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MASTER'S THESIS

Improving Transportation Investment Decisions Through Life-Cycle Cost Analysis

Comparative LCCA of Bridges

Marco Ditrani

MASTER OF SCIENCE PROGRAMME
Civil and Mining Engineering

Luleå University of Technology
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Cover: The figure illustrates one of the bridge types studied, a reinforced concrete slab bridge over Aspan, NE of Ava, between Umeå and Örnsköldsvik (No 24-1876-1).

Acknowledgement

First of all, I would like to dedicate this work to my parents, Emanuele and Giuseppina, who supported me constantly with their presence and love, and to my family.

This project has been carried out from June to September 2009 at Vägverket (the Swedish Road Administration) in Luleå. The aim has been to increase the knowledge of Life-Cycle Cost Analysis of Bridges. I would like to thank Vägverket for financing my work.

A special thanks to Prof. Lennart Elfgren, Advisor in Sweden at Luleå University of Technology, who gave me the possibility to develop this project, for his help, suggestions and motivation, and to Mr. Per Andersson, M. Sc. Eng., Vägverket, for his endless support.

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Luleå and Milan in December 2009

Marco Ditrani

Summary

The aim and scope of the project is to study and apply Life Cycle Cost Analysis (LCCA) to standard bridges with a length of ca 20 m. Eleven bridges of reinforced concrete in northern Sweden have been studied with data from BaTMan, a Swedish bridge data base. Two alternative designs with timber (Glulam) and soil-steel (SuperCor) have also been studied.

The concept of Present Value Method, Annuity Cost, and Societal Costs are described and the importance is discussed of parameters such as inflation and interest rates. In the analysis the following choices were made: interest rate 4 % and inflation rates for Maintenance, Repair and Rehabilitation (MR&R) 1,5 %, for planning and design 2 %, for dismantling 3 % and for user's costs 5 %. Methods are described for calculating user costs and for performing traffic analysis with a Swedish model called Sampers. Historical data and forecasts are presented.

A sensitivity analysis is performed to understand how and how much the parameters involved in the analysis influence the final result. The life cycle costs for the eleven bridges vary between 4 and 20 Mkr and their annuity costs between 7 and 39 kkr. The lower costs refer to bridges with low initial investment (2,5 Mkr) and low traffic (20 vehicles/day), whereas the higher costs refer to bridges with high initial investment (11 Mkr) and high traffic (5000 vehicles/day). Of the life cycle costs, initial investments are 45 – 84%, user costs are 0,6 – 47 %, maintenance, repair and rehabilitation (MR&R) are 4 – 14 %, dismantling are 1,4 – 5,6 % and planning and design costs are 0,7 – 3,8 %.

Bridge designs with timber and soil-steel (SuperCor) are presented based on information collected from producers. LCCA has then been performed for three scenarios with different traffic volumes (100, 500 and 5000 vehicles per day in 2009), which reflect the situation in different Swedish regions. The estimated life cycle costs for the three scenarios are 2,3 Mkr, 2,4 Mkr and 4,4 Mkr for the soil-steel bridges and 2,5 Mkr, 2,7 Mkr and 4,7 Mkr for the timber bridges respectively. The annuity costs are 9 kkr, 9 kkr and 17 kkr for the soil-steel bridges and 10 kkr, 11 kkr and 19 kkr for the timber bridges respectively.

The main conclusions from the project are that initial costs, user costs and life length have the highest influence on the life cycle costs and the annuity costs. Furthermore there exist no unique type of bridge that can be seen as the most cost efficient one. Rather, the economic efficiency depends on the location of the bridge and on the traffic volumes in that particular area. Future development is needed regarding data and stochastic analysis and other models for forecasting of traffic, interest rates and inflation rates. Data bases need to be updated with initial costs, MR&R and life lengths for various bridge designs. Finally improved, user friendly software for LCCA would improve the beneficial use of this important concept for transportation investment decisions.

Sammanfattning (Summary in Swedish)

Bättre investeringsbeslut för transportinfrastruktur med hjälp av livscykelkostnadsanalyser (LCCA). En jämförelse mellan broar av amerad betong, stål, limträ och valv av korrugerad stålplåt

Målet med detta projekt är att sudera och tillämpa livscykelkostnadsanalys (LCCA) för standardbroar med längden ca 20 m. Elva broar av armerad betong i norra Sverige har studerats med hjälp av data från BaTMan, en svensk brodatabas. Två alternativa utformningar med trä respektive valv av korrugerat stål har också studerats.

Begrepp som nuvärdesanalys, annuitetskostnader och användarkostnader beskrivs liksom betydelsen av räntenivå och inflation. I analysen har följande värden änvänts: ränta 4%, inflation för underhållskostnader 1,5 %, för planering och projektering 2%, för rivning 3% och för användarkostnader 5 %. Metoder beskrivs för att beräkna användarkostnader och trafikanalyser med hjälp av Sampers - ett samordnat svenskt modellsystem för analys av persontransporter. Historiska data och prognoser för framtida trafik presenteras för broarna.

En sensitivitetsanalys genomförs för att undersöka vilka parametrar som har störst inverkan. Livscykelkostnaderna för de elva broarna varierar mellan 4 och 20 Mkr och deras annuitetskostnader mellan 7 och 39 kkr. De lägre kostnaderna hänför sig till broar med låg intiell kostnad (2,5 Mkr) och låg trafikintensitet (20 fordon/dygn) medan de högre kostnaderna hänför sig till broar med hög initiell kostnad (11 Mkr) och hög trafikintensitet (5000 fordon/dygn). Av livscykelkostnaderna utgör den ursprungliga investeringskostnaden 45 – 84 %, användarkostnaderna 0,6 – 47 %, reparation och underhåll 4 – 14 %, rivning 1,4 – 5,6 % och planering och projektering 0,7 – 3,8 %.

Broar utformade av trä och valv av korrugerat stål presenteras baserade på data från leverantörer. Livscykelkostnadsanalyser har därefter utförts för tre scenarior med 100, 500 och 5000 fordon per dygn. De uppskattade livscykelkostnaderna är 2,3 Mkr, 2,4 Mkr och 4,4 Mkr för valvbron av korrugerat stål och 2,5 Mkr, 2,7 Mkr och 4,7 Mkr för träalternativet. Annuitetskostnaderna är 9 kkr, 9 kkr och 17 kkr för valvbron och 10 kkr, 11 kkr och 19 kkr för träbron.

En slutsats av projektet är att de initiella investeringskostnaderna, användarkostnaderna och livslängden är de parametrar som har störst inverkan på livscykelkostnaderna och annuitetskostnaderna. Det står vidare klart att ingen speciell brotyp kan utpekas som varande mest effektiv, medan däremot brons läge och trafikvolym spelar stor roll. Fortsatt arbete behövs för att utveckla bättre modeller för att förutsäga trafikflöden samt ränta och inflation. Databaser, som BaTMan, behöver uppdateras med investeringskostnader och livslängder, samt kostnader för reparation och underhåll för olika brotyper. Slutligen skulle förbättrade, lättanvända program öka och förenkla användningen av denna viktiga metod för att ta fram underlag för investeringar i vår transportinfrastruktur.

Compendio (Summary in Italian)

Miglioramento delle Scelte di Investimento nelle Infrastrutture di Trasporto Attraverso l'Analisi del Costo nel Ciclo di Vita – Analisi Comparativa del Costo nel Ciclo di Vita dei Ponti

Lo scopo di questo elaborato di tesi consiste nell'analisi di diverse tipologie di ponti a campata unica, di circa 20m di luce, attraverso l'"Analisi del Costo nel Ciclo di Vita" o Life Cycle Cost Analysis (LCCA), apportando miglioramenti al metodo di analisi stesso. Sono stati studiati con tale metodologia undici ponti in cemento armato siti nel nord della Svezia anche grazie ai dati presenti nel database nazionale BaTMan (Bridge and Tunnel Management). Sono stati presi inoltre in considerazione due tipologie alternative ai ponti precedentemente analizzati: ponti in legno (glulam) e ponti in acciaio corrugato (SuperCor).

Vengono poi descritti i concetti di Attualizzazione dei capitali, Costo Annuo, Costi per la Società e discussa l'importanza dei parametri che rientrano nell'analisi come i tassi di interesse e di inflazione. Nelle analisi sono state considerate le seguenti crescite medie annue percentuali: tasso di interesse pari al 4%, tasso di inflazione per la manutenzione pari all'1,5%, per la pianificazione&progettazione 2%, per la demolizione 3% ed infine per il costo utenti 5%. Sono stati poi descritti i metodi utilizzati per il calcolo del costo utenti e l'analisi di traffico, quest'ultima realizzata attraverso l'uso del modello di traffico Nazionale SAMPERS. Vengono poi presentati i dati storici di traffico e calcolate le previsioni dei volumi futuri.

E' stata inoltre sviluppata un'analisi di sensitività per comprendere come e quanto la variazione dei parametri coinvolti nell'analisi influenza i risultati finali. Il costo del ciclo di vita degli undici ponti analizzati varia tra 4 e 20 Milioni di Corone Svedesi (Mkr) ed il costo annuale tra 7 e 39 mila Corone Svedesi (kkr). I costi inferiori si riferiscono a ponti con investimento iniziale basso (2,5 Mkr) o bassi volumi di traffico (20 veicoli/giorno), mentre i costi più alti si riferiscono a ponti con alti investimenti iniziali (11 Mkr) o traffico intenso (5000 veicoli/giorno). Rispetto al costo totale nel ciclo di vita, l'impatto degli investimenti iniziali varia tra 45 e 84%, i costi utente tra 0,6 e 47%, la manutenzione tra 4 e 14%, la demolizione tra 1,4 e 5,6% e la pianificazione&progettazione tra 0,7 e 3,8%.

Le analisi riguardanti i ponti in legno e quelli in acciao corrugato sono basate su informazioni ottenute direttamente dalle aziende produttrici. In questo caso la LCCA è stata sviluppata per tre diversi scenari di traffico (100, 500 e 5000 veicoli/giorno nel 2009), che riflettono la situazione in diverse regioni della Svezia. Il costo nel ciclo di vita per i tre diversi scenari è stato rispettivamente di 2,3 Mkr, 2,4 Mkr e 4,4 Mkr per i ponti in acciaio corrugato e 2,5 Mkr, 2,7 Mkr e 4,7 Mkr per i ponti in legno. I costi annuali sono rispettivamente 9 kkr, 9kkr e 17 kkr per i ponti in acciaio corrugato e 10 kkr, 11kkr e 19 kkr per i ponti in legno.

Le conclusioni che si possono trarre da questo elaborato sono innanzitutto che il costo iniziale, il costo utente e la durata della vita utile sono i parametri che più influenzano il costo totale durante l'intera vita del ponte. Inoltre, non esiste un'unica tipologia di ponte più efficiente dal punto di vista economico di un'altra in assoluto, ma ciò dipende dalla localizzazione dell'opera, ed in particolare dalle condizioni di traffico nell'area di interesse. Possibili sviluppi futuri sono l'utilizzo di modelli stocastici per le previsioni di traffico, tassi di interesse e di inflazione. E' inoltre necessario il continuo aggiornamento dei databases con costi iniziali, di manutenzione e vita di servizio. Infine, l'implementazione di un software per l'analisi del costo del ciclo di vita renderebbe più efficiente e diffuso l'utilizzo di questo metodo di analisi allo scopo di migliorarne l'impiego nella valutazione di strategie di investimento nel settore delle infrastrutture di trasporto.

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Introduction

There is a general aim to reduce the costs for the maintenance, repair and rehabilitation (MR&R) and disturbances for users of roads and bridges. One way to reach this goal is to collect information and gain knowledge about previous maintenance costs and investment for different types of bridges. The goal of this project is to perform Life Cycle Cost Analyses (LCCA) for different kinds of bridges located in the north of Sweden, in the regions of Norrbotten and Västerbotten, and to compare these results in order to understand which is the most cost-efficient type of bridge in a particular environment and which is the impact of the different costs items on the whole Life Cycle Cost of a project to be able to take efficient strategic decisions in the future and to reduce the total costs.

Furthermore, the perspectives of Timber and SuperCor bridges will be analyzed with the tool of LCC-Analysis and the results will be compared.

Life Cycle Cost Analysis is performed on different types of bridges: Beam and Slab Bridges, Slab Bridges and Slab Frame Bridges, with the total length around 20 m, the most common in Sweden, focusing on initial investments, maintenance, repair and rehabilitation (MR&R), user costs and demolition.

1. Life Cycle Cost Analysis of Bridges

1.1 Improving Transportation Investment Decision Trough Life Cycle Cost Analysis

There is an increased demand on efficient use of investments for transportation infrastructure. This motivates the use of Life Cycle cost Analysis (LCCA) as a tool for decision makers. In the face of increasing public scrutiny, transportation agency officials are under great obligation to demonstrate their stewardship of taxpayer investments in transportation infrastructure. Many transportation agencies are investigating economic tools that will help them choose the most cost effective project alternative and communicate the value of those choices to the public. The Federal Highway Administration (FHWA) in the United States believes that Life Cycle Cost Analysis (LCCA) can help transportation agencies with this process.

LCCA is an engineering economic analysis tool that allows transportation officials to quantify the differential costs of alternative investment options for a given project. LCCA can be used to study new construction projects and to examine preservation strategies for existing transportation assets. LCCA considers all agency expenditures and user costs throughout the life of an alternative, not only initial investments.

More than a simple cost comparison, LCCA offers sophisticated methods to determine and demonstrate the economical merits of the selected alternative in an analytical and fact-based manner. LCCA helps transportation agencies answer questions like "which design alternative results in the lowest total cost to the agency over the life of the project?", "To what level of detail have the alternatives been investigated?", "What are the user-cost impacts of alternative preservation strategies?".

LCCA's structured methodology provides the information and documentation necessary for successful public dialogue. Because of this, LCCA is a valuable tool to demonstrate a transportation agency's commitment to infrastructure preservation, US FHA [4].

LCCA has also been treated by e.g. Barr et al (1994) [1], Ryall et al (2000) [2], State of Alaska (1999) [3], Yanev (2007) [5], Kumar (2008) [6], Ostwald (1991) [7], Eriksen et al (2008) [8], Racatanu (2000) [9], Biondini and Frangopol (2008) [27] and Malerba (2009) [28]. Methods to increase the life length of exisiting bridges have been summarized and developed in the EC project Sustainable Bridges, see SB(2008), [29].

1.2 How Life Cycle Cost Analysis Works

Project teams using the LCCA process first define reasonable design or preservation strategy alternatives. For each proposed alternative, they identify initial construction or rehabilitation activities, and the timing for those activities. From this information, a schedule of activities is constructed for each project alternative.

Next, activity cost is estimated. Best practice LCCA calls for including not only direct agency expenditures (for example, construction or maintenance activities) but also user costs. User costs are costs to the public resulting from work zone activities, including lost time and vehicle expenses. A predicted schedule of activities and their associated agency and user costs combine to form a projected expenditure stream for each project alternative.

Once the expenditure streams have been determined for the different competing alternatives, the objective is to calculate the total Life Cycle Cost for each alternative. Because money spent at different times have different values to an investor, the projected activity costs for a project alternative cannot simply be added together to calculate the total Life Cycle Cost. LCCA uses discounting to convert anticipated future costs to present money values so that the lifetime costs of different alternatives can be directly compared. Discounting is an economical method of accounting for the time value of an investment. Because the level of service provided by each project alternative in the analysis is assumed to be the same, LCCA allows transportation agencies to evaluate alternatives on the basis of their Life Cycle Cost. The results of the analysis can be used to revisit the design or preservation strategies behind the project [4].

1.3 LCC Models for Bridges

1.3.1 Present Value Method

PRESENT VALUE FOR A SINGLE CASH FLOW

The present value method is commonly used for discounting purposes. All past, present and future cash flows are discounted to a common point of time, the present, so as to account for the changes in money's purchasing power over time, see e.g. Troive (1998) [11].

The present value B_0 of a future cash flow B, expected to fall due n years later, may be calculated by:

$$B_o = \frac{B}{(1+r)^n} \tag{1.1}$$

where B_o : the present value

B: cash flow, in constant money

r: real, inflation adjusted, discount rate for costing purposes

In Figure 1.1 and Figure 1.2, the present value for a future cash flow of 1000 €, expected to fall due after n years, is shown for various discount rates. In Figure 1.2 a logarithmic is scale used for the present value axis.

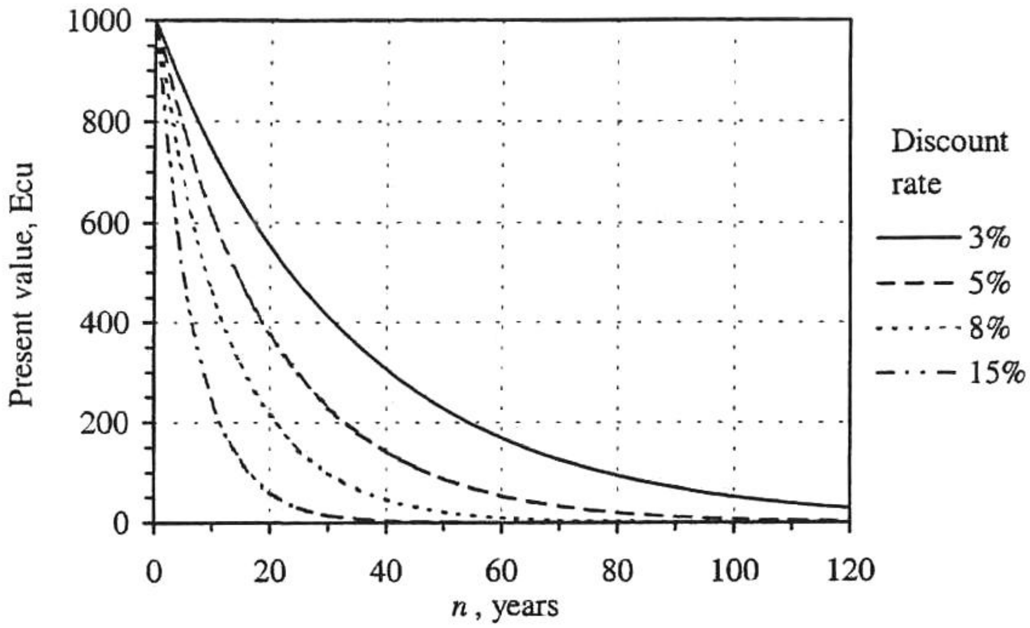


Figure 1.1 - Present value for a future cash flow of 1000 € [11].

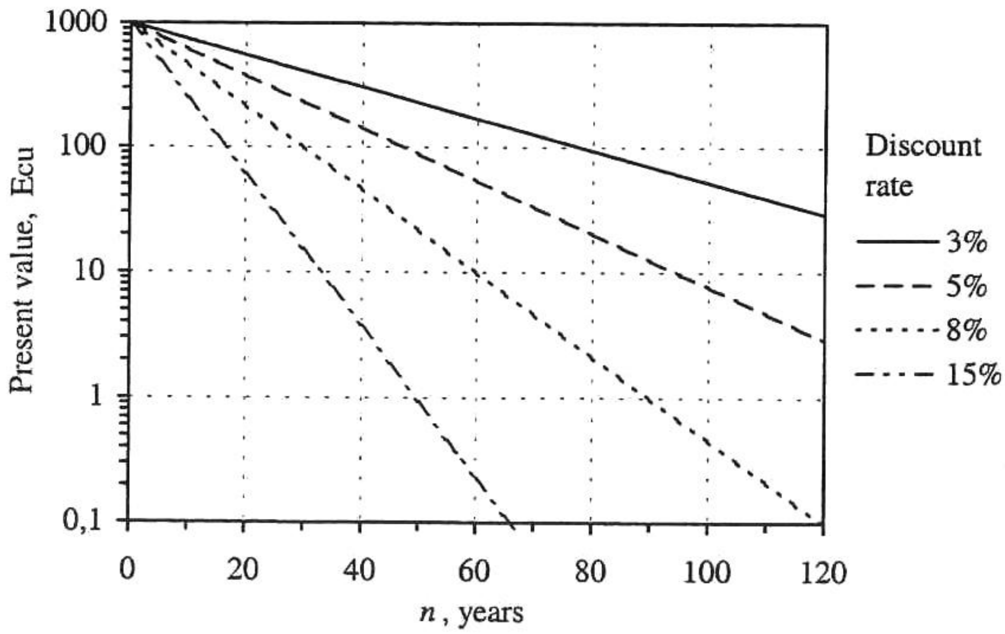


Figure 1.2 - Present value for a future cash flow of 1000 €, logarithmic scale [11].

PRESENT VALUE FOR AN ANNUAL CASH FLOW

The present value B_0 for a future cash flow *B*, expected to fall due every year during the time period n, may be calculated by:

$$B_0 = B(1+r)^{-1} + B(1+r)^{-2} + \cdots + B(1+r)^{-n} = \quad (1.2)$$

$$= B\left[\frac{1}{1+r} + \frac{1}{(1+r)^2} + \cdots + \frac{1}{(1+r)^n}\right] = \quad (1.3)$$

$$= \frac{B}{(1+r)^n}[(1+r)^{n-1} + (1+r)^{n-2} + \cdots + (1+r)^0 \quad (1.4)$$

This is a geometrical series that can be written as:

$$B_0 = \frac{B}{(1+r)^n}\sum_{i=0}^{n-1}(1+r)^i = B \cdot \frac{1-(1+r)^n}{(1+r)^n[1-(1+r)]} = B \cdot \frac{(1+r)^n - 1}{r(1+r)^n} \quad (1.5)$$

Dividing numerator and denominator by$(1+r)^n$, the following equation is achieved:

$$B_0 = B \cdot \frac{1-(1+r)^{-n}}{r} \quad (1.6)$$

The present value for a future annual cash flow of 10 €, expected to fall due every year during n years, is shown for various discount rates in Figure 1.3 [11].

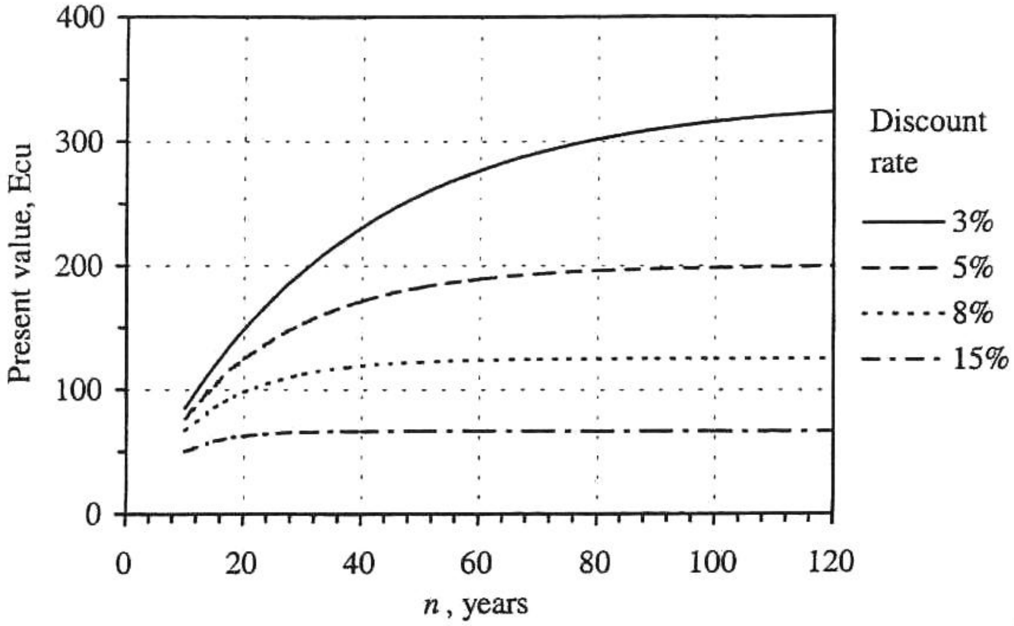


Figure 1.3 - Present value for a future annual cash flow of 10 € [11].

PRESENT VALUE FOR A PERIODICAL CASH FLOW

A future cash flow, expected to fall due periodically every p year during the n years, can be discounted to present value by:

$$B_0 = B(1+r)^{-p} + B(1+r)^{-2p} + \cdots + B(1+r)^{-mp} = \tag{1.7}$$

$$= B\left[\frac{1}{(1+r)^p} + \frac{1}{(1+r)^{2p}} + \cdots + \frac{1}{(1+r)^{mp}}\right] = \tag{1.8}$$

$$= \frac{B}{(1+r)^{mp}}[(1+r)^{m-1} + (1+r)^{m-2} + \cdots + (1+r)^0 \tag{1.9}$$

Here m is the number of times the cash flow is expected to fall due during the n years;$mp \leq n$. If the cash flow is some kind of maintenance, repair or rehabilitation cost, the cash flow at year n is not relevant and should therefore not be counted for.

The number of times the cash flow is expected to fall due, m, may then be calculated by:

$$m = trunk\left(\frac{n-1}{p}\right) \tag{1.10}$$

The equation of the present value above is a geometrical series that can be rewritten as

$$B_0 = \frac{B}{[(1+r)^p]^m} \cdot \sum_{i=0}^{m-1} [(1+r)^p]^i = \tag{1.11}$$

$$= B \cdot \frac{1-[(1+r)^p]^m}{(1+r)^{mp}\,[1-(1+r)^p]} = \tag{1.12}$$

$$= B \cdot \frac{(1+r)^{mp} - 1}{(1+r)^{mp}\,[(1+r)^p - 1]} \tag{1.13}$$

By dividing numerator and denominator by $(1+r)^{mp}$, the following equation is achieved:

$$B_0 = B \cdot \frac{1-(1+r)^{-mp}}{(1+r)^p - 1} \tag{1.14}$$

The present value for a periodical cash flow of 1000 €, expected to fall due periodically during 100 years, by length of periods, p, is shown for various discount rates in Figure 1.4 [11].

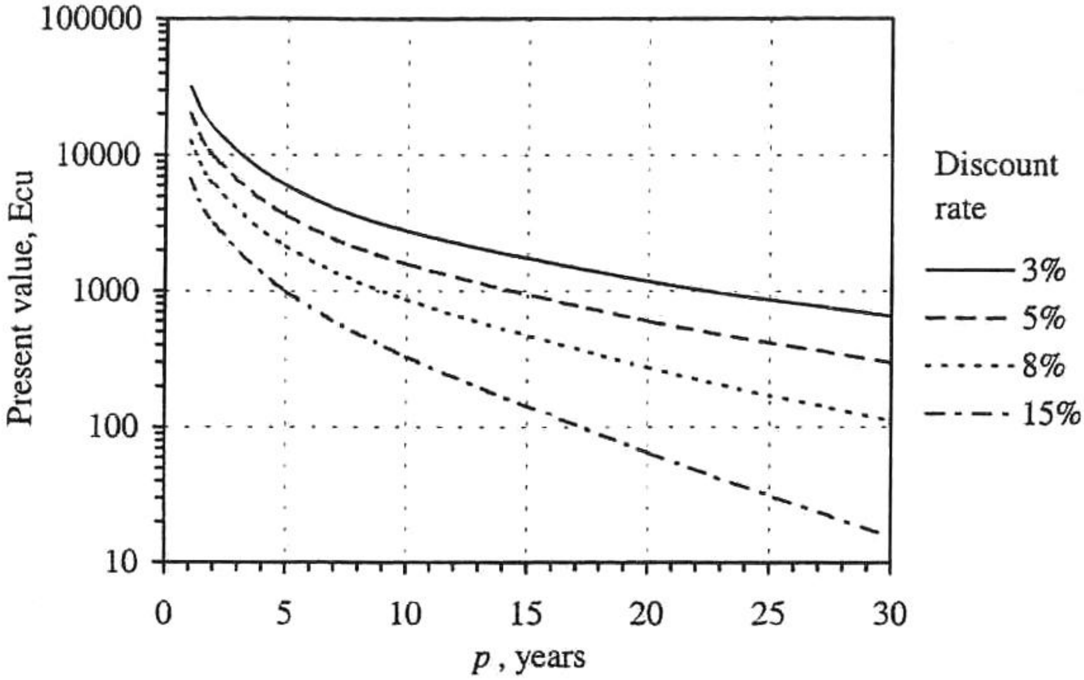


Figure 1.4 - Present value for a periodical cash flow of 1000 € [11].

1.3.2 Annuity Cost

When expected service life differ, the investments may preferably be compared on an annual equivalent basis. The annuity cost is the inverse of the present value for annual costs:

$$A = B_0 F_A = B_0 \frac{r}{1-(1+r)^{-n}} \tag{1.15}$$

Where B_o : the present value

F_A : annuity factor

n: service life, number of years

r : real, inflation adjusted, discount rate for costing purposes

The annuity factor versus the time n in years over which the present value shall be distributed, is shown for various discount rates in the figure below [11].

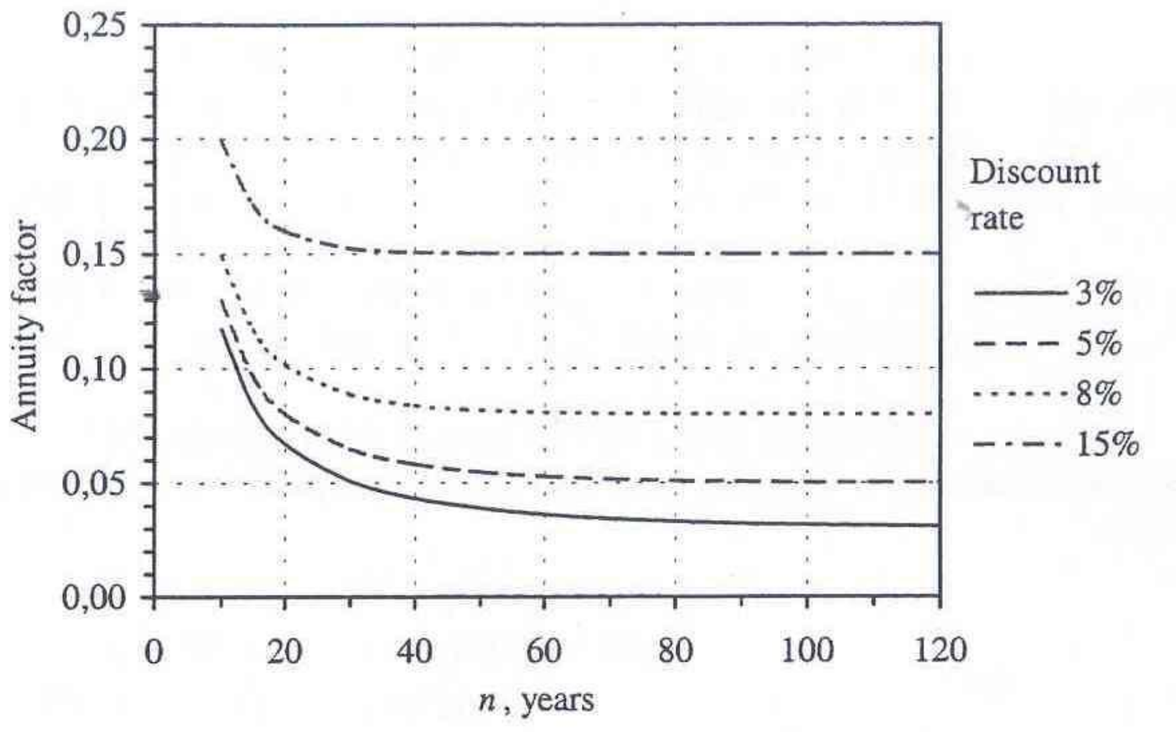


Figure 1.5 - Annuity factor versus the time

1.3.3 Societal costs

During the operation of maintenance, repair and rehabilitation of a bridge it is necessary to close part of the road for a certain period of time, this certainly affect the average time the users remain on the road, because it is necessary to create an alternative path or use a traffic light or a sign to let the works go on on the road. These operations end up in an extra expenditure of time and fuel, but also increase the probability of accidents.

Some empirical formulas have been developed to estimate this extra cost, Sundquist (2008) [15]:

For what concern the user costs due to delay:

$$LCC_{user,delay} = \sum_{t=0}^{T} \left(\frac{L}{v_r} - \frac{L}{v_n} \right) ADT_t \cdot N_t (r_L w_L + (1 - r_L) w_D) \cdot \frac{1}{(1+r)^t} \tag{1.16}$$

Where L : length of affected roadway

v_r : traffic speed during bridge work activity

v_n : normal traffic speed

ADT_t : average daily traffic (i.e: cars per day at time t)

N_t : number of days of road work at time t

r_L : amount of commercial traffic

w_L : hourly time value for commercial traffic

w_D : hourly time value for drivers

t : studied time interval

r : real, inflation adjusted, discount rate for costing purposes

The user costs due to the operations are estimated by:

$$LCC_{user\ ,operating} = \sum_{t=0}^{T} \left(\frac{L}{v_r} - \frac{L}{v_n}\right) ADT_t \cdot N_t (r_L(o_L + o_G) + (1 - r_L) o_D) \cdot \frac{1}{(1+r)^t} \qquad (1.17)$$

Where the new notations represents

o_L : operating cost for the commercial traffic vehicles

o_G : operating cost for transported goods

o_D : operating cost for cars

T : time interval

The cost for the increased number of accidents is:

$$LCC_{society\ ,accident} = \sum_{t=0}^{T} (A_r - A_n) ADT_t \cdot N_t \cdot C_{acc} \frac{1}{(1+r)^t} \qquad (1.18)$$

Where the new notations represent

A_r : normal accident rate per vehicle-kilometer

A_n : accident rate during roadwork

C_{acc} : cost for each accident for the society

The risk of failure is

$$LCC_{society\ ,failure} = \sum_{j=1}^{n} K_{H,j} \cdot R_j \frac{1}{(1+r)^j} \qquad (1.19)$$

Where R_j : probability for a specified failure coupled to $K_{H,j}$

$K_{H,j}$: cost of failure

(one value for ultimate limit state and one for serviceability limit state) [15]

1.3.4 Discount rate

Discounting is performed to calculate the present value of a cash flow, associated with an investment. The process of discounting is defended by economists as reflecting the way people behave and value things. Both consumers, via a positive rate of time preference, and producers, via the opportunity cost of capital, are observed to treat the future as less important than the present. An essential condition is the existence of a free market for borrowing or lending money. One of the major issue associated with discounting is the choice of discount rate. Economic calculations based on discounted cash flows are very sensitive to the value of the discount rate. The present value of a given future cost amount decreases as the discount rate increases. Thus projects with cost savings are often evaluated with low rather than high discount rates. At any given discount rate, the farther into the future that any given amount occurs, the smaller its present value will be. To verify the influence of the discount rate on the results from the LCC calculations, a comparison can be made for alternative discount rates (see Figure 1.1).

In a LCC comparison, the same fixed discount rate shall be used for all alternatives. It is usually preferable that the discount rate does not include inflation. In that way, and if the relative price level is considered unchanged, the future costs and incomes may be discounted based on the same price as they are worth today. Henceforth, the discount rate refers to Real Interest Rate calculated for costing purposes. When the rate of inflation is included in the operation of discounting, the discount rate refers to Nominal Interest Rate.

The discount rate for public investments may be chosen in several different ways. The following alternatives are the most common:

- Actual interest rate on the market
- Discount rate of the best alternative investment
- Politically decided discount rate
- Discount rate calculated for society purposes

In the application of CBA (Cost Benefit Analysis) for public investments, the discount rate may be calculated as

$$r = i + g \cdot e \qquad (1.20)$$

Where r : discount rate

i : indicates how much the society prefers a benefit today compared to tomorrow

g : rate of change of the consumption

e : elasticity of margin utility, a value that considers the relation between the cost for investment and the total income of the society

Choices of discount rate for costing purposes in the public sector have been frequently debated. The choice of discount rate for investments in the public sector has become a political issue. In conformity with most other decisions made by the governments, decisions over discount rates are often influenced by lobbying from pressure groups. The risk of uncertainty associated with an investment may be considered by choosing a high discount rate. A high discount rate usually decreases the willingness to invest in risky projects. The future benefit of a new bridge may be as major reason for bridge replacement. However, usually a lower value for the discount rate is chosen for investments within the transport sector than for commercial use. The underlying philosophy is that public sector activities are supposed to be of low risk. The public investment shall be compatible with a good but speculative investment in the open market. Public projects are typically mandated to use a specific rate. Examples of discount rates used in some countries varies between 2% in Switzerland and 10% in the United States, however, in most developed countries, varies between 6 and 8%. In the United States, a high discount rate was chosen to discourage public expenditures at a time (early 1990s) when it had reached uncomfortably high levels.

In Sweden, 4% is recommended for cost benefit analysis, CBA, within the transport sector.

In UK, different discount rates are attracted for different public expenditures. For example, 8% is attracted for highways, 6% for hospitals and 3% for forestry. The discount rate at 8%, used by the Department of Transport in UK and set in 1989, has to be compared to an average commercial return which at the time was 11%.

Discount rates have significant implications to the design of bridges which are difficult to reconcile with assessed design lives. Several approaches have been made on differing discount rates, but none have been seen by economists as philosophically sound.

1.3.5 Dealing with inflation

During the past several decades, inflation has been a significant factor in the rising costs of products and services and in reduction of the purchasing power of money. Inflation is a continuing rise in general price levels caused by an increase in the volume of money and credit relative to available goods. The figure below depicts inflation and its effect on the purchasing power of money.

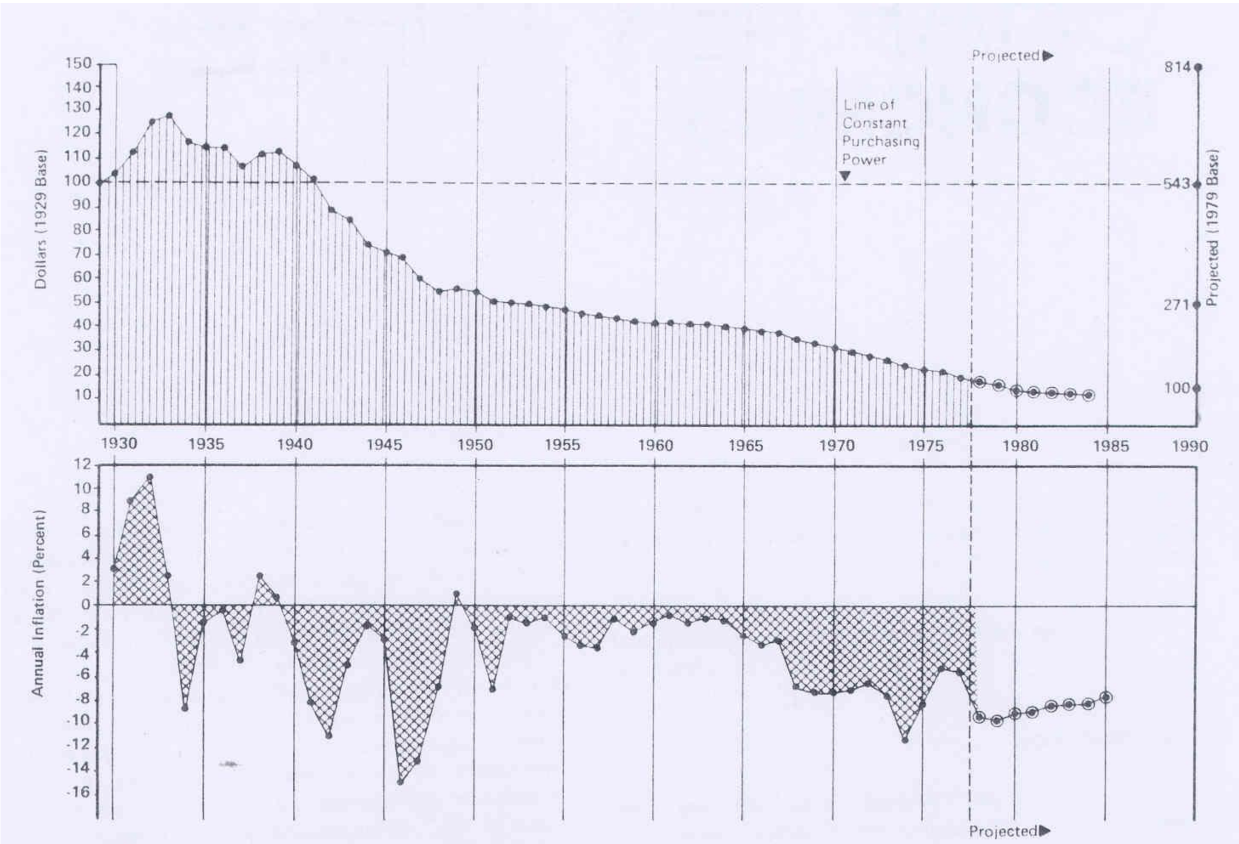


Figure 1.6 - Inflation and its effect on the purchasing power of money

Gerald A.Fleischer and Arnold Reisman were pioneers in formally extending existing quantitative methods of economic evaluation to the arena of decision making in an economic age characterized by inflation. Their paper titled "Investment Decision Under Condition of Inflation", published in the *International Journal of Production Research* in 1967, discussed and developed models for use with differing rates of inflation, [26].

During the past several years, inflation has escalated to alarming new heights. It is no wonder, then, that inflation should be considered in a life cycle study. However, the problem that creates inconsistencies in an analysis is not so much that future costs will be greater than today's costs, but the uncertainty about *how much* costs will increase, and what rate of inflation should be assumed as the analysis base.

The U.S. Office of Management and Budget (OMB) requires that all estimates costs for each year of a planning (design) period. The *differential rate* of inflation, or *escalation rate*, has been defined as "that rate of inflation above the general devaluation of the purchasing power of the money".

Cost escalation can have a profound effect on the financial performance of an alternative. This is especially true when the rate of cost increase is high (as has been seen with fossil fuel prices over the 1973 – 1980 period). Government agencies have made various estimates concerning fuel price increases relative to the overall economic price indices. The figure below presents an example of this information from the National Aeronautics and Space Administration (NASA).

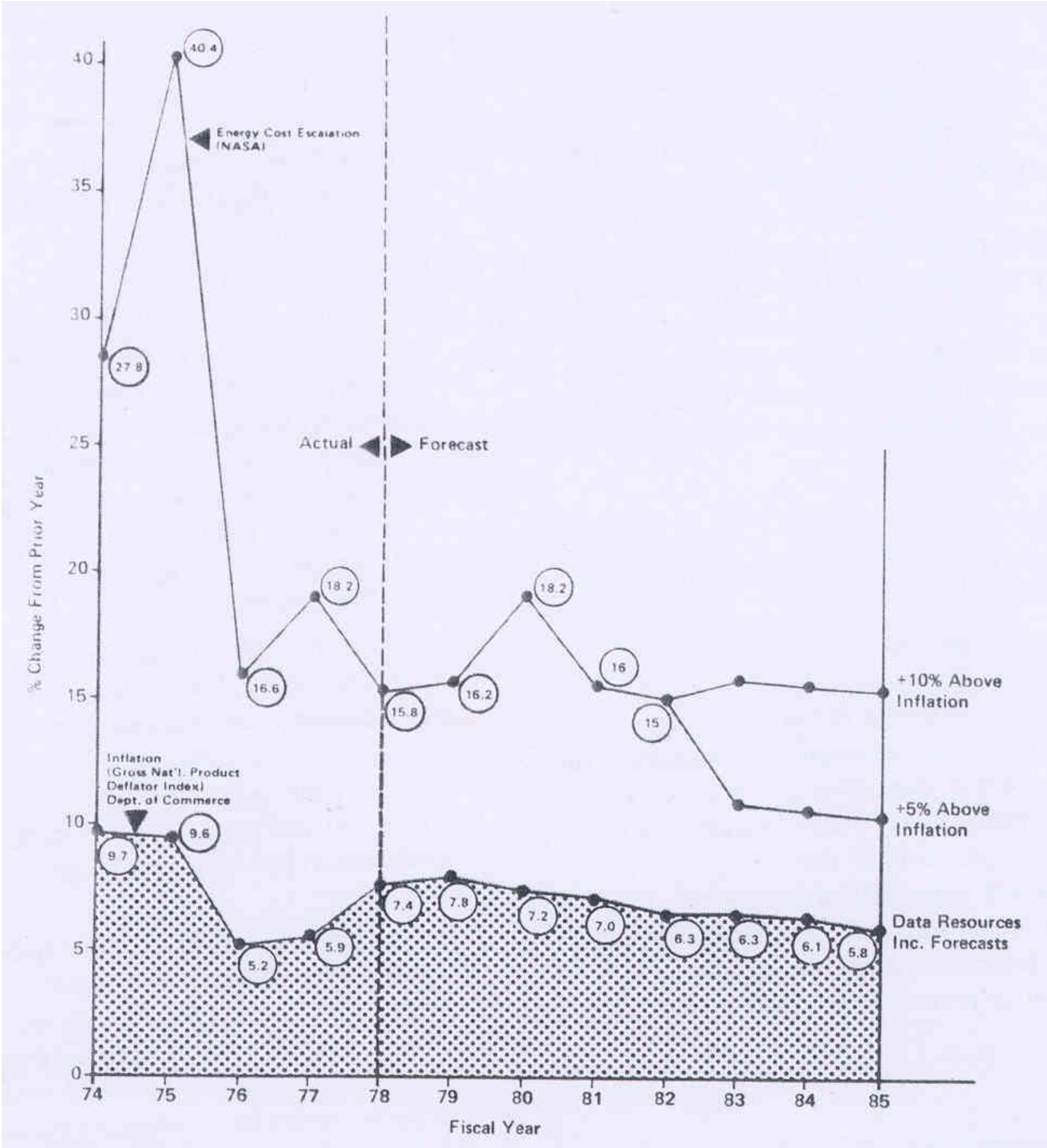


Figure 1.7 - Estimates concerning fuel price increases, NASA.

