for reparation but also by validating the formula used to calculate the risk cost for the standstill time. The standstill time has a huge impact on the economic risk calculation and it is important that the standstill costs represent real-world situations in order for the model to provide realistic results. The validation can be made by comparing the calculations in the CBA-model with standstill calculations made by the Swedish Transport Administration or Sweco Management. An update of the standstill time should be made to reduce the uncertainty of this parameter and to have a more precise calculation of the standstill time in the CBA-model. The full potential of the CBA-model is when applied on climate change adaptation measures that differ in the remaining risk.

9 Conclusion

The objectives in this study were to gather information about damages due to flooding on railway, to adapt the current CBA-model to railway projects and evaluate how well the model works to apply on an area of Götalandsbanan. The gathering of the damages was done in MSB's database, a questionnaire and meetings with consultants at Sweco. The information about damages was very sparse and only some of the information was detailed enough to be included in the CBA-model. Focus was put on developing a new model structure for CBA rather than achieving a complete data basis for the CBA. This study has resulted in a new CBA-model for railway projects with information about damages and damage costs. In order to make the CBA-model able to be applied on real railway projects, further updates of damage costs should be made. For example by letting experts make a more extensive collection of damages costs.

The most important factor to investigate further is the risk cost for the standstill since that parameter has the highest uncertainty in the CBA-model. The standstill time is currently ranging between two days and four weeks since that is the different repairmen times for the damages on the railway facility. In order to test the model it was applied to *Rävlandatunneln* at Götalandsbanan and two measure alternatives were evaluated. The results of the case study indicates that it is socioeconomic preferable to do an investment in a climate change adaptation measure, but not which of the alternatives that is the best one to invest in. Even though the result is that one would save more money if investing in alternative two (storm water pipe though Rävlandatunneln), one cannot say that the difference is significant since there is a small difference between the alternatives and due to the large uncertainties. Even though many aspects of the presented CBA-model need to be further developed, the model can hopefully be a first step in the development of a practically useful method and tool for identifying relevant and reasonable flooding protection measure in railway projects in Sweden.

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Appendix

A. Questionnaire

Konsekvenser av översvämning på höghastighetsjärnväg/konventionell järnväg

Bakgrundsinformation

Vilket av följande alternativ är det arbetsområde som du arbetar mest med alt. har mest kunskap inom?

- ☐ Höghastighetsjärnväg
- ☐ Konventionell järnväg
- ☐ Geoteknik
- ☐ Översvämningar
- ☐ Övrigt: ______

Lämna gärna ditt namn, mail, yrke och företag i textraden nedan

Ditt svar

BAKÅT NÄSTA

Konsekvenser av översvämning på höghastighetsjärnväg/konventionell järnväg

Skador på järnvägsanläggningen

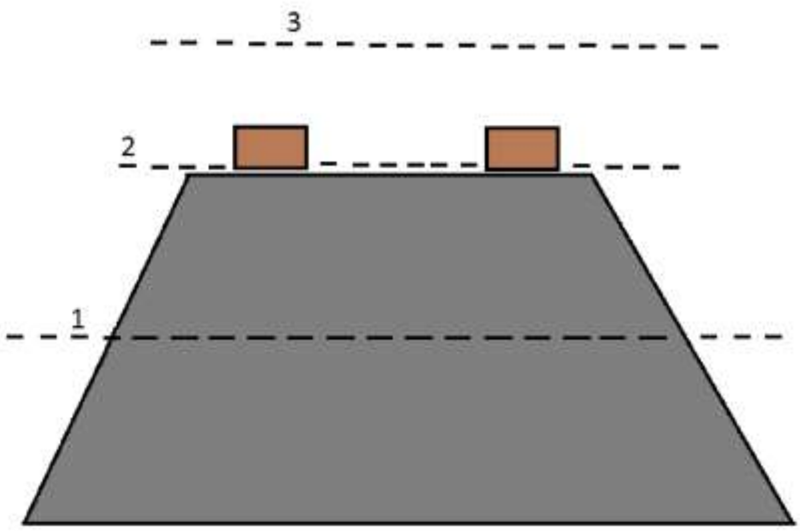
Detta avsnitt behandlar skador på järnvägsanläggningen orsakade av översvämningar och är uppdelat i frågor gällande banvallen, järnvägstunnlar, järnvägsbroar och skärningar. Frågorna börjar med en fråga om konsekvenser (skadehändelse). Fyll i de som ni tycker är viktigast att ta hänsyn till. Med konsekvens menas de skador som kan ske på höghastighetsbanan, alltså själva anläggningen. Olycksrisker såsom urspårning är alltså inte fokus i just denna studie. För att bedöma hur ofta en konsekvens (skada) sker vill jag att ni anger sannolikhet i den mån ni kan. Detsamma gäller för skadekostnader.