The concept of differential cost escalation requires that variables be adjusted from today's money purchasing levels only if they are above the *general economy inflation rate*. Non escalation of these items and the corresponding effect upon the results may be included in the sensitivity analysis. In order to compare design alternatives, both present and future costs for each alternative must somehow be brought to a common point of time. Two method are commonly used. Cost may be converted in today's cost (preset worth) or, they may be converted to an annual series of payments (annualized). Either method will properly allow comparison between design alternatives [10].

1.3.6 The Role of Interest and Inflation Rates

In LCC studies it is common practice to estimate future costs in constant dollars and to use an assumed inflation rate to transform these estimates to actual dollars. The choice of an inflation rate for such projections can strongly affect the computed LCC. The table below shows the effect of the inflation rate on the 10-year LCC of a project whose yearly cost $1 in constant dollars (reflection prices and wages at the start of the project).

Table 1.1 - Effect of the inflation rate on yearly cost

Inflation rate [%/y_r]	LCC	% increase over zero inflation
0	10.0	-
2	11.17	11.7
4	12.49	24.9
6	13.97	39.7
8	15.65	56.5
10	17.53	75.3
15	23.35	133.5

Frequently LCC studies take into account the “time value money” by discounting future expenditures using an assumed discount rate (interest rate). The effect of discounting on LCC (assuming no inflation) is illustrated by the table 1.2.

Table 1.2 - Effect of discounting on LCC (assuming no inflation)

Discount rate [%/y_r]	LCC	% decrease over zero discounting
0	10.0	-
2	8.98	10.2
4	8.11	18.9
6	7.36	26.4
8	6.71	32.9
10	6.14	38.6
15	5.02	49.8

These tables show how strongly LCC computations reflect the choice of rates. Even when both inflation and discounting are considered, if a wide range of possible choices for the rates is permitted, then the comparison of a project with high initial cost and, say, another project with low initial cost but comparatively high recurring costs can vary drastically.

Here is presented a simplified method of LCC calculation using a single parameter V that combines the effect of inflation and discounting, taking advantage of the fact that to a large extend, they cancel each other out. Historical data on interest rates and inflation rates from 1950 to 1976 are analyzed to determine how stable the parameter V is and to indicate a reasonable value for this parameter and the accuracy one can expect from its use in LCC projections.

Whenever the "time value of money" is considered, the life-cycle cost is the sum of all costs in the life-cycle discounted at an interest rate i to some time point t_0. One might choose t_0 to be the beginning of the operational phase or, perhaps, the time of first expenditure not yet committed.

Furthermore, it is common practice to pick a time point t_1 at which wages and prices are known and then to estimate all costs in "*t_1 – dollars*". *Actual dollar* expenditures are estimated by transforming from *t_1 – dollars*, using an assumed inflation rate j (for simplicity, we ignore the straightforward refinement where different j's are applied to different types of costs such as labor costs or material costs).

There is a good reason to choose t_o and t_1 to coincide. The LCC then depends only on

$$V = \frac{1+j}{1+i} \tag{1.21}$$

This is because expenditure at time t of an amount C in t_1 – *dollars* implies a cost in actual dollars of

$$C(1+j)^{t-t_1} \tag{1.22}$$

And the discounted value of this at time t_0 is

$$C(1+j)^{t-t_1}(1+i)^{-(t-t_0)} \tag{1.23}$$

Which, if $t_0 = t_1$, is equal to CV^{t-t_0}. Thus, one can compute the LCC by specifying only the assumed V rather than both i and j. Specifically, if $C_1,\ldots,C_n$ are the estimated yearly costs in current dollars, then the LCC (evaluated at the present) is given by

$$LCC = \sum_{k=1}^{n} C_k V^k \tag{1.24}$$

There are obvious advantages to dealing with only one "arbitrary" parameter. For example, one can bracket the LCC by computing it using "high" or "low" choices of V. A more important benefit from considering V is to reduce substantially the seeming unpredictable of future interest and inflation rates. Historically, interest rates tend to exceed inflation rates by about 2-3%. This tendency has e.g. been showed for the years 1950 to 1976 for the long-term Treasury bond yield and the index of consumers prices by the US Bureau of Labor Statistics.

Furthermore, V is essentially a function of the difference of rates, *i – j*, as shown in the figure below (In fact, the approximation $V = 1 - \left(\frac{i-j}{1+i}\right) \approx 1 - (i-j)$ is good enough for most purposes).

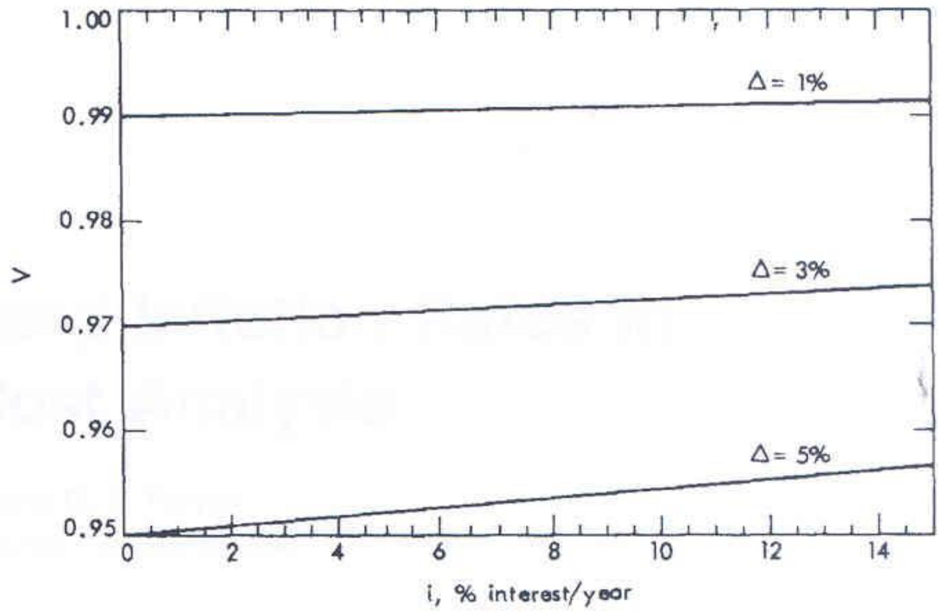


Figure 1.8 – The inflation rate parameter V = (1+j /(1-i) as function of the difference ∆ = I – j, where I and j are interest rate and inflation rate respectively.

It is natural, then, to ask how stable is V historically or, more important, how much do LCC's vary when computed using the *actual* interest and inflation rates over different historical period?

A study was made using the inflation and interest rate data for 1950 – 1976 to determine what actual LCCs would have been for projects spanning 5, 10, 15, 20 year subintervals of that period, assuming costs of one dollar per year expressed in current dollars at the start of the project. The LCC for, say, a 10 years project starting in year m is then obtained from the formulas

$$i_k = interest\ rate\ in\ year\ k$$

$$j_k = inflation\ rate\ in\ year\ k$$

$$V_k = \frac{1 + j_k}{1 + i_k} \qquad (1.25)$$

$$LCC = V_m + (V_m V_{m+1}) + \cdots + (V_m V_{m+1} \dots V_{m+9}) \tag{1.26}$$

The results of this computation are displayed in the figure below:

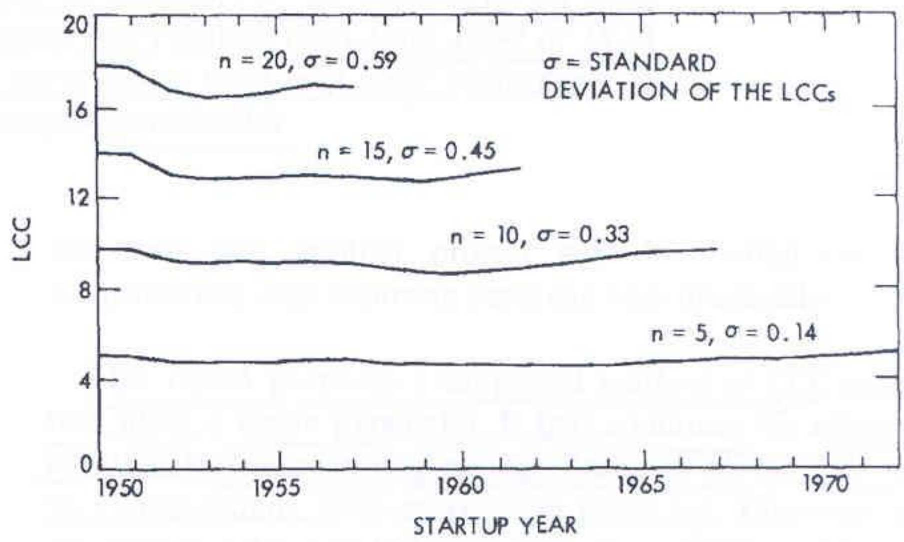


Figure 1.9 – Stability of the parameter V from 1950 to 1976 in calculation of LCC for projects with different life times n [years].

The conclusion indicated by these results is clearly that LCCs based on actual rates are quite stable historically. Over this 27-year period the variations of LCCs are a relatively small percentage of the LCCs themselves. If this stability continues (and recall that the actual yearly rate fluctuations are considerable), it should be possible to choose a value of V that will project future expenses with a reasonable degree of accuracy and confidence. Standardizing the V to be use in LCC calculations for the US Deep Space Network (DSN) has the advantages of simplicity and uniformity [12]. What is a good choice of V for DSN? The value of V that yields a 10-year LCC matching the average of the 10-year LCCs in Figure 1.9 is 0.983, and choosing V=0.98 (for simplicity seems reasonable).

This choice agrees very well with the data for 5, 10, 15 and 20 years. A good case can be made for setting V=1, thereby letting interest and inflation cancel completely and simplifying LCC calculations. How much difference does it make in the LCC when one makes small changes in V? Routine computation shows that for V between 0.9 and 1, each decrease of 0.01 in V yields about the same percentage decrease in LCC, the amount of this decrease depending on the length of the life cycle. Table 1.3 illustrates the outcomes for n=5, 10, 15 and 20 years with V=0.97 and 0.98. Note that for a 10 year project the LCC with V=1 is 10 and drops to about 9.5, 9.0, 8.5 as V goes through 0.99, 0.98 and 0.97.

Table 1.3 – LCC of a project costing 1$ per year

n° years	V=0.97	V=0.98	% increase
5	4.57	4.71	3.1
10	8.49	8.96	5.6
15	11.86	12.81	8.0
20	14.75	16.29	10.4

As pointed out in the beginning, the choice of inflation and discount rates can have a powerful effect on the results of LCC calculations. Inflating costs without discounting (or the reverse) can easily lead to making the wrong choice between competing projects. Even when both rates are used, arbitrary choices can lead to a wide range of possible results.

This analysis shows that inflation and discounting largely cancel each other and it is essentially only the difference between them that affects LCC. This difference is relatively small, discount rates generally being slightly higher than inflation rates. Furthermore, fluctuations in the rates tend to cancel out over project lifetimes. As a consequence, a single parameter V can be chosen to estimate the net effect of future discount and inflation rates with a reasonable degree of confidence. The value V=0.98, reflecting discount rates about 2% higher than inflation rates, is recommended for DSN use, based on a good fit to actual rates over the period 1950 – 1976 [12].

2. Comparative Life Cycle Cost Analysis of Bridges

2.1 Introduction

In order to understand which is the most cost efficient type of bridge that can be built with a span of 20 m, the idea is to collect historical data on operation of inspection, maintenance, repair, rehabilitation and dismantle to perform the Life Cycle Cost Analysis on existing bridges and compare the results. In this chapter all the bridges are presented and the Life Cycle Cost Analysis is performed.

2.2 Bridges analyzed

In this paragraph all the bridges that has been analyzed are listed in a table, with main characteristics and picture.

In the map below it is possible to look at the position of all the bridges included in the analysis.

Figure 2.1 – Locations of the bridges analyzed

BRIDGES ANALYZED IN NORRBOTTEN AND VÄSTERBOTTEN REGIONS

Table 2.1 – List of the bridges included in the analysis

n°	type n°	Construction Type	Material	Code (BaTMan)
1	I	Beam and Slab Bridge (balkbro fritt upplagd)	Steel + Concrete	24-1790-1
2	II	Slab Bridge (Plattbro)	Concrete	24-1861-1
3		Slab Bridge (Plattbro fritt upplagd)	Concrete	24-1497-1
4		Slab Bridge (Plattbro fritt upplagd)	Concrete	24-1753-1
5		Slab Bridge (Plattbro fritt upplagd)	Concrete	24-1876-1
6	III	Slab Frame Bridge (Plattram 2-leds)	Concrete	24-417-1
7		Slab Frame Bridge (Plattram 2-leds)	Concrete	24-471-1
8		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-1432-1
9		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-1674-1
10		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-1888-1
11		Slab Frame Bridge (Plattram 2-leds)	Concrete	25-780-1

1	Name/Code	Bro över Skivsjöån vid Skivsjön / 24-1790-1

Type	***Beam and Slab Bridge***
Material	Steel
Length	26 m
Width	7.3 m
Carry capacity	20/33 ton
Location city/län	Vindeln / Västerbotten
Year of construction	2003
Owner	Vägverket – SN

2	Name/Code	Bro över Järvsjöån 4km O Siksjö / 24-1861-1

Type	***Slab Bridge***
Material	Reinforced Concrete
Length	19 m
Width	7 m
Carry capacity	26/36 ton
Location city/län	Vilhelmina / Västerbotten
Year of construction	2004
Owner	Vägverket – SN

3	Name/Code	Bro över Gide älv vid Tallberg / 24-1497-1

Type	***Slab Bridge***
Material	Reinforced concrete
Length	26 m
Width	7 m
Carry capacity	18/29 ton
Location city/län	Åsele / Västerbotten
Year of construction	1990
Owner	Vägverket – SN

4	Name/Code	Bro över de sk Småälvarna o Antholmen i Skellefteå / 24-1753-1

Type	Slab Bridge
Material	Reinforced concrete
Length	18 m
Width	7 m
Carry capacity	12/18 ton
Location city/län	Skellefteå / Västerbotten
Year of construction	2001
Owner	Vägverket – SN

5	Name/Code	Bro över Aspan NO Ava / 24-1876-1

Type	Slab Bridge
Material	Reinforced concrete
Length	20 m
Width	15.2 m
Carry capacity	26/36 ton
Location city/län	Nordmaling / Västerbotten
Year of construction	2005
Owner	Vägverket – SN

6	Name/Code	Bro över Malån 3km so Malå / 24-417-1

Type	Slab Frame Bridge
Material	Reinforced concrete
Length	23 m
Width	7.9 m
Carry capacity	22/24 ton
Location city/län	Malå / Västerbotten
Year of construction	1983
Owner	Vägverket – SN

7	Name/Code	Bro över Kåge älv vid Stavaträsk i Skellefteå / 24-471-1

Type	*Slab Frame Bridge*
Material	Reinforced concrete
Length	19 m
Width	6.9 m
Carry capacity	16/18 ton
Location city/län	Skellefteå / Västerbotten
Year of construction	1987
Owner	Vägverket – SN

8	Name/Code	Bro över Paktaijåkka 0.7km N Tornehamn kyrkogårds hållplats / 25-1432-1

Type	*Slab Frame Bridge*
Material	Reinforced concrete
Length	19 m
Width	7.9 m
Carry capacity	22/25 ton
Location city/län	Kiruna / Norrbotten
Year of construction	1982
Owner	Vägverket – SN

9	Name/Code	Bro över Soukolojoki vid Kieri i Kuivakangas / 25-1674-1

Type	*Slab Frame Bridge*
Material	Reinforced concrete
Length	22 m
Width	9 m
Carry capacity	27/29 ton
Location city/län	Övertorneå / Norrbotten
Year of construction	1990
Owner	Vägverket – SN

10	Name/Code	Bro över lokalväg vid Månsbyn i Kalix / 25-1888-1

Type	*Slab Frame Bridge*
Material	Reinforced concrete
Length	16 m
Width	15.1 m
Carry capacity	29/37 ton
Location city/län	Kalix / Norrbotten
Year of construction	2002
Owner	Vägverket – SN

11	Name/Code	Bro över Aleån vid Selsjöns nordspets i Luleå / 25-780-1

Type	*Slab Frame Bridge*
Material	Reinforced Concrete
Length	17 m
Width	7.4 m
Carry capacity	14/18 ton
Location city/län	Luleå / Norrbotten
Year of construction	1988
Owner	Vägverket – SN

2.3 LCC – Analysis

2.3.1 Choice of the parameters

One of the parameters that most influence the result of a LCC Analysis is the interest rate. The analysis can be performed at different degree of accuracy; it is possible to consider the interest rate constant, without any influence of inflation. In this case, the cost that is planned today is going to be the same in the future and the Present Value will end up to be a cost that is less than the real one. When the inflation is considered, taking into account the fact that goods today cost, probably, less than tomorrow, the result is more accurate. The inflation rate can be approximately chosen constant, if any complex mathematical model is taken into consideration in order to calculate it. In this case, it is possible to consider a unique parameter, “V”, which is the ratio between 1+j and 1+i, where j and i are respectively the inflation and the interest rate. A third way to perform the Life Cycle Cost Analysis is to consider a constant interest rate and constant inflation rates that change depending on the goods that are considered. In this report the third solution is adopted. The motivations to this choice a study made in the USA where the stability is shown in the LCCA of the parameter V during the years 1950 – 1976 [12], and for what concern the choice of different ‘inflations’ on the reality of economy. The cost of goods will increase in a different manner compared to the cost of the time of the users for example.
The table that follow shows the different ‘V-parameters’ used in the analysis. The values are an average; in fact one of the further development of LCCA would be to find out more accurate values or functions (of time) for these parameters. They are calculated as follow and the choice reflects the way the different items in the LCCA will decrease or increase comparing to the cost of money.

Table 2.2 – V parameters used in the LCCA

V = 1+j/1+i		***Inflation j***	***Interest i***
V_users	1.009615385	5 %	4 %
V_MR&R	0.975961538	1,5 %	4 %
V_investment	0.961538462	0 %	4 %
V_planning&design	0.980769231	2 %	4 %
V_dismantle	0.990384615	3 %	4 %

2.3.2 Compared LCC - Analysis

In order to perform the LCCA of the bridges listed in the paragraph 2.2 it was necessary to investigate all the types of costs that occurred on every single bridge. All of these information, like initial investments, timing and costs for the maintenance, repair and rehabilitation (MR&R), user's costs and final expenditures for the demolishing have been found through the database BaTMan [22], the physical archive in the offices of Vägverket in Luleå and private companies involved in these operations.

In the tables below all the costs occurred during the past life of the bridge and the ones that have been planned for the future are summarized, until the end of the service life. It is also estimated the cost for disposal. All the costs are discounted to the present and to the year of construction of the bridge, taking into account an interest rate of 4%, as fixed by the policies of the Swedish Government.

2.3.2.1 User's cost

Because an infrastructure like a bridge is built for the society, and not for a single private owner, the users have to be taken in high consideration during the managing operations. When a bridge needs to be inspected, an element has to be replaced or restored; all of these operations affect the users, because they affect the regular traffic flow on the bridge. Time lost by the users, through rerouting or delays of commercial and non-commercial traffic has a cost that can be calculated using the formulas presented in the paragraph 1.3.3. Another way to calculate the user costs is to use the tool present in BaTMan (Bridge and Tunnel Management), the National Database of Vägverket (Figure 2.2).

Figure 2.2 – BaTMan tool to calculate user costs [22]

In the first box is asked for the number of days the operation is going to take, then if the user cost that has to be calculated is referred to regular cars or trucks, then the amount of traffic and the expected length of the delay is requested. In the white box it is possible to feed the length of the rerouting if it is the case. All the parameters concerning commercial and non-commercial hourly cost are implemented in the tool. The result is the cost for the users shown on the right, in kkr (Kilo-SEK).

The weak point of this tool, in my opinion, is the fact that the future growth of the traffic is not taken in consideration; it is possible just to visualize the traffic related to the last survey, so the user has no information about the real (forecasted) traffic in the year the operation is taking place.

To solve this problem, and make the analysis more reliable, the future traffic has been calculated using the traffic model SAMPERS, the national traffic model, implemented in software described in detail in the next paragraph.

2.3.2.1.1 SAMPERS model

BACKGROUND – The planning process

Swedish transportation authorities have a long tradition of developing traffic models. The first generation of traffic models was developed in the beginning of the 1980s, a second generation during the first half of the 1990s. These models have also been frequently used in a large number of projects but also as a part of the regular national strategic transport investment plan. The national planning process has been a four-year cycle of revising a ten-year investment scheme. The first step in this process is to undertake an analysis to decide on a general policy (like promoting accessibility or focus on environmental protection). Here the models are used to analyze a few main alternatives, representing major differences in transportation policy and economic development (such as heavily increased petrol taxes to reduce carbon dioxide emission). Based on the decision on the general policy, taken by parliament, the next step is to perform a more detailed analysis on what projects to include in the ten-year investment plan. The outcome of this process also contains tradeoffs between rail and road investment, which makes essential to base the analysis on the same forecasting tool and the same assumptions on economic development, land use, etc.

The actors in the process are the sector authorities (notably the road administration and the rail administration), and a coordination authority (The Swedish Institute for Communication Analysis SIKA). The forecasting work is carried out by the different actors, and coordinated by SIKA. The cost benefit score is a major assessment criterion in establishing the investment plan. Thus it is vital also in this respect that projects in different sectors can be compared on equal grounds.

Finally, the next ten-year investment plan is approved by the parliament. As can be expected, the political process does affect the outcome of the investment scheme.

CAUSE FOR NEW MODELS AND A NEW FORECASTING SYSTEM

The previously used models covered car ownership, trip frequency, destination choice, mode choice and route choice for long distance, regional and local trips. The trip frequency, destination and mode choice models were nested logic models divided into private and business long distance trips (>100 Km) and seven trip purposes for regional and local trips.
For route choice, and for choice of public transport sub models for regional and local trips, the assignment package EMME/2 was used. The models were rather comprehensive but not integrated into one single system, as a result of them being developed sequentially over the years by different organizations.
One of the main problems with the old models was the lack of integration and their use unfriendliness. A new national travel survey had also been carried out, which made it possible to update, improve and extend the performance of the travel demand models.
A major innovation in the system is a model for long distance trips, extended to include departure time and ticket type choice.

SCOPE OF NEW SYSTEM

The general scope of the SAMPERS project was first to develop a user-friendly computer traffic forecasting system, and also to develop new models covering all trips in Sweden, Algers and Beser (2000) [13].

ALL TRIPS
By the notion all trips is meant trips having at least the origin or the destination in Sweden. Trips between for example Finland and Denmark are not modeled. As in previous systems, this means that domestic long distance trips, regional and local trips are modeled. The previous models that had been used by the national planning authorities did not contain a model for international trips, so this is a new element in the model system.

LEVEL OF DETAIL
It is obvious that different applications require different level of detail in the forecasting system. An analysis of a road link in an urban environment requires a higher geographical

resolution than an analysis of a high-speed train service. Therefore, local and regional trips are handled with a higher resolution than long distance and international trips. For local and regional trips, Sweden is divided into 6000 zones, which would imply very large matrices and corresponding problems if no further breakdown were made. Therefore, 5 regions are defined, which are run separately.

For domestic long distance trips, 670 zones are defined. The same zones are used in Sweden for international travel, and Europe is divided into 200 zones, coarser as the distance increases.

INTEGRATED SYSTEM

In order to make the models user friendly, the demand models, the database and EMME/2 system had to be integrated into one software under the window NT operating system. An important task for the system is also to make it possible to add car trips from the 700-zone level to the regional 6000 level, and to add up train trips from the regional, long distance and international levels.

To get a travel forecast is seldom the final step in an investment or policy analysis. To make successive steps in the analysis easier, an effects module and a cost benefit module were required to be included in the system, as well as a module for accessibility analy

MODEL OVERVIEW

The models that have been used in the project and will be described in more detail below are the following:

- regional models
- long distance models
- international models

All models are of the discrete logit type, except for an ordinary least square trip frequency model for foreigners' travelling to Sweden. Experience from earlier national model studies are also brought into the project.

DATA

The main data source for the travel behavior to be modeled was the national Swedish travel survey, RiksRVU 94-98, which is a continuous travel survey containing 30 000 interviews for the entire interview period. The travel survey contains a one-day diary including all trips, supplemented by trips over 100 Km made last month, and trips over 300 Km made the second last month.

This data set is however not sufficient for international trips, and data collected in other major infrastructure investigations were also used.

The client using the EMME/2 system supplied the transport supply data. Specifically for long distance trips, data not only for different seasons, days and time of the day but also for different years was supplied in order to match the development of the infrastructure over time (such as the introduction of the high speed train X2000).

Statistics Sweden produced Land use data. This data was produced at the Small Area statistics level, and then aggregated to the zoning system used in the different segments mentioned above. The number of zones used were as follows:

- local and regional trips: 6000 zones;
- domestic long distance trips: 670 zones;
- international trips: 180 zones outside and 670 zones inside Sweden.

REGIONAL MODELS

GENERAL

The task for the regional model is to produce estimates of trips for the following models: car as driver, car passenger, bus, commuter train, bicycle and walk. The models work on a tour basis. Work tours are defined as home based tours, having a model structure as in Figure 2.2.

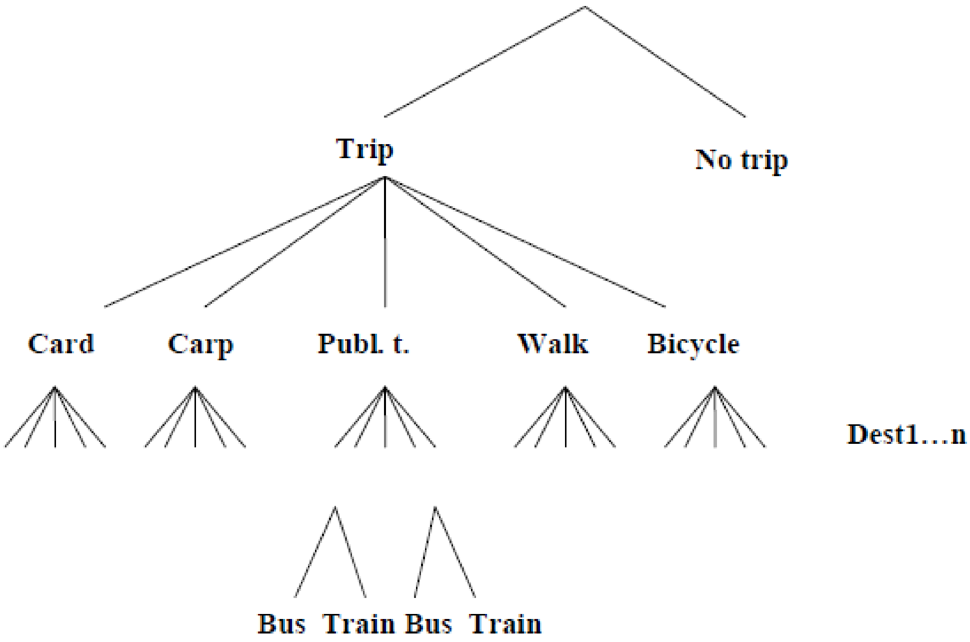


Figure 2.3 – Model structure for home base tours

In order to better reflect similarities of the bus and train alternatives, a structure containing two mode choice levels was adopted, as can be seen from the figure. Public transport mode choice is now handled at two levels in the model. First, there is a general public transport mode at the mode choice level. Then there is a bus – train mode choice at the lowest level of the model. This mode structure gave a better fit for all trip purposes except for business trips.

There are 5 others trip purposes defined, for which home based tour models have been defined, with the same structure as in Figure 2.2 (except for business trips, for which too few trains trips were reported, forcing the train mode to be omitted from the business trip model).

These trip purposes are:

- business
- school
- social
- recreation
- other

The aim of the model structure is also to capture trip chaining when fulfilling this task. This has been done by conditioning secondary destinations and work based tours on the work tour. Thus, if a person has made a work tour, he/she can choose to make for example a shopping trip not only as an ordinary home based trip, but also as a work based tour or as an intermediate stop on the way from work to home. This will of course not capture all types of trip chaining, but a fair share. The structure for non work tours will therefore take the form shown in Figure 2.4 (the work is currently ongoing):

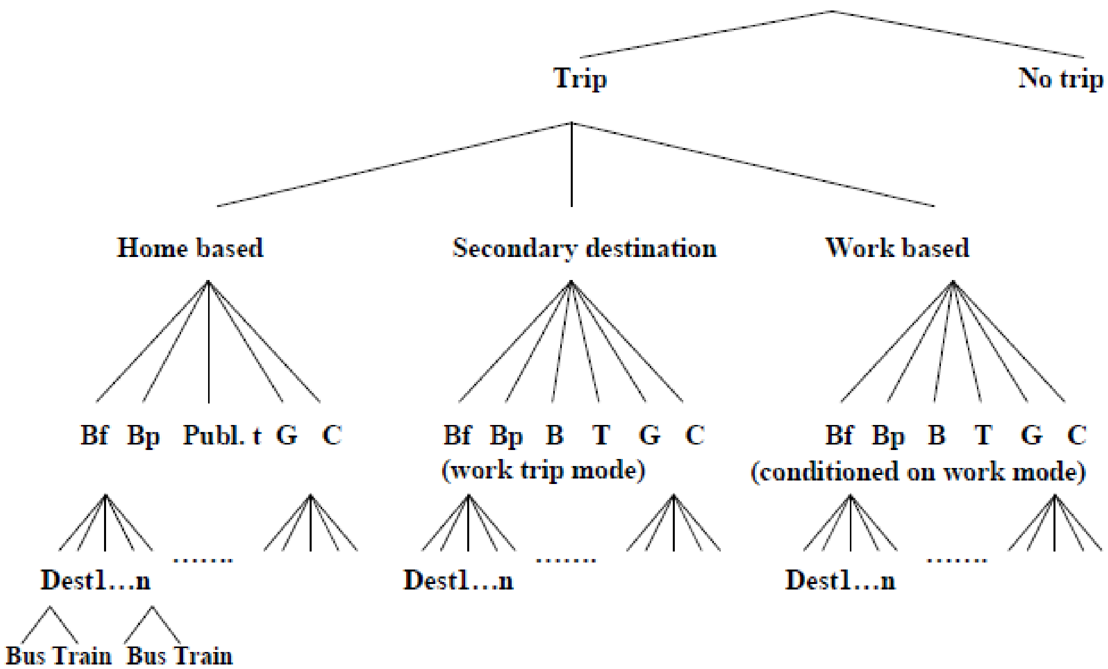


Figure 2.4 – Preliminary model structure for non-working tours

WORK TOURS

A base model was first developed on the total regional data set. Then, the same specification was used on the different data sets for each of the five sub regions. A major finding is that the cost and in-vehicle time parameters are very similar in the different regions. Therefore, a model including a number of region specific constants was formulated. In this way, the major part of the original differences could be accommodated in one single model.

The model was simultaneously estimated, and contains significant logsum parameters between the different choice dimensions.

Concerning travel time components, it has been found that a piecewise linear formulation of (first) waiting time and auxiliary time gives significant improvements. It has also been found that the in-vehicle time parameter is very similar for the different models. An important part of the cost variable is related to Swedish taxation rules, making it possible to deduct work trip travel cost in some cases. The implementation of the model allows for analyzing effects of changes in these rules.

The number of destination variables has been very limited. The only size variable used was the log of the total number of employees. Another variables that turned out to be significant was a dummy variable indicating the central area in each country. This variable was defined to be mode specific, and was supposed to account for omissions of parking costs, parking search times, etc.

Socio-economic variables have also been included, such as car ownership, license holding, gender and type of employment.

The value of time for work trips amounts to 50 SEK per hour, which is about 40 % higher than what was found in the 1994 Swedish Value of Time Study, based on Stated Preference data (Algers et al., 1995) [13].

NON WORK TOURS

For home based tours, models including mode, destination and frequency choice have been estimated. As for work tours, regional differences were captured by region specific constants rather than estimating one model for each sub region, the main reason being scarcity of data for the train mode.

As for work tours, cost and in-vehicle time parameters get significant values. Also, the resulting values of time are substantially higher than those found in the 1994 Swedish Value of Time Study.

Generally, destination choice is a weak part in travel demand models. In previous Swedish models, size variables have normally defined as the number of employed persons in different economic sectors, because of the general availability of this information. Such variables give of course a very parsimonious characterization of a destination zone. In this project, an extra effort was made to improve this part of the model. This was done by collecting information on a number of zone attributes, such as number of university students, number of beds in hospitals, number of summer house square meters, dummy variables for supply on winter and summer activities (like skiing facilities and camping facilities) etc. These variables improved the model significantly.

Most of the models contain individuals from 7 – 74 years. This is of course a fairly heterogeneous group, and the models contain many variables to account for that. It may well be that further segmentation with regard to age would turn out to be efficient.

All models, except for school trip frequency, contain significant logsum parameters integrating the different choice dimensions.

DOMESTIC LONG DISTANCE MODELS

MODEL STRUCTURE

Long distance trips are modeled as tours, longer than 100 Km in one direction. The models for these trips are defined to be car, bus, normal Inter-city (IC) trains, X2000 (high-speed) train and air.

A two-phase approach has been defined in this case. The first phase concerns the development of a nested disaggregate logit model with frequency, destination and mode choice, which had been used before [13]. In the second phase, departure time, class and access/egress mode choice is added to the choices modeled in the first phase. At this time, only the first phase model has been developed.

The model structure of the first phase model is such that frequency choice is at the highest level. Mode choice at the middle level and destination choice is at the lowest level. In this phase, access/egress is treated in a simple way, like adding a mode specific access/egress distance variable in the main mode choice model.

Two trip purposes have been defined – private trips and business trips.

ESTIMATION RESULTS

Both for business trips and private trips, mode and destination choice models have been estimated simultaneously. It turns out that for private trips there is some heterogeneity related to the number of days at the destination. Therefore a further segmentation according to this criterion was made. The first segment model concerns those staying away for more than 5 days, and the second segment model concerns those staying away 5 days or less. The latter model contains a further partial segmentation, where time components are segmented on those who make a day trip, and those who stay away up to 5 days. The specifications are also different in structure – it turns out that the first segment (duration > 5 days) requires the mode choice to be at the lowest level. Thus it seems that we explain destination choice relatively less well for trips with longer duration, which are often vacation trips.

For the destination choice, size variables were first defined as the number of employed persons in different economic sectors. As for the regional models, the extra variables for destination choice improved the model significantly.

Frequency models have been estimated using disaggregate data, but taking the observation period to be less than the maximum trip frequency, thereby allowing the use of observed frequencies in terms of probabilities, to make a trip in the defined period (Daly, 1997, see [13]). As an example, if no one makes more than 10 trips in a month, then a tenth of a month can be taken as the observation period. The probability to make a trip in such a period will range from one for the observed maximum frequency, to zero for those not having made a trip, and values in between for the rest. The advantage of this approach is that the choice becomes a binary choice.

Values of time for domestic long distance private trips for those staying away up to 5 days have been calculated based on the mode and destination choice model. The values are higher for trips with a shorter duration, probably related to a sharper time constraint. The value of time for trips exceeding 5 days was substantially lower. The in-vehicle values of time in the mode and destination model are on the average reasonably close to those found in the 1994 Swedish Value of Time study (which was not segmented in the same way) (Algers et al., 1995) [13].

Also for business trip, values of time have been calculated. As for private trips, trips with shorter duration have higher values of time. As can be expected, time values for business trips are substantially higher than for private trips.

INTERNATIONAL MODELS

International trips are classified into two main models – one for Swedes travelling to and from other countries, and one for non-Swedes travelling to and from Sweden. There is no important exception from this rule; namely the short trips being made between the very south of Sweden and the Danish island Sjaelland (including Copenhagen). These trips are handled as an extension of the regional model for the southern region.

MODEL STRUCTURE

The model structure contains three choice dimensions – trip frequency, mode choice and route choice, where routes are classified according to the ferry connection. This structure is depicted in Figure2.5 below.

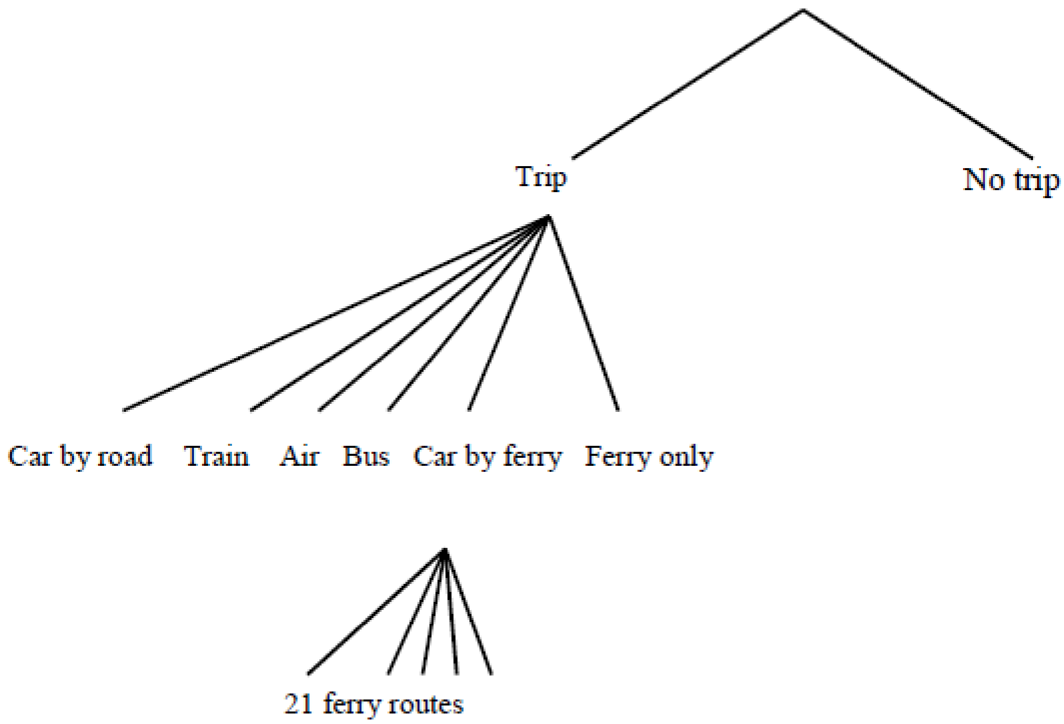


Figure 2.5 – Structure of international trips generated in Sweden

The RiksRVU travel survey did not contain information on the route choice, so other data sources were needed to get the route choice part of the model. A joint estimation of the model is therefore deployed in order to get parameter estimates for the full model structure.

The estimation has resulted in significant estimates for time and cost variables for the mode route choice parts, and in significant estimates of main variables such as income and accessibility (logsum variables from the mode and route choice parts).

CAR OWNERSHIP MODEL

As required by the client, the car ownership model implemented in the system is a previously developed cohort based model for car ownership, based on individual entry and exit probabilities for car ownership. The model was developed by the Swedish National Road and Transport Institute. The model gives zonewise car ownership levels. The main variables in this model are income, fuel price, age and company car.

VALIDATION

The currently implemented models are now being validated. The validation of the models is made in different ways. In the estimation phase, the ability of the model to replicate the choices actually made is tested for different classification of the data. After implementation, the models are compared with the base information from the travel survey. Finally, the model predictions for the base year are compared to other sources of information, mainly traffic counts. Also, elasticities are calculated before and after model implementation.

SYSTEM DESIGN

WINDOW MENU SYSTEM

The SAMPERS system is built up as a Windows menu system. The software is developed using Visual Basic as the basic program language. The system contains a number of basic features, that can be put together to forecast scenarios, which in turn can form a forecasting project. Scenarios are given properties that relate all runs within the scenario to a certain database for zonal data, forecasting year etc. In the same way, projects are given properties that relate all scenarios to the same level of aggregate result output. For the forecasting, the following features may be invoked by the users:

- car ownership model
- the EMME/2 system, directly or by macros
- regional models
- domestic long distance models
- international models
- disaggregation of trips from national to regional level
- iteration (such as car assignment and a regional model run)

The main menu is shown in Figure 2.6, where the user (by clicking on menu buttons) has put together two scenarios, in order to forecast the effects of an extended high-speed train network. The first scenario and the second scenario is the extended high-speed train network. In the base scenario (which might of course have been run already), the first steps are to calculate supply matrices for the different modes. This is done by invoking EMME/2 macros. Input and output are defined by setting the properties of the macros.

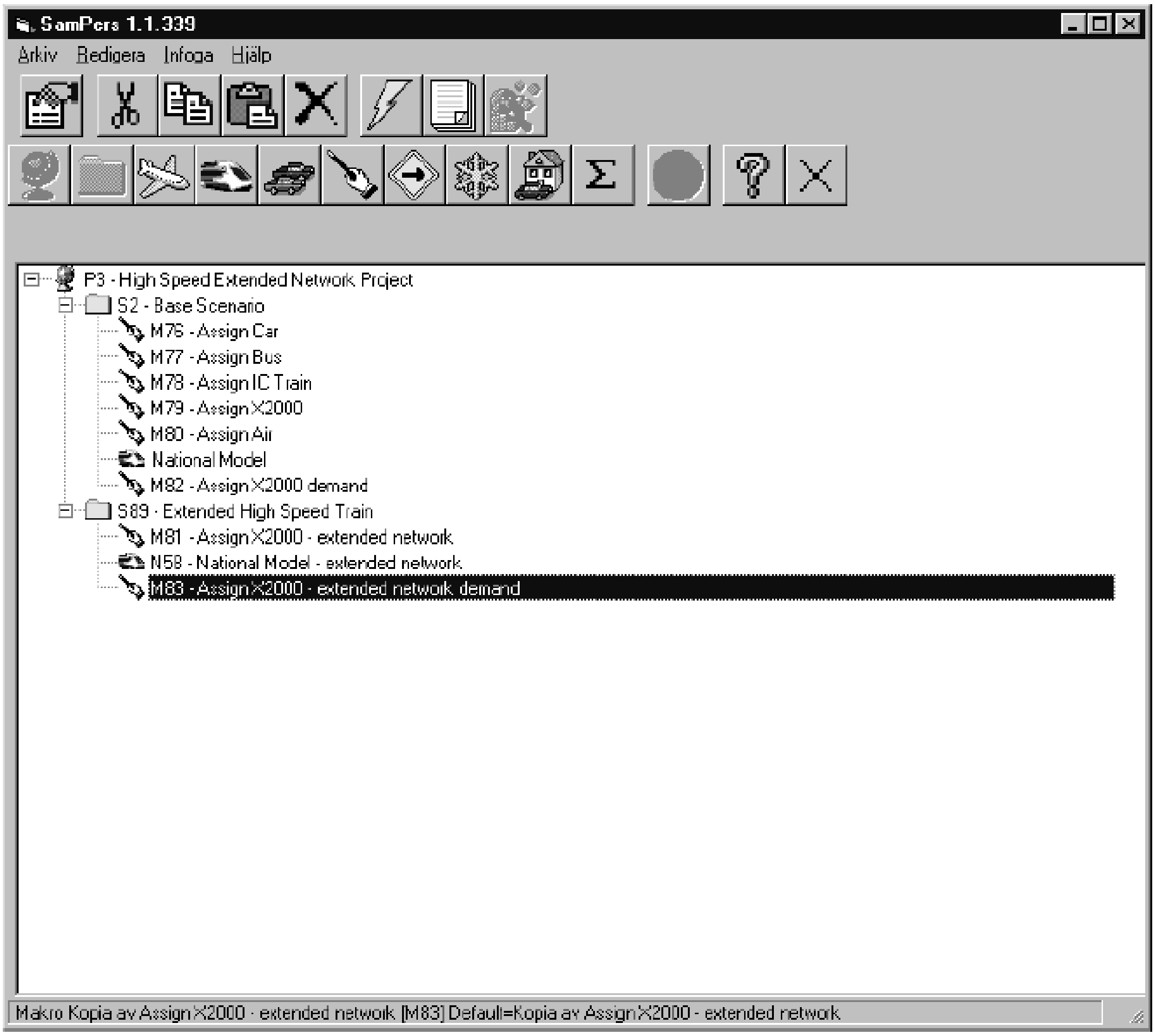


Figure 2.6 – SAMPERS main menu

The next step is then to run the domestic long distance model, using the supply data created by the previous macro steps. As for the macros, input and output is defined by setting the properties of the domestic long distance model. The last step is then to assign the resulting trips to the network, again by invoking EMME/2 macros for the different modes.

The first step in the extended high-speed scenario is the supply macro for high-speed train, which in this scenario has an extended network. The supply for other modes is not changed, and does not have to be recalculated. The next step is to run the domestic long distance model, now with properties set to match the new high-speed train supply. In a final step, a new assignment is made of the resulting demand matrix for the high-speed train mode.

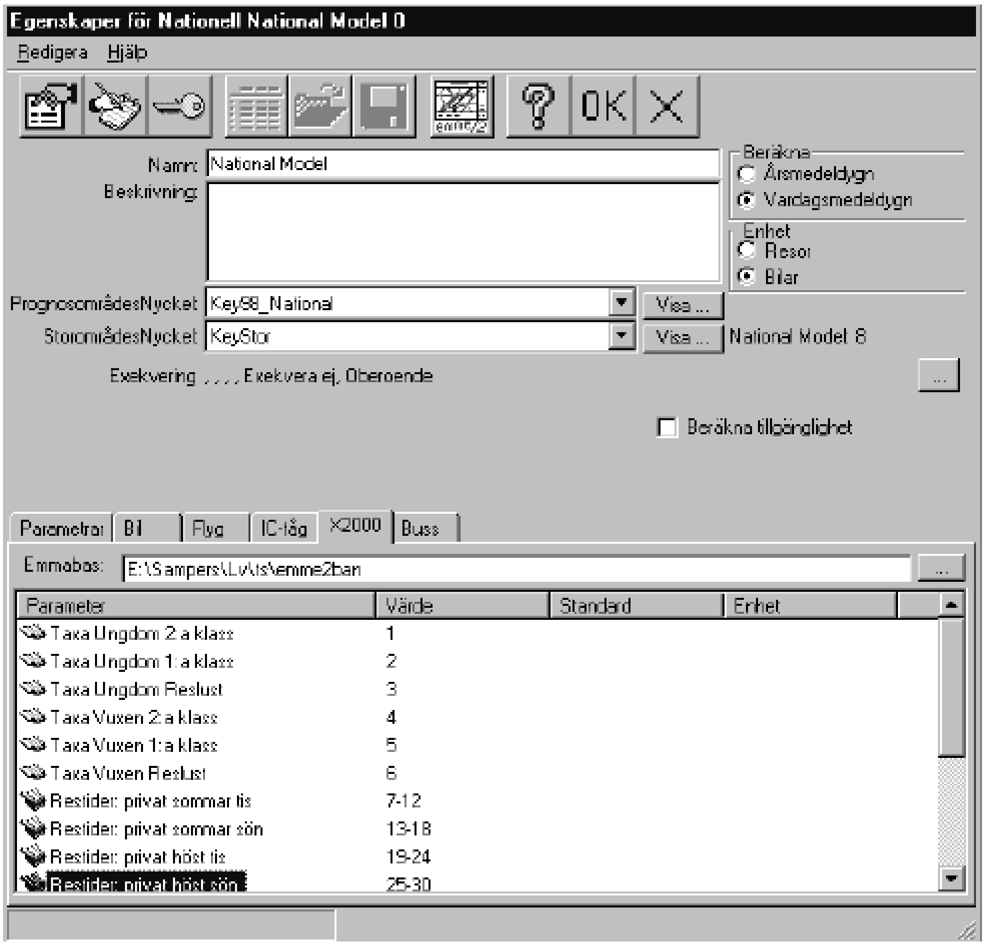


Figure 2.7 – Examples of property sheet for the national model

The definition of the scenarios can be made separately from the actual running of the macros and models, to make the work as efficient as possible. Different steps can also be assigned to different computers, to give complicated runs (such as running many regional models) a shorter turnaround time. Dependencies between different steps can be introduced to ensure that steps are carried out in the right sequence.

EMME/2 INTEGRATION

The supply data needed for the models to be run are created in the EMME/2 system. Normally a number of travel time component matrices need to be exported from the EMME/2 databank to be accessed by the forecasting software. Then, result matrices need to be imported back into the EMME/2 databank. This may be very time- and storage consuming, and in order to avoid this a more direct process was implemented. Thus, in the SAMPERS system the EMME/2 databank is directly accessed from the SAMPERS modules, for reading as well as for writing.

RESULTS

When the scenarios in the example are run, the user may want to look at the results. For EMME/2 macros, results are stored in the EMME/2 databank, and can be viewed by invoking the EMME/2 system directly from the SAMPERS menu. For model runs, results are always produced at an aggregate level in the form of tables. If the user wants, then also the Cognos PowerPlay system can be invoked from the SAMPERS system, allowing results to be graphically displayed for a rich variety of categories. In Figure 2.8, the travel demand of a scenario is displayed with regard to mode and trip length.

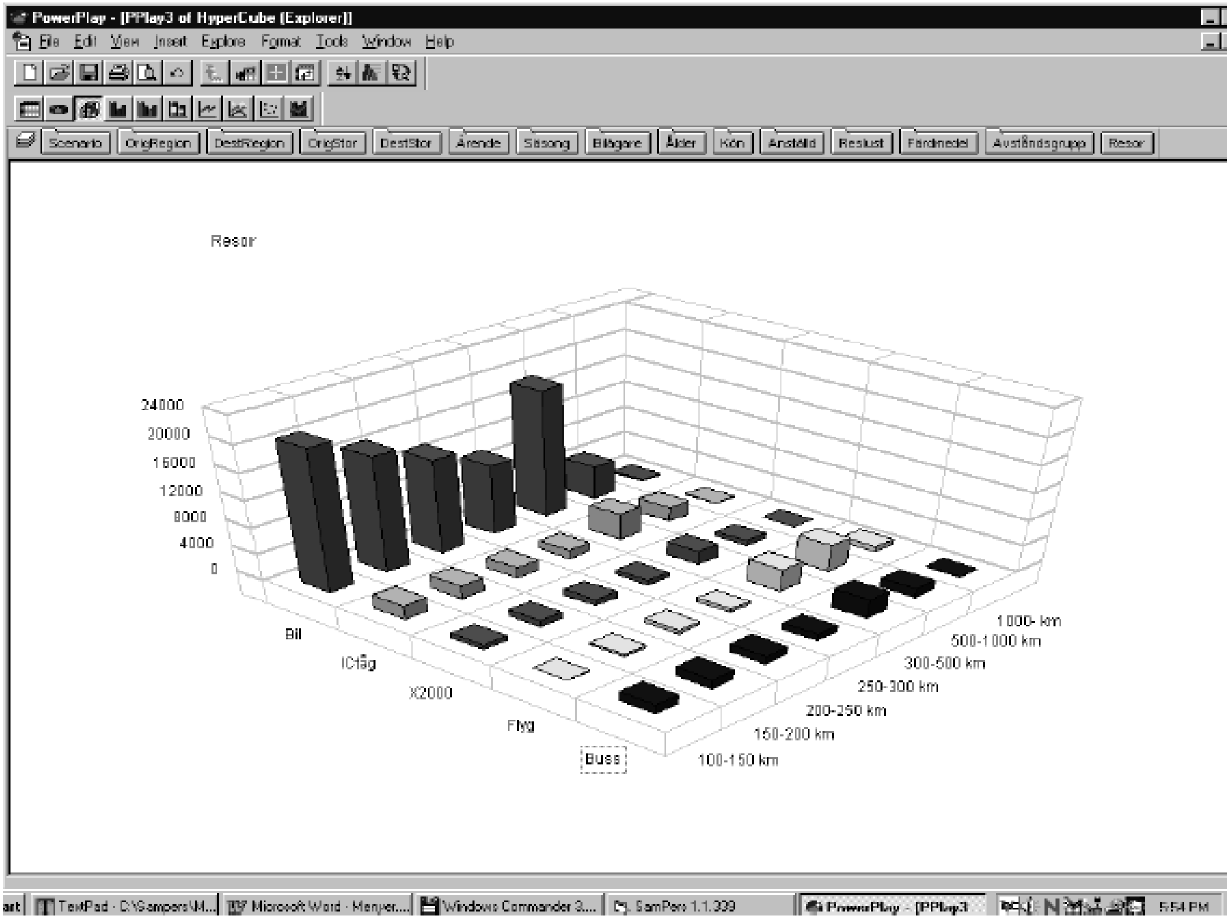


Figure 2.8 – Cognos PowerPlay graph showing results from the national model

COST BENEFIT CALCULATION

The demand to forecast is often only a partial result in the planning process. Environmental impact and cost benefit calculations are further steps that are required by decision makers.
The SAMPERS system contains two modules to match these requirements. In the effect module, emissions and accident rates are calculated. Then, in the cost – benefit module, these travel time and vehicle cost changes. As the other SAMPERS modules, the effect modules scenario calculations are performed as separate steps like macros and model runs.

Accessibility

Yet another result dimension is formed by different accessibility measures. SAMPERS also contains an accessibility module, where a number of different accessibility measures can be analyzed in a GIS-oriented way using ESRI MapObject (Figure 2.9). Some of these measures are related to a single scenario, whereas other measures relate to scenario differences. There are three different types of accessibility measures:

- impedance measure, i.e. travel time or generalized cost to reach certain areas
- closeness, i.e. how many work places can be reached within a certain time
- model based data, i.e. passenger distance travelled, or logsum measures

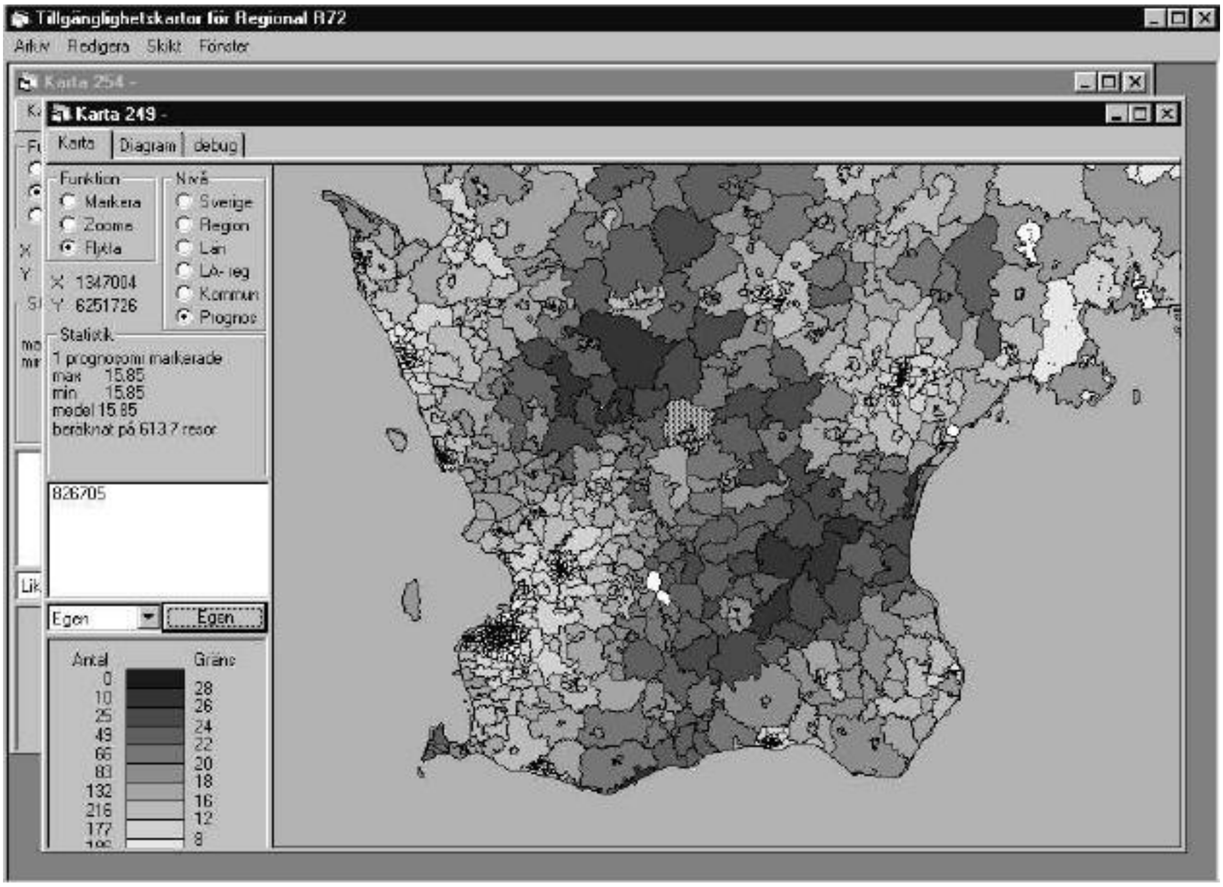


Figure 2.9 – MapObject application in SAMPERS accessibility module

The SAMPERS model system contains many improvements over previous model system:

- it covers all personal trip making
- it is based on recent data, covering all trips
- the model structures are enhanced
- all models, including assignment is handled within the same user-friendly software
- effects, cost benefit and accessibility analysis can be carried out in the system

However, as can be expected from a system containing a high level of geographical and socio-economic detail, run times are long. On a standard PC, run times for the regional models (which takes the longest time to run), vary from 4 to about 30 hours, depending on the size of the region. If a full set of models is to be run on one computer, several days are needed to capture road network capacity restraints. The possibility to run a project on different computers can however reduce the run times substantially.

Therefore, it is currently being discussed to create a sketch version of the system, in which some of the socio-economic detail is given up in favour of increased speed. For example, gender and age groups may be reduced, which may cut run time by a factor of at least four.
The price is some aggregation error and less socio-economic detail in the results, which may not be too important until the end of the analysis process.
There are still some parts in the system that are not yet developed. These are regional trip chaining, long distance access/egress mode choice and departure time and ticket type choice for domestic long distance trips. They will not only add to the capability of the system, but will also make the system more time consuming to run [13].

2.3.2.2 Historical Traffic Data and Forecast Calculation

As explained in paragraph 2.3.2.1, a function for the traffic during the whole service life of the bridge is needed in order to calculate the cost for users. First the historical data on traffic have been collected for each of the roads the different bridges are located in. This was possible with the help of a web application, in use in Vägverket, through which is possible to look at all the surveys in the whole Sweden approximately from 1989 to 2008. The data available are 'total traffic', 'cars', 'trucks', presented as number of vehicles but also as 'pair of axis'. We should notice that the most reliable data is the 'pair of axis' but the tool implemented in BaTMan use 'cars' and 'trucks' in order to calculate the costs for users, so an approximation has been necessary.
Then, with the help of the SAMPERS traffic model, it was possible to get information on the traffic forecast. The forecast is given for a specific area, and different forecasts are given for cars and trucks. In the tables below are shown the traffic forecasts for the whole of Sweden, calculated according to the SAMPERS model. One prediction is made for 2020 and another for 2040.

Table 2.4 – Traffic forecasting for the whole Sweden – ETT forecast

		EET forecast					
CARS		Input Spreadsheet Cars 2006-2020	Annual increase	cars 2020-2040	Annual increase	Input Spreadsheet Cars 2006-2040	Annual increase
Group	**Group Name**	factor	till 2020	factor	from 2020	Factor	2006-2040
10	Stockholm	1.22	1.5%	1.19	0.9%	1.45	1.1%
30	Uppsala	1.25	1.6%	1.19	0.9%	1.49	1.2%
40	Södermanland	1.06	0.4%	1.21	1.0%	1.29	0.7%
50	Östergötland	1.13	0.9%	1.15	0.7%	1.30	0.8%
60	Jönköping	1.08	0.5%	1.20	0.9%	1.30	0.8%
70	Kronoberg	1.11	0.7%	1.20	0.9%	1.33	0.9%
80	Kalmar	1.10	0.7%	1.17	0.8%	1.28	0.7%
90	Gotland	1.08	0.6%	1.10	0.5%	1.19	0.5%
100	Blekinge	1.13	0.8%	1.16	0.7%	1.30	0.8%
121	Skåne Sydväst	1.26	1.6%	1.20	0.9%	1.51	1.2%
122	Skåne Nordväst	1.14	0.9%	1.25	1.1%	1.42	1.0%
123	Skåne Öst	1.13	0.8%	1.21	1.0%	1.36	0.9%
124	Skåne Nordöst	1.03	0.2%	1.25	1.1%	1.28	0.7%
141	Stor-Göteborg	1.11	0.7%	1.22	1.0%	1.35	0.9%
142	Södra VVÄ	1.16	1.0%	1.23	1.1%	1.43	1.1%
143	Östra VVÄ	1.03	0.2%	1.24	1.1%	1.27	0.7%
144	Västra och Norra VVÄ	1.00	0.0%	1.19	0.9%	1.19	0.5%
145	Längs E18 VVÄ	1.07	0.5%	1.17	0.8%	1.25	0.7%
181	Östra Örebro län	1.09	0.6%	1.20	0.9%	1.30	0.8%
182	Västra Örebro län	1.04	0.3%	1.20	0.9%	1.24	0.6%
183	Norra Örebro län	1	0%	1.11	0.5%	1.11	0.3%
191	Nordvästra Västmanland	1	0%	1.20	0.9%	1.20	0.5%
192	Sydvästra Västmanland	1.06	0.4%	1.22	1.0%	1.30	0.8%

193	Östra Västmanland	1.10	0.7%	1.21	1.0%	1.33	0.8%
200	Dalarna	1.02	0.2%	1.19	0.9%	1.22	0.6%
210	Gävleborg	1.07	0.5%	1.17	0.8%	1.26	0.7%
220	Västernorrland	1.01	0.1%	1.14	0.7%	1.15	0.4%
230	Jämtland	1.04	0.3%	1.15	0.7%	1.20	0.5%
241	Västerbottens kust och inland	1.07	0.5%	1.15	0.7%	1.23	0.6%
242	Västerbottens fjäll och inland	1.00	0.0%	1.14	0.6%	1.14	0.4%
251	Norrbottens kust och inland	1.13	0.9%	1.19	0.9%	1.35	0.9%
252	Norrbottens fjäll och inland	1	0%	1	0%	1	0%
Total		1.12	0.8%	1.20	0.9%	1.34	0.9%

EET forecast						
Trucks	Input spreadsheet trucks 2006-2020	Annual increase	trucks 2020-2040	Annual increase	Input spreadsheet trucks 2006-2040	Annual increase
Region	Factor	till 2020	Factor	from 2020	Factor	2006-2040
Stockholm	1.30	1.9%	1.45	1.9%	1.88	1.9%
Uppsala	1.35	2.2%	1.53	2.1%	2.06	2.2%
Södermanland	1.33	2.1%	1.51	2.1%	2.01	2.1%
Östergötland	1.32	2.0%	1.49	2.0%	1.96	2.0%
Jönköping	1.32	2.0%	1.49	2.0%	1.97	2.0%
Kronoberg	1.26	1.7%	1.39	1.7%	1.76	1.7%
Kalmar	1.16	1.0%	1.23	1.0%	1.42	1.0%
Gotland	1.48	2.8%	1.75	2.8%	2.58	2.8%
Blekinge	1.27	1.7%	1.41	1.7%	1.79	1.7%
Skåne	1.35	2.2%	1.54	2.2%	2.08	2.2%
Halland	1.34	2.1%	1.52	2.1%	2.05	2.1%
Västra Götaland	1.36	2.2%	1.54	2.2%	2.09	2.2%
Värmland	1.18	1.2%	1.27	1.2%	1.50	1.2%
Örebro	1.31	2.0%	1.48	2.0%	1.94	2.0%
Västmanland	1.37	2.3%	1.57	2.3%	2.15	2.3%
Dalarna	1.25	1.6%	1.38	1.6%	1.73	1.6%
Gävleborg	1.15	1.0%	1.22	1.0%	1.41	1.0%
Västernorrland	1.13	0.9%	1.19	0.9%	1.34	0.9%
Jämtland	1.11	0.7%	1.16	0.7%	1.28	0.7%
Västerbotten	1.17	1.1%	1.24	1.1%	1.45	1.1%
Norrbotten	1.09	0.6%	1.14	0.6%	1.24	0.6%
Totalt Riket	1.28	1.8%	1.43	1.8%	1.83	1.8%

Table 2.5 – Traffic forecasting for the whole Sweden – REF forecast

Cars			**REF forecast**					
			Input spreadsheet cars			Annual increase	Input spreadsheet Cars	Annual increase
Group	**Group name**		2006-2020	Annual increase	cars 2020-2040		2006-2040	
10	Stockholm		Faktor	till 2020	Faktor	från 2020	Faktor	2006-2040
30	Uppsala		1.32	2.0%	1.15	0.7%	1.52	1.2%
40	Södermanland		1.39	2.4%	1.14	0.7%	1.59	1.4%
50	Östergötland		1.17	1.1%	1.17	0.8%	1.36	0.9%
60	Jönköping		1.23	1.5%	1.12	0.6%	1.38	0.9%
70	Kronoberg		1.19	1.3%	1.16	0.7%	1.37	0.9%
80	Kalmar		1.23	1.5%	1.16	0.7%	1.42	1.0%
90	Gotland		1.22	1.4%	1.12	0.6%	1.36	0.9%
100	Blekinge		1.17	1.1%	1.06	0.3%	1.25	0.6%
121	Skåne Sydväst		1.23	1.5%	1.12	0.5%	1.38	0.9%
122	Skåne Nordväst		1.38	2.3%	1.15	0.7%	1.59	1.4%
123	Skåne Öst		1.26	1.7%	1.20	0.9%	1.51	1.2%
124	Skåne Nordöst		1.24	1.5%	1.16	0.8%	1.44	1.1%
141	Stor-Göteborg		1.14	0.9%	1.20	0.9%	1.36	0.9%
142	Södra VVÄ		1.22	1.4%	1.17	0.8%	1.43	1.0%
143	Östra VVÄ		1.26	1.7%	1.19	0.9%	1.51	1.2%
144	Västra och Norra VVÄ		1.12	0.8%	1.19	0.9%	1.34	0.9%
145	Längs E18 VVÄ		1.10	0.7%	1.15	0.7%	1.26	0.7%
181	Östra Örebro län		1.17	1.1%	1.13	0.6%	1.32	0.8%
182	Västra Örebro län		1.20	1.3%	1.15	0.7%	1.38	0.9%
183	Norra Örebro län		1.14	1.0%	1.16	0.7%	1.32	0.8%
191	Nordvästra Västmanland		1.03	0.2%	1.14	0.7%	1.17	0.5%
192	Sydvästra Västmanland		1.08	0.5%	1.20	0.9%	1.29	0.8%
193	Östra Västmanland		1.18	1.2%	1.18	0.8%	1.38	1.0%
200	Dalarna		1.21	1.4%	1.16	0.7%	1.40	1.0%
210	Gävleborg		1.13	0.9%	1.17	0.8%	1.32	0.8%
220	Västernorrland		1.18	1.2%	1.14	0.6%	1.34	0.9%
230	Jämtland		1.10	0.7%	1.10	0.5%	1.21	0.6%
241	Västerbottens kust och inland		1.14	0.9%	1.11	0.5%	1.27	0.7%
242	Västerbottens fjäll och inland		1.18	1.2%	1.10	0.5%	1.30	0.8%
251	Norrbottens kust och inland		1.09	0.6%	1.11	0.5%	1.21	0.6%
252	Norrbottens fjäll och inland		1.24	1.6%	1.15	0.7%	1.42	1.0%
Total			1	0%	1.02	0.1%	1.02	0.1%
			1.23	1.5%	1.15	0.7%	1.42	1.0%

	REF forecast					
	Input spreadsheet trucks 2006-2020 Factor	Annual increase till 2020	trucks 2020-2040 Factor	Annual increase from 2020	Input spreadsheet Trucks 2006-2040 Factor	Annual increase 2006-2040
Stockholm	1.31	2.0%	1.48	2.0%	1.94	2.0%
Uppsala	1.38	2.3%	1.58	2.3%	2.18	2.3%
Södermanland	1.37	2.3%	1.56	2.3%	2.13	2.3%
Östergötland	1.37	2.3%	1.56	2.3%	2.14	2.3%
Jönköping	1.37	2.3%	1.56	2.3%	2.14	2.3%
Kronoberg	1.31	2.0%	1.47	2.0%	1.93	2.0%
Kalmar	1.16	1.1%	1.24	1.1%	1.43	1.1%
Gotland	1.48	2.8%	1.75	2.8%	2.58	2.8%
Blekinge	1.28	1.8%	1.42	1.8%	1.81	1.8%
Skåne	1.39	2.4%	1.59	2.4%	2.21	2.4%
Halland	1.35	2.2%	1.54	2.2%	2.08	2.2%
Västra Götaland	1.38	2.3%	1.58	2.3%	2.18	2.3%
Värmland	1.19	1.3%	1.29	1.3%	1.54	1.3%
Örebro	1.37	2.3%	1.56	2.3%	2.14	2.3%
Västmanland	1.39	2.4%	1.60	2.4%	2.23	2.4%
Dalarna	1.28	1.8%	1.42	1.8%	1.82	1.8%
Gävleborg	1.19	1.2%	1.28	1.2%	1.53	1.2%
Västernorrland	1.15	1.0%	1.22	1.0%	1.40	1.0%
Jämtland	1.15	1.0%	1.21	1.0%	1.39	1.0%
Västerbotten	1.19	1.2%	1.28	1.2%	1.52	1.2%
Norrbotten	1.10	0.7%	1.15	0.7%	1.27	0.7%
Totalt Riket	1.31	2.0%	1.49	2.0%	1.95	2.0%

The tables show two different kind of forecast, made for two different scenarios: the first one, "EET forecast", is made as all the National Politics on environment (CO_2 emission reduction, sustainable development, etc.) are respected. The second prevision, "REF forecast", is developed from the present data without take into account any change in the behavior of the users; this result in a slower increment of traffic for the first scenario and a faster for the second one.

2.3.2.3 LCC – Analysis

In this paragraph it is presented how the results of all the Life Cycle Cost Analysis have been organized for each bridge presented in the paragraph 2.2. First, a table shows some basic information on the bridge and some economic parameters that will be used into the LCCAnalysis. A sample table is shown below.

Table 2.6 – Basic economical and technical information about the bridge

bridges information		economic information	
BaTMan code	24-1790-1	interest rate	0.04
year of construction	2003	inflation rate	0.015
expected service life [years]	120	year update costs	2009
		currency [SEK]	1

The “Bridge Information” consist on the “BaTMan code”, that is the code the bridge is named into the BaTMan database, than the year of construction of the bridge and the expected service life, that could vary depending on the technology adopted and the type of the bridge.

In the column “Economic Information” the interest and inflation rates for the money and another year we want to discount the costs, present year, are listed.

Then the main table is presented (Table 2.7 in the next page), with the costs during the whole life of the bridge; initial investment (‘Planning and Design’ and ‘Material and Construction’), Maintenance, Repair and Rehabilitation (MR&R), dismantle and user costs.

Table 2.7 – Summary of the calculations for the LCCA of bridge presented in Table 2.6

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	2003	100000.00	112356.71	153.01	100000.00	136.18
material and construction	2003	5364000.00	6787171.22	9242.72	5364000.00	7304.66
users cost	2003	105000.00	99141.06	135.01	105000.00	142.99
MR&R						
yearly inspection (10)	yearly	1000.00	37933.69	51.66	37933.69	51.66
yearly maintenance (11)	yearly	2000.00	75867.37	103.32	75867.37	103.32
users cost for yearly op.	service life	8000.00	13412.56	18.27	14205.21	19.34
MR&R cost 1 (1+4)	2020	273000.00	208892.27	284.47	180517.20	245.83
users cost 1	2020	2000.00	2222.01	3.03	2353.32	3.20
MR&R cost 2 (2)	2040	724000.00	340527.63	463.73	294271.75	400.74
users cost 2	2040	11000.00	14798.83	20.15	15673.40	21.34
MR&R cost 3 (1+3+4)	2060	1100000.00	318024.47	433.08	274825.33	374.26
users cost 3	2060	51000.00	83085.29	113.14	87995.38	119.83
MR&R cost 4 (2)	2080	799000.00	141993.57	193.37	122705.75	167.10
users cost 4	2080	14000.00	27618.57	37.61	29250.75	39.83
MR&R cost 5 (1+4)	2100	130000.00	14201.01	19.34	12272.01	16.71
users cost 5	2100	4000.00	9555.48	13.01	10120.18	13.78
Dismantle						
Dismantle (5)	2123	440000.00	146249.91	199.16	138012.66	187.94
users cost	2123	66000.00	196482.26	267.57	208093.78	283.38
		total LCC	8629533.91	11751.64	7073097.77	9632.10

For all of these cost items the Present Value and the Discount Value are calculated. Furthermore, in order to compare bridges with different service life, the Annuity Cost is calculated for both the Present Value and the Discount Value.

The approach here is to calculate also the cost the users have to carry, because of the disturbances caused by the interruptions of normal traffic flows.

In parenthesis, next to the vary operations that are taken into considerations, there are the references to the description of the operation that is performed.

In the histogram below the costs occurred during the whole life of the bridge are shown in a more user-friendly form, to highlight how the costs are spread during the service life. In the histograms are excluded the yearly costs, in order to let the histogram be clearer, of course these costs are taken into account in the calculations.

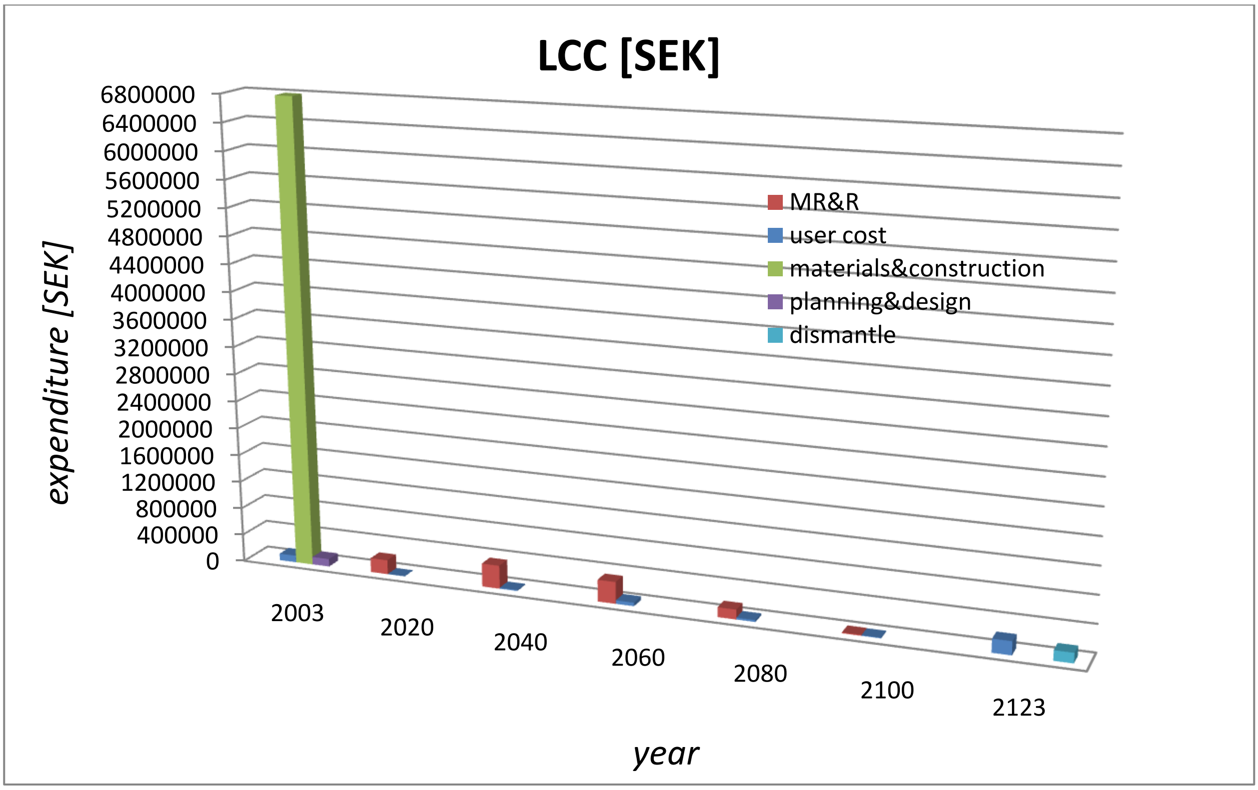


Figure 2.10 – Costs spread over the service life

It is also presented the historical traffic volume on the road the bridge is located in and the forecast until 2040 thanks to the SAMPERS model, presented in the paragraph 2.3.2.1.1. Trough a linear extrapolation it has also been possible to forecast the traffic for the future years (a sample is shown in Figure 2.11 in the next page).

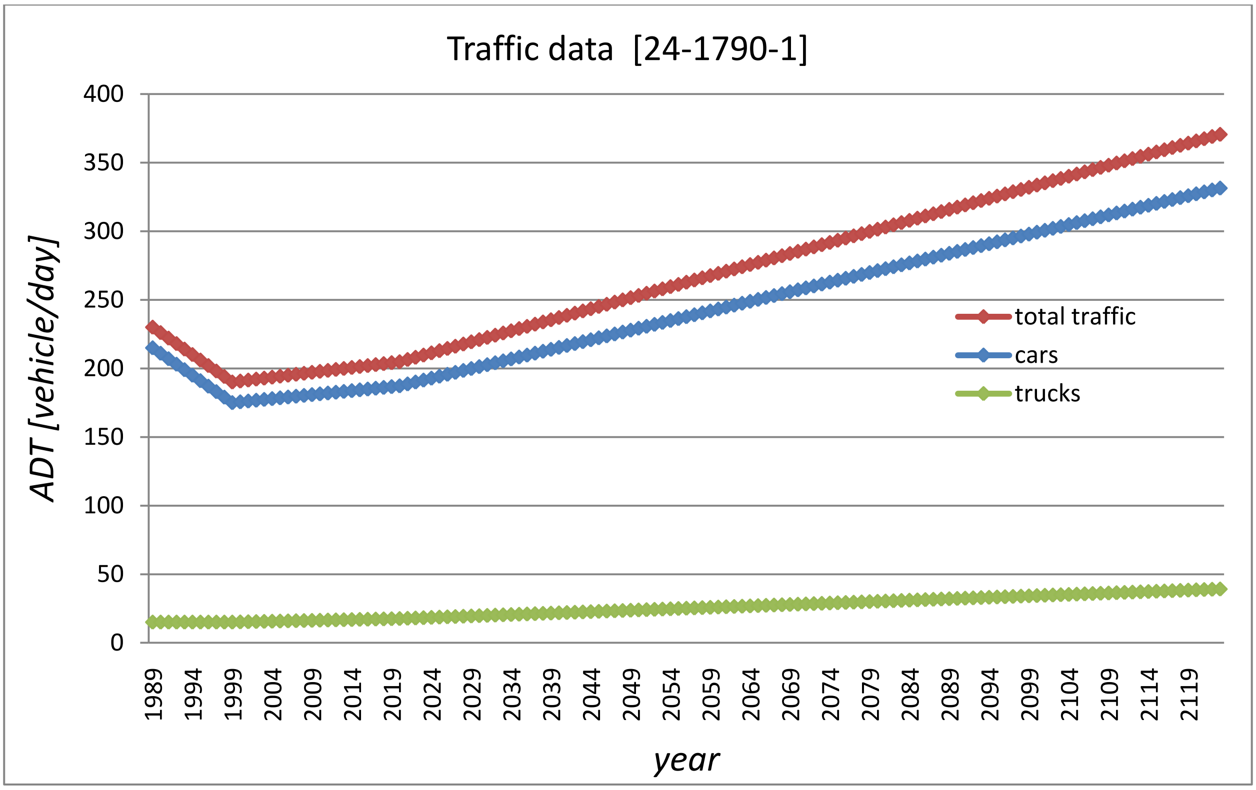


Figure 2.11 – Plot of the past, present and future traffic volumes

Finally, the percentages of impact of the different cost items on the total Life Cycle Cost of the project are shown through the cake-diagrams below.

Table 2.8 - Percentages of impact of the different cost items on the total Life Cycle Cost

% on the total LCC (discount at the year of construction)		
	Costs	%
MR&R	998393.10	14.1
user costs	472692.02	6.7
initial investment	5364000.00	75.8
planning and design	100000.00	1.4
Dismantle	138012.66	2.0

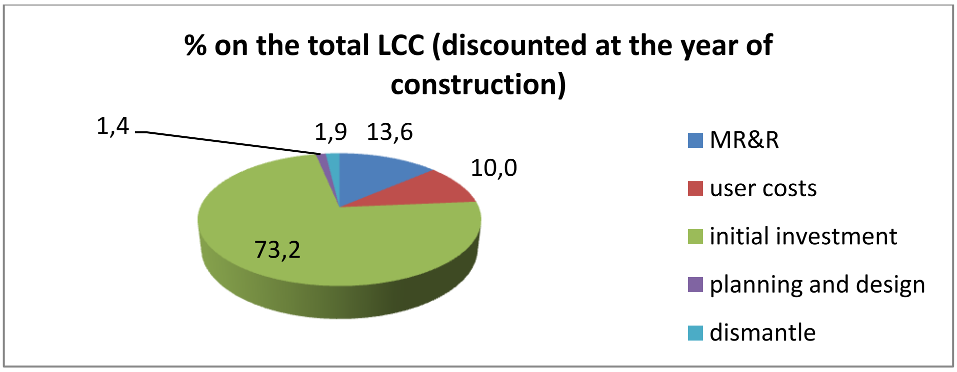


Figure 2.12 – Percentages of impact of the different cost items on the total LCC (discounted at the year of construction)

Table 2.9 - Percentages of impact of the different cost items on the total Life Cycle Cost% on the total LCC (PV 2009)		
	costs	%
MR&R	1137440.02	13.2
user costs	446316.05	5.2
initial investment	6787171.22	78.7
planning and design	112356.71	1.3
dismantle	146249.91	1.7

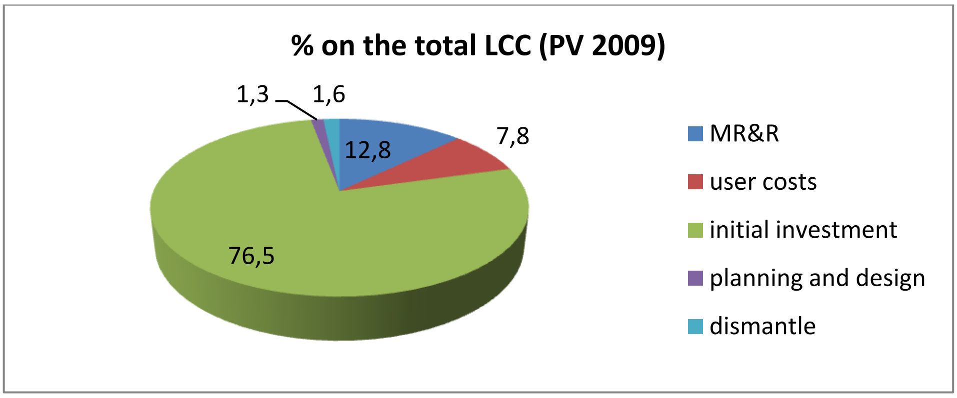


Figure 2.13 – Percentages of impact of the different cost items on the total LCC (present value 2009)

All the different operations of main maintenance are listed in the table below, such that they can be recalled in parenthesis in the tables that shows the Life Cycle Cost Analysis results, with the number on the left column of the table.

Table 2.10 – Description of the operations on the bridges analyzed

n°	***Operation***	***Description***
1	Adjust settlement connection road / Adjust road / adjust embankment	Remove asphalt and replace the gravel under asphalt. Then put new asphalt
2	Repaint steel	Take away all the paint that loose and replace the several layers with new paint
3	change fence	Remove the old fence and replace it with a new and safer fence
4	change pavement / Change isolation on deck	Remove the asphalt/concrete and the waterproofing and replace it with concrete or new waterproof and asphalt
5	Demolition	Take down the old bridge, separate different parts and disposal it
6	Repair concrete	Repair damages on concrete, hammering away bad concrete and cast new concrete. It is often on the edgebeam
7	Adjust slope	To adjust/strengthen the slope with filling with material (rocks)
8	Repaint bearing	Take away all the paint that is loose and replace the several layers with new paint. Often we paint the bearings on place without removing the them. Then we put grease(oil) in place where it is not possible to paint
9	Exchange bearings	Take away old bearing and replace them with new.
10	Yearly inspection	Check from a distance inferior than arm-length all part of the bridge
11	Yearly maintenance	Cleaning the bridge, remove vegetation around and on the bridge, change some parts on the fence, perform small repairing that do not have so much affect on the traffic.

All the tables, graphs, histograms and cake-diagrams are shown in APPENDIX A1 – Life-Cycle Cost Calculations of the Bridges in the North of Sweden.

2.4 Results

In the tables below are summarized the results obtained from the LCCA presented in the previous paragraph (see APPENDIX A1 for detailed calculations).

Table 2.11 – Summary of the results

PV 2009 [SEK]				
n°	***Bridge code***	***Service Life [years]***	***Total LCC***	***Annuity Cost***
1	24-1790-1	120	8 629 534	11 752
2	24-1861-1	120	4 989 279	6 777
3	24-1497-1	100	5 204 830	12 033
4	24-1753-1	120	9 628 595	11 712
5	24-1876-1	120	19 951 560	27 170
6	24-417-1	90	6 705 193	20 371
7	24-471-1	100	6 908 271	15 971
8	25-1432-1	100	5 528 032	12 643
9	25-1674-1	80	8 135 651	30 361
10	25-1888-1	100	16 869 118	38 999
11	25-780-1	100	4 005 242	9 260

Table 2.12 – Summary of the different Cost Items on the total

PV 2009 [SEK]						
		Impact of different cost items on total LCC				
n°	***Bridge Type / Material***	***Initial investment***	***MR&R***	***User costs***	***Planning & design***	***Dismantle***
1	Beam and Slab Bridge/ STEEL	6 787 171 (78,7 %)	1 137 440 (13,2 %)	446 316 (5,2 %)	112 357 (1,3 %)	146 250 (1,7 %)
2	Slab Bridge/ CONCRETE	4 201 102 (84,4 %)	498 110 (10 %)	28 443 (0,6 %)	110 196 (2,2 %)	151 427 (3 %)
3	Slab Bridge/ CONCRETE	3 872 389 (74,4 %)	671 110 (12,9 %)	301 823 (5,8 %)	144 621 (2,8 %)	214 888 (4,1 %)
4	Slab Bridge/ CONCRETE	4 892 634 (50,8 %)	624 851 (6,5 %)	3 733 373 (38,8 %)	116 806 (1,2 %)	260 931 (2,7 %)
5	Slab Bridge/ CONCRETE	9 439 589 (47,3 %)	800 880 (4 %)	9 319 372 (46,7 %)	108 077 (0,5 %)	283 642 (1,4 %)
6	Slab Frame Bridge/ CONCRETE	3 063 579 (45,7)	931 728 (13,9 %)	2 220 913 (33,1 %)	165 677 (2,5 %)	323 296 (4,8 %)
7	Slab Frame Bridge/ CONCRETE	5 687 805 (82,3 %)	566 062 (8,2 %)	115 171 (1,7 %)	153 291 (2,2 %)	385 937 (5,6 %)
8	Slab Frame Bridge/ CONCRETE	3 661 878 (66,2 %)	784 242 (14,2 %)	735 164 (13,3 %)	168 926 (3,1 %)	177 822 (3,2 %)
9	Slab Frame Bridge/ CONCRETE	5 149 139 (63,3 %)	861 204 (10,6 %)	1 758 818 (21,6 %)	144 621 (1,8 %)	221 869 (2,7 %)
10	Slab Frame Bridge/ CONCRETE	11 005137 (65,2 %)	639 842 (3,8 %)	4 873 428 (28,9 %)	114 560 (0,7 %)	236 151 (1,4 %)
11	Slab Frame Bridge/ CONCRETE	2 490 693 (62,2 %)	450 142 (11,2 %)	597 090 (14,9 %)	150 348 (3,8 %)	316 968 (7,9 %)

First of all we can notice that the most cost-efficient bridge, at a first sight, is the number 2, a slab bridge followed by the number 11, a slab frame bridge, because they present the two lowest Annuity Costs among the eleven bridges analyzed (as it can be notice from Table 2.7). For what concern the bridge number 2, the reason this bridge is so cost-efficient is why it is subjected to the smallest traffic volume among all the bridges analyzed, and this is reflected on the user costs (see Table 2.8). On the other hand, the bridge number 11, with an annuity cost of 9 260 SEK has the smallest initial investment among the totality of the bridges included in the analysis. Initial investment is, in most of the cases, the factor that more influence the final total life cycle cost of a bridge. As it can be seen from the tables, bridges with high initial investment results to have high life cycle costs. The second factor that influence the final total cost, in order of importance, is the cost for users. In many cases it is higher than the cost for the maintenance itself, that is one of the causes of this cost. The main factor that influence this cost item is the location of the bridge; but it is important to notice that also in areas like the northern regions, poorly populated, user costs are in many cases pretty influent. Another important factor that influence the cost-efficiency of a bridge is the service life. In the histogram below we can notice the influence of the service life on the annuity cost for the different bridges analyzed. In general, for service lifes longer than 100 years, the annuity cost decrease consistently.