Skalor för sannolikhet och skadekostnad är angett från 1-5 och förklaringar av begreppen står nedan:

Sannolikhet	
1=Mycket låg	1 gång av 10 000 gånger
2=Låg	1 gång av 10 000 gånger - 1 gång av 1000 gånger
3=Måttlig	1 gång av 1000 gånger – 1 gång av 100 gånger
4=Hög	1 gång av 100 gånger – 1 gång av 10 gånger
5=Mycket hög	1 gång av 10 gånger

Skadekostnad	
1=Mycket små	< 100 000 kr
2=Små	100 000 kr - 1Mkr
3=Måttliga	1-5 Mkr
4=Stora	5-10 Mkr
5=Mycket stora	>10 Mkr

Bilden illustrerar en banvall med tre olika tänkta översvämningsnivåer 1=vatten står upp i banvallen, 2=vatten når till rälsens underkant, 3=vatten står över rälsen



Vilken är den viktigaste skadehändelse på järnvägen som kan inträffa vid nivå 1, 2 respektive 3? Skriv de tre skadehändelserna i text-rutan nedan.

Ditt svar

Hur sannolikt är det att skadehändelsen på järnvägen vid nivå 1, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om skadehändelsen vid nivå 1, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Hur sannolikt är det att skadehändelsen på järnvägen vid nivå 2, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om skadehändelsen vid nivå 2, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

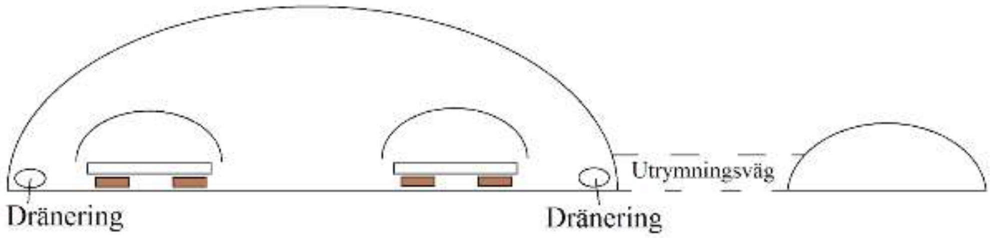
Hur sannolikt är det att skadehändelsen på järnvägen vid nivå 3, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om skadehändelsen vid nivå 3, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Bilden illustrerar en järnvägstunnel



Nämn tre skadehändelser på/i en järnvägstunnel som kan orsakas av en översvämning. Skriv de tre skadehändelserna i text-rutan nedan.

Ditt svar

Givet att en översvämning sker i tunneln. Hur sannolikt är det att den första skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den första skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Givet att en översvämning sker i tunneln. Hur sannolikt är det att den andra skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den andra skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

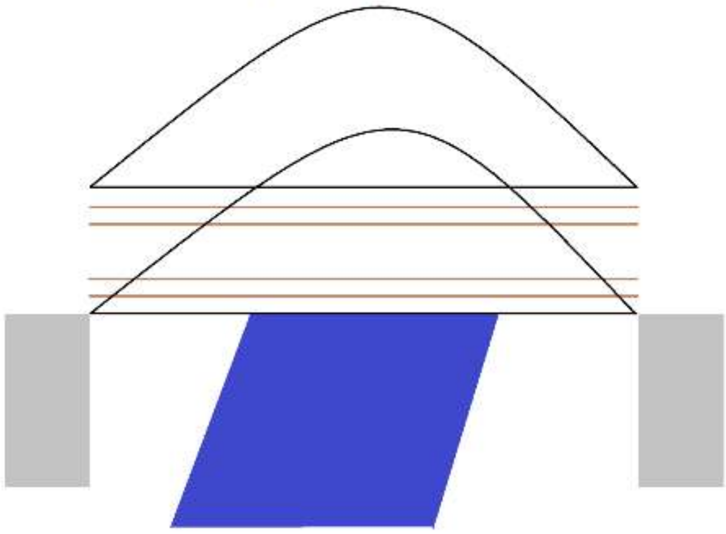
Givet att en översvämning sker i tunneln. Hur sannolikt är det att den tredje skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den tredje skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Bilden illustrerar en järnvägsbro



Nämn tre skadehändelser på/i en järnvägsbro/trumma som kan orsakas av en översvämning. Skriv de tre skadehändelserna i text-rutan nedan.