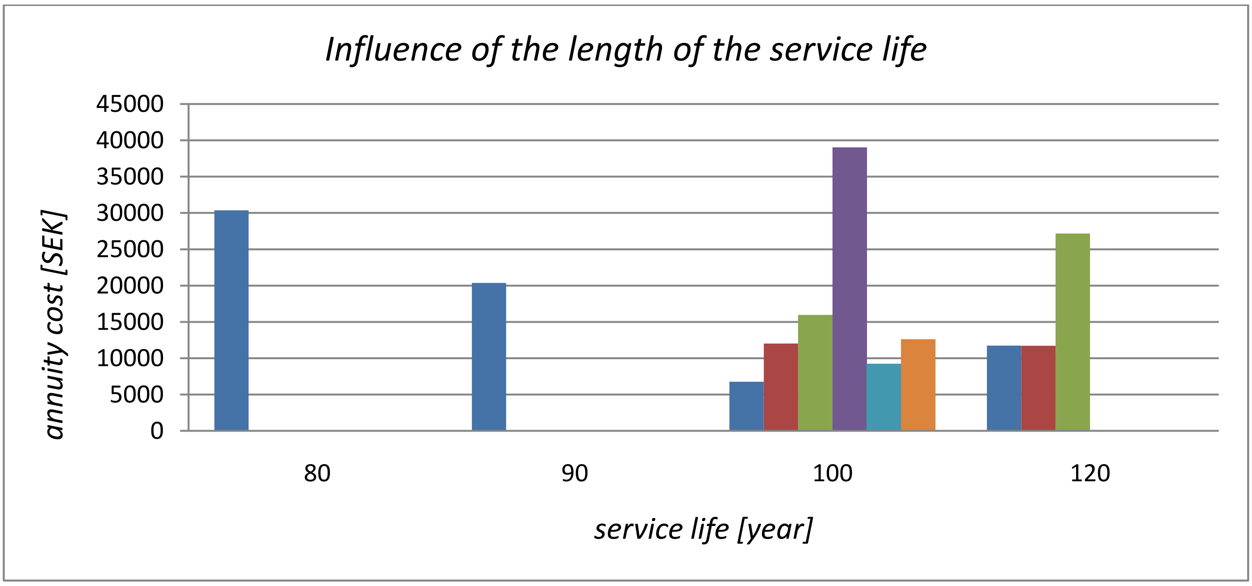


Figure 2.14 – Influence of the length of the service life on annuity cost

2.4.1 Statistical Analysis

In this paragraph I express in details the different dependences of the cost items and the service life on the total LCC and annuity cost, through the calculation of mean values, variance, covariance and the Pearson's correlation coefficient.

PEARSON'S CORRELATION COEFFICIENT

Pearson's correlation coefficient between two variables is defined as the covariance of the two variables divided by the product of their standard deviations:

$$\rho_{X,Y} = \frac{COV(X,Y)}{\sigma_X \sigma_Y}$$

The absolute value of both the sample and population Pearson correlation coefficients are less than or equal to 1. Correlations equal to 1 or -1 correspond to data points lying exactly on a line (in the case of the sample correlation), or to a bivariate distribution entirely supported on a line (in the case of the population correlation). The Pearson correlation coefficient is symmetric: *corr*(*X*,*Y*) = *corr*(*Y*,*X*).

The correlation coefficient ranges from −1 to 1. A value of 1 implies that a linear equation describes the relationship between X and Y perfectly, with all data points lying on a line for which Y increases as X increases. A value of −1 implies that all data points lie on a line for which Y decreases as X increases. A value of 0 implies that there is no linear correlation between the variables.

More generally, note that

$$(X_i - \bar{X})(Y_i - \bar{Y}) > 0$$

if and only if Xi and Yi lie on the same side of their respective means. Thus the correlation coefficient is positive if Xi and Yi tend to be simultaneously greater than, or simultaneously less than, their respective means. The correlation coefficient is negative if Xi and Yi tend to lie on opposite sides of their respective means.

In the table below are summarized the results of the statistical analysis, for detailed calculations see APPENDIX B1 – Statistical Analysis Calculations.

Table 2.13 – Results of the Statistical Analysis

distributions		
X_i	***Y_i***	***Pearson's correlation index***
total LCC	initial investment	0.9139
total LCC	MR&R	0.1897
total LCC	users cost	0.9269
total LCC	planning and design	-0.5937
total LCC	Dismantle	0.0814
total LCC	service life	0.2801
annuity cost	initial investment	0.7306
annuity cost	MR&R	0.2134
annuity cost	users cost	0.6199
annuity cost	planning and design	-0.1519
annuity cost	Dismantle	0.1639
annuity cost	service life	-0.4015

The results of this Statistical Analysis show an high correlation between initial investment and user costs with total LCC and annuity cost, as we can see from the table above, where the Pearson's Correlation Index reach 0,91 and 0,93 with the total LCC and 0.73 and 0.62 with the annuity cost. The invers correlation between planning and design and total LCC, and planning and design and annuity cost, equal respectively to -0.59 and -0.15 has no practical meaning, but the other inverse correlation between service life and annuity cost, of -0.40 shows, statistically, that when the service life increase, the annuity cost decrease.

3. Perspectives of Timber and Soil-Steel Bridges

3.1 Introduction

The most common types of bridges in Sweden, and in Europe, about the ones with a span around 20 m, are flat frame, followed by composite concrete/steel and steel bridges. These bridges have been designed without taken into account the Life Cycle Cost Analysis. New and innovative types of bridges, like Timber and Soil-Steel Bridges have nowadays to be considered as an alternative solution. In order to consider one of these alternatives a LCCA will be performed to find out if it is really economical and cost efficient to adopt one of these solutions.

3.2 Timber Bridges

Wood is one of the earliest building materials, and as such often its use has been based more on tradition than on principles of engineering. However, the structural use of wood and wood-based materials has increased steadily in recent times, including a renewed interest in the use of timber as a bridge material. Supporting this renewed interest has been an evolution of our understanding of wood as structural material and our ability to analyze and design safe, durable and functional timber bridge structures.

An accurate and complete understanding of any material is key to its proper use in structural applications, and structural timber and other wood-based materials are no exception to this requirements [14].

TIMBER AS A BRIDGE MATERIAL

Wood has been widely used for short- and medium-span bridges. Although wood has the reputation of being a material that provides only limited service life, wood can provide long-standing and serviceable bridge structures when properly protected from moisture. For example, many covered bridges from the early 19th century still exist and are in use. Today, rather than protecting wood by a protective shelter as with covered bridge of yesterday, wood preservatives which inhibit moisture and biological attack have been used to extend the life of modern timber bridges.

As with any structural material, the use of wood must be based on a balance between its inherent advantages and disadvantages, as well as consideration of the advantages and disadvantages of other construction materials. Some of the advantages of wood as a bridge material include:

- Strength
- Light weight
- Constructability
- Energy absorption
- Economics
- Aesthetics

These advantages must be considered against the three primary disadvantages:

- Decay
- Insect attack
- Combustibility

Wood can withstand short-duration overloading with little or no residual effects. Wood bridges require no special equipment for construction and can be constructed in virtually any weather conditions without any negative effects.

Wood is a naturally durable material resistant to freeze-thaw effects as well as deicing agents. Furthermore, large-size timber provide good fire resistance as a result of natural charring. However, if inadequately protected against moisture, wood is susceptible to decay and biological attack. With proper detailing and the use of preservatives treatments, the threat of decay and insects can be minimized. Finally, in many natural settings, wood bridges offer an aesthetically pleasing and unobtrusive option.

PROPERTIES OF WOOD AND WOOD PRODUCTS

It is important to understand the basic structure of wood in order to avoid many of the pitfalls relative to the misuse and/or misapplication of the material. Wood is a natural, cellular, anisotropic, hygrothermal and viscoelastic material, and by its natural origins contains a multitude of inclusions and other defects [14].

Physical properties of wood

One physical aspect of wood that deserves attention here is the effect of moisture on the physical and mechanical properties and performance of wood. Many problems encountered with wood structures, especially bridges, can be traced to moisture. The amount of moisture present in wood is described by the moisture content (MC), which is defined by the weight of the water contained in the wood as a percentage of the weight of the oven-dry wood. As wood is dried, water is first evaporated from the cells cavities, then as drying continues, water from the cell walls is drown out. The point at which free water in the cell cavities is completely evaporated, but the cell walls are still saturated, is termed the *fiber saturation point* (FSP). The FBS is quite variable among and within species, but is on the order of 24% to 34%. The FSP is an important quantity since most physical and mechanical properties are dependent on changes in MC below the FSP. Finally, wood releases and absorbs moisture to and from the surrounding environment. When the wood equilibrates with the environment and moisture is not transferring to or from the material, the wood is said to have reached its *equilibrium moisture content* (EMC). The table below provides the average EMC as a function of dry-bulb temperature and relative humidity.

TABLE 20.1 Moisture Content (%) of Wood in Equilibrium with Temperature and Relative Humidity

Temp. (°C)	Relative Humidity (%)																			
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	98
0	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3	26.9
5	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3	26.9
10	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	'9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3	26.9
15	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1	26.8
20	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9	26.6
25	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6	26.3
30	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	20.8	23.3	26.0
35	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	20.5	22.9	25.6
40	1.1	2.2	3.2	4.1	5.0	5.7	6.4	7.1	7.8	8.6	9.3	10.1	11.1	12.2	13.4	14.9	16.8	20.3	22.7	25.4
45	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	20.1	22.4	25.2
50	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0	24.7
55	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5	24.2

Adapted from USDA, 1987 [10].

Figure 3.1 - Average EMC as a function of dry-bulb temperature and relative humidity

The *Wood Handbook* provides other tables that are specific for given species or species groups and allow designers better estimates of in-service moisture contents that are required for their design calculations.

Wood shrinks and swells as its MC changes below the FSP; above the FSP, shrinkage and swelling can be neglected. Wood machined to a specified size at an MC higher than the expected in service will therefore shrink to a smaller size in use. Conversely, if the wood is machined at an MC lower than that expected in service, it will swell. Either way, shrinkage and swelling due to changes in MC must be taken into account in design. In general, the shrinkage along the grain is significantly less than that across the grain. For example, as a rule of thumb, a 1% dimensional change across the grain can be assumed for each 4% change in MC, whereas a 0.02% dimensional change in the longitudinal direction may be assumed for each 4% change in MC. More-accurate estimates of dimensional changes can be made using published values of shrinkage coefficient for various species.

In addition to simple linear dimensional changes in wood, drying of wood can use warp of various types. Bow (distortion in the weak direction), crook (distortion in the strong direction), twist (rotation distortion), and cup (cross-sectional distortion similar to bow) are common forms of warp and, when excessive, can adversely affect the structural use of the member. Finally, drying stresses (internal stress resulting from differential shrinkage) can be quite significant and can lead to checking (cracks formed along the growth rings) and splitting (cracks formed across the growth rings) [14].

MECHANICAL PROPERTIES OF WOOD

The mechanical properties of wood are also functions of the MC. Above the FSP, most properties are invariant with changes in MC, but most properties are highly affected by changes in the MC below the FSP. For example the modulus of rupture of wood increases by nearly 4% for a 1% decrease in moisture content below the FSP. The following equation is a general expression for relating any mechanical property to MC:

$$P_{MC} = P_{12}\left(\frac{P_{12}}{P_g}\right)^{(12-MC)/(FSP-MC)} \tag{3.1}$$

Where P_{MC} : property of interest at any MC below FSP

P_{12} : property at 12% MC

P_g : property in the green condition (at FSP)

For structural design purposes, using an equation such as the one above, would be cumbersome. Therefore, design values are typically provided for a specific maximum MC (e.g. 19%) and adjustments are made for “wet use”.

Load history can also have a significant effect on the mechanical performance of wood members. The load that causes failure is a function of the rate and duration of the load applied to the member. That is, a member can resist higher magnitude loads for shorter durations or, stated differently, the longer a load is applied, the less able is a wood member to resist that load. This response is termed *load duration effect* in wood design. The figure below illustrate this effect by plotting the time-to-failure as a function of the applied stress expressed in terms of the short-term (static) ultimate strength.

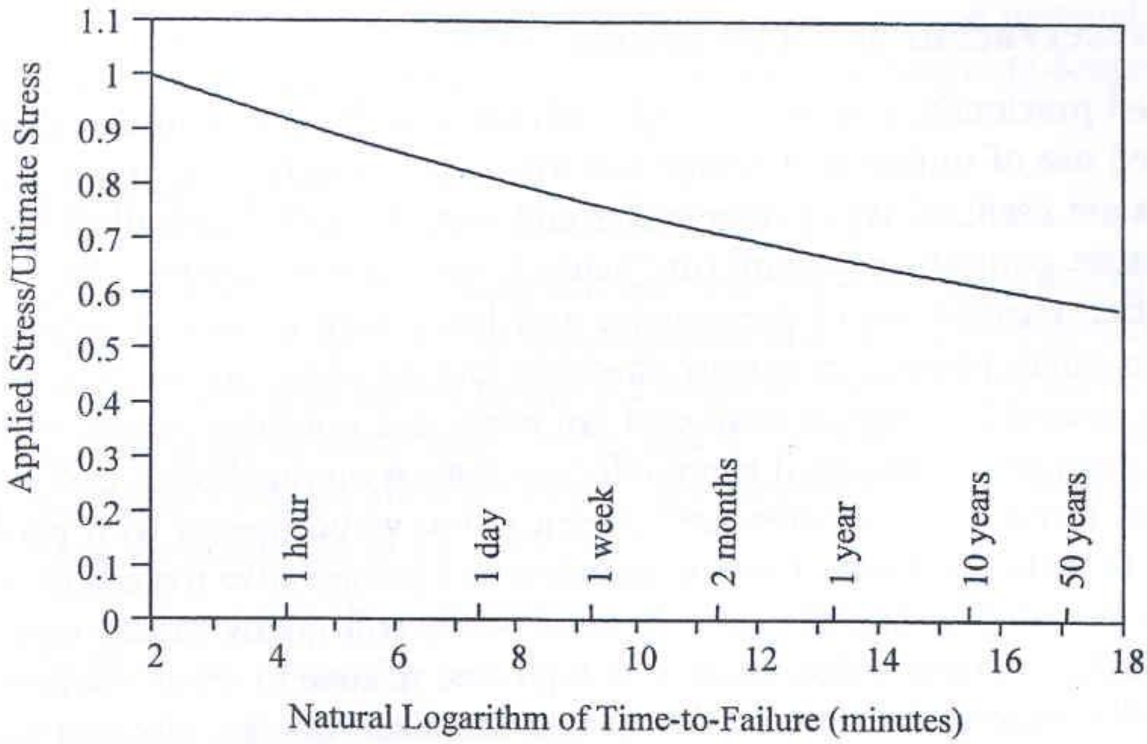


Figure 3.2 – Curve for current ‘load duration’ design

There are many theoretical models proposed to represent this response, but the line shown in the Figure 3.2 was developed at the U.S. Forest Product Laboratory in the early 1950s and is the basis for current design “load duration” adjustment factors.

The design factors derived from the relationship illustrated in Figure 3.2 are appropriate only for stresses and not for stiffness or, more precisely, the modulus of elasticity. Related to load duration effects, the deflection of a wood member under sustained load increases over time. This response, termed *creep effects*, must be considered in design when deformation or deflections are critical from either a safety or serviceability standpoint. The main parameters that significantly affect the creep response of wood are stress level, moisture content, and temperature. In broad terms, a 50% increase in deflection after a year or two is expected in most situations, but can easily be upward of 200% given certain condition. In fact, if a member is subjected to continuous moisture cycling, a 100 to 150% increase in deflection could occur in a matter of a few weeks. Unfortunately, the creep response of wood, especially considering the effect of moisture cycling, is poorly understood and little guidance is available to the designer.

Wood, being a fibrous material, is naturally resistant to fatigue effect, particularly when stressed along the grain. However, the fatigue strength of wood is negatively affected by the natural presence of inclusions and other defects. Knots and slop of grain in particular reduce fatigue resistance. Regardless of this, wood performs well in comparison with structural steel and concrete. In fact, the fatigue strength of wood has been shown to be approximately double that of the most common metals when evaluated at comparable stress levels relative to the ultimate strength of the material. The potential for fatigue-induced failure is considered to be rather low for wood, and thus fatigue is typically not considered in timber bridge design [14].

WOOD AND WOOD-BASED MATERIALS FOR BRIDGE CONSTRUCTION

The natural form of timber is the log. In fact, many primitive and “rustic” timber bridges are nothing more than one or more logs tied together. For construction purposes, however, it is simpler to use regular elements in bridges and other structures rather than round logs. Solid sawn lumber is cut from logs and was the mainstay of timber bridge construction for years. Solid sawn lumber comes in a variety of sizes including boards (less than 38 mm thick and 38 to 387 mm wide), dimension lumber (38 to 89 mm thick and 38 to 387 mm wide), and timbers (anything greater than 89 by 89 mm). Based on size and species, solid sawn lumber is graded by various means, including visual grading, machine evaluated lumber (MEL), and machine stress rated (MSR), and engineering design values are assigned. In the mid-1990s glulam timber began to receive significant use in bridges. Glulams are simply large sections formed by laminating dimension lumber glued together. Sections as large as 1.5 m deep are feasible with glulams. Today, while solid sawn lumber is still used extensively, the changing resource base and shift to plantation-grown trees has limited the size and quantity of the raw material. Therefore, it is becoming increasingly difficult to obtain high-quality, large-dimension timbers for construction. This change in raw material, along with a demand for stronger and more cost effective material, initiated the development of alternative products that can replace solid lumber such as glulams.

Other engineering products such as wood composite I-joints and structural composite lumber (SCL) also resulted from this evolution. SCL includes such products as laminated veneer lumber (LVL) and parallel strand lumber (PSL). These products have steadily gained popularity and now are receiving widespread use in building construction, and they are beginning to find their way into bridge construction as well. The future may see expanded use of these and other engineering wood composites [14].

PRESERVATION AND PROTECTION

As mentioned previously, one of the major advances in the 20th century allowing for continued and expanded use of timber as a bridge material is pressure treatment. Two basic types of wood preservatives are used in the US: oil-type preservatives and waterborne preservatives. Oil-type preservatives include creosote, pentachlorophenol (or "penta"), and copper naphthenate. Creosote can be considered the first effective wood preservative and has a long history of satisfactory performance. Creosote also offer protection against checking and splitting caused by changes in MC. While creosote is a natural by-product from coal tar, penta is a synthetic pesticide. Penta is an effective preservatives treatment; however, it is not effective against marine borers and is not used in marine environments. Penta is a "restricted-use" chemical, but wood treated with penta is not restricted. Copper naphthenate has received recent attention as a preservative treatment, primarily because it is considered an environmentally safe chemical while still giving satisfactory protection against biological attack. Its primary drawback is its high cost relative to other treatments. All these treatments generally leave the surface of the treated member with an oily and unfinishable surface.

Furthermore, the member may “bleed” or leach preservative unless appropriate measure are taken.

Most timber bridge applications utilize oil-type preservatives for structural elements such as beams, decks, piles, etc. They offer excellent protection against decay and biological attack, are noncorrosive, and are relatively durable. Oil-type preservatives are not, however, recommended for bridge elements that may have frequent or repeated contact by humans or animals since they can cause skin irritations.

Waterborne preservatives have the advantage of leaving the surface of the treated material clean and , after drying, able to be painted or stained. They also do not cause skin irritations and, therefore, can be used where repeated human and/or animal contact is expected. Waterborne preservatives use formulations of inorganic arsenic compounds in a water solution. They do, however, leave the material with a light green, grey or brownish color. But again the surface can be later painted or stained. A wide variety of waterborne preservatives are available, but the most common include chromated copper arsenate (CCA), ammoniacal copper arsenate (ACA), and ammoniacal copper zinc arsenate (ACZA). Leaching of these chemicals is not a problem with these formulations since they each are strongly bound to the wood. CCA is commonly used to treat southern pine, ponderosa pine, and red pine, all of which are relatively accepting of treatment. ACA and ACZA are used with species that are more difficult to treat, such as Douglas fir and larch. One potential drawback to CCA and ACA is a tendency to be corrosive to galvanized hardware. The extent to which this is a problem is a function of the wood species, the specific preservative formulation, and service conditions. However, such corrosion seems not to be an issue for hot-dipped galvanized hardware typical in bridge applications.

Waterborne preservatives are used for timber bridges in applications where repeated or frequent contact with humans or animal is expected. Such examples include handrails and decks for pedestrian bridges. Additionally, waterborne preservatives are often used in marine applications where marine borer hazards are high.

Any time a material is altered due to chemical treatments its microlevel structure may be affected, thus affecting its mechanical properties. Oil-type preservatives do not react with the cellar structure of the wood and, therefore, have little to no effect on the mechanical properties of the material. Waterborne preservatives do react, however, with the cell material, thus they can affect properties.

Although this is an area of ongoing research, indications are that the only apparent effect of waterborne preservatives is to increase load duration effects, especially when heavy treatment is used for saltwater applications. Currently, no adjustments are recommended for design values of preservative treated wood vs. untreated materials.
In addition to preservative treatment, fire-retard chemical treatment is also possible to inhibit combustion of the material. These chemical react with the cellular structure in wood and can cause significant reductions in the mechanical properties of the material, including strength.
Generally, fire retardants are not used in bridge applications. However, if fire-retardant-treated material is used, the designer should consult with the material producer or treater to obtain appropriate design values [14].

3.2.1 Types of Timber Bridges

Timber bridge come in a variety of forms, many having evolved from tradition. Most timber bridges designed today, however, are the results of fairly recent developments and advances in the processing and treating of structural wood. The typical timber bridge is a single- or two-span structure. Single-span timber bridges are typically constructed with beams and a transverse deck or a slab-type longitudinal deck. Two-span timber bridges are often beam with transverse decks. These and other common timber bridge types are presented below [14].

3.2.1.1 Superstructures

As with any bridge, the structural makeup can be divided into three basic components: the superstructure, the deck and the substructure. Timber bridge superstructures can be further classified into six basic types: beam superstructures, longitudinal deck (or slab) superstructure, trussed superstructures, trestles, suspension bridges, and glulam arches.

Beam Superstructures

The most basic form of a timber beam bridge is a log bridge. It is simply a bridge wherein logs are laid alternately tip-to-butt and bound together. A transverse deck is then laid over the log beams. Obviously, spans of this type of bridge are limited to the size of logs available, but spans of 6 to 18 m are reasonable. The service life of a log bridge is typically 10 to 20 years.

The sawn lumber beam bridge is another simple form. Typically, made of closely spaced 100 to 200 mm wide by 300 to 450 mm deep beams, sawn lumber beams are usually used for clear spans up to 9 m. With the appropriate use of preservatives treatments, sawn lumber bridges have average service lives of approximately 40 years. A new alternative to sawn lumber is structural composite lumber (SCL) bridge. Primarily, laminated veneer lumber (LVL) has been used in replacement of solid sawn lumber in bridges. LVL can be effectively treated and can offer long service as well.

Glulam timber beam bridges are perhaps the most prevalent forms of timber bridges today. A typical glulam bridge configuration is illustrated in the figure below.

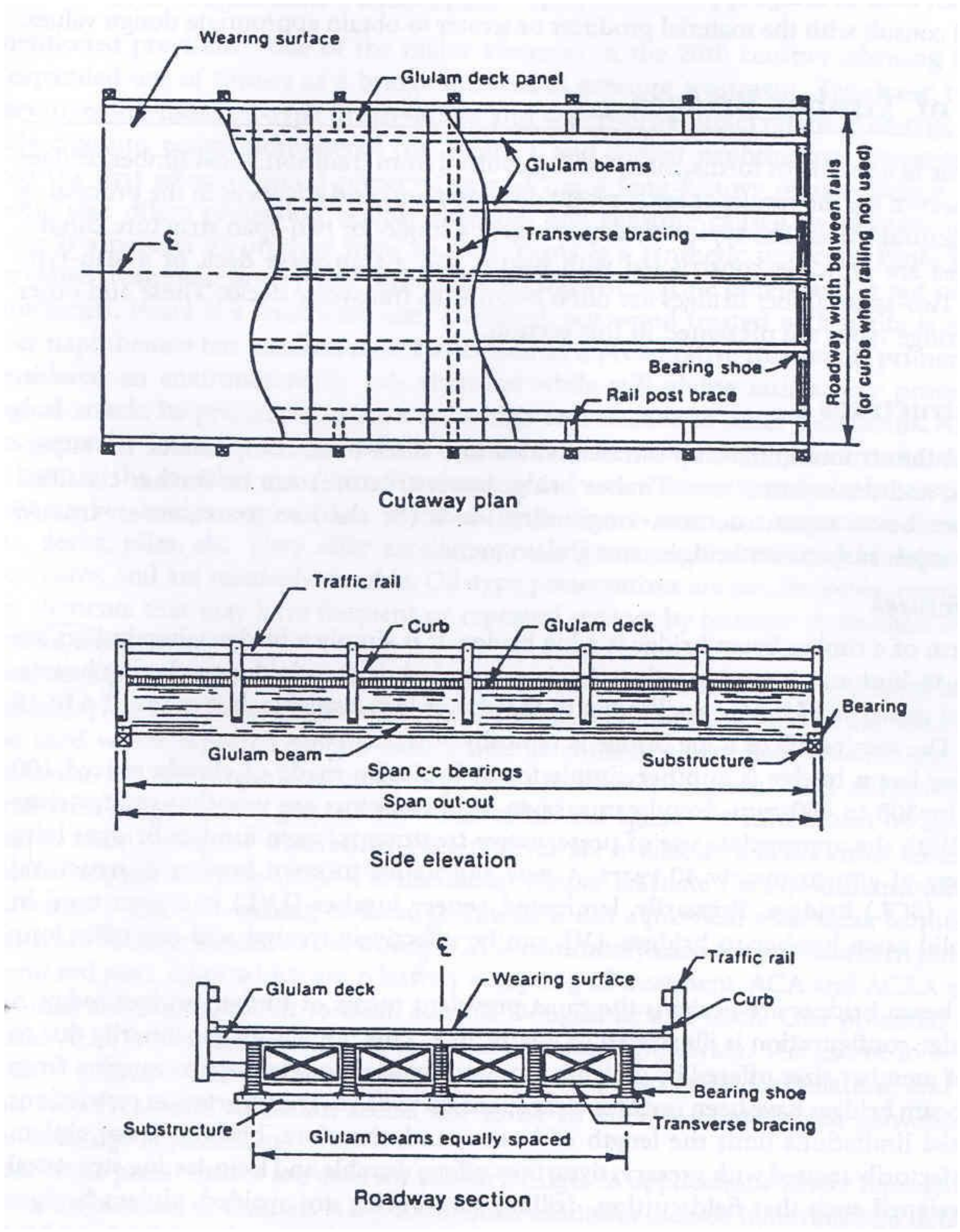


Figure 3.3 - Typical glulam bridge configuration

This popularity is primarily due to the large variety of member sizes offered by glulams. Commonly used for clear spans ranging from 6 to 24 m, glulam beam bridges have been used for clear spans up to 45 m. Transportation restriction rather than material limitations limit the length of beams, and, therefore, bridges. Since glulam timber can be satisfactorily treated with preservatives, they offer a durable and long-lasting structural element. When designed such that field cutting, drilling, and boring are avoided, glulam bridges can provide a service life of at least 50 years [14].

Longitudinal Deck Superstructures

Longitudinal deck (or slab) superstructure are typically either glulam or nail-laminated timber placed longitudinally to span between supports. A relatively new concept in longitudinal deck system is the stress-laminated timber bridge, which is similar to the previous two forms except that continuity in the system is developed through the use of high-strength steel torsion roads. In any case, the wide faces of the laminations are oriented vertically rather than horizontally as in a typical glulam beam. Since glulam timbers have depths typically less than the width of a bridge, two or more segments must be used. When continuity is needed, shear dowels must be used to provide interconnection between slabs. When continuity is not required, construction is simplified. Longitudinal deck system are relatively simple and offer a relatively low profile, making them an excellent choice when vertical clearance is a consideration. Longitudinal decks are economical choices for clear spans up to approximately 10 m. Since the material can be effectively treated, the average service life of a longitudinal timber deck superstructure is at least 50 years. However, proper maintenance is required to assure an adequate level of prestress, which is maintained in stress-laminated systems.

Trussed Superstructures

Timber trusses were used extensively for bridges in the first half of the 20th century. Many different truss configurations were used including king post, multiple king post, Pratt, Howe, lattice, long and bowstring trusses, to name a few. Clear spans of up to 75 m were possible. However, their use has declined due primarily to high fabrication, erection, and maintenance costs. When timber trusses are use today, it is typically driven more by aesthetics than by structural performance or economics.

Trestles

Another form of timber bridge is simply a timber deck structure supported by steel cables. Timber towers, in turn, support the steel suspension cables. Although there are examples of vehicular timber suspension bridges, the more common use of this form of timber bridge is as a pedestrian bridge. They are typically used for relatively long clear spans, upward of 150 m. Since treated wood can be used throughout, 50-years service lives are expected.

Glued Laminated Arches

One of the most picturesque forms of timber bridges is perhaps the glulam arch. Constructed from segment circular or parabolic glulam arches, either two- or three-hinge arches are used. The glulam arch bridge can have clear spans in excess of 60 m, and since glulam timber can be effectively treated, service life of at least 50 years are well within reason. Although the relative first and life cycle cost of arch bridges have become high, they are still a popular choice when aesthetics is an issue [14].

3.2.1.2 Timber Decks

The deck serve two primary purposes: first, is the part of the bridge structure that forms the roadway, and it distribute the vehicular loads to the supporting elements of the superstructure. Four basic types of timber decks are sawn lumber plants, nailed laminated decks, glulam decks, and composite timber-concrete decks. The selection of a deck type depends mainly on the level of load demand.

Lumber Plants

The lumber plant deck is perhaps the simplest deck type. It is basically sawn lumber, typically 75 to 150 mm thick and 250 to 300 mm wide, placed flatwise and attached to the supporting beams with large spikes. Generally, the planks are laid transverse to the beams and traffic flow, but can be placed longitudinally on cross beams as well. Lumber plants are only used for low-volume bridges. They are also of little use when protection of the supporting members is desired since water freely travels between adjacent plants. Additionally, when a wearing surface such as asphalt is desired, lumber planks are not recommended since deflections between adjacent planks will result in a cracking and deterioration of the wearing surface.

Nailed Laminated and Glulam Decks

Nailed laminated and glulam decks are essentially as described previously, for longitudinal deck (or slab) superstructures. Nailed laminated systems are typically 38-mm-thick by 89- to 285-mm-deep lumber placed side by side and nailed or spiked together along its length. The entire deck is nailed together to act as a composite section and oriented such that the lumber is laid transverse to the bridge span across the main supporting beams, which are spaced from 0.6 to 1.8 m. Once a quite popular deck system, its use has declined considerably in favor of glulam decks.

A glulam deck is a series of laminated panels, typically 130 to 220 mm thick by 0.9 to 1.5 m wide. The laminations of the glulam panel are oriented with their wide face vertically. Glulam decks can be used with the panels in the transverse or longitudinal directions. They tend to be stronger and stiffer than nailed laminated systems and offer greater protection from moisture to the supporting members. Finally, although doweled glulam panels cost more to fabricate, they offer the greater amount of continuity. With this continuity, thinner decks can be used, and improved performance of the wearing surface is achieved due to reduced cracking and deterioration. A typical glulam deck is shown in the figure below.

Figure 3.4 – Typical Swedish Timber bridge with glulam deck [24]

Composite Timber-Concrete Decks

The two basic types of composite timber-concrete deck systems are the T-section and the slab (see Figure 3.4). The T-section is simply a timber stem, typically a glulam, with a concrete flange that also serves as the bridge deck. Shear dowels are plates that are driven into the top of the timber stem and develop the needed shear transfer. For a conventional single-span bridge, the concrete is proportioned such that it takes all the compression force while the timber resists the tension. Composite T-sections have seen some use in recent years; However, high fabrication costs have limited their use.

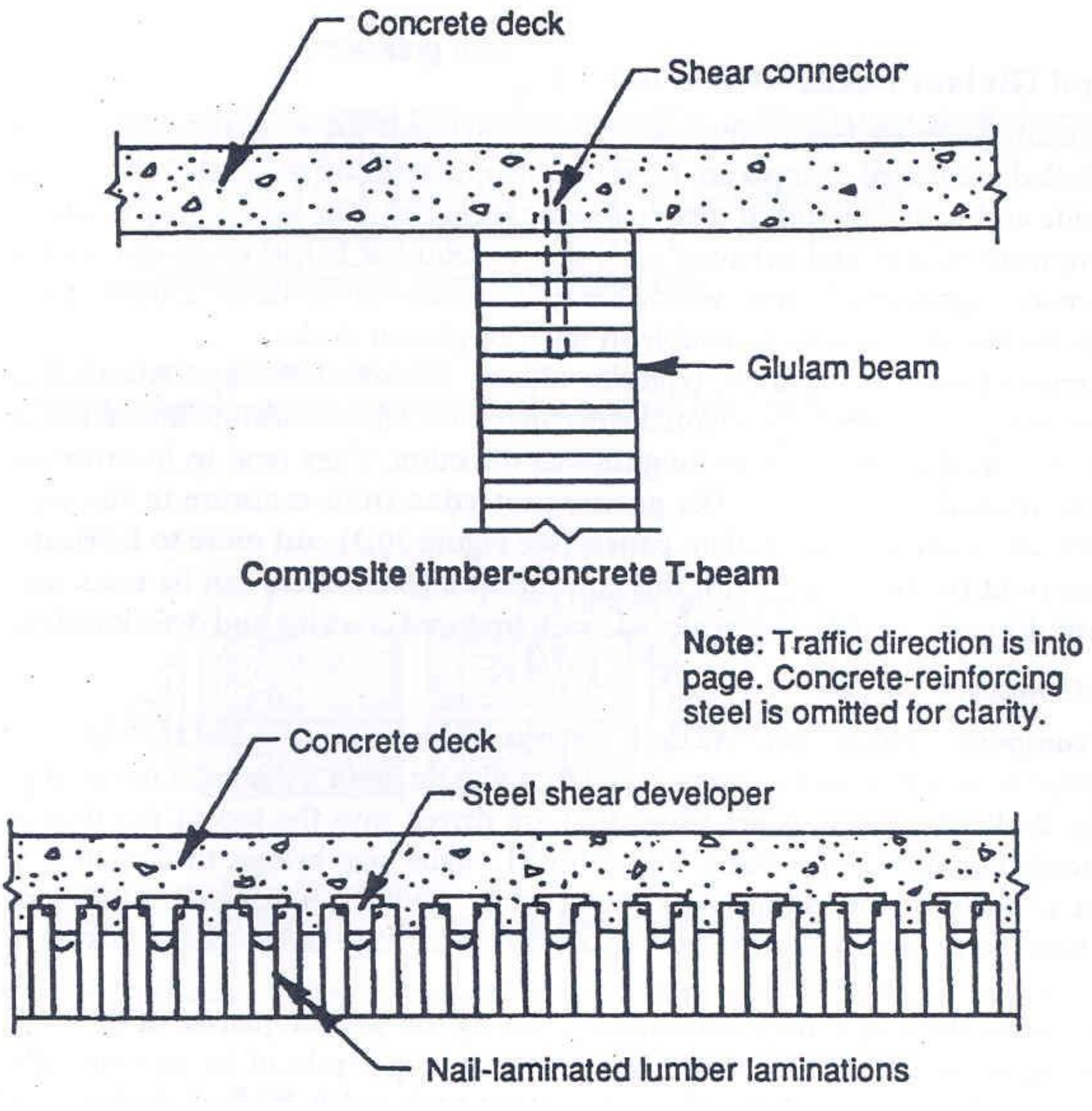


Figure 3.5 – Composite timber – concrete deck

Composite timber-concrete slabs were used considerably during the second quarter of the 20th century, but receive little use today. They are constructed with alternating depths of lumber typically nailed laminated with a concrete slab poured directly on top of the timber slab. With a single span, the concrete again carries the compressive flexural stresses while the timber carries the flexural stresses. Shear dowels or plates are driven into the timber slab to provide the required shear transfer between the concrete and the timber [14].

3.2.1.3 Substructures

The substructure supports the bridge superstructure. Load transferred from the superstructures to the substructures are, in turn, transmitted to the supporting soil or rock. Specific types of substructures that can be used are dependent on a number of variables, including bridge loads, soil and site conditions, etc. Although a timber bridge superstructure can be adapted to virtually any type of substructure regardless of material, the following presentation is focused on timber substructures, specifically timber abutments and bents. In Sweden, reinforced concrete is often used in the substructures.

Abutments

Abutments serve the dual purpose of supporting the bridge superstructure and embankment. The simplest form of a timber abutment is a log, sawn lumber, or glulam placed directly on the embankment as a spread footing. However, this form is not satisfactory for any structurally demanding situation. A more common timber abutment is the timber pile abutment. Timber piles are driven to provide the proper level of load-carrying capacity through either end bearing or friction. A backwall and wing walls are commonly added using solid sawn lumber to retain the embankment. A continuous cap beam is connected to the top of the piles on which the bridge superstructure is supported. A timber posts abutment can be considered a hybrid between the spread footing and pile abutment. Timber posts are supported by a spread footing, and a backwall and wing walls are added to retain the embankment. Pile abutments are required when soil conditions do not provide adequate support for a spread footing or when uplift is a design concern.

Bents

Bents are a support system used for multi-span bridges between the abutments. Essentially, timber bents are formed from a set of timber piles with lumber cross bracing. However, when the height of the bent exceeds that available for a pile, frame bents were quite common in the early days of the railroad, but, due to high cost of fabrication and maintenance, they are not used often for new bridges [14].

3.2.2 LCC – Analysis of Timber Bridges

One of the main goal of the Life Cycle Cost Analysis is to make optimal decision when comparing different possible solutions. Here is analyzed the possibility to build a Timber bridge on a span of 20 m instead of the more classic typology.
Thanks to the help provided by the personnel of Martinsson, a Swedish based wooden factory [24], it was possible to collect information on timing and costs of inspections, maintenance, repair and rehabilitation, initial investment and dismantle of Timber Bridges. Here, as done before with the other analysis, different parameters that take into account the difference in growing of goods, money and user time has been considered.
Furthermore, because this is a general analysis, it is not possible to fix a definite traffic forecast, so three different scenarios were considered, depending on the number of vehicles. The different scenarios reflect high and low traffic volumes, 5000, 500 and 100 vehicles per day in 2009. The forecasts for three different regions in Sweden, given by SAMPERS, has been used: Stockholm, Norrbotten and Västerbotten. Three different 'initial values' have been taken into consideration, because the forecast for Norrbotten and Västerbotten are similar, and the analysis would have been the same.
Furthermore, in the table that follows, the operations considered into the analysis are listed, so that they can be recalled in parenthesis (in the left column) in the tables that summarized the costs of Life Cycle Cost Analysis that follows.

Table 3.1 – operations and description of operations on Timber Bridges

n°	Operation	Description
1	Exchange isolation	Remove the asphalt/concrete and the waterproofing and replace it with concrete or new waterproof and asphalt
2	Exchange panels	Remove the old panels at the sides of the bridge and mount new ones
3	Exchange of dripping plates	Remove the old dripping plates at the sides of the bridge and mount new ones
4	Exchange expansion joints	Remove the old expansion joints at the sides of the bridge and mount new ones
5	Paint the lower surface of the deck	Take away the old paint and replace with new paint
6	Yearly inspection	Check from a distance inferior than arm-length all part of the bridge
7	Periodical maintenance	remove vegetation around and on the bridge, change some parts on the fence, mainly small repairing that do not have so much affect on the traffic, adjust/strengthen the slope with filling with material (rocks)
8	Demolition	Take down the old bridge, separate different parts and disposal it

The three traffic scenarios are presented here, for all the calculations see APPENDIX A2 – Life-Cycle Cost Calculations of Timber Bridges.

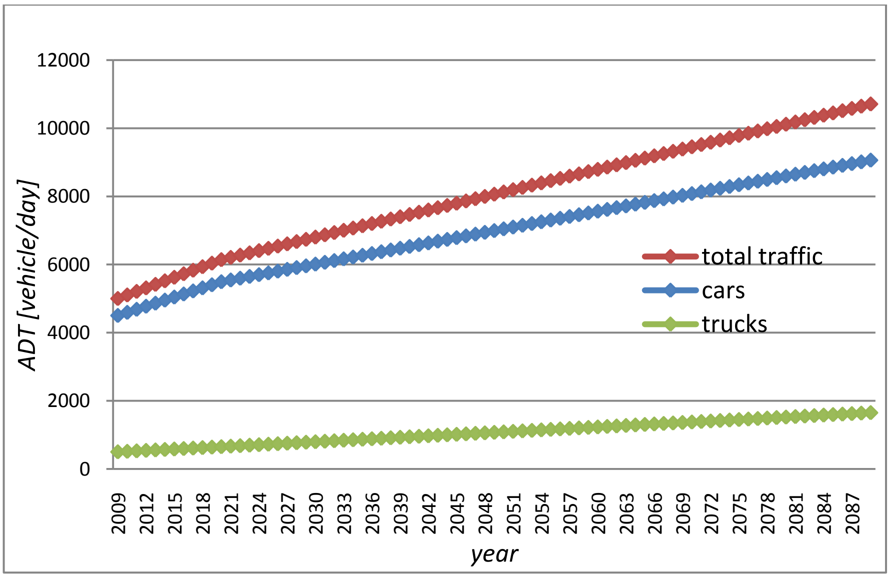


Figure 3.6 – Scenario 1, High traffic volume and Stockholm forecast

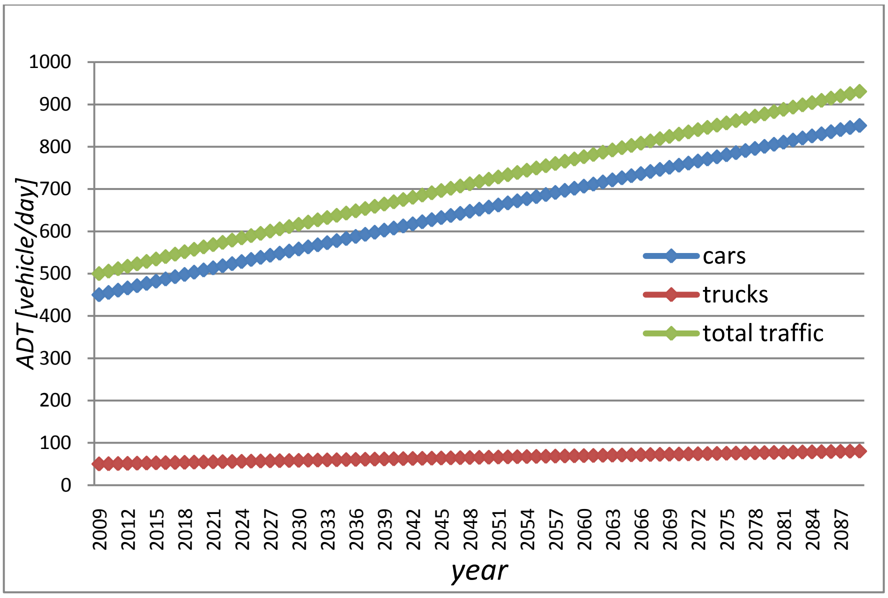


Figure 3.7 - Scenario 2, low traffic volume and Norrbotten (coast) forecast

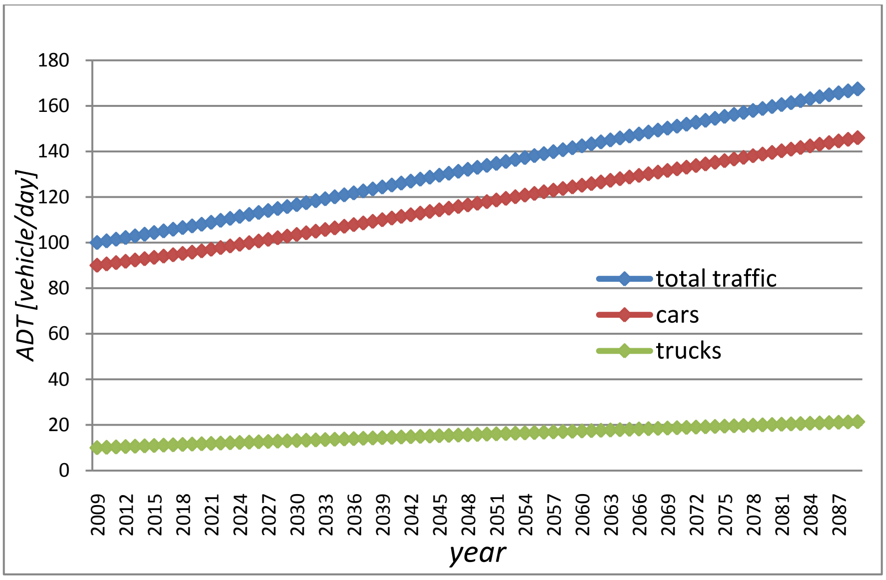


Figure 3.8 - Scenario 3, low traffic volume and Västerbotten (coast) forecast

3.2.3 Results – Timber Bridges

The results obtained from the Life Cycle Cost Analysis of Timber bridges can be summarized in the table below:

Table 3.2 – summary of the results from LCCA on Timber Bridges

PV 2009			
[SEK]	Scenario 1	Scenario 2	Scenario 3
Total LCC	4 705 779	2 657 317	2 485 054
Annuity cost	18 946	10 698	10 005
Impact of the cost items on the total LCC			
Initial investment	1 925 000 (40,9 %)	1 925 000 (72,4 %)	1 925 000 (77,5%)
Planning&design	100 000 (2,1 %)	100 000 (3,8 %)	100 000 (4 %)
MR&R	257 253 (5,5 %)	257 253 (9,7 %)	257 253 (10,4 %)
User costs	2 261 949 (48,1 %)	213 487 (8 %)	41 225 (1,7 %)
Dismantle	161 577 (3,4 %)	161 577 (6,1 %)	161 577 (6,5 %)

In the first scenario the impact on the total LCC of user costs is pretty high, almost a half, and it is also the most influent factor. In fact, when the users decrease the total LCC and the Annuity Cost are almost halved. Basically in this kind of analysis the only factor that change is the user costs, because neither the area, nor the timing or type of operations is changed, as we are analyzing the same bridge. The traffic volume can influence the timing and type of maintenance, but this is taken into account in the design phase. Furthermore, the most influent factor for the maintenance is the weather.

This also mean that it would be a good and cost efficient choice to build Timber bridges sparsely populated areas (with relatively low investment costs also), where the impact of user costs is small, and this will be reflected on the annuity cost.

3.3 Soil-Steel Bridges

Bridges of soil-steel structures built as traffic objects of small spans are attractive because of their architectonic values as well as technical qualities and low costs associated with them. Essential elements of such structures are: steel shell supported on a foundation, soil backfill surrounding it and the kind of roadway.

Erection of these type of bridges is far different from classic structure engineering and the form of soil-steel objects. The shell can be made of flat or corrugated steel and the soil backfill can be put without extra assembly scaffolding. The support of the shell is of elastic construction made from steel sheet piles crowned with a steel top girt or by a foundation of reinforced concrete. The technology applied allows to shorten the time of bridge construction to a necessary minimum, especially under the conditions of soil saturated with water [16].

CLASSIFICATION

Traffic structures such as culverts or small bridges of soil-steel construction can be divided into two basic groups: rigid construction which are mainly made of brittle materials and elastic ones. In elastic constructions, there is a profitable collaboration between a thin shell and a soil backfill when vertical loads from the roadway are transferred. Thus during designing such objects we consider both backfill and roadway on the construction and not filling like in vaulted bridges. The carrying system of an elastic construction is very heterogeneous as it consists of a spring shell, road pavement and thickened loose material (soil backfill).

The shape of the shell cross sections may be diversified. Basically they are adjusted to the kinds of obstacles like water or traffic ones. Taking account of a longitudinal section along the circumferential strip, the shells of soil-steel objects are divided into open and closed (pipe) ones. The shape of a shell is usually associated with the thickness of soil backfill over a shell in the middle of the span. The tendency to design the constructions of small height (small thickness of backfill) in these objects is because of a natural trend of gaining the largest possible area underneath the bridge at a minimum amount of soil over the construction. That is why there are shells of small height, the so called *Box Culvert*. In such objects, unlike typical bridges of this kind, with a thick layer of soil backfill over the shell, we may expect local effects under the load caused by traffic. In order to smooth the results of loads caused by vehicle wheels in the objects of small thickness of the backfill, sometimes concrete plates made over the shell and under the road are used.

Corrugated sheets of two kinds, being different in wavelength and height, are used as shell constructions. Their trade names are Multi Plate (MP) and Super Core (SP). The sheets vary in thicknesses depending on predicted shell strain. In the case of specifically great values of internal forces, multilayer systems or additional ribbing reinforcement ones are used. Open shells are usually supported by the foundation most often made of reinforced concrete. The real state of the shell effort is meaningfully influenced by soil backfill setting Machelsjy eta l (2006), [16]. Recent Swedish research on Soil Steel Flexible Culverrts is also presented in Pettersson (2007) [21]..

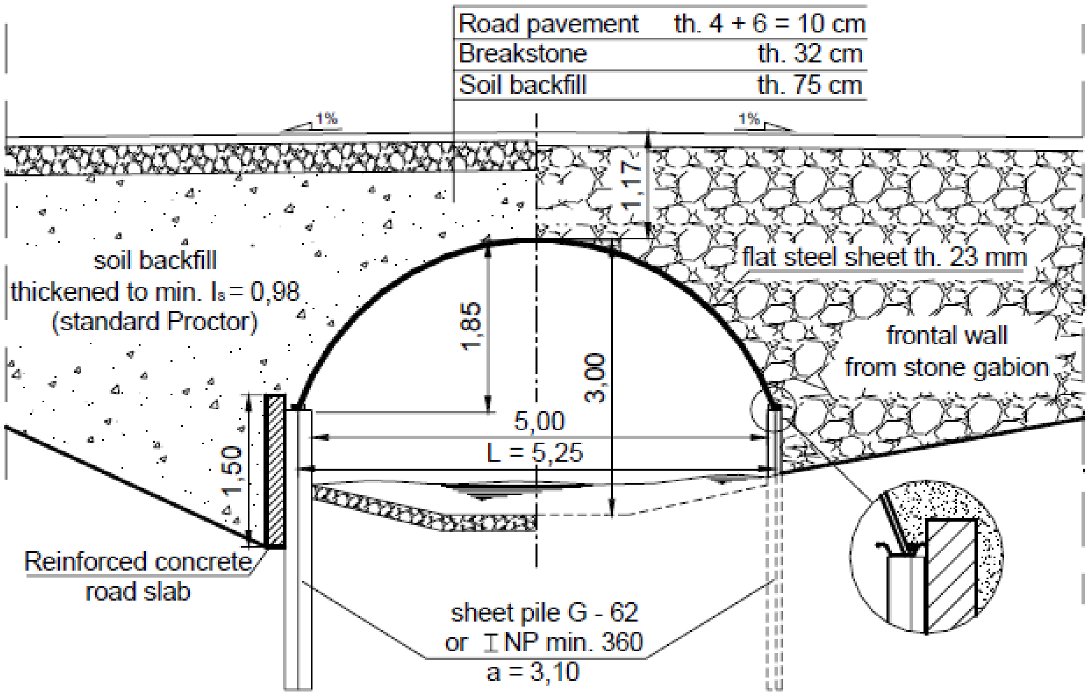


Figure 3.9 – Scheme flat steel sheet – soil bridge [16].

Here are presented the three different types of corrugated steel used for the construction of the soil-steel bridges:

Helcor/TC: Helically corrugated steel bridges

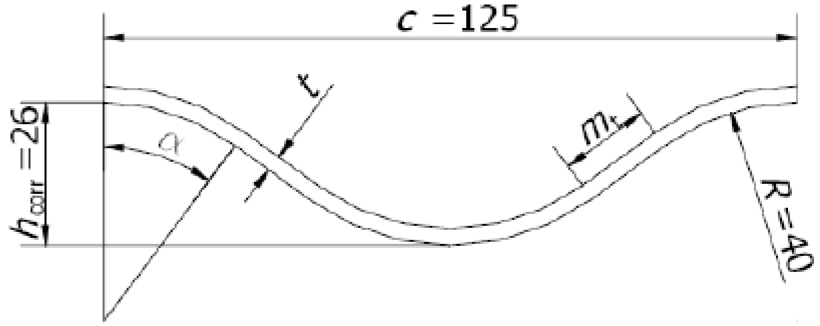


Figure 3.10 – Cross section of a Helically corrugated steel component

The corrugation is 125x26mm, they are produced in circular and pipe arches with diameters up to 3.4 m (circular) and 4.4 m (pipe arches). The steel quality is S235JR according to EN 10 326. An Hot dip Galvanized with TrenchCoat is also possible [17].

Figure 3.11 – Circular structure at desired length

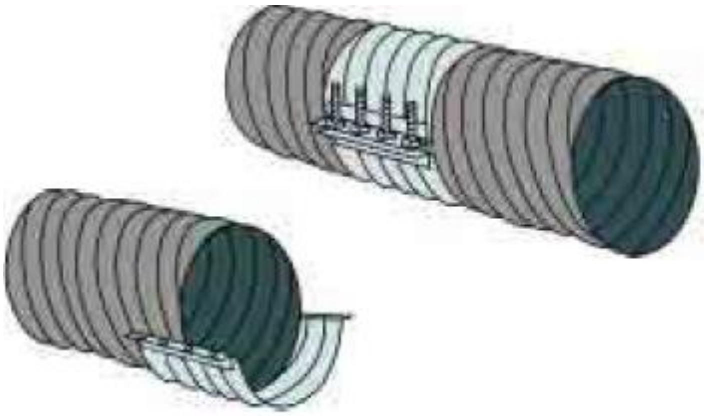
Figure 3.12 – Coils

Figure 3.13 – Continuing manufacturing process

Using a special machine it is possible to deform a circular structure in a controlled manner: the result is a well defined pipe arch.

Figure 3.14 – Machine to define pipe arches

Couplings between circular and pipe arches are made from the same corrugation. Angle irons and treated bars are used to tighten the parts [17].



Figures 3.15 (left) and 3.16 (right) – Two pipes tighten together

Figure 3.17 - Two pipes tighten together

Very high resistance to corrosion, abrasion and UV-radiation is given by the trenchCoat treatment.

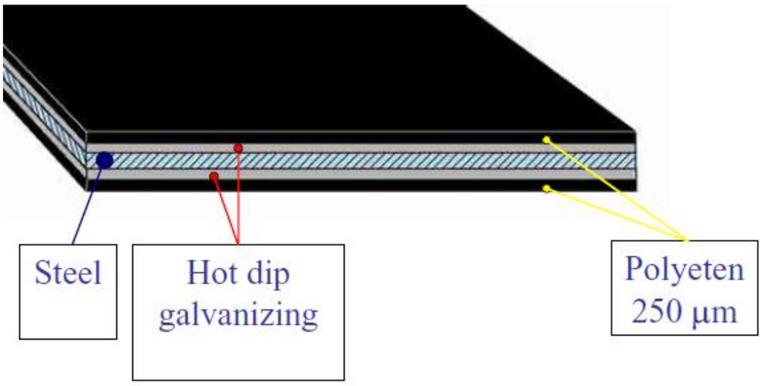
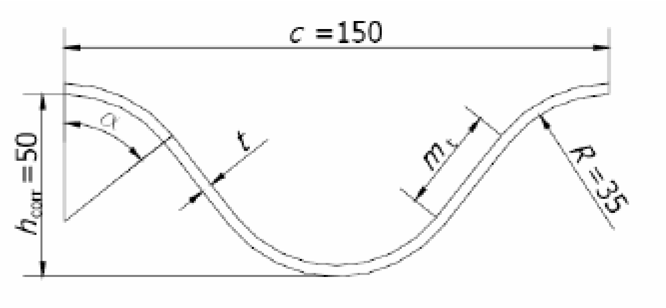
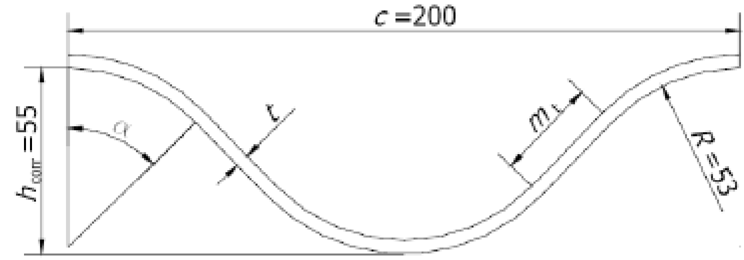


Figure 3.18 - TrenchCoat treatment

MP150 and MP200: Multiplate MP150 and MP200





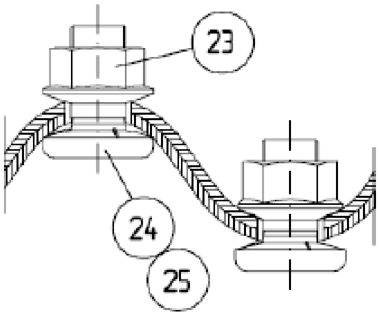
Figures 3.19 (up) and 3.20 (down) – Corrugation size of multiplates

The corrugation is 150x50mm and 200x55mm. The diameters available are up to about 12 m; a variety of shapes are possible. The steel quality used is S275JR according to EN 10 025. Hot dip galvanized with epoxy coating is an option to avoid abrasion and corrosion.

The production line includes corrugation, hole punching, curving and hot dip galvanizing [17].

Figure 3.21 – production line

The plates are bolded together using special M20 bolds and nuts of grade 8.8



Figures 3.22 (left) and 3.23 (right) – plates bolded together

SuperCor: SuperCor 381x140

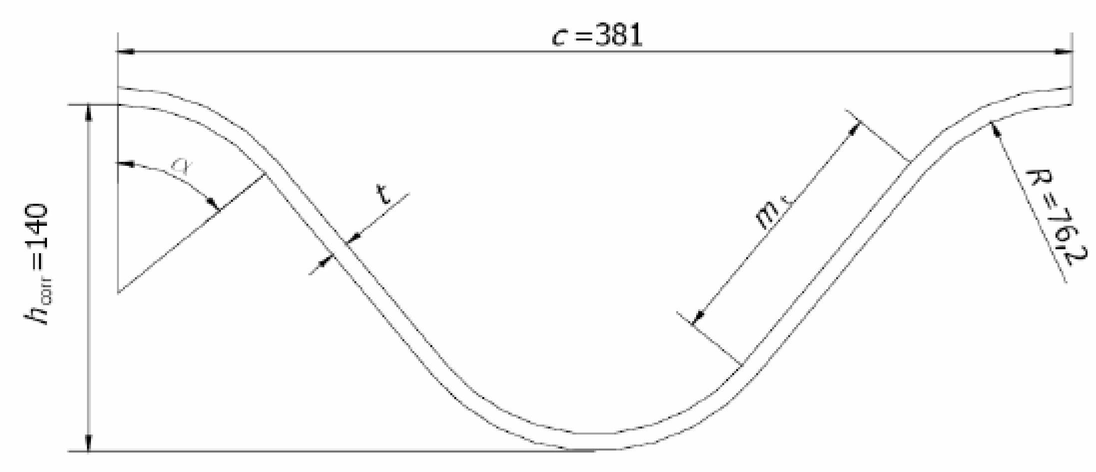
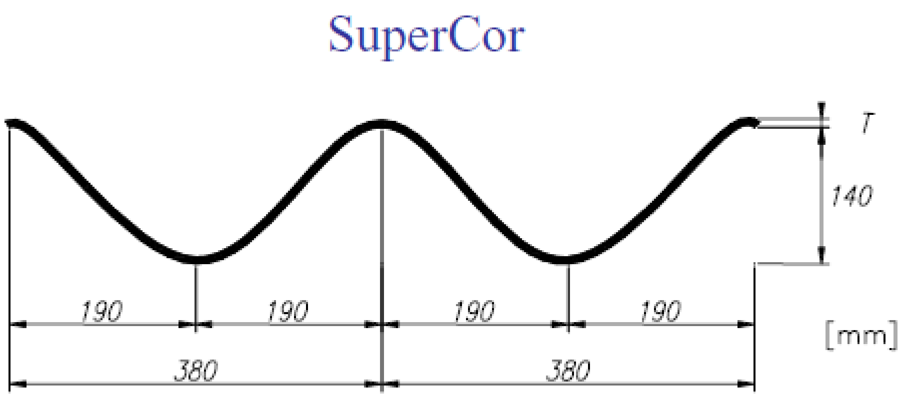
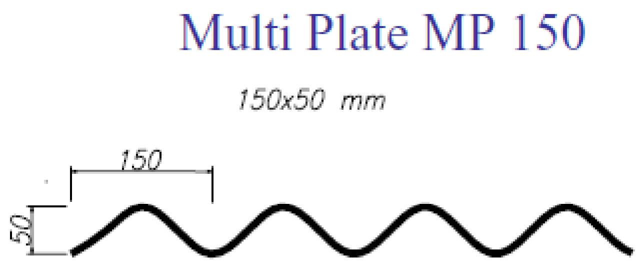


Figure 3.24 – Corrugation size of a SuperCor plate

The corrugation is 381x140, this mean that SuperCor has significantly larger section modulus and moment of inertia in comparison with MP150 so large span up to 25 m structures are possible, they also provide nine times the stiffness of conventional structural pates [17].





Figures 3.25 (up) and 3.26 (down) – Corrugation size of SuperCor and Multiplates

The specifications for corrugation profile 381mmx140mm are shown in the table below:

Table 3.3 - specification for SuperCor profiles [18]

Wall Thickness						Tangent									
Specified		Uncoated (T)		Area		Length (TL)		Angle(Δ)	Moment of Inertia		Section Modulas		Radius of Gyration	
(mm)	(in.)	(mm)	(in.)	(mm^2/mm)	($in^2./ft$)	(mm)	(in.)	(degrees)	(mm^4/mm)	($in^4./in.$)	(mm^3/mm)	($in^3./in$)	(mm)	(in.)
3.5	0.140	3.42	0.135	4.784	2.260	110.8	4.361	49.75	11710.7	0.714	152.72	0.2367	49.48	1.948
4.2	0.170	4.18	0.165	5.846	2.762	109.8	4.323	49.89	14332.5	0.875	186.05	0.2884	49.52	1.949
4.8	0.188	4.67	0.184	6.536	3.088	109.2	4.299	49.99	16037.0	0.979	207.54	0.3217	49.54	1.950
5.5	0.218	5.45	0.215	7.628	3.604	108.2	4.259	50.13	18740.1	1.144	241.38	0.3741	49.57	1.952
6.3	0.249	6.23	0.245	8.716	4.118	107.2	4.220	50.28	21441.2	1.308	274.87	0.4260	49.60	1.943
7.1	0.280	7.01	0.276	9.807	4.633	106.1	4.179	50.43	24124.5	1.472	308.24	0.4776	49.64	1.954
8.1	0.319	8.00	0.315	11.06	5.225	104.9	4.131	50.62	27259.0	1.663	347.00	0.5380	49.65	1.955

They are produced in closed structures and arches (see Figure 3.25). The steel quality is S315MC according to EN 10 149. Hot dip galvanizing with epoxy coating is an option to avoid abrasion and corrosion.

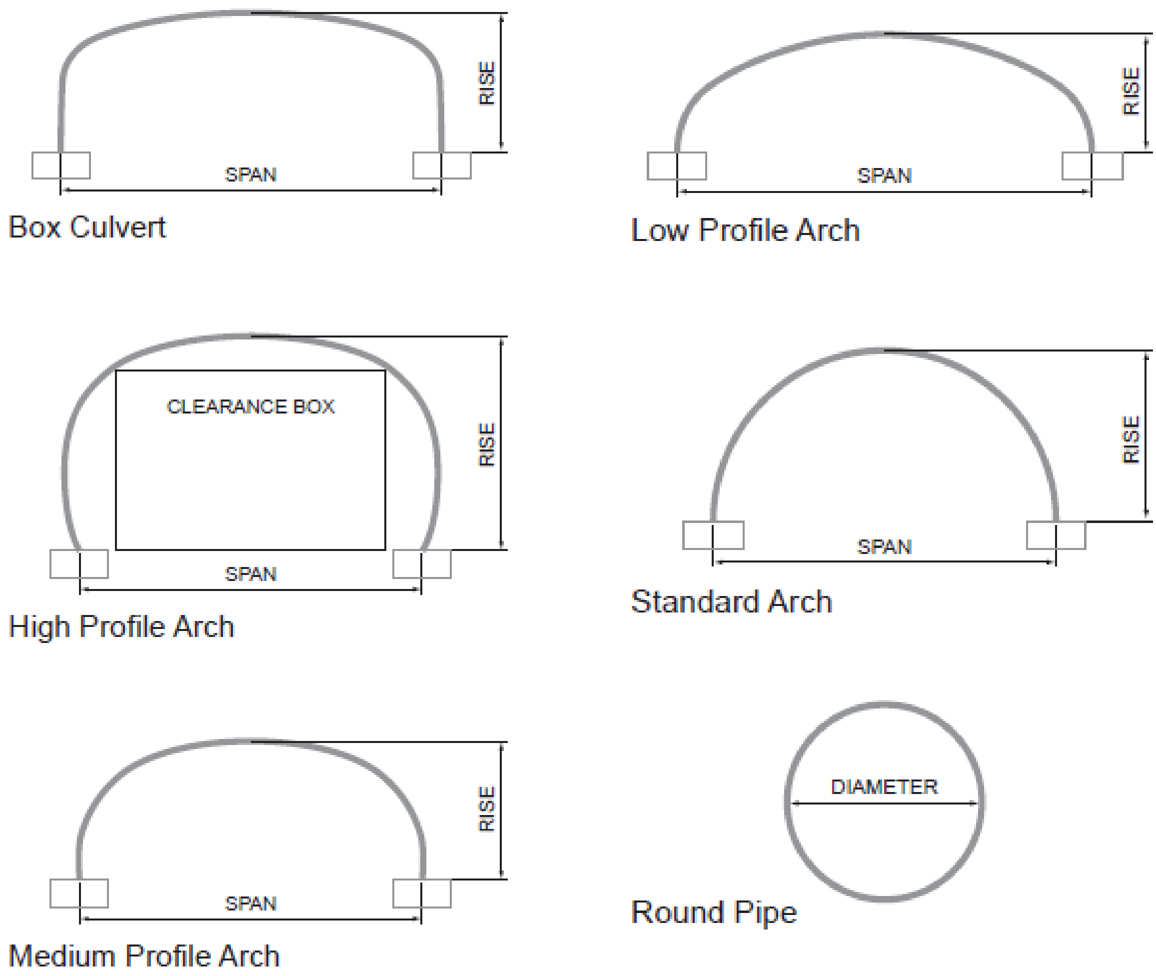


Figure 3.27 – Different shapes available for SuperCor's corrugation profile

SuperCor boxes combine the strength and cost advantages of SuperCor corrugation profile with a special continuous reinforcement along the length of the structure. The extra strength of continuous reinforcement permits designs exceeding 15 m.

Various footer options are suitable for different construction sites:

- Precast or cast-in-place concrete footings – the most common footer type, in which a receiving angle is embedded in concrete;
- Steel footer pads – used as a timesaving alternative to concrete in sites with non-erodible stream beds. If the site permits, footings should be buried a minimum of 600 mm below flow line. When footer pads are buried, the published end area of the box will be reduced;
- Full steel invert – for applications in erodible stream beds requiring a corrugated steel floor or invert. To prevent undermining of the invert, we recommend to use of an optional toewall for the upstream and downstream ends.

Well-designed end treatments are essential to the structural and hydraulic performance of SuperCor boxes, as well as enhancing their appearance.

Headwall options include:

- Bolt-a-bin retaining wall system;
- Welded wire gabion baskets;
- Concrete, cast-in-place or precast;
- Sheet pile walls;
- Bolt-a-plate walls;
- MSE wall systems with welded wire wall or concrete face.

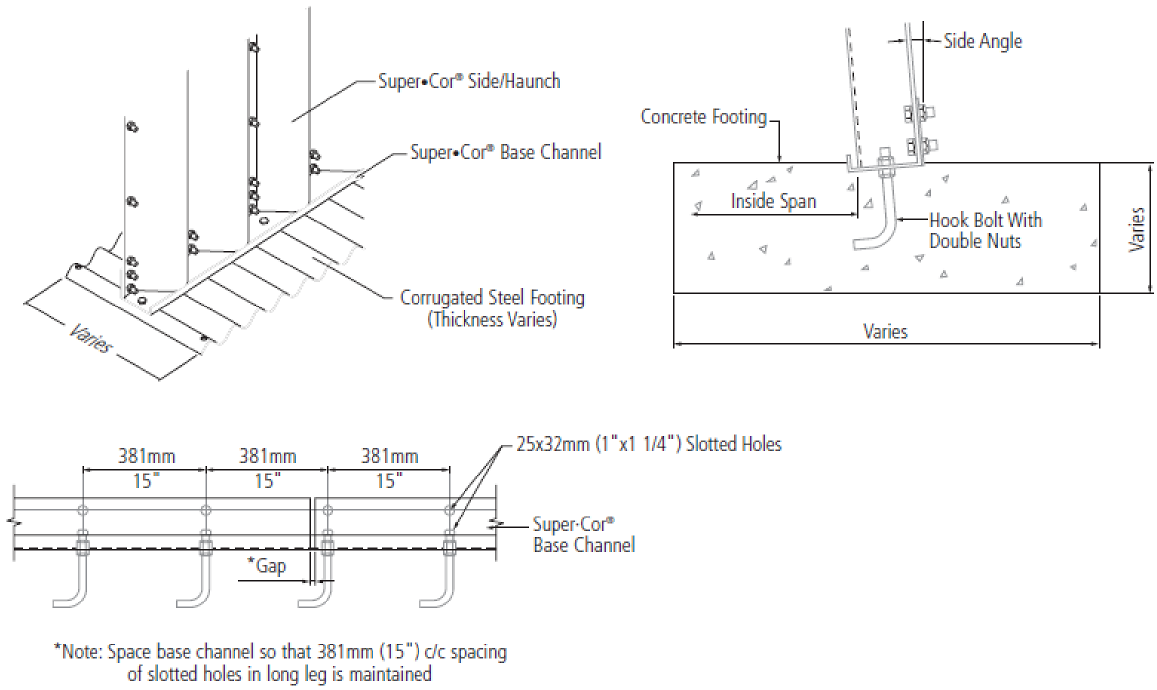


Figure 3.28 SuperCor footing

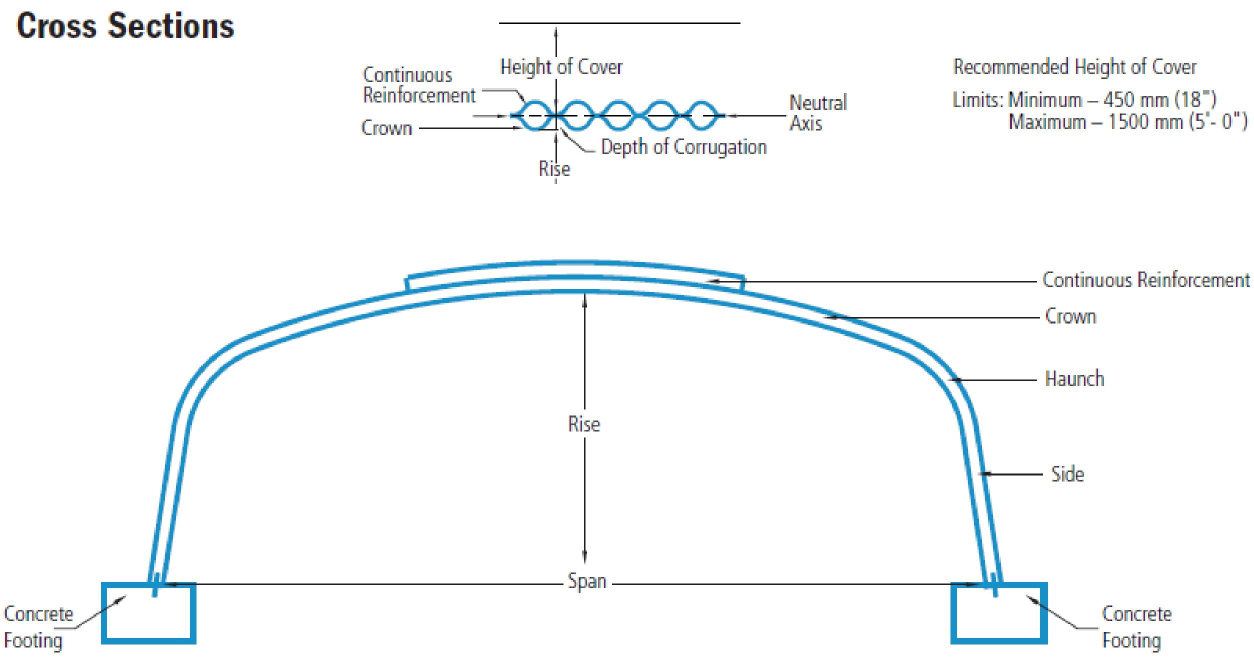


Figure 3.29 – SuperCor arch cross section

INSTALLATION

SuperCor structures distribute superimposed loads to the surrounding 'engineering' backfill. It is therefore essential to use care during installation and backfilling to ensure proper performance.

Different plats are bolded together with the geometry shown in the figure 3.28.

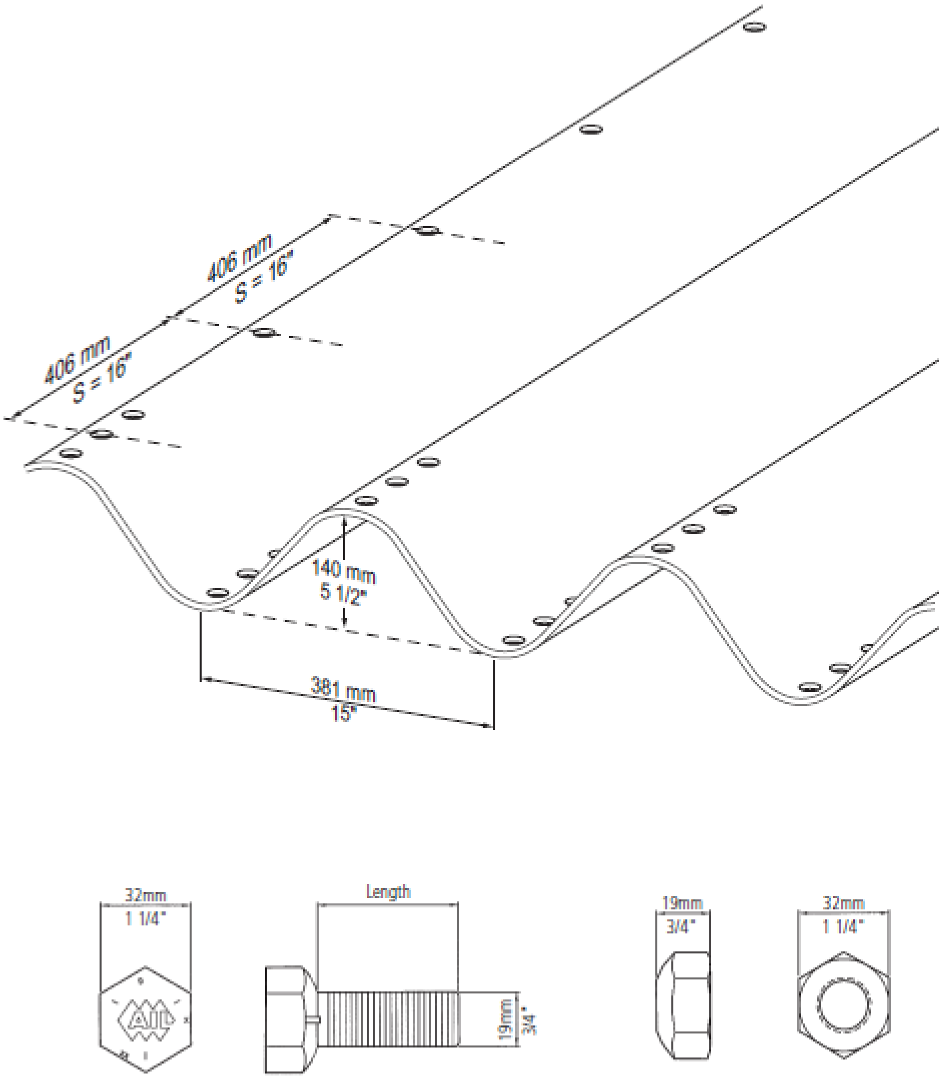


Figure 3.30 - bold system for SuperCor plates

EXCAVATION

Trench excavation will vary, depending on the nature of the insitu material, It is necessary to provide an excavated area that ensures adequate distance from soils with questionable structural integrity. If the native soil is stable, excavate only that area required to provide minimum bedding and enough room for compaction equipment to manouvre. For stream crossing applications, local authorities will impose guidelines for construction activity.

FOUNDATIONS

SuperCor structures are flexible and can accommodate some differential settlement without distress. It is important, nevertheless, to minimize differential settlement by removing and replacing poor foundation material, or by using a pile foundation. Preparation should be confined to minimum, but practical widths, and should result in a uniform base for the structure. A bedding of loose material will provide a slight cushion and the bedding may be flat or shaped, depending on the structure configuration and construction methods being used. It is essential that all corrugations be filled.

ASSEMBLY

A SuperCor structure arrives at the job site in bundles curved to the proper radius. Included are bolts and any other special hardware that may be required. Instructions, as well as diagram listing all components, are also included. Assembly is easy, requiring relatively simple tools. Correct lapping, bolt-tightening and shape-monitoring are all important to achieve the correct design dimensions.

BACKFILL

The back-filling process is well specified in Bro 2004. It is one of the most important activities that will give the structure its bearing capacity during the service life. The parameters of the soil must be considered and the compaction must be performed according to plan.

INSPECTION

Inspection should be performed on a full-time basis by qualified personnel. Backfill is placed in a balanced manner in 150 mm to 200 mm lifts for the entire backfill envelope. Compaction testing is required to ensure that backfill material is compacted to a minimum of 95% Standard Proctor Density. It is a good idea to assess the compaction equipment and have it use approved by the geotechnical engineer or qualified inspector.

It should be noted that the area just up to the water level has shown to be sensitive to corrosion attacks. Also, the outside ends of structures under roads that are salted during wintertime, have shown signs of corrosion.

Figure 3.31 – Signs of corrosions in a cylinder culvert

If treated with Hot dip galvanizing Fe/Zn 115 µm and epoxy 240 µm outside according to the Swedish Bridge Code, Bro 2002, and designed according to the Swedish Railroad Bridge code BV Bro, the life time expectancy is 80 years.

END FINISH

Special attention must be paid to beveled or skewed ends. Incomplete structural rings must be reinforced with steel or concrete (or tied back), to maintain structural integrity. It is necessary to exercise caution when placing backfill around them to avoid distortion. Standard end finishes are squared, beveled, partially beveled or skewed.

FREEZING PROTECTION

By providing a good material in the bedding of the structure, damage from freezing can be avoided. The actual climate at the construction site must be known. Also, the properties of the soil at the site is of large importance when designing the bedding.

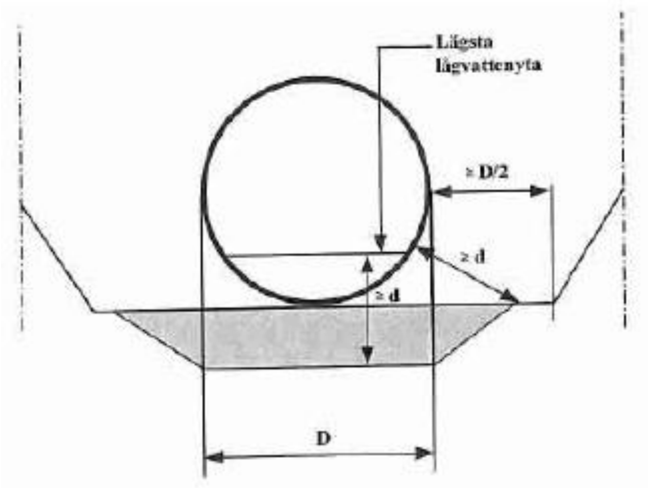


Figure 3.32 – Freezing protection

The thickness of this protection layer can be reduced using insulation, as shown in the figure below:

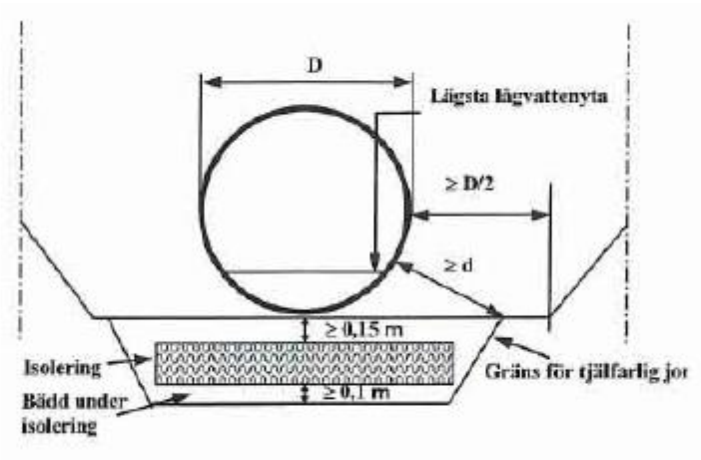


Figure 3.33 – Insulation for freezing protection

THICKNESS OF PLATE STEEL SHEET

The changes in the thickness t of plate steel sheet in the range of 5 mm < t < 30 mm influence the value of geometrical parameters given in the table below:

Table 3.4 – influence of thickness on geometrical parameters

t [mm]	5	10	15	20	23	25	30
A [mm^2/mm]	5	10	15	20	23	25	30
I [mm^4/mm]	10	83.3	281.2	666.7	1013.9	1302.1	2250.0

Where A: area of the cross section

I: moment of inertia

The influence of the thickness of the plane steel sheet on the coordinate values ξ(t) is presented in the figures 3.32 – 3.34 [16].

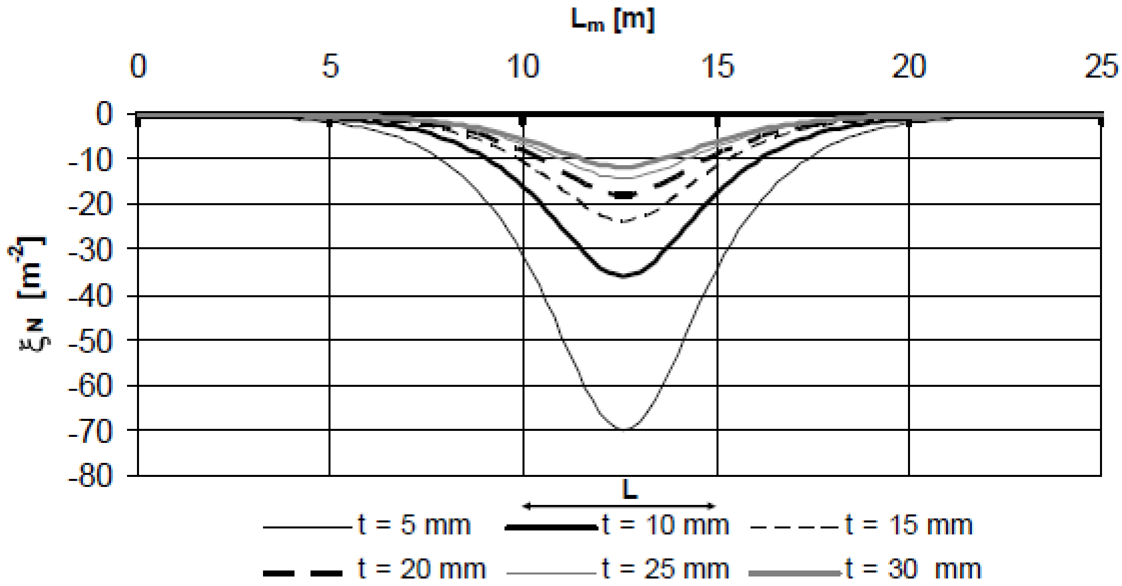


Figure 3.34 - Influence lines σ_N(t) in the crown [16]

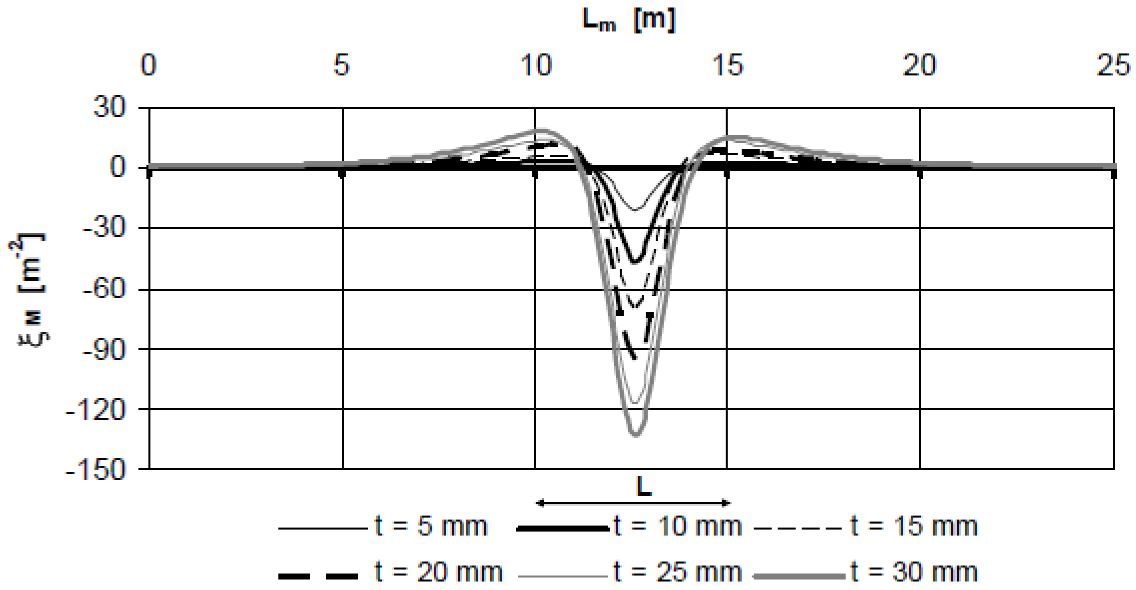


Figure 3.35 - Influence lines $\sigma_M(t)$ in the crown

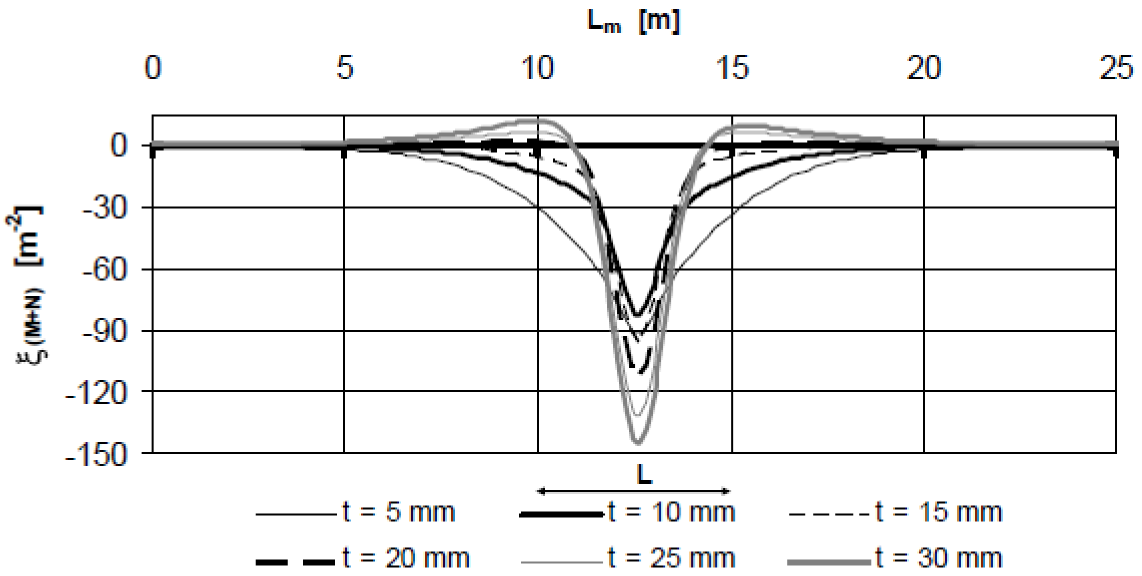


Figure 3.36 - Influence lines $\sigma_{M+N}(t)$ in the crown

Based on the analysis of partial results we can claim that along with the thickness increase the axial force $\sigma_N(t)$ decrease and the bending moments $\sigma_M(t)$ increase. It is caused by an increase in the area and moment of inertia of the cross section of the steel sheet, the shell rigidity increases towards the soil backfill. Greater thickness (rigidity) of the shell steel sheet causes greater normal stresses than those due to the bending moment. An increase in the cross section area of the steel sheet is responsible for a decrease in a normal stresses due to axial force.