Ditt svar

Givet att en järnvägsbro/trumma utsätts för en översvämning. Hur sannolikt är det att den första skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolihet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den första skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Givet att en järnvägsbro/trumma utsätts för en översvämning. Hur sannolikt är det att den andra skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den andra skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

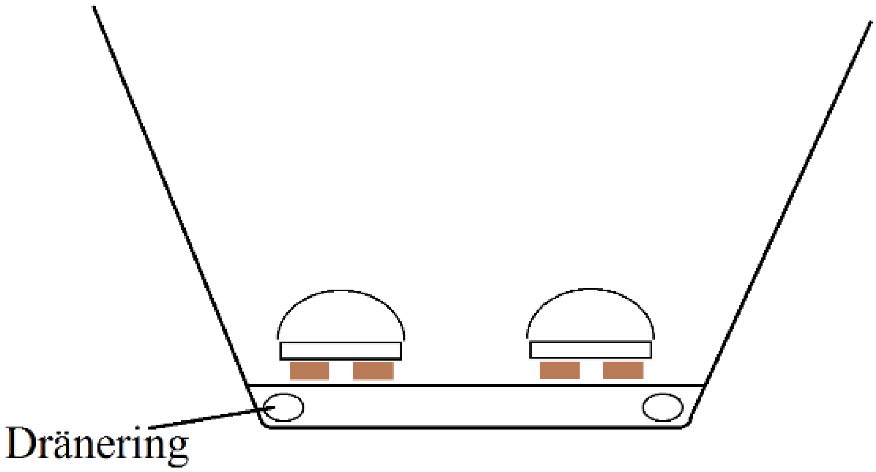
Givet att en järnvägsbro/trumma utsätts för en översvämning. Hur sannolikt är det att den tredje skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den tredje skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Bilden illustrerar en skärning



Nämn tre skadehändelser på/i en skärning som kan orsakas av en översvämning. Skriv de tre skadehändelserna i text-rutan nedan.

Ditt svar

Givet att en skärning utsätts för en översvämning. Hur sannolikt är det att den första skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den första skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Givet att en skärning utsätts för en översvämning. Hur sannolikt är det att den andra skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den andra skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Givet att en skärning utsätts för en översvämning. Hur sannolikt är det att den tredje skadehändelsen, som du skrev ovan, inträffar?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den tredje skadehändelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

BAKÅT NÄSTA

Skicka aldrig lösenord med Google Formulär

Konsekvenser av översvämning på höghastighetsjärnväg/konventionell järnväg

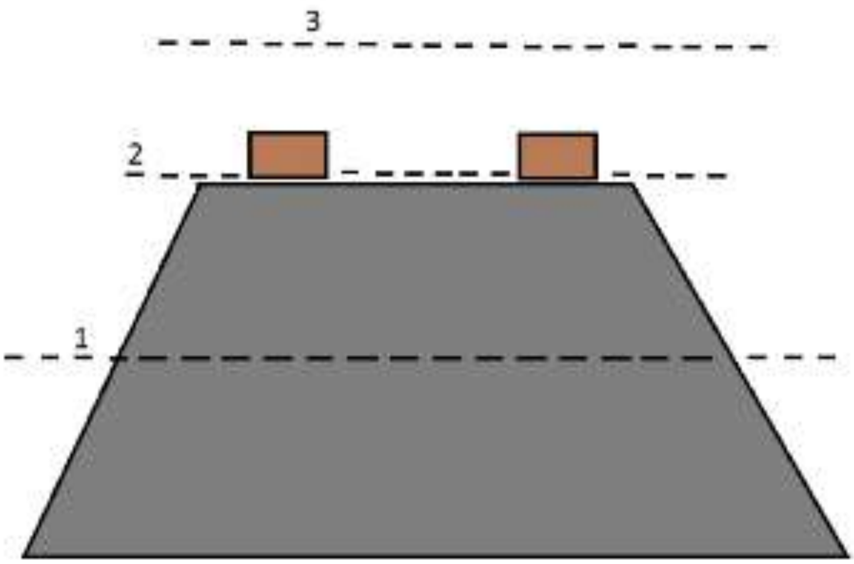
Konsekvenser för järnvägstrafik

Detta avsnitt behandlar konsekvenser för järnvägstrafiken orsakade av översvämningar. Frågorna behandlar stillestånd och situationer när tågen kan behöva köras i avsevärt lägre hastigheter. För att bedöma hur ofta en konsekvens (skadehändelse) sker vill jag att ni anger sannolikhet i den mån ni kan. Detsamma gäller för skadekostnader. Skalor för sannolikhet och skadekostnad är angett från 1-5 och förklaringar av begreppen står nedan:

Sannolikhet	
1=Mycket låg	1 gång av 10 000 gånger
2=Låg	1 gång av 10 000 gånger - 1 gång av 1000 gånger
3=Måttlig	1 gång av 1000 gånger – 1 gång av 100 gånger
4=Hög	1 gång av 100 gånger – 1 gång av 10 gånger
5=Mycket hög	1 gång av 10 gånger

Skadekostnad	
1=Mycket små	< 100 000 kr
2=Små	100 000 kr - 1Mkr
3=Måttliga	1-5 Mkr
4=Stora	5-10 Mkr
5=Mycket stora	>10 Mkr

Bilden illustrerar en banvall med tre olika tänkta översvämningsnivåer 1=vatten står upp i banvallen, 2=vatten når till rälsens underkant, 3=vatten står över rälsen.



Vilken av 1,2 eller 3 i bilden ovan är en kritisk översvämningsnivå för att orsaka stillestånd på en höghastighetsjärnväg?

Ditt svar

Givet att ett stillestånd sker på järnvägen. Vilka är de tre viktigaste händelserna som kan inträffa?

Ditt svar

Hur sannolikt är det att den första händelsen, som du skrev ovan, inträffar vid ett stillestånd på järnvägen?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den första händelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Hur sannolikt är det att den andra händelsen, som du skrev ovan, inträffar vid ett stillestånd på järnvägen?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den andra händelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

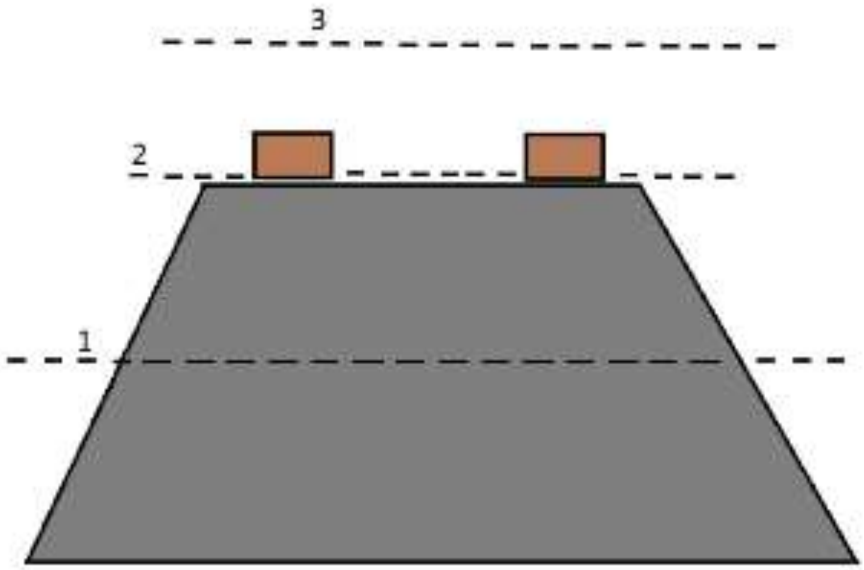
Hur sannolikt är det att den tredje händelsen, som du skrev ovan, inträffar vid ett stillestånd på järnvägen?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den tredje händelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Bilden illustrerar en banvall med tre olika tänkta översvämningsnivåer 1=vatten står upp i banvallen, 2=vatten når till rälsens underkant, 3=vatten står över rälsen



Vilken av 1,2 eller 3 i bilden ovan är en kritisk översvämningsnivå för att ett höghastighetståg skall behöva köra med avsevärt lägre hastigheter?

Ditt svar

Givet att tåget tvingas med avsevärt lägre hastigheter. Vilka är de tre viktigaste händelserna som kan inträffa?

Ditt svar

Hur sannolikt är det att den första händelsen, som du skrev ovan, inträffar då tåget tvingas köra med avsevärt lägre hastigheter?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket stor sannolikhet

Vilken är skadekostnaden om den första händelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader

Hur sannolikt är det att den andra händelsen, som du skrev ovan, inträffar då tåget tvingas köra med avsevärt lägre hastigheter?

	1	2	3	4	5	
Mycket låg sannolikhet	○	○	○	○	○	Mycket hög sannolikhet

Vilken är skadekostnaden om den andra händelsen, som du skrev ovan, uppstår?

	1	2	3	4	5	
Mycket små skadekostnader	○	○	○	○	○	Mycket stora skadekostnader