From the charts presented in figures 3.32 – 3.34 we can infer that thinner steel sheets are not profitable in term of resistance, because in some sections of the shell great normal stresses may appear. The optimum solution seems to be the application of plane steel sheets whose thickness ranges between 15 and 25 mm.

THICKNESS OF SHELL STEEL SHEETS OF THE MP 150-50 TYPE

The values of geometrical parameters of the shells defined on the basis of the *Handbook of Steel Drainage & Highway Construction Products* are given in Table 3.5. The changes in the thickness of the steel sheet of the MP 150-50 type in the shell of the object of the size given earlier is presented in Figures 3.35 - 3.37.

Table 3.5 – geometrical parameters function of the thickness

t [mm]	*A [mm²/mm]*	*I [mm⁴/mm]*	$h_c = h_f + t$ *[mm]*
3.0	3.520	1057.5	53
4.0	4.828	1457.6	54
5.0	6.149	1867.1	55
6.0	7.461	2278.3	56
7.0	8.712	2675.1	57

$h_f = 50\ mm$: height of the steel sheet wave

h_c : total height of the cross section of the steel shell

Considering the analysis of partial results, we can say that the stresses due to axial forces essentially influence the changes in the values of total normal stresses in the shell as the function of steel sheet thickness. We can arrive at the conclusion that an increase in bending moment in the shell is proportional to an increase in its moment of inertia, thus the values of normal stresses associated with those values are roughly constant. In the case of stresses being the result of axial forces, the proportion is opposite. The axial force increase is small, but the cross section area of the shell increases more than twice as much.

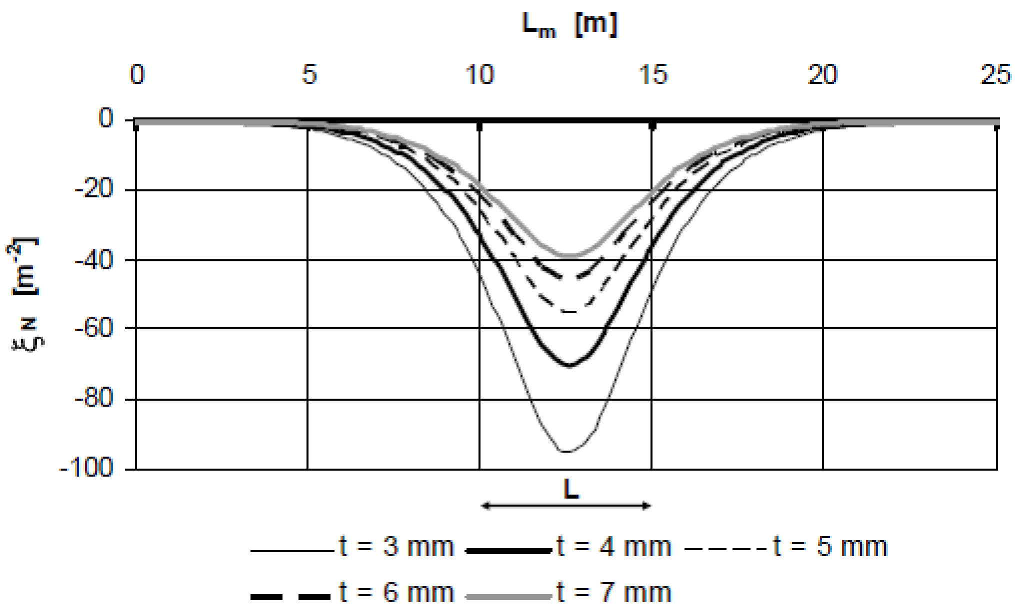


Figure 3.37 – Influence lines $\sigma_N(t)$ in the crown

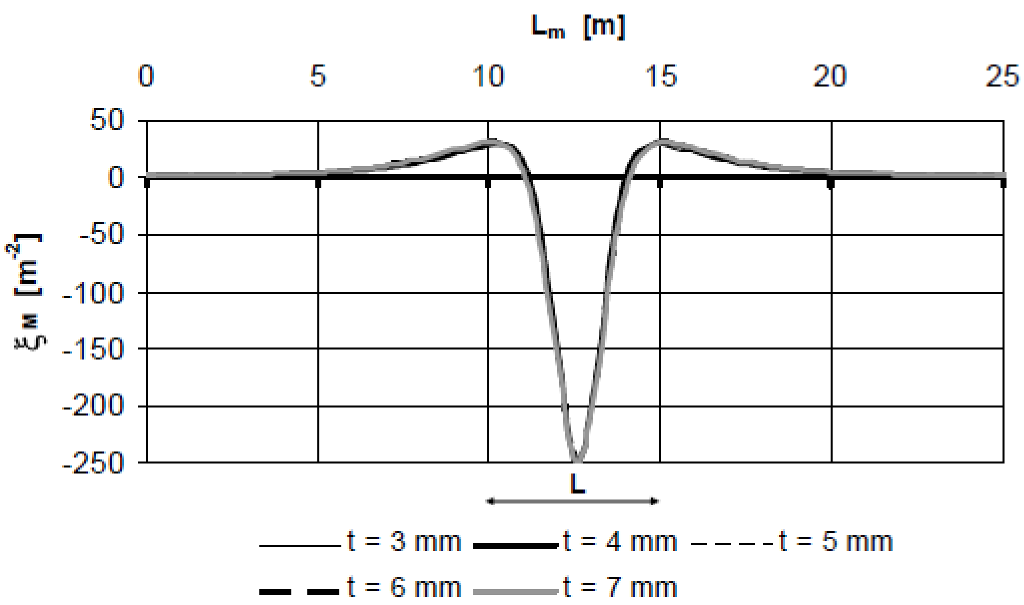


Figure 3.38 – Influence lines $\sigma_M(t)$ in the crown

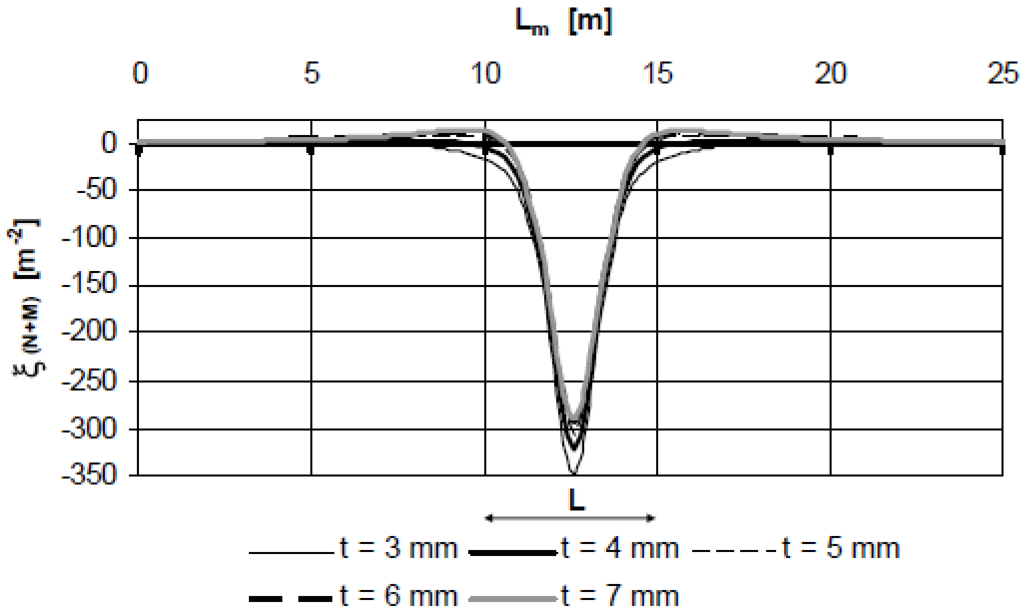


Figure 3.39 – Influence lines $\sigma_{N+M}(t)$ in the crown

The results of the resistance analysis show that it is effective to apply the shell built up from thick steel sheets. However, the thickness setting should be based on economical criteria since using steel sheets of big thickness reduces normal stresses to the level of a few MPa, because at the steel resistance of 200 MPa it results from a minimum material stress of the construction. In the case of the shells of 200-55, SC 380-140 and SC 400-150 types, the character of the stress in the system is similar [16].

3.3.1 LCC – Analysis of Super Cor Bridges

One of the main goal of Life Cycle Cost Analysis is to make optimal decision when comparing different possible solutions. Here it is analyzed the possibility to build a SuperCor bridge on a span of 20 m instead of the more classic typology. Thanks to the help provided by Lars Halsing and Adriano Maglica, the first working in a private company, ViaCon [25], and the second in a Government one, Vägverket, it was possible to collect information on timing and costs of inspections, maintenance, repair and rehabilitation, initial investment of SuperCor Bridges. Here, as done before with the other analysis, different parameters that take into account the difference in growing of goods, money and user time has been considered.

Furthermore, because this is a general analysis, it is not possible to fix a definite traffic forecast, so the solution adopted was to consider three different scenarios, depending on the number of vehicles, 5000, 500 and 100 vehicles per day in 2009. The different scenarios reflect high and low traffic volumes. The forecasts for three different regions in Sweden has been adopted: Stockholm, Norrbotten and Västerbotten. Three different 'initial values' have been chosen, because the forecast for Norrbotten and Västerbotten are similar, and the analysis would have been the same.

Table 3.6 – operation and description of operations for SuperCor Bridges

n°	***Operation***	***Description***
1	Washing	Wash the steel culvert and gabions
2	Repaint steel	Take away all paint that loose and replace the several layers with new paint
3	Yearly inspection	Check from a distance inferior than arm-length all part of the bridge
4	Periodical maintenance	Remove the asphalt/concrete and the waterproofing and replace it with concrete or new waterproof and asphalt, remove vegetation around and on the bridge, change some parts on the fence, mainly small repairing that do not have so much affect on the traffic, adjust/strengthen the slope with filling with material (rocks)
5	Demolition	Take down the old bridge, separate different parts and disposal it

Here the three different scenarios are presented:

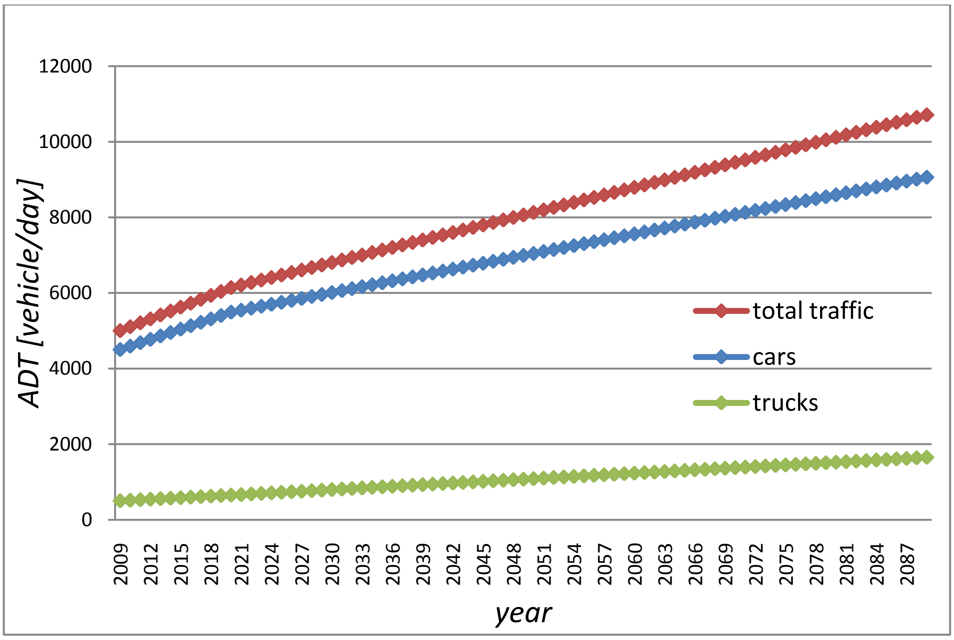


Figure 3.40 - Scenario 1, high traffic volume and Stockholm Region forecast

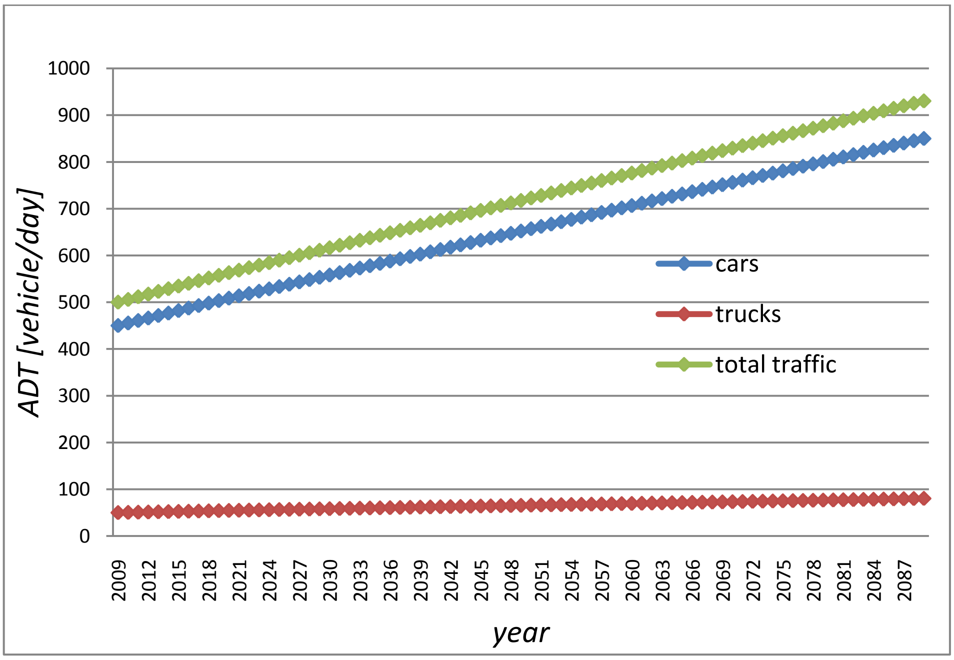


Figure 3.41 - Scenario 2, low traffic volume and Norrbotten (coast) Region forecast

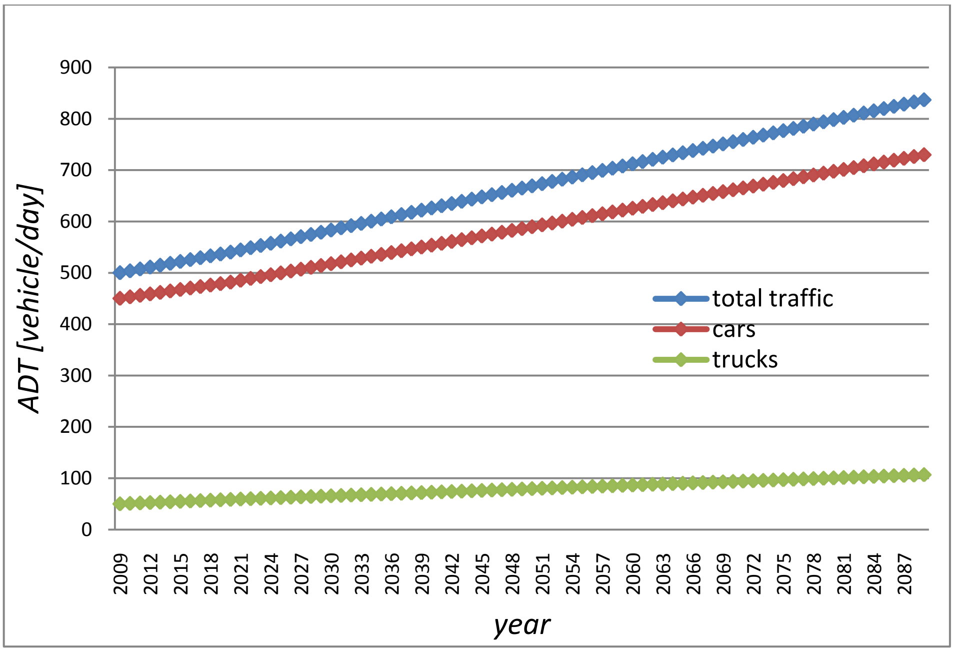


Figure 3.42 - Scenario 3, low traffic volume and Västerbotten (coast) Region forecast

3.3.2 Results – Soil-Steel Bridges

The results obtained from the Life Cycle Cost Analysis on SuperCor bridges can be summarized in the table below:

Table 3.7 – summary of the results from LCCA of SuperCor Bridges

PV 2009			
[SEK]	Scenario 1	Scenario 2	Scenario 3
Total LCC	4 423 791	2 373 717	2 274 821
Annuity cost	17 096	9 497	9 150
Impact of the item costs on the total LCC			
Initial investment	1 379 000 (31,2 %)	1 379 000 (58,1 %)	1 379 000 (60,6 %)
Planning&design	100 000 (2,3 %)	100 000 (4,2 %)	100 000 (4,4 %)
MR&R	740 405 (16,7 %)	740 405 (31,2 %)	740 405 (32,5 %)
User costs	2 169 762 (49 %)	119 688 (5 %)	20 792 (0,9 %)
Dismantle	34 624 (0,8 %)	34 624 (1,5 %)	34 624 (1,5 %)

The costs for MR&R, dismantle and design, and initial investment are fixed among the three different scenarios because the same bridge is analyzed; only the cost for users change according to the change of area. The expenditures and timing of the maintenance are more dependent on the weather, so seems reasonable to keep the same MR&R costs and timing for different traffic scenarios. As it can be seen from the table, the final Life Cycle Cost depends consistently on the user costs; in the first scenario, the one that reflect the situation of high traffic volume and forecast for the area of Stockholm, the user costs is half of the total. Furthermore, this kind of bridge presents a low investment cost, that let the annuity cost be so competitive.

4. Sensitivity Analysis

In order to understand how the different parameters influence the result of the LCCA, in this chapter a sensitivity analysis is performed. The different scenarios taken into consideration are shown below. The results are referred to the LCCA of bridge number 1.

1) These parameters **are the same** as the ones used in the previous analysis.

V parameters		
V_users	1.009615385	5%/year
V_MR&R	0.975961538	1,5%/year
V_investment	0.961538462	0%/year
V_planning&design	0.980769231	2%/year
V_dismantle	0.990384615	3%/year
	interest rate	4%/year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	553971.83	3.8
user costs	5211062.74	36.1
initial investment	8363000.00	57.9
planning and design	100000.00	0.7
Dismantle	220707.22	1.5

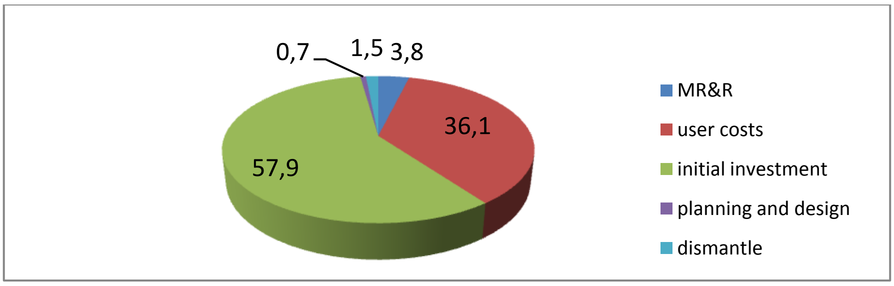


Figura 4.1 – Percentages of impact of the different cost items on the total LCC (discounted at the year of construction) – case 1

% on the total LCC (PV 2009)		
	costs	%
MR&R	639841.58	3.8
user costs	4873428.33	28.9
initial investment	11005137.47	65.2
planning and design	114559.78	0.7
dismantle	236150.75	1.4

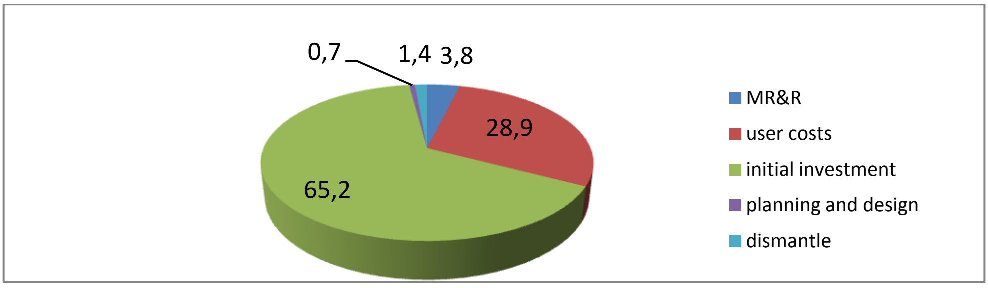


Figura 4.2 – Percentages of impact of the different cost items on the total LCC (present value 2009) – case 1

	LCC (PV 2009)	Annuity Cost (PV 2009)	LCC (discounted to the year of cons.)	Annuity Cost (discounted to the year of cons.)
Total	16 869 118	38 999	14 448 742	33 404

2) In this case **the 'inflations' are considered equal to the interest rate**.

V parameters		
V_users	1	4%/year
V_MR&R	1	4%/year
V_investment	1	4%/year
V_planning&design	1	4%/year
V_dismantle	1	4%/year
	interest rate	4%/year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	1499535.26	10.7
user costs	3498000.00	24.9
initial investment	8363000.00	59.6
planning and design	100000.00	0.7
dismantle	580000.00	4.1

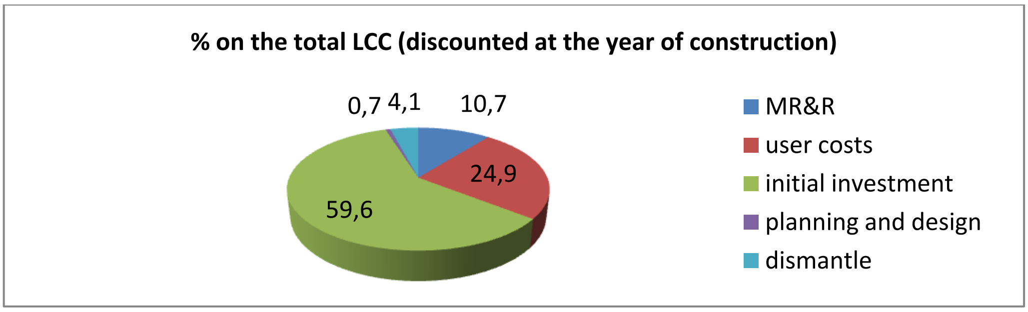


Figure 4.3 – Percentages of impact of the different cost items on the total LCC (discounted at the year of construction) – case 2

% on the total LCC (PV 2009)		
	costs	%
MR&R	1499535.26	10.7
user costs	3498000.00	24.9
initial investment	8363000.00	59.6
planning and design	100000.00	0.7
dismantle	580000.00	4.1

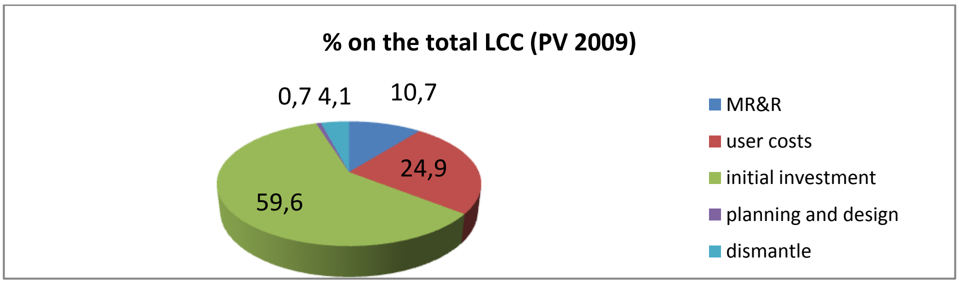


Figure 4.4 – Percentages of impact of the different cost items on the total LCC (present value 2009) – case 2

	LCC (PV 2009)	Annuity Cost (PV 2009)	LCC (discounted to the year of cons.)	Annuity Cost (discounted to the year of cons.)
Total	14 040 535	32 460	14 040 535	32 460

3) Here is considered **an increment of the inflation of 1%** respect to the scenario No 1.

V parameters		
V_users	1.019230769	6%/year
V_MR&R	0.985576923	2,5%/year
V_investment	0.971153846	1%/year
V_planning&design	0.990384615	3%/year
V_dismantle	1	4%/year
	interest rate	4%/year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	800753.28	4.3
user costs	8977762.29	47.7
initial investment	8363000.00	44.4
planning and design	100000.00	0.5
dismantle	580000.00	3.1

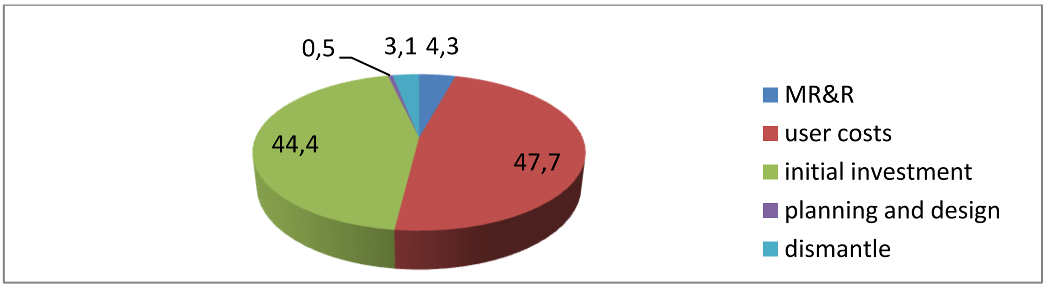


Figure 4.5 – Percentages of impact of the different cost items on the total LCC (discounted at the year of construction) – case 3

% on the total LCC (PV 2009)		
	costs	%
MR&R	876673.41	4.5
user costs	7857066.34	39.9
initial investment	10264690.41	52.1
planning and design	106997.30	0.5
dismantle	580000.00	2.9

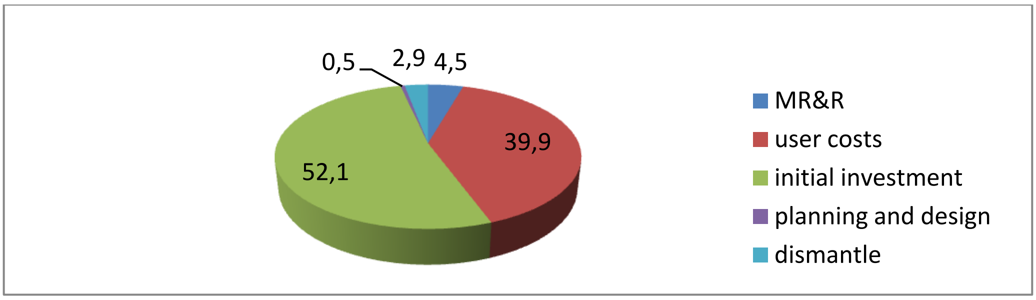


Figura 4.6 – Percentages of impact of the different cost items on the total LCC (present value 2009) – case 3

	LCC (PV2009)	Annuity Cost (PV2009)	LCC (discounted to the year of construction)	Annuity Cost (discounted to the year of construction)
Total [SEK]	19 685 427	45 510	18 821 516	43 513

4) In this scenario the increment **of inflation is 2%.**

V parameters		
V_users	1.028846154	7%/year
V_MR&R	0.995192308	3,5%/year
V_investment	0.980769231	2%/year
V_planning&design	1	4%/year
V_dismantle	1.009615385	5%/year
	interest rate	4%/year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	1205923.04	4.2
user costs	17547012.84	61.1
initial investment	8363000.00	29.1
planning and design	100000.00	0.3
dismantle	1510163.50	5.3

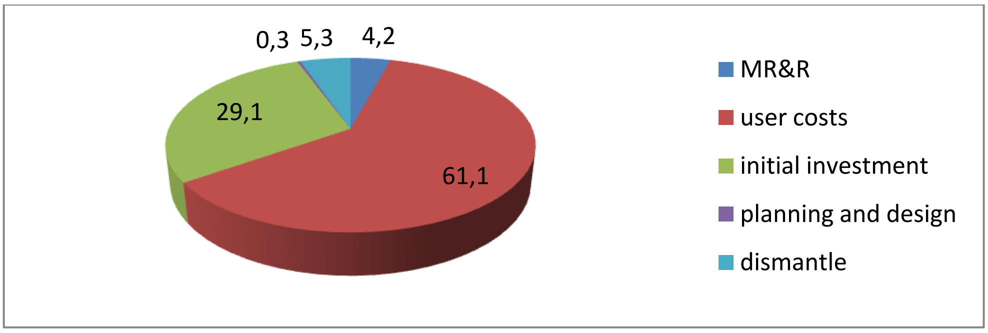


Figura 4.7 – Percentages of impact of the different cost items on the total LCC (discounted at the year of construction) – case 4

% on the total LCC (PV 2009)		
	costs	%
MR&R	1244158.23	4.7
user costs	14379709.92	53.8
initial investment	9580634.44	35.9
planning and design	100000.00	0.4
dismantle	1412317.21	5.3

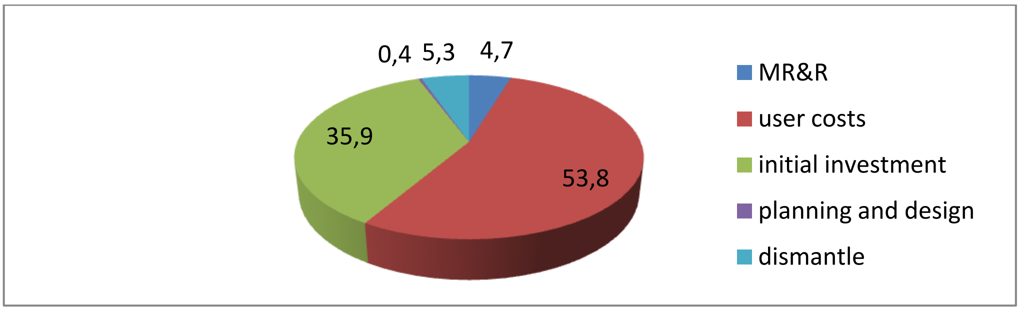


Figura 4.8 – Percentages of impact of the different cost items on the total LCC (present value 209) – case 4

	LCC (PV2009)	Annuity Cost (PV2009)	LCC (discounted to the year of construction)	Annuity Cost (discounted to the year of construction)
Total [SEK]	26 716 820	61 766	28 726 099	66 411

5) In this scenario **inflation is 2% more** than the one adopted in the analysis, but this growth is followed by the one of the interest rate so that the difference is the same as the one of the parameters used for the analysis (when interest rate was 4%).

V parameters		
V_users	1.009433962	7%/year
V_MR&R	0.976415094	3,5%/year
V_investment	0.962264151	2%/year
V_planning&design	0.981132075	4%/year
V_dismantle	0.990566038	5%/year
	interest rate	6%/year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	563111.44	3.9
user costs	5164990.24	35.8
initial investment	8363000.00	58.0
planning and design	100000.00	0.7
dismantle	224787.09	1.6

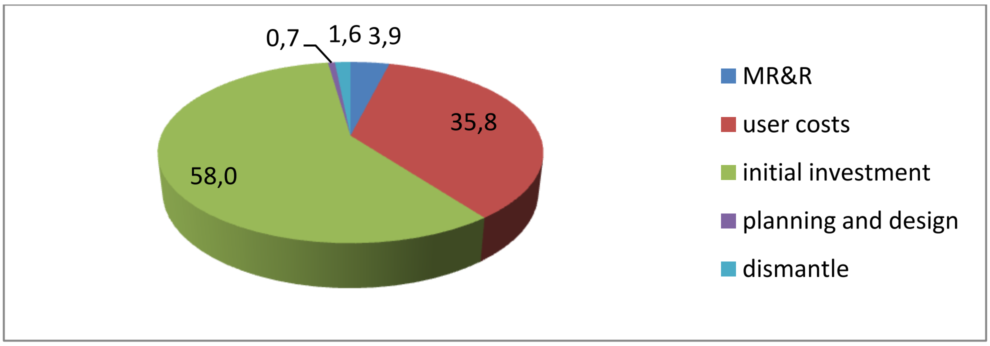


Figura 4.9 – Percentages of impact of the different cost items on the total LCC (discounted at the year of construction) – case 5

% on the total LCC (PV 2009)		
	costs	%
MR&R	648862.76	3.9
user costs	4836421.22	28.8
initial investment	10947172.24	65.2
planning and design	114263.54	0.7
dismantle	240207.93	1.4

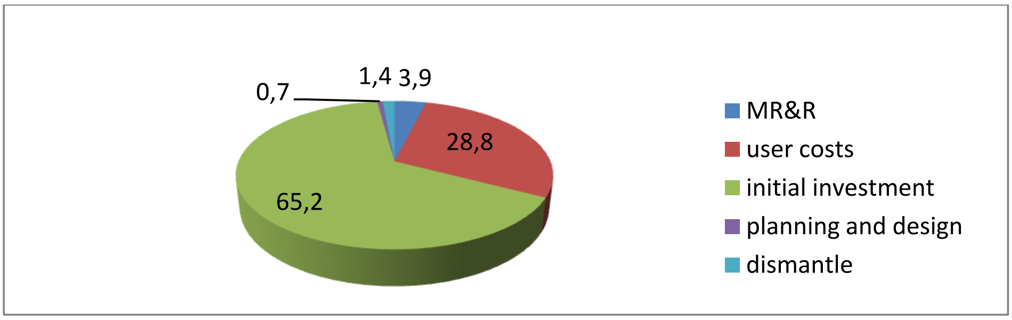


Figura 4.10 – Percentages of impact of the different cost items on the total LCC (present value 2009) – case 5

	LCC (PV2009)	Annuity Cost (PV2009)	LCC (discounted to the year of construction)	Annuity Cost (discounted to the year of construction)
Total [SEK]	16 786 928	38 809	14 415 889	33 28

6) In this last sensitivity analysis the **inflation rate is not taken into consideration**. The different "V – parameter" are shown below:

V parameters		
V_users	0.961538462	0 %/year
V_MR&R	0.961538462	0 %/year
V_investment	0.961538462	0 %/year
V_planning&design	0.961538462	0 %/year
V_dismantle	0.961538462	0 %/year
	interest rate	4%/year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	348408.39	3.2
user costs	1956996.10	18.2
initial investment	8363000.00	77.6
planning and design	100000.00	0.9
dismantle	11484.02	0.1

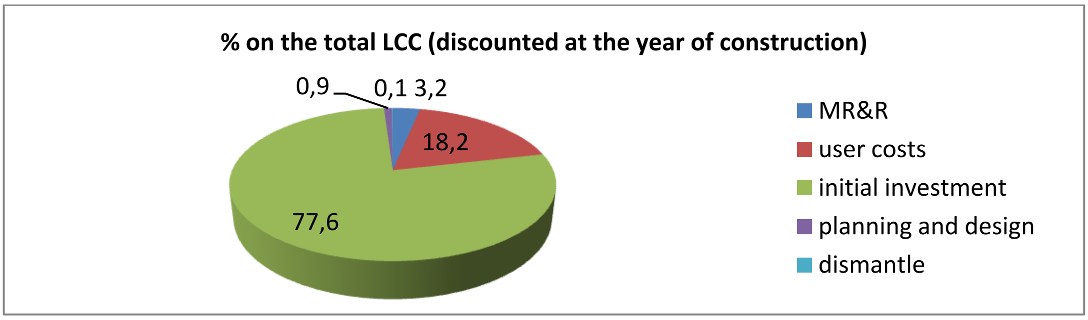


Figura 4.11 – Percentages of impact of the different cost items on the total LCC (discounted at the year of construction) – case 6

% on the total LCC (PV 2009)		
	costs	%
MR&R	429562.78	3.0
user costs	2575273.36	18.2
initial investment	11005137.47	77.7
planning and design	131593.18	0.9
dismantle	15112.19	0.1

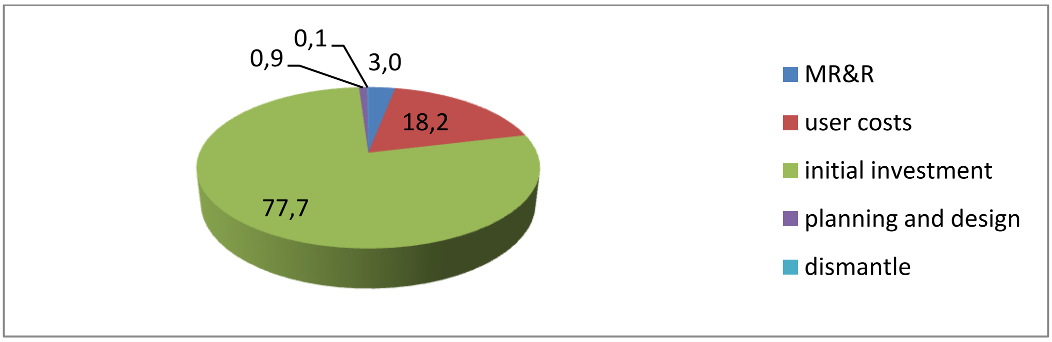


Figura 4.12 – Percentages of impact of the different cost items on the total LCC (present value 2009) – case 6

	LCC (PV2009)	Annuity Cost (PV2009)	LCC (discounted to the year of construction)	Annuity Cost (discounted to the year of construction)
Total [SEK]	14 156 679	32 725	10 779 889	24 922

From the sensitivity analysis can be noticed that the LCC is very sensible to the change of inflation rate but when the difference between inflation and interest rates is kept constant the difference from one analysis to another is really slight, around 0,5 %.

Furthermore, when the inflation is not considered into the analysis, the final Life Cycle Cost results underestimated, around 19 % when the present value in 2009 is calculated and around 25% when the costs are discounted to the year of construction, as shown in the last sensitivity analysis.

5. Conclusions and Future Development

5.1 Conclusions

The conclusions we can draw from the analyses are that some costs items influence the final Life Cycle Cost more than others. Initial investment is, in most of the cases, the factor that most influences the final LCC of a bridge. As it can be seen from the table 2.2, project alternatives with high initial investment result to have high life cycle costs and high annuity cost. The second factor that influence the final total cost, in order of importance, is the user cost. In many cases it is higher than the cost for the maintenance itself that is one of the causes of this cost. The main factor that influences this cost item is the location of the bridge: densely or sparsely populated area; but it is important to notice that also in areas like the northern regions, sparsely populated, user costs are in many cases pretty influent. Another important factor that influence the annuity cost is the service life of the bridge. In the histogram below we can notice the influence of the service life and the type of bridge on the annuity cost for the different bridges analyzed. In general, for service life longer than 100 years, the annuity cost decrease consistently.

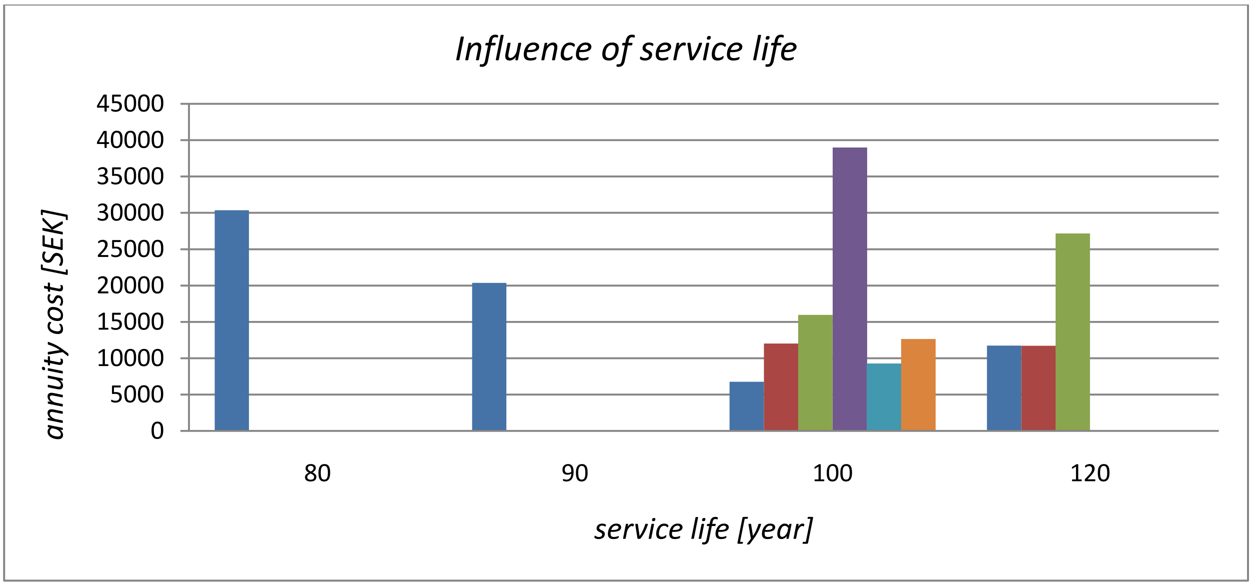


Figure 5.1 – Influence of the length of the service life on the annuity cost

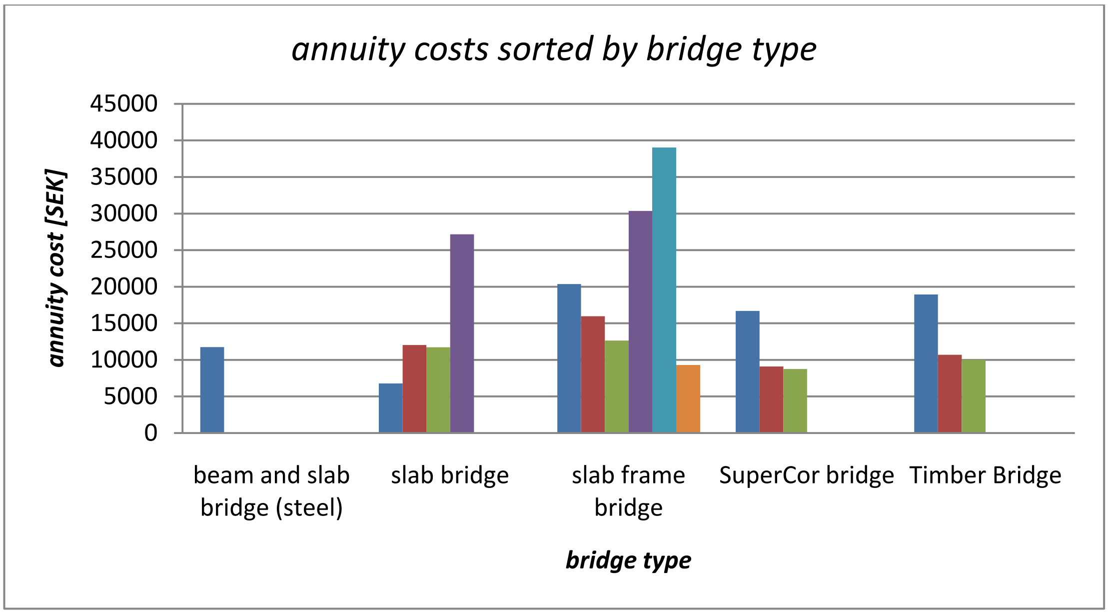


Figure 5.2 – Influence of bridge type on annuity cost

When an operation that can extend the service life of the bridge is planned in the Life Cycle Cost Analysis, the annuity cost decrease in each of the cases studied between the 38,3 % and the 39,3 %.

The Life Cycle Cost do not decrease, but it grows instead, to take into consideration the costs for the operation to extend the service life (strengthening for example, the most common operation to extend the service life) but this decrease in the annuity cost mean that it is possible to save around the 38 % of the whole cost, because the life cycle cost is spread on a longer lifespan.

When a comparison is done between the results of the analysis of SuperCor and Timber Bridges (shown in the table below) we can notice that for every scenario the SuperCor bridges are more cost efficient then the Timber ones, they are 6,4 % cheaper in the first scenario, 14,41 % in the second and 12,46 % in the last one.

Table 5.1 - Summary of the results from LCCA of SuperCor and Timber Bridges

Present Value 2009						
[SEK]	**Scenario 1**		**Scenario 2**		**Scenario 3**	
	SuperCor	Timber	SuperCor	Timber	SuperCor	Timber
Total LCC	4 423 791	4 705779	2 373 717	2 657317	2 274 821	2 485054
Annuity Cost	17 096	18 946	9 497	10 698	9 150	10 005
Impact of the cost items on the total LCC						
Initial investment	1 379 000 (31,2 %)	1925 000 (40,9%)	1 379 000 (58,1 %)	1 925000 (72,4%)	1 379 000 (60,6 %)	1925 000 (77,5%)
Planning & design	100 000 (2,3 %)	100 000 (2,1 %)	100 000 (4,2 %)	100 000 (3,8 %)	100 000 (4,4 %)	100 000 (4 %)
MR&R	740 405 (16,7 %)	257 253 (5,5 %)	740 405 (31,2 %)	257 253 (9,7 %)	740 405 (32,5 %)	257 253 (10,4 %)
User costs	2 169 762 (49 %)	2 261949 (48,1%)	119 688 (5 %)	213 487 (8 %)	20 792 (0,9 %)	41 225 (1,7 %)
Dismantle	34 624 (0,8 %)	161 577 (3,4 %)	34 624 (1,5 %)	161 577 (6,1 %)	34 624 (1,5 %)	161 577 (6,5 %)

The reason is that the initial investment is constantly smaller for a SuperCor than for a Timber Bridge. The impact of user cost is similar in the first scenario, but then it becomes bigger and bigger: in the third scenario the user costs of SuperCor are half of the ones of the Timber Bridge. According to the results we should prefer these kinds of bridges just for small traffic volumes, because the annuity cost is small when compared to the other 'classical' types, such as slab, slab frame and beam and Slab Bridge.

Finally, it has to be highlighted also the need to keep constant the standard of living of the people when a project alternative is chosen: if the only choice criteria is the cost efficiency, some areas, likely the less populated, could see the standard of living of their inhabitants decrease too much. If the initial investment is small in order to increase the number of operations for maintenance, but in area sparsely populated, the impact on user cost will not be so high, is an cost efficient solution, but the limit has to be to keep the standard of living the people are used to at the same level as before, because in this case the few users will have lot of disturbance and user costs.

A summary of the annuity costs for all the studied bridges are given in table 5.2. It can be seen that there exist no unique type of bridge that is more cost effective than the others. Rather, the economic efficiency depends on the location of the bridge, and on the traffic volumes in that particular area.

Table 5.2 - Summary of Life Cycle cost for studied bridges. Maximum costs are indicated with **bold blue** and minimum costs with ***bold red italics***.

Bridge	**Lenth**	**Width**	**Area**	**Life length**	**Traffic 2009**	**Annuity Cost**	**Annuity/area**	**Annuity/(area*traffic)**
No/BaTMan Code	m	m	m2	years	vehicles/day	kkr	kkr/m2	kr/(m2*veh/day)
1/24-1790-1	26	7.3	189.8	120	200	11 752	62	310
2/24-1861-1	19	7	133	120	20	***6 777***	***51***	**2 548**
3/24-1497-1	26	7	182	100	370	12 033	66	179
4/24-1753-1	18	7	126	120	2 800	11 712	93	33
5/24-1876-1	20	15.2	304	120	**5 000**	27 170	89	***18***
6/24-417-1	23	7.9	181.7	90	1 900	20 371	112	59
7/24-471-1	19	6.9	131.1	100	105	15 971	122	1 160
8/25-1432-1	19	7.9	150.1	100	720	12 643	84	117
9/25-1674-1	22	9	198	80	1 410	30 361	153	109
10/25-1888-1	16	15.1	241.6	100	4 300	**38 999**	**161**	38
11/25-780-1	17	7.4	125.8	100	300	9 260	74	245
Glulam 1	20	7	140	80	100	10 005	71	715
Glulam 2	20	7	140	80	500	10 698	76	153
Glulam 3	20	7	140	80	**5 000**	18 946	135	27
Soil-steel 1	20	7	140	80	100	9 150	65	654
Soil-steel 2	20	7	140	80	500	9 497	68	136
Soil-steel 3	20	7	140	80	**5 000**	17 096	122	24

5.2 Future developments

Based on the results and methodology adopted, some developments may be proposed:

- Improvement of mathematical models that describe traffic, interest and inflation rate forecasts will be fundamental to get more reliable results (and the use of stochastic models for example);
- Extend and update use of data bases to collect information on initial investments, operation of MR&R, and time and costs related to;
- Increase the number and sites of traffic surveys: they give valuable information when the tendency of the traffic volume is needed over the years;
- Include in the Life-Cycle Cost Analysis the reliability of construction companies as a parameter when choosing between different alternatives. The reliability of the information the companies give to the project leader is of fundamental importance; information could be too optimistic and the consequent choice of the project alternative will result in an uneconomic decision;
- Include in the LCCA different strategies to manage the traffic delays: because the user cost is an influent parameter, the choice of good strategies to minimize it will end up in a important decrement of the total LCC;
- Finally, complete and user friendly software that includes all of these different aspects and developments of the Life-Cycle Cost Analysis would be a necessary tool to estimate the costs.

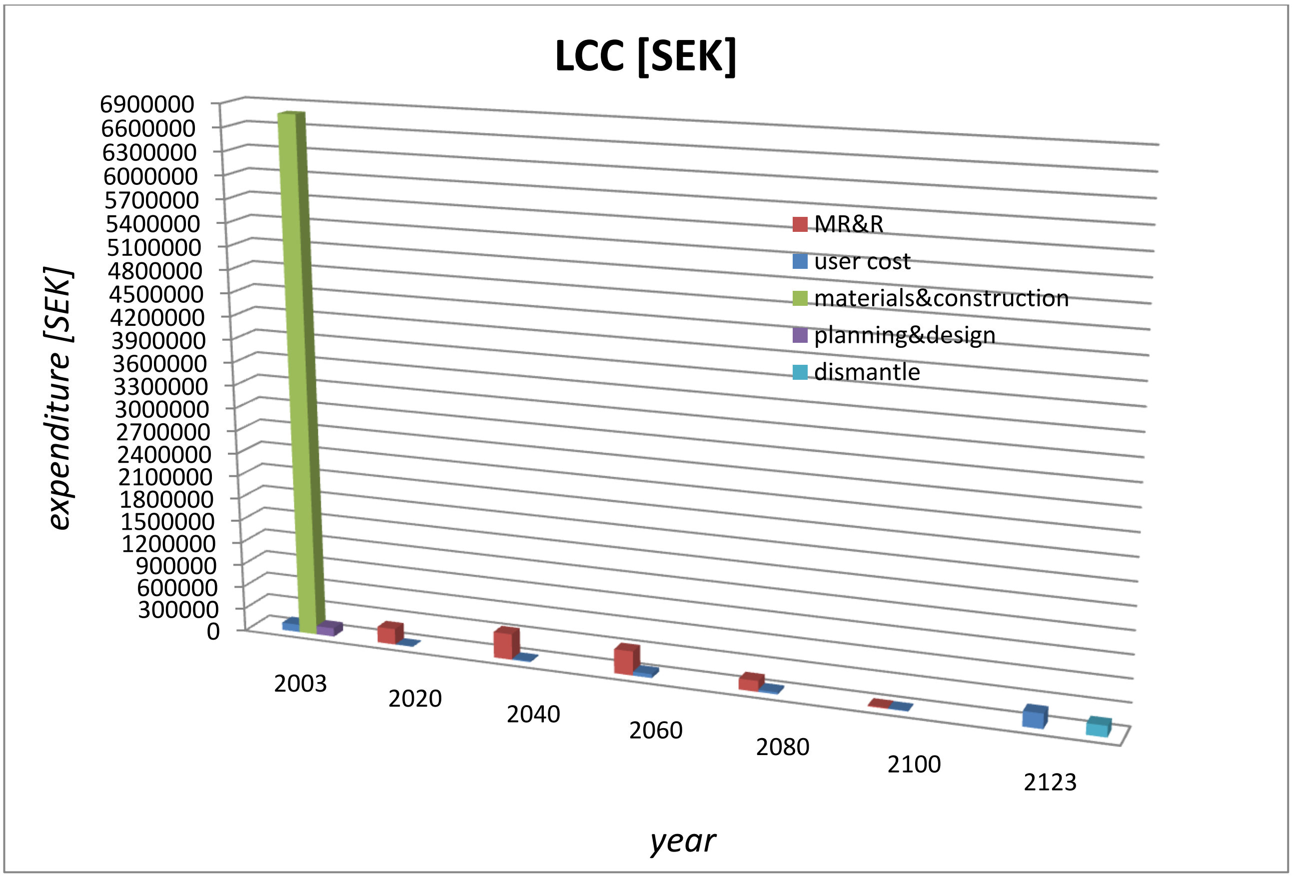
APPENDIX A1 – Life-Cycle Cost Calculations for bridges in the North of Sweden

n°	***Operation***	***Description***
1	Adjust settlement connection road / Adjust road / adjust embankment	Remove asphalt and replace the gravel under asphalt. Then put new asphalt
2	Repaint steel	Take away all the paint that loose and replace the several layers with new paint
3	Change fence	Remove the old fence and replace it with a new and safer fence
4	Change pavement / Change isolation on deck	Remove the asphalt/concrete and the waterproofing and replace it with concrete or new waterproof and asphalt
5	Demolition	Take down the old bridge, separate different parts and disposal it
6	Repair concrete	Repair damages on concrete, hammering away bad concrete and cast new concrete. It is often on the edge beam
7	Adjust slope	To adjust/strengthen the slope with filling with material (rocks)
8	Repaint bearing	Take away all the paint that is loose and replace the several layers with new paint. Often we paint the bearings on place without removing them. Then we put grease(oil) in place where it is not possible to paint
9	Exchange bearings	Take away old bearing and replace them with new.
10	Yearly inspection	Check from a distance inferior than arm-length all part of the bridge
11	Yearly maintenance	Cleaning the bridge, remove vegetation around and on the bridge, change some parts on the fence, perform small repairing that do not have so much affect on the traffic.

Bridge 24-1790-1

bridges information		economic information	
BaTMan code	24-1790-1	interest rate	0.04
year of construction	2003	inflation rate	0.015
expected service life [years]	120	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	2003	100000.00	112356.71	153.01	100000.00	136.18
material and construction	2003	5364000.00	6787171.22	9242.72	5364000.00	7304.66
users cost	2003	105000.00	99141.06	135.01	105000.00	142.99
MR&R						
yearly inspection (10)	yearly	1000.00	37933.69	51.66	37933.69	51.66
yearly maintenance (11)	yearly	2000.00	75867.37	103.32	75867.37	103.32
users cost for yearly op.	service life	8000.00	13412.56	18.27	14205.21	19.34
MR&R cost 1 (1+4)	2020	273000.00	208892.27	284.47	180517.20	245.83
users cost 1	2020	2000.00	2222.01	3.03	2353.32	3.20
MR&R cost 2 (2)	2040	724000.00	340527.63	463.73	294271.75	400.74
users cost 2	2040	11000.00	14798.83	20.15	15673.40	21.34
MR&R cost 3 (1+3+4)	2060	1100000.00	318024.47	433.08	274825.33	374.26
users cost 3	2060	51000.00	83085.29	113.14	87995.38	119.83
MR&R cost 4 (2)	2080	799000.00	141993.57	193.37	122705.75	167.10
users cost 4	2080	14000.00	27618.57	37.61	29250.75	39.83
MR&R cost 5 (1+4)	2100	130000.00	14201.01	19.34	12272.01	16.71
users cost 5	2100	4000.00	9555.48	13.01	10120.18	13.78
dismantle						
Dismantle (5)	2123	440000.00	146249.91	199.16	138012.66	187.94
users cost	2123	66000.00	196482.26	267.57	208093.78	283.38
		total LCC	8629533.91	11751.64	7073097.77	9632.10


LCC [SEK]
expenditure [SEK]
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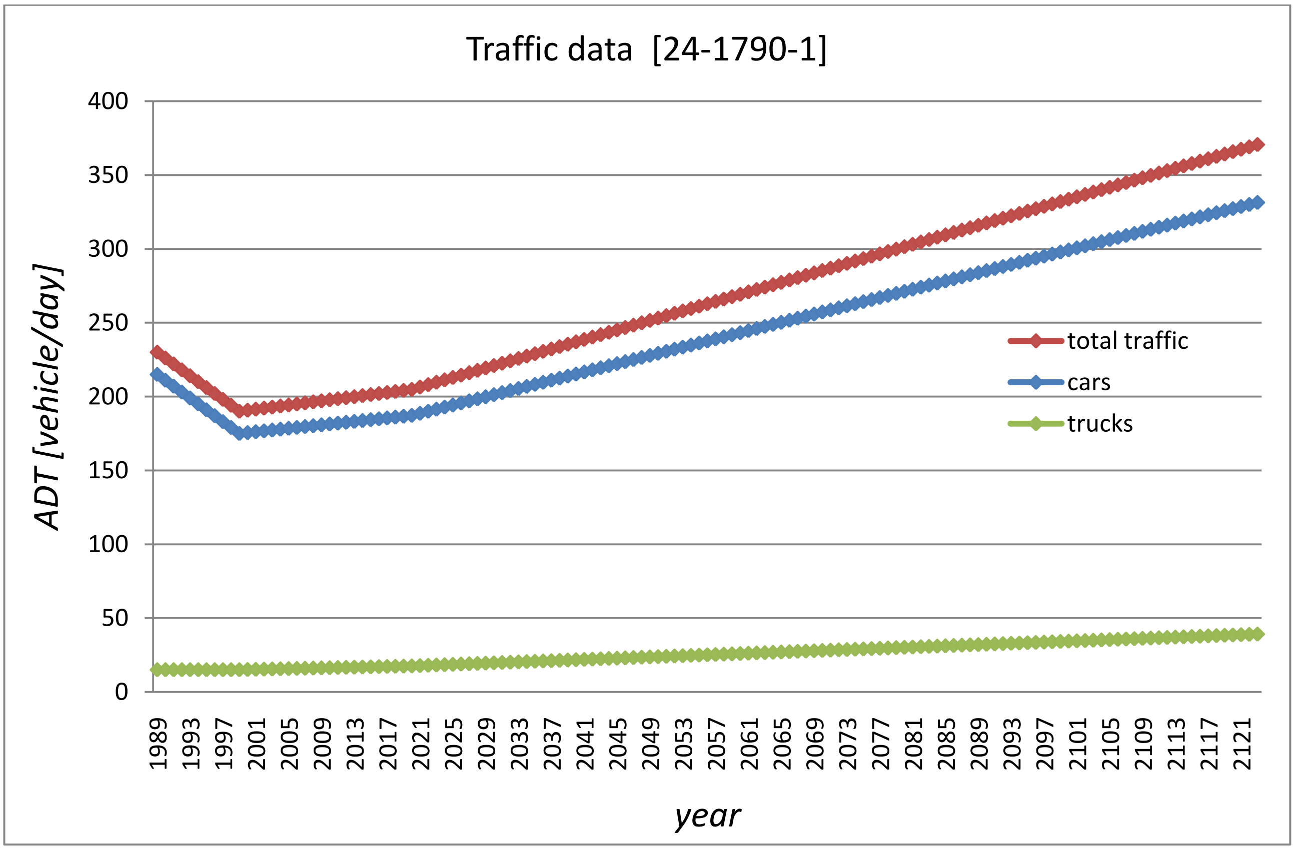
6600000
6300000
6000000
5700000
5400000
5100000
4800000
4500000
4200000
3900000
3600000
3300000
3000000
2700000
2400000
2100000
1800000
1500000
1200000
900000
600000
300000
0
MR&R
user cost
materials&construction
planning&design
dismantle
2003
2020
2040
2060
2080
2100
2123
year


Traffic data [24-1790-1]
ADT [vehicle/day]
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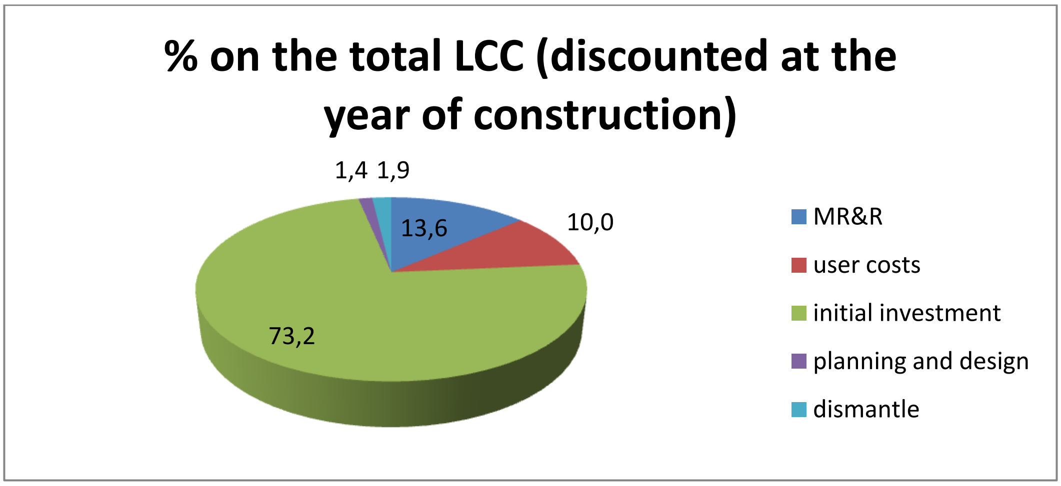
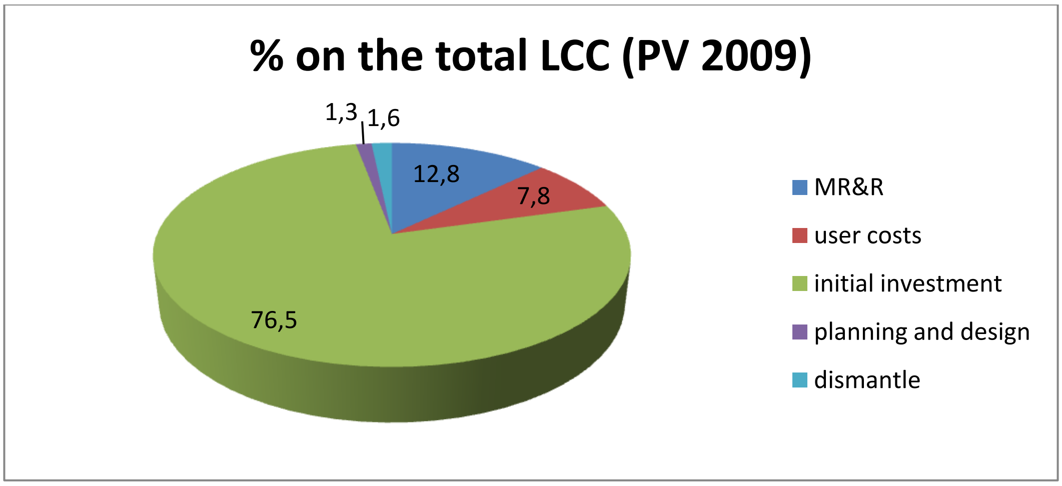
350
300
250
200
150
100
50
0
total traffic
cars
trucks
1989
1993
1997
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
2053
2057
2061
2065
2069
2073
2077
2081
2085
2089
2093
2097
2101
2105
2109
2113
2117
2121
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	998393.10	14.1
user costs	472692.02	6.7
initial investment	5364000.00	75.8
planning and design	100000.00	1.4
dismantle	138012.66	2.0



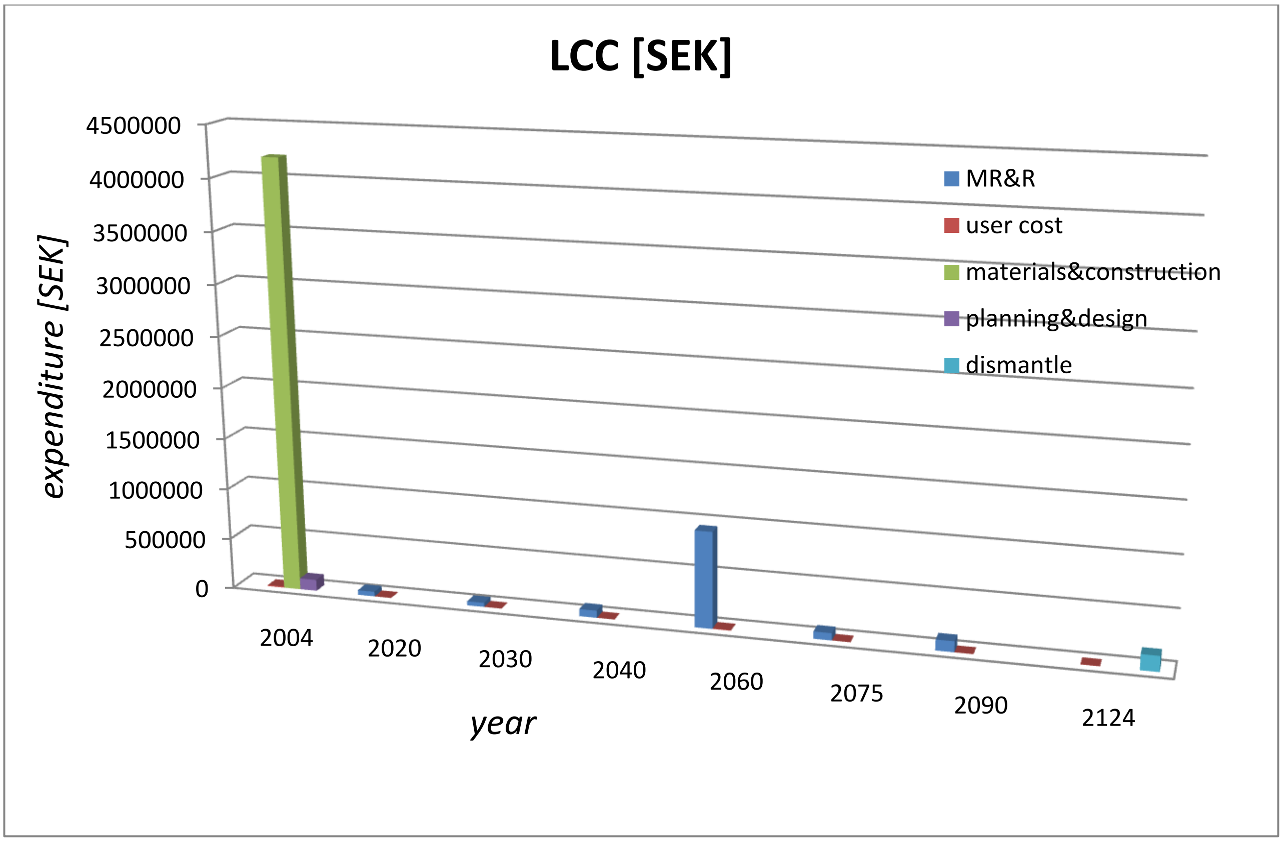
% on the total LCC (PV 2009)		
	costs	%
MR&R	1137440.02	13.2
user costs	446316.05	5.2
initial investment	6787171.22	78.7
planning and design	112356.71	1.3
dismantle	146249.91	1.7

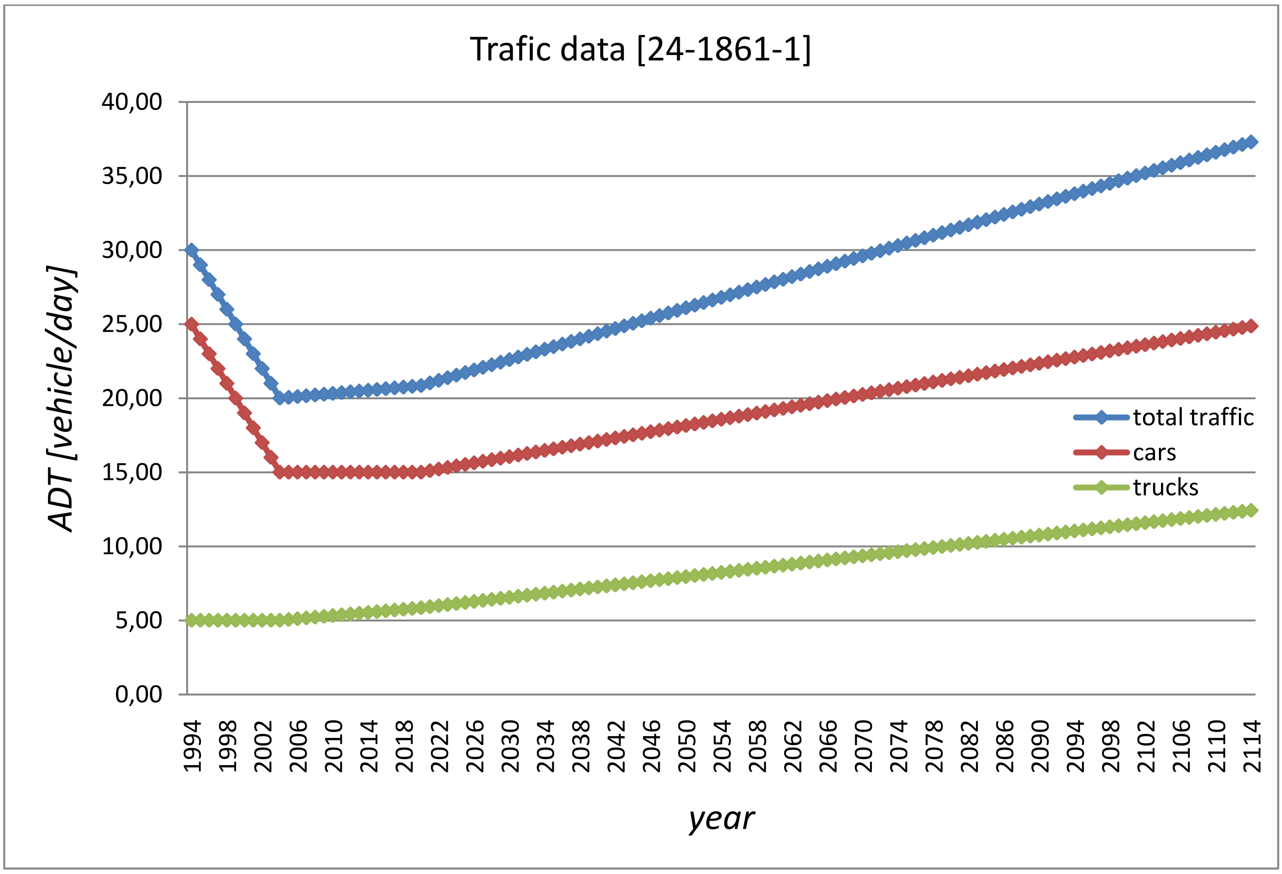


Bridge 24-1861-1

bridges information		economic information	
BaTMan code	24-1861-1	interest rate	0.04
year of construction	2004	inflation rate	0.015
expected service life [years]	120	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	2004	100000.00	110196.00	150.06	100000.00	136.18
material and construction	2004	3453000.00	4201102.47	5721.03	3453000.00	4702.27
users cost	2004	11000.00	10486.07	14.28	11000.00	14.98
MR&R						
yearly inspection (10)	yearly	500.00	18966.84	25.83	18966.84	25.83
yearly maintenance (11)	yearly	2000.00	75867.37	103.32	75867.37	103.32
users cost for yearly op.	service life	0.00	0.00	0.00	0.00	0.00
MR&R cost 1 (1)	2020	60000.00	45910.39	62.52	40651.31	55.36
users cost 1	2020	0.00	0.00	0.00	0.00	0.00
MR&R cost 2 (6)	2030	40000.00	23996.44	32.68	21247.62	28.93
users cost 2	2030	0.00	0.00	0.00	0.00	0.00
MR&R cost 3 (1+7)	2040	70000.00	32923.94	44.84	29152.47	39.70
users cost 3	2040	0.00	0.00	0.00	0.00	0.00
MR&R cost 4 (1+3+4+8)	2060	940000.00	271766.36	370.09	240635.23	327.70
users cost 4	2060	6000.00	9774.74	13.31	10253.80	13.96
MR&R cost 3 (1+7)	2075	70000	14049.36	19.13	12439.99	16.94
users cost 3	2075	0	0.00	0.00	0.00	0.00
MR&R cost 4 (1+6)	2090	105000.00	14629.79	19.92	12953.94	17.64
users cost 4	2090	1000.00	2170.86	2.96	2277.26	3.10
dismantle						
Dismantle (5)	2124	460000.00	151427.47	206.21	144285.96	196.49
users cost	2124	2000.00	6011.26	8.19	6305.87	8.59
		total LCC	4989279.38	6777.13	4179037.67	5690.98


LCC [SEK]
expenditure [SEK]
4500000
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
2004
2020
2030
2040
2060
2075
2090
2124
year
MR&R
user cost
materials&construction
planning&design
dismantle


Trafic data [24-1861-1]
ADT [vehicle/day]
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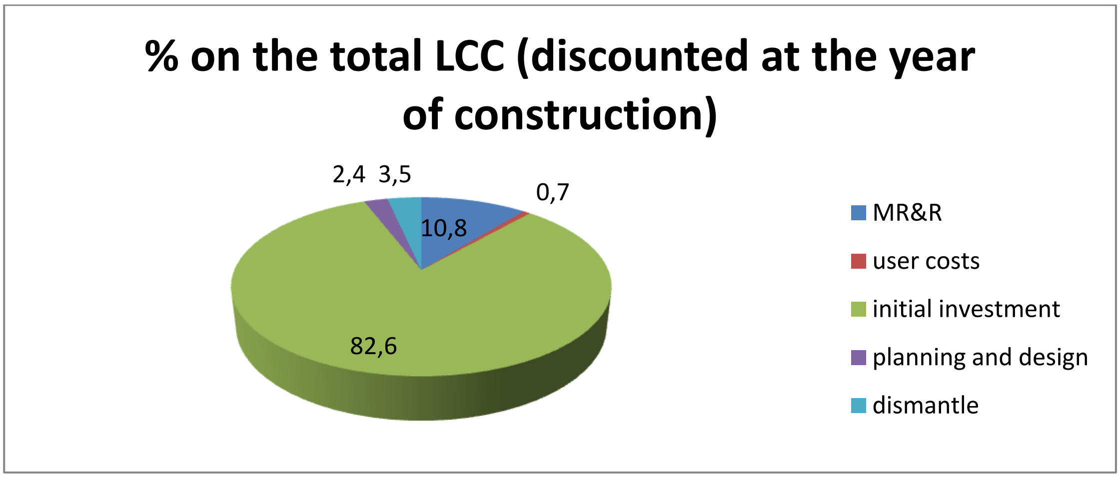
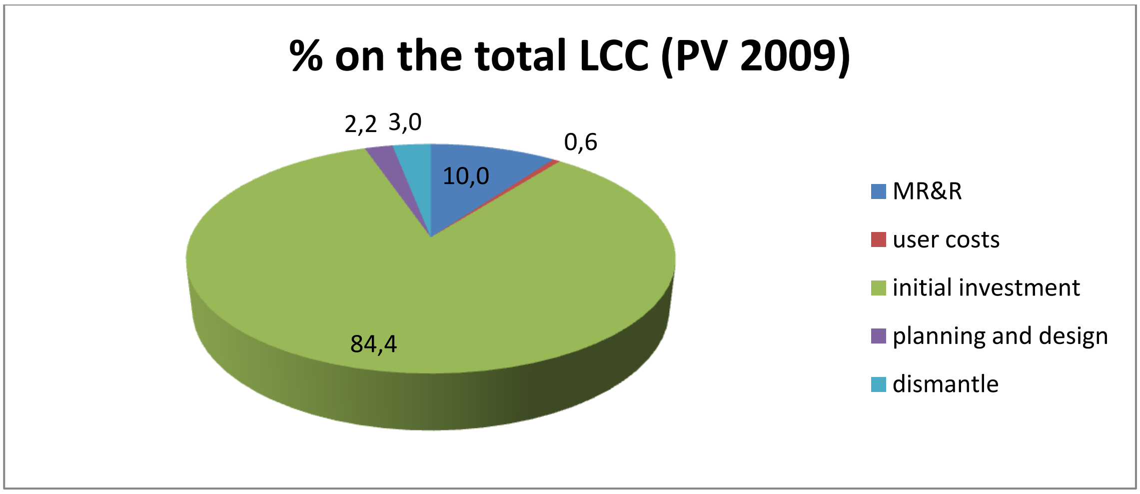
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
1994
1998
2002
2006
2010
2014
2018
2022
2026
2030
2034
2038
2042
2046
2050
2054
2058
2062
2066
2070
2074
2078
2082
2086
2090
2094
2098
2102
2106
2110
2114
year
total traffic
cars
trucks

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	451914.77	10.8
user costs	29836.94	0.7
initial investment	3453000.00	82.6
planning and design	100000.00	2.4
dismantle	144285.96	3.5



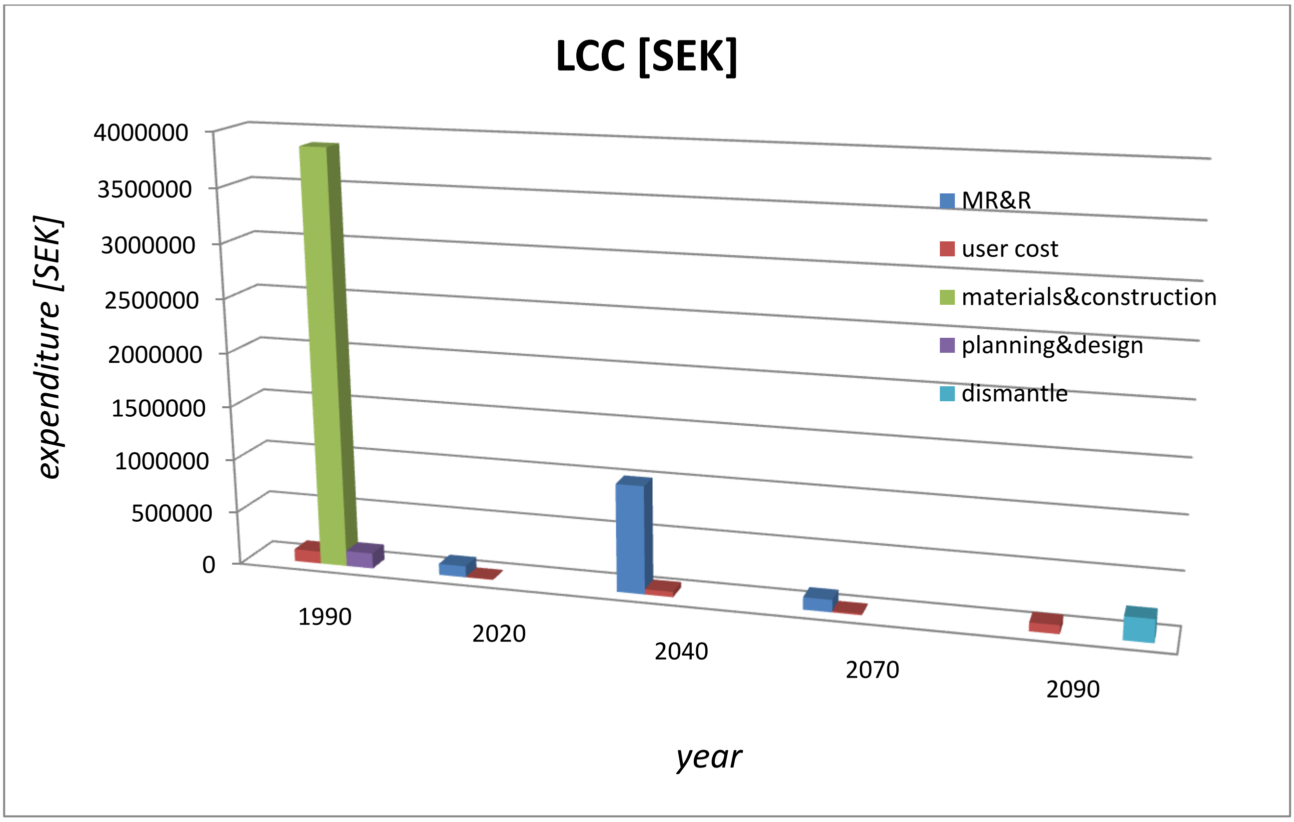
% on the total LCC (PV 2009)		
	costs	%
MR&R	498110.50	10.0
user costs	28442.94	0.6
initial investment	4201102.47	84.4
planning and design	110196.00	2.2
dismantle	151427.47	3.0



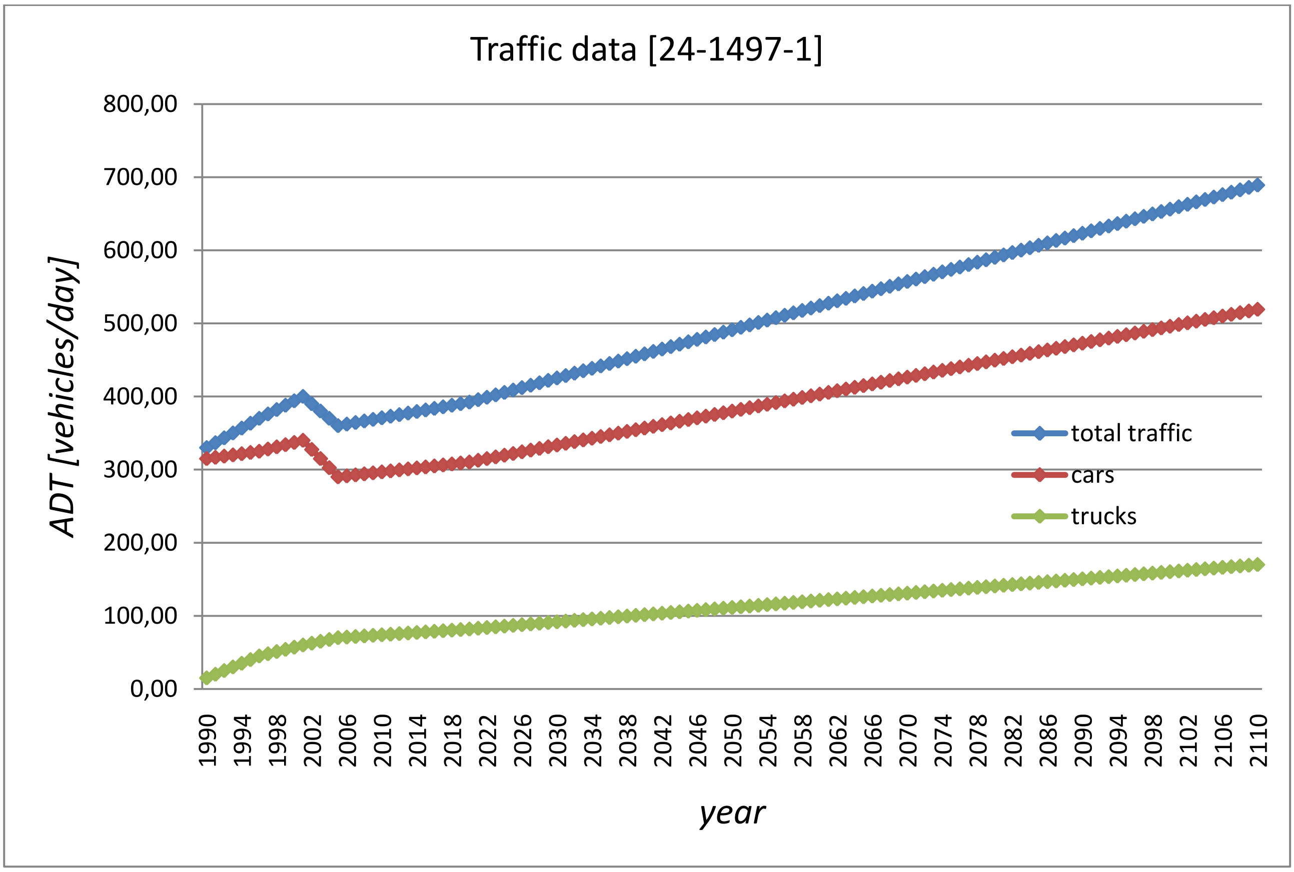
Bridge 24-1497-1

bridges information		economic information	
BaTMan code	24-1497-1	interest rate	0.04
year of construction	1990	inflation rate	0.015
expected service life [years]	100	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	1990	100000.00	144620.61	334.35	100000.00	231.19
material and construction	1990	1838000.00	3872388.79	8952.49	1838000.00	4249.23
users cost	1990	138000.00	115057.74	266.00	138000.00	319.04
MR&R						
yearly inspection (10)	yearly	500.00	18307.05	42.32	18307.05	42.32
yearly maintenance (11)	yearly	2000.00	73228.21	169.29	73228.21	169.29
users cost for yearly op.	service life	10000.00	13453.48	31.10	16136.08	37.30
MR&R cost 1 (1+6+7)	2020	105000.00	80343.18	185.74	50602.32	116.99
users cost 1	2020	5000.00	5555.02	12.84	6662.68	15.40
MR&R cost 2 (3+1+4+8)	2040	1006000.00	473164.08	1093.90	298011.57	688.97
users cost 2	2040	49000.00	65922.07	152.40	79066.78	182.79
MR&R cost 3 (1+6+7)	2070	115000.00	26067.10	60.26	16417.77	37.96
users cost 3	2070	12000.00	21512.69	49.73	25802.28	59.65
Dismantle						
Dismantle (5)	2090	470000.00	214888.20	496.80	178848.95	413.48
users cost	2090	37000.00	80321.99	185.69	96338.02	222.72
		total LCC	5204830.23	12032.94	2935421.70	6786.34

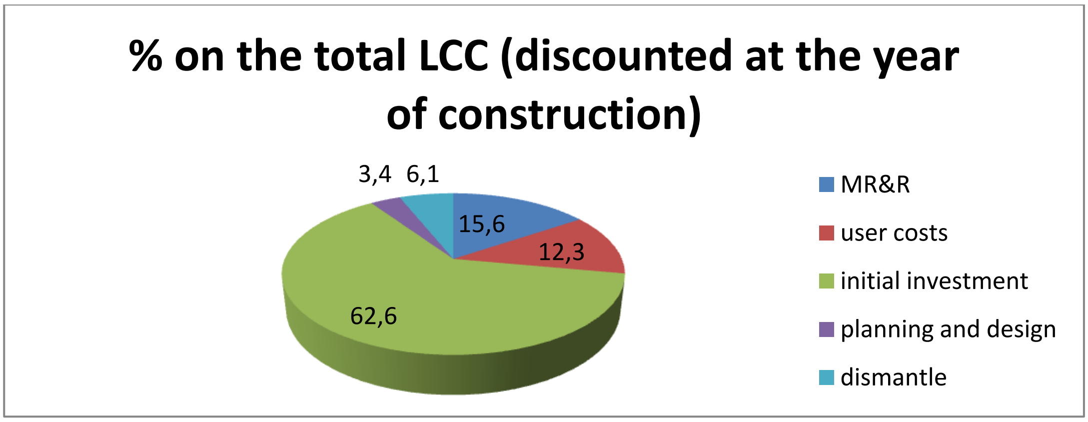


LCC [SEK]
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
expenditure [SEK]
MR&R
user cost
materials&construction
planning&design
dismantle
1990
2020
2040
2070
2090
year

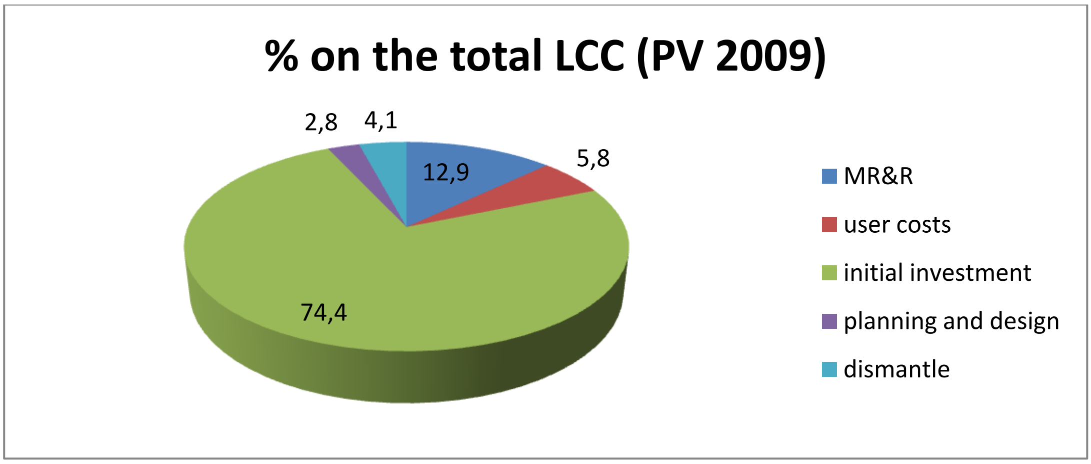


Traffic data [24-1497-1]
800,00
700,00
600,00
500,00
400,00
300,00
200,00
100,00
0,00
ADT [vehicles/day]
total traffic
cars
trucks
1990
1994
1998
2002
2006
2010
2014
2018
2022
2026
2030
2034
2038
2042
2046
2050
2054
2058
2062
2066
2070
2074
2078
2082
2086
2090
2094
2098
2102
2106
2110
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	456566.92	15.6
user costs	362005.83	12.3
initial investment	1838000.00	62.6
planning and design	100000.00	3.4
dismantle	178848.95	6.1



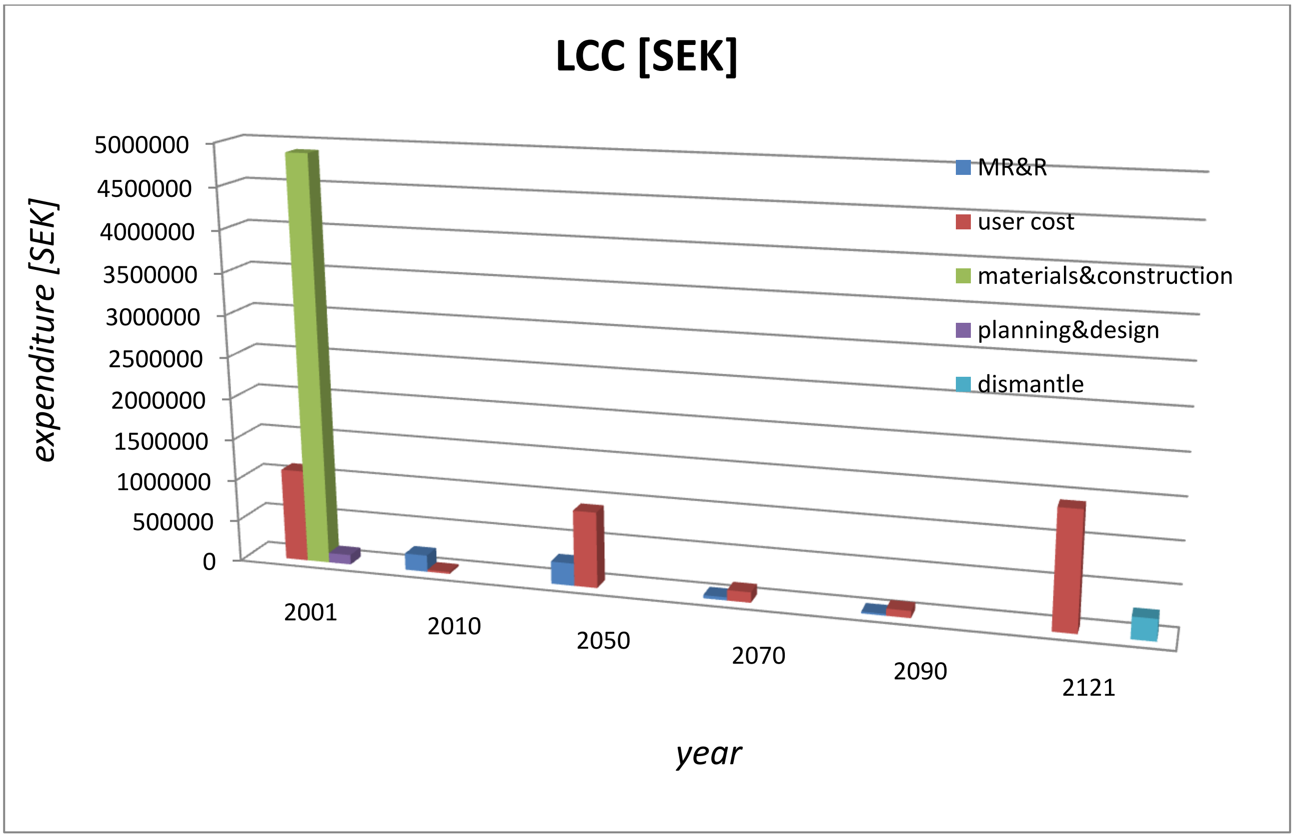
% on the total LCC (PV 2009)		
	costs	%
MR&R	671109.63	12.9
user costs	301823.00	5.8
initial investment	3872388.79	74.4
planning and design	144620.61	2.8
dismantle	214888.20	4.1

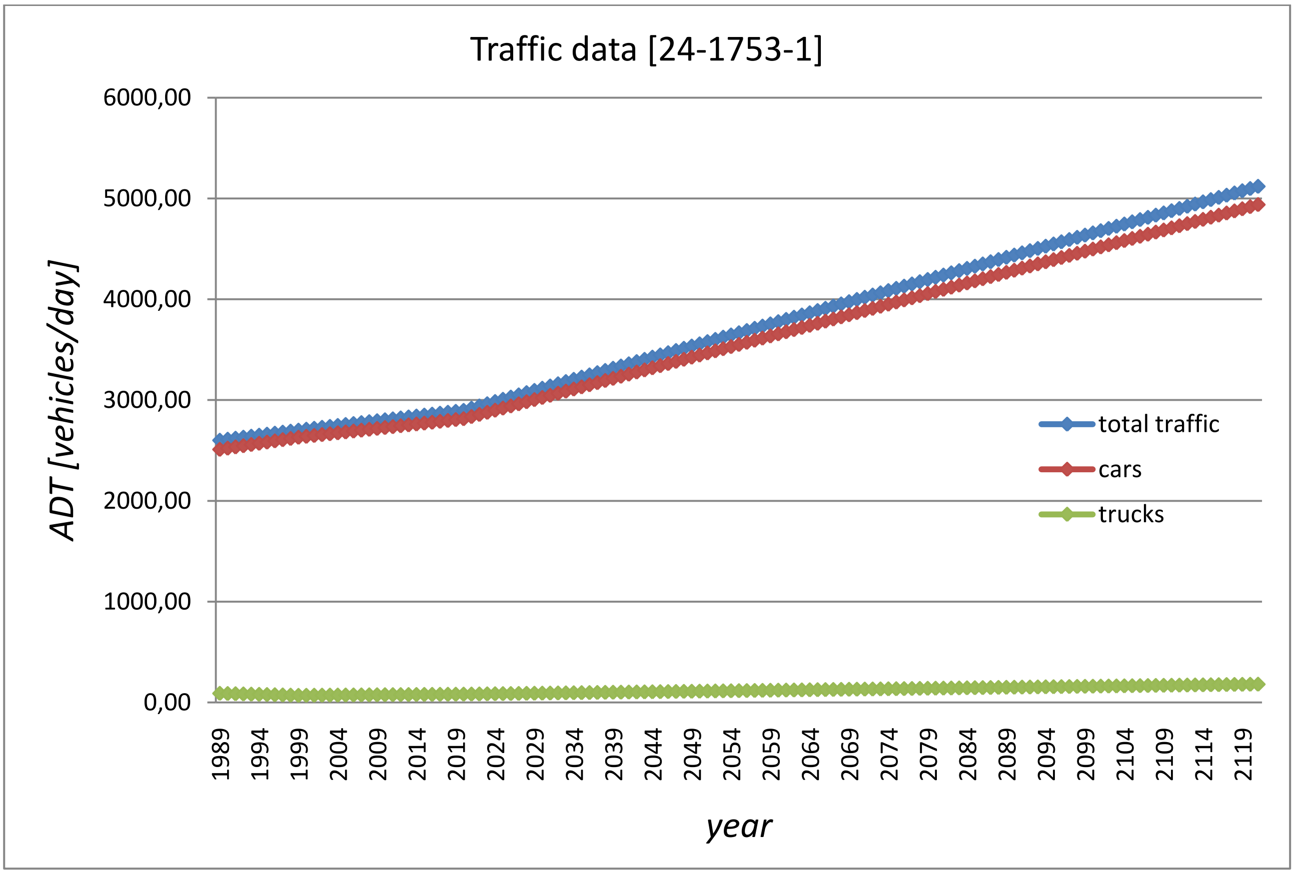


Bridge 24-1753-1

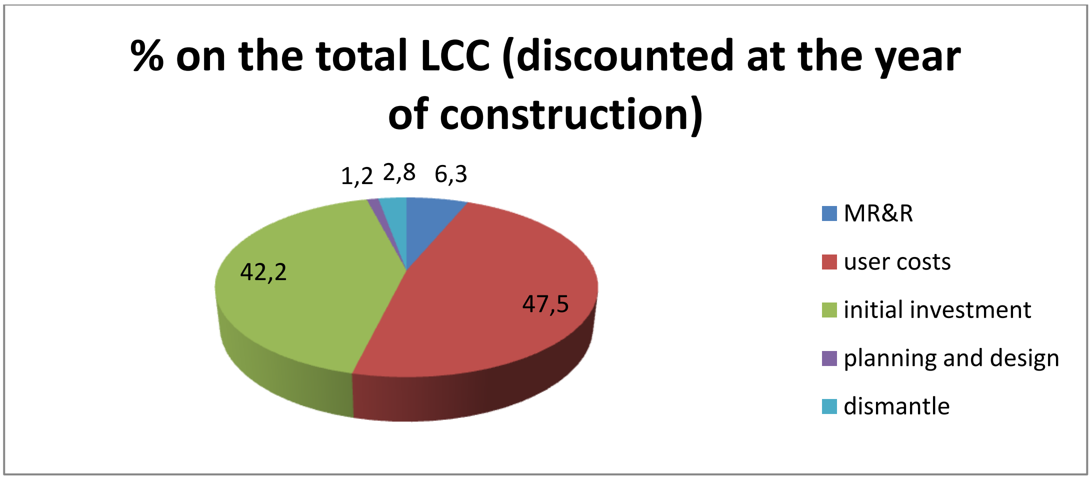
bridges information		economic information	
BaTMan code	24-1753-1	interest rate	0.04
year of construction	2001	inflation rate	0.015
expected service life [years]	120	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	2001	100000.00	116806.05	159.07	100000.00	136.18
material and construction	2001	3575000.00	4892634.36	6662.76	3575000.00	4868.41
users cost	2001	1110000.00	1028194.56	1400.19	1110000.00	1511.59
MR&R						
yearly inspection (10)	yearly	500.00	18966.84	25.83	18966.84	25.83
yearly maintenance (11)	yearly	2000.00	75867.37	103.32	75867.37	103.32
users cost for yearly op.	service life	83000.00	136517.40	185.91	147379.02	200.70
MR&R cost 1 (1+6)	2010	206000.00	201048.08	273.79	165486.11	225.36
users cost 1	2010	24000.00	24230.77	33.00	26158.62	35.62
MR&R cost 2 (1+3+7)	2050	734000.00	270667.98	368.59	222791.44	303.40
users cost 2	2050	616000.00	911958.47	1241.90	984515.91	1340.71
MR&R cost 3 (1+6+7)	2070	165000.00	37400.62	50.93	30785.09	41.92
users cost 3	2070	70000.00	125490.71	170.89	135475.03	184.49
MR&R cost 4 (1+4)	2090	150000.00	20899.71	28.46	17202.91	23.43
users cost 4	2090	39000.00	84663.72	115.29	91399.75	124.47
dismantle						
Dismantle (5)	2121	770000.00	260931.13	355.33	241522.15	328.90
users cost	2121	487000.00	1422317.18	1936.90	1535479.89	2091.01
		total LCC	9628594.94	11711.97	8478030.16	11545.32

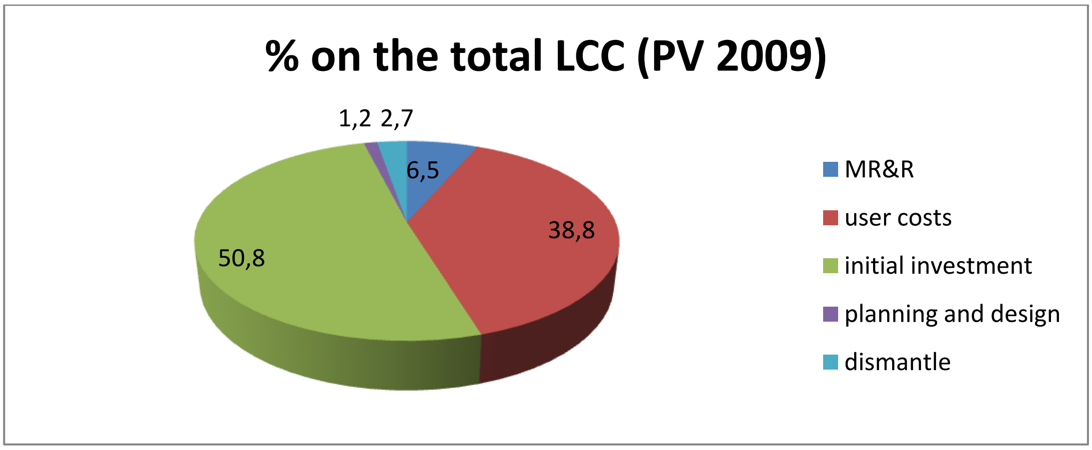

LCC [SEK]
expenditure [SEK]
5000000
4500000
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
2001
2010
2050
2070
2090
2121
year
MR&R
user cost
materials&construction
planning&design
dismantle


Traffic data [24-1753-1]
ADT [vehicles/day]
6000,00
5000,00
4000,00
3000,00
2000,00
1000,00
0,00
1989
1994
1999
2004
2009
2014
2019
2024
2029
2034
2039
2044
2049
2054
2059
2064
2069
2074
2079
2084
2089
2094
2099
2104
2109
2114
2119
year
total traffic
cars
trucks

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	531099.77	6.3
user costs	4030408.24	47.5
initial investment	3575000.00	42.2
planning and design	100000.00	1.2
dismantle	241522.15	2.8



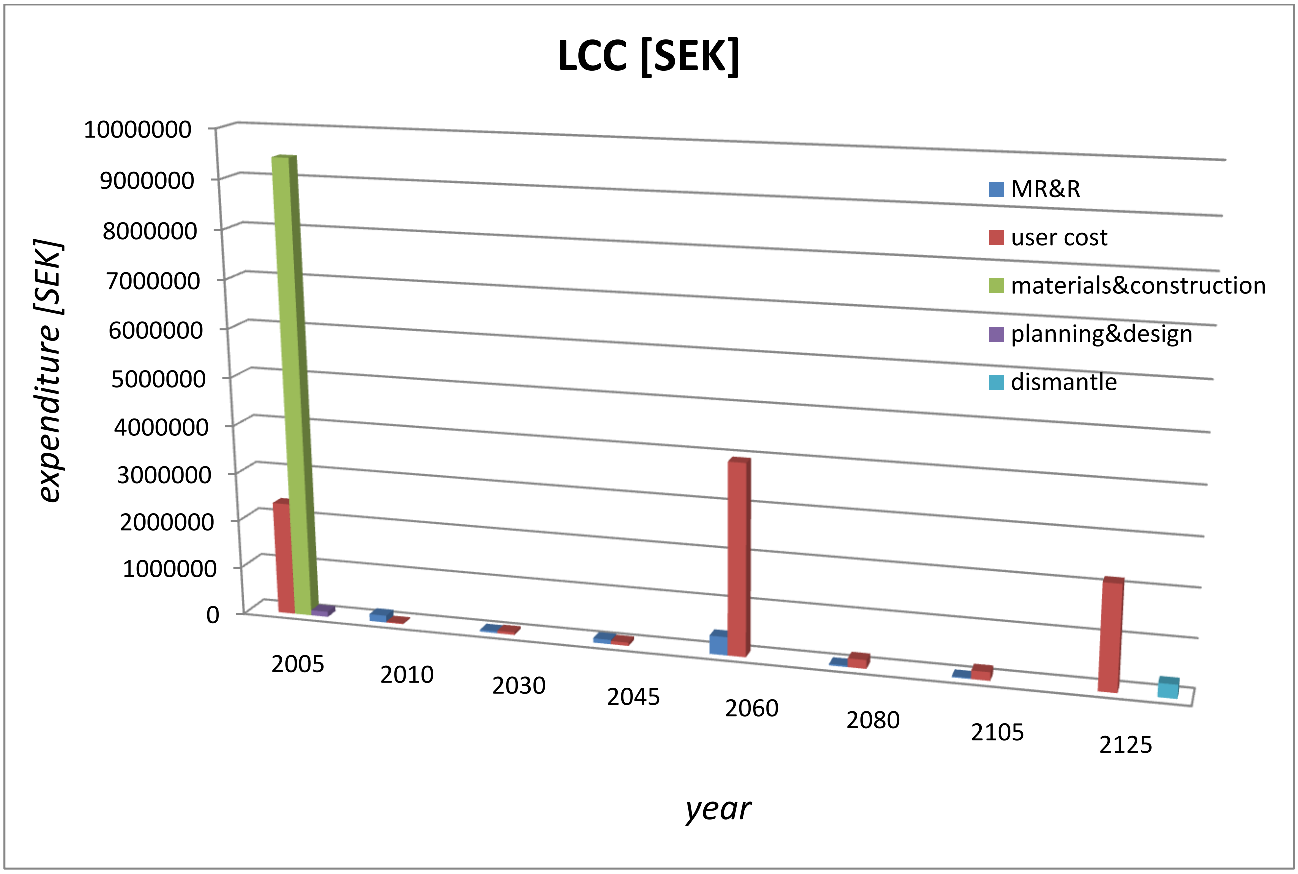
% on the total LCC (PV 2009)		
	costs	%
MR&R	624850.60	6.5
user costs	3733372.81	38.8
initial investment	4892634.36	50.8
planning and design	116806.05	1.2
dismantle	260931.13	2.7

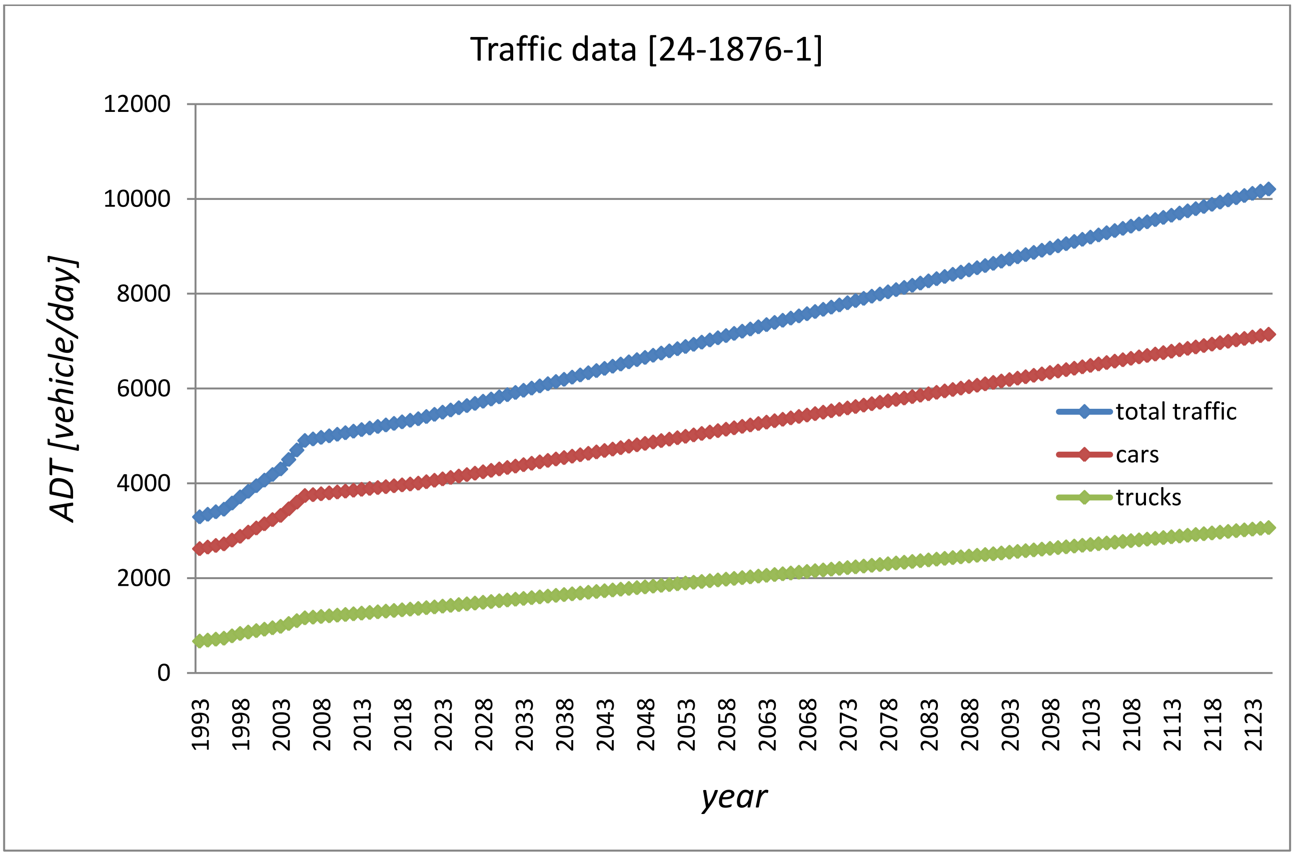


Bridge 24-1876-1

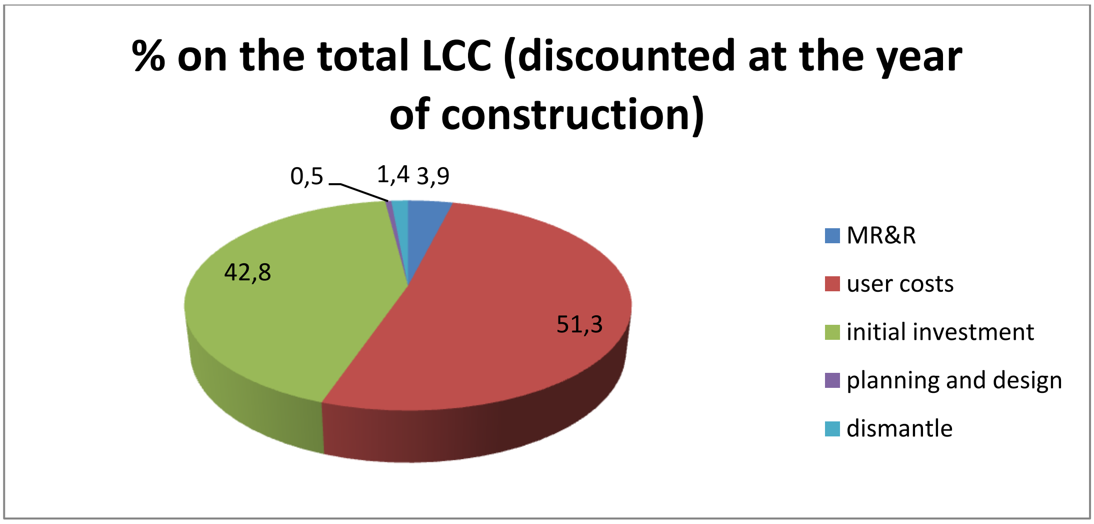
bridges information		economic information	
BaTMan code	24-1876-1	interest rate	0.04
year of construction	2005	inflation rate	0.015
expected service life [years]	120	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	2005	100000.00	108076.85	147.18	100000.00	136.18
material and construction	2005	8069000.00	9439588.72	12854.77	8069000.00	10988.31
users cost	2005	2445000.00	2353179.33	3204.54	2445000.00	3329.58
MR&R						
yearly inspection (10)	yearly	500.00	18966.84	25.83	18966.84	25.83
yearly maintenance(11)	yearly	2000.00	75867.37	103.32	75867.37	103.32
users cost for yearly op.	service life	209000.00	357174.16	486.40	371111.04	505.38
MR&R cost 1 (1+4)	2010	150000.00	146394.23	199.36	132817.34	180.87
users cost 1	2010	19000.00	19182.69	26.12	19931.20	27.14
MR&R cost 2 (6)	2030	65000.00	38994.21	53.10	35377.81	48.18
users cost 2	2030	43000.00	52570.68	71.59	54621.98	74.38
MR&R cost 3 (1+7)	2045	215000.00	89539.73	121.93	81235.63	110.63
users cost 3	2045	48000.00	67741.65	92.25	70384.92	95.85
MR&R cost 4 (1+3+4+8)	2060	1310000.00	378738.23	515.76	343613.29	467.93
users cost 4	2060	2424000.00	3948994.82	5377.71	4103083.95	5587.55
MR&R cost 5 (1+6+7)	2080	175000	31099.97	42.35	28215.70	38.42
users cost 5	2080	92000.00	181493.46	247.16	188575.30	256.80
MR&R cost 6 (1+7)	2105	220000.00	21279.54	28.98	19306.03	26.29
users cost 6	2105	70000.00	175416.39	238.88	182261.11	248.20
Dismantle						
Dismantle (5)	2125	870000.00	283641.62	386.26	272888.67	371.62
users cost	2125	713000.00	2163619.38	2946.40	2248043.46	3061.37
		total LCC	19951559.88	27169.89	18860301.65	25683.83

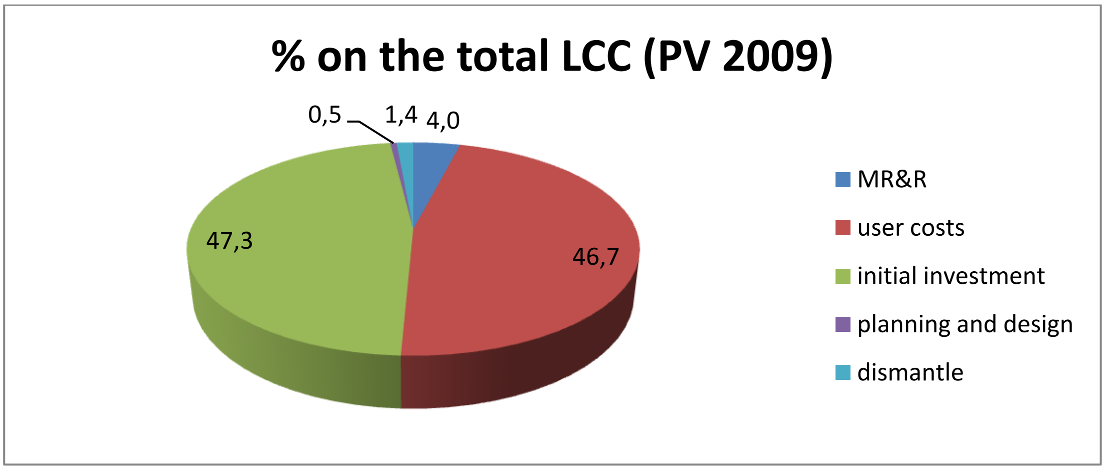

LCC [SEK]
expenditure [SEK]
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
MR&R
user cost
materials&construction
planning&design
dismantle
2005
2010
2030
2045
2060
2080
2105
2125
year


Traffic data [24-1876-1]
ADT [vehicle/day]
12000
10000
8000
6000
4000
2000
0
total traffic
cars
trucks
1993
1998
2003
2008
2013
2018
2023
2028
2033
2038
2043
2048
2053
2058
2063
2068
2073
2078
2083
2088
2093
2098
2103
2108
2113
2118
2123
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	735400.02	3.9
user costs	9683012.96	51.3
initial investment	8069000.00	42.8
planning and design	100000.00	0.5
dismantle	272888.67	1.4



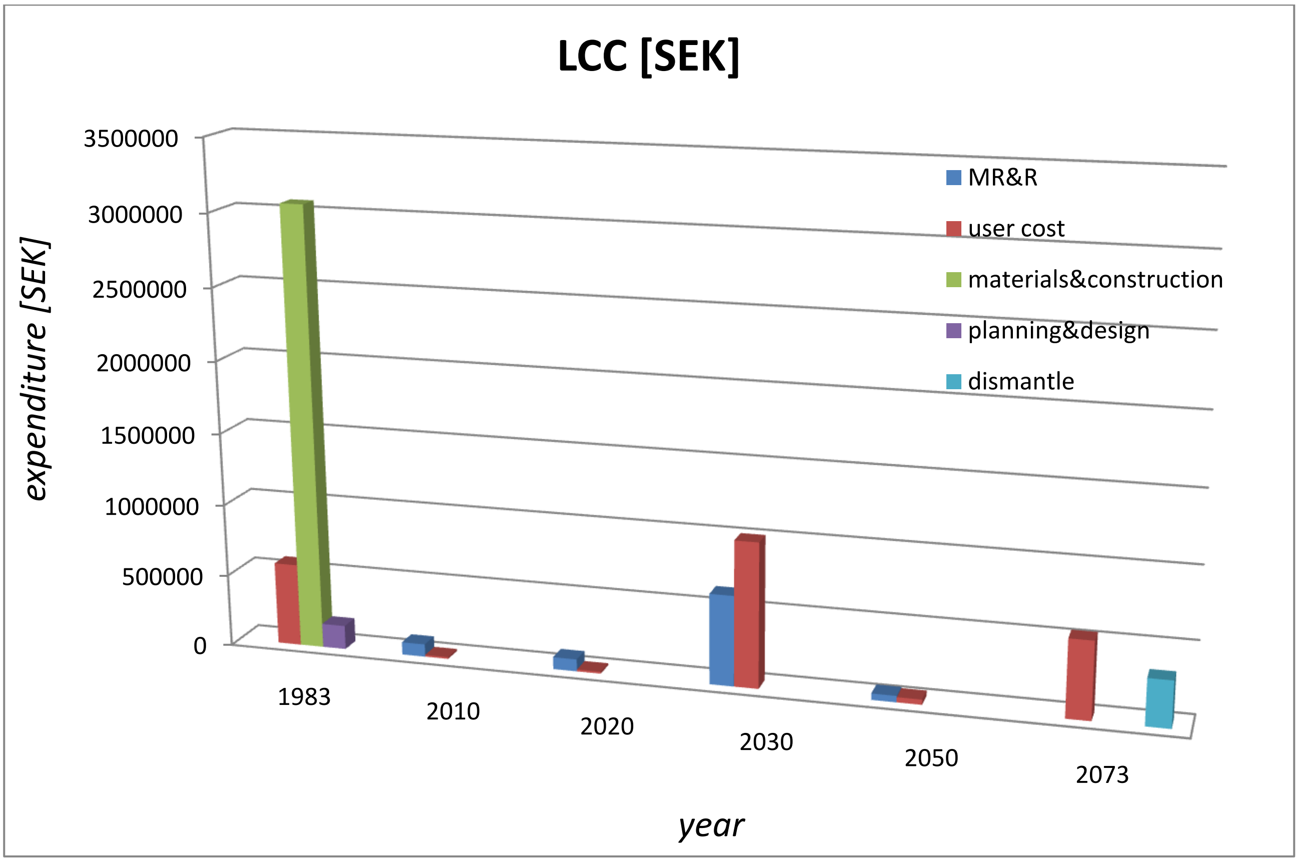
% on the total LCC (PV 2009)		
	costs	%
MR&R	800880.12	4.0
user costs	9319372.56	46.7
initial investment	9439588.72	47.3
planning and design	108076.85	0.5
dismantle	283641.62	1.4



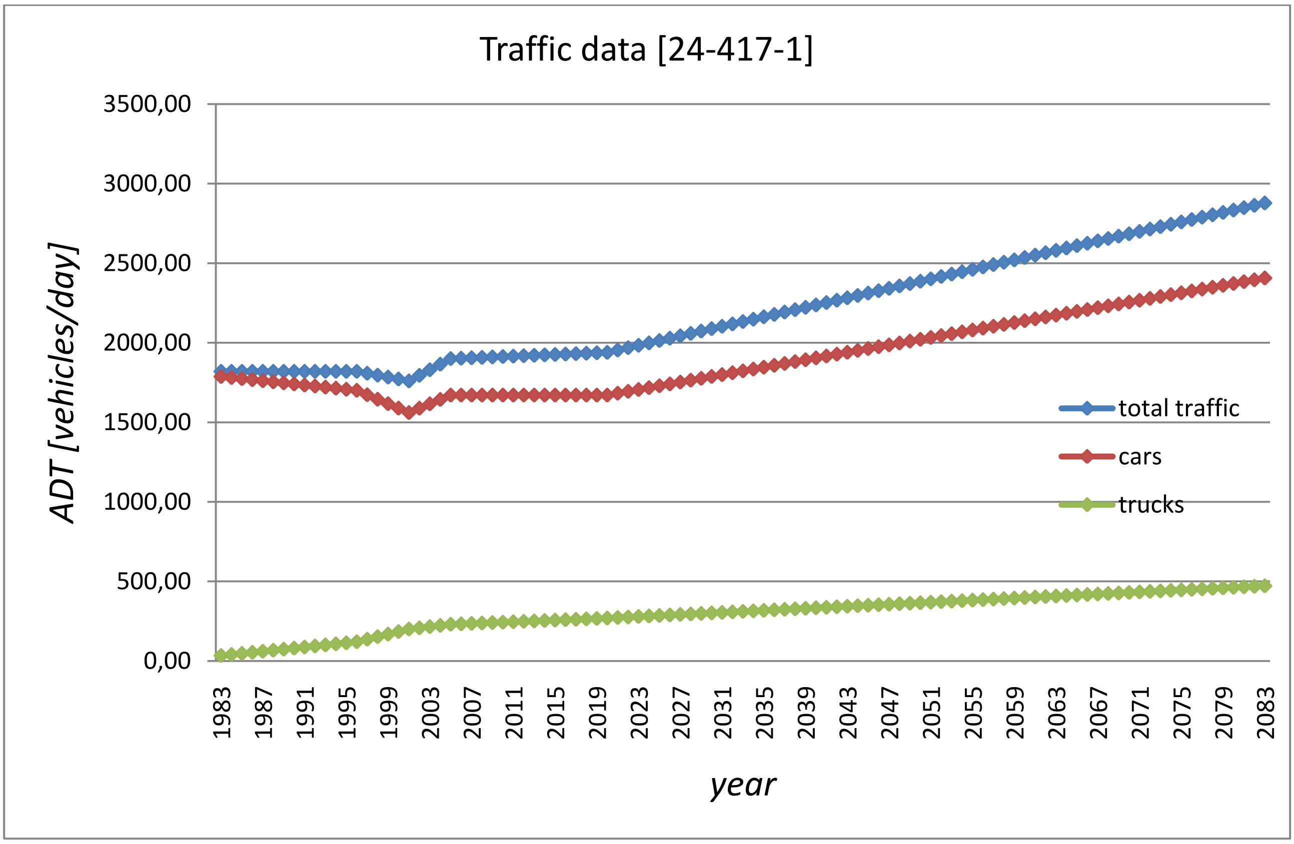
Bridge 24-417-1

bridges information		economic information	
BaTMan code	24-417-1	interest rate	0.04
year of construction	1983	inflation rate	0.015
expected service life [years]	90	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	1983	100000.00	165677.05	503.34	100000.00	303.81
material and construction	1983	1105000.00	3063579.11	9307.43	1105000.00	3357.09
users cost	1983	735000.00	573102.61	1741.14	735000.00	2233.00
MR&R						
yearly inspection (10)	yearly	500.00	17832.88	54.18	17832.88	54.18
Yearly maintenance(11)	yearly	2000.00	71331.54	216.71	71331.54	216.71
users cost for yearly op.	service life	37000.00	44377.72	134.82	56914.11	172.91
MR&R cost 1 (6+7)	2010	90000.00	87836.54	266.86	46657.93	141.75
users cost 1	2010	12000.00	12115.38	36.81	15537.89	47.21
MR&R cost 2 (1+4)	2020	110000.00	84169.05	255.71	44709.80	135.83
users cost 2	2020	12000.00	13332.05	40.50	17098.25	51.95
MR&R cost 3(1+3+4+7)	2030	1044000.00	626306.99	1902.78	332688.31	1010.74
users cost 3	2030	821000.00	1003733.25	3049.43	1287280.72	3910.87
MR&R cost 4 (1+7)	2050	120000.00	44250.90	134.44	23505.65	71.41
users cost 4	2050	24000.00	35530.85	107.95	45568.06	138.44
Dismantle						
Dismantle (5)	2073	600000.00	323295.69	982.20	251478.54	764.01
users cost	2073	292000.00	538721.46	1636.68	690906.42	2099.04
		total LCC	6705193.07	20370.98	4841510.12	14708.94

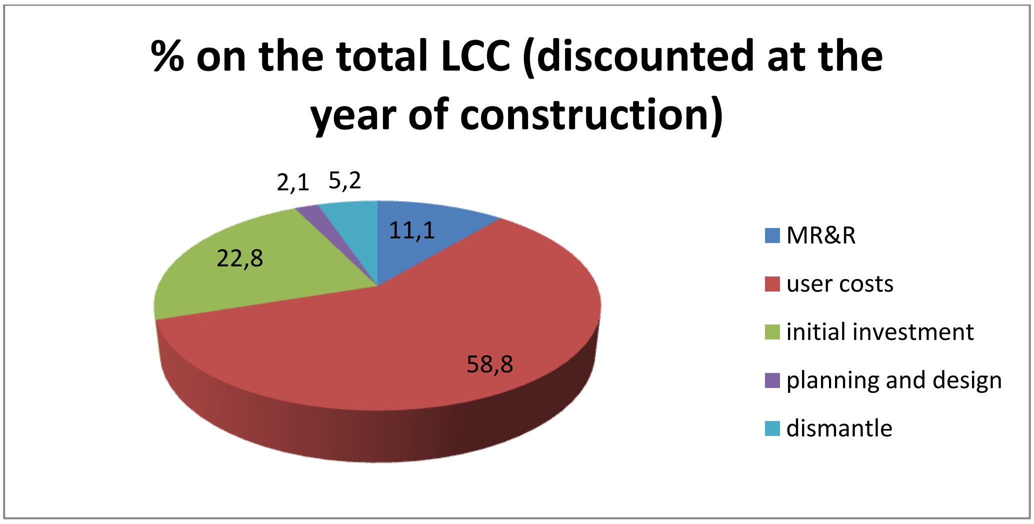


LCC [SEK]
expenditure [SEK]
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
MR&R
user cost
materials&construction
planning&design
dismantle
1983
2010
2020
2030
2050
2073
year

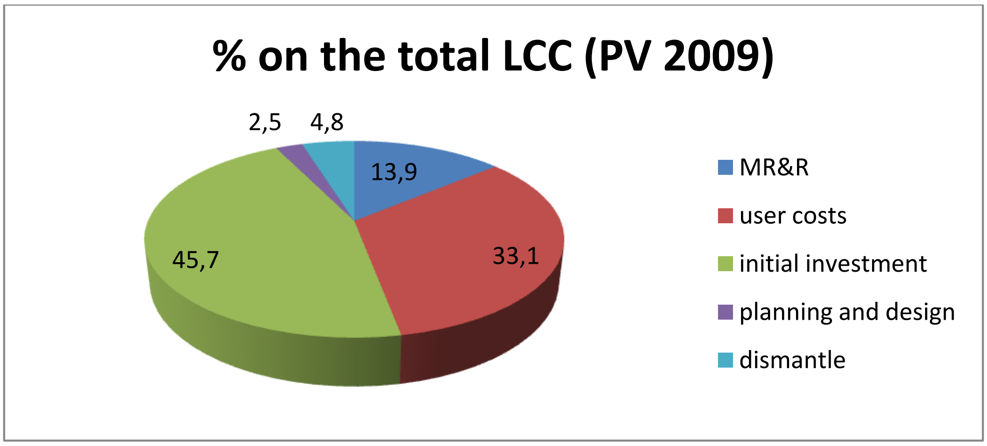


Traffic data [24-417-1]
ADT [vehicles/day]
3500,00
3000,00
2500,00
2000,00
1500,00
1000,00
500,00
0,00
total traffic
cars
trucks
1983
1987
1991
1995
1999
2003
2007
2011
2015
2019
2023
2027
2031
2035
2039
2043
2047
2051
2055
2059
2063
2067
2071
2075
2079
2083
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	536726.11	11.1
user costs	2848305.46	58.8
initial investment	1105000.00	22.8
planning and design	100000.00	2.1
dismantle	251478.54	5.2



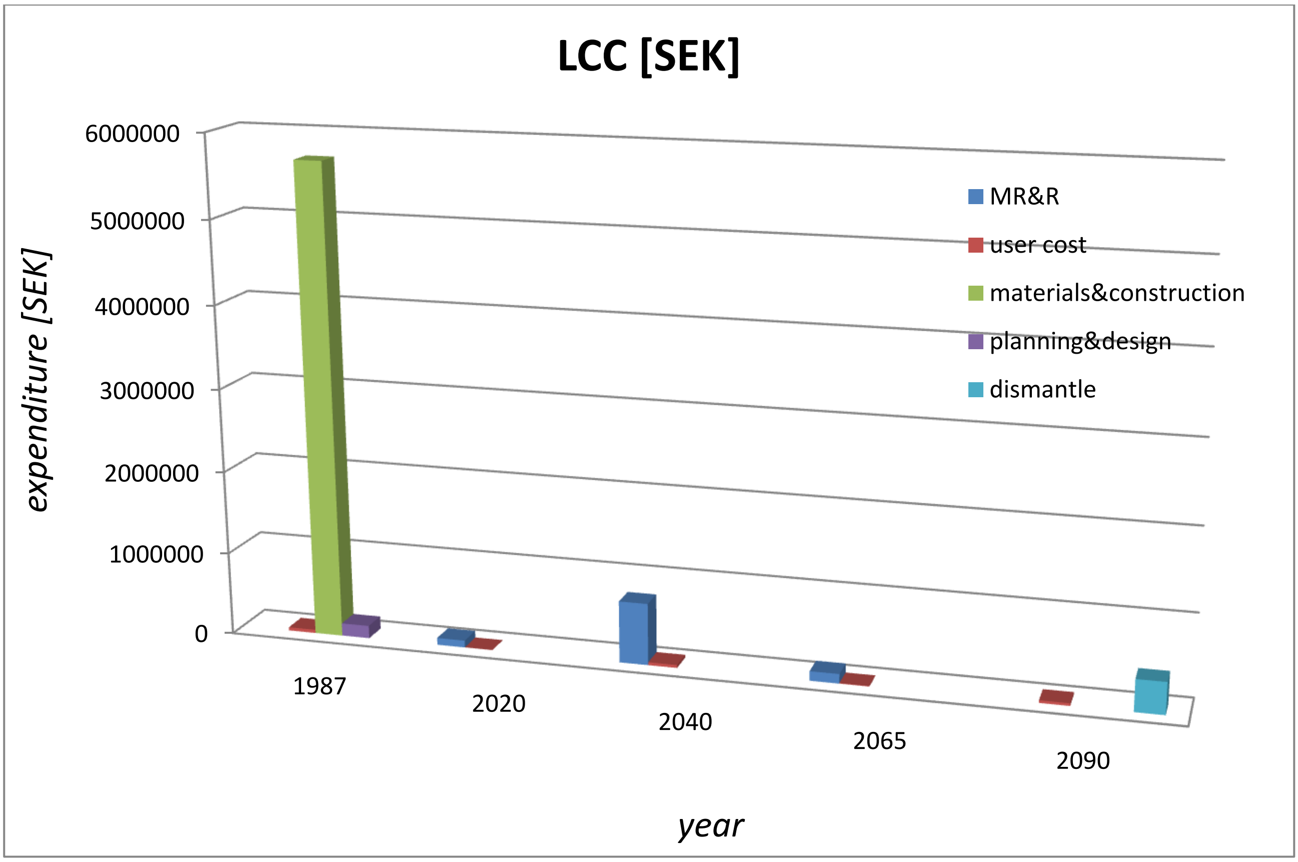
% on the total LCC (PV 2009)		
	costs	%
MR&R	931727.90	13.9
user costs	2220913.32	33.1
initial investment	3063579.11	45.7
planning and design	165677.05	2.5
dismantle	323295.69	4.8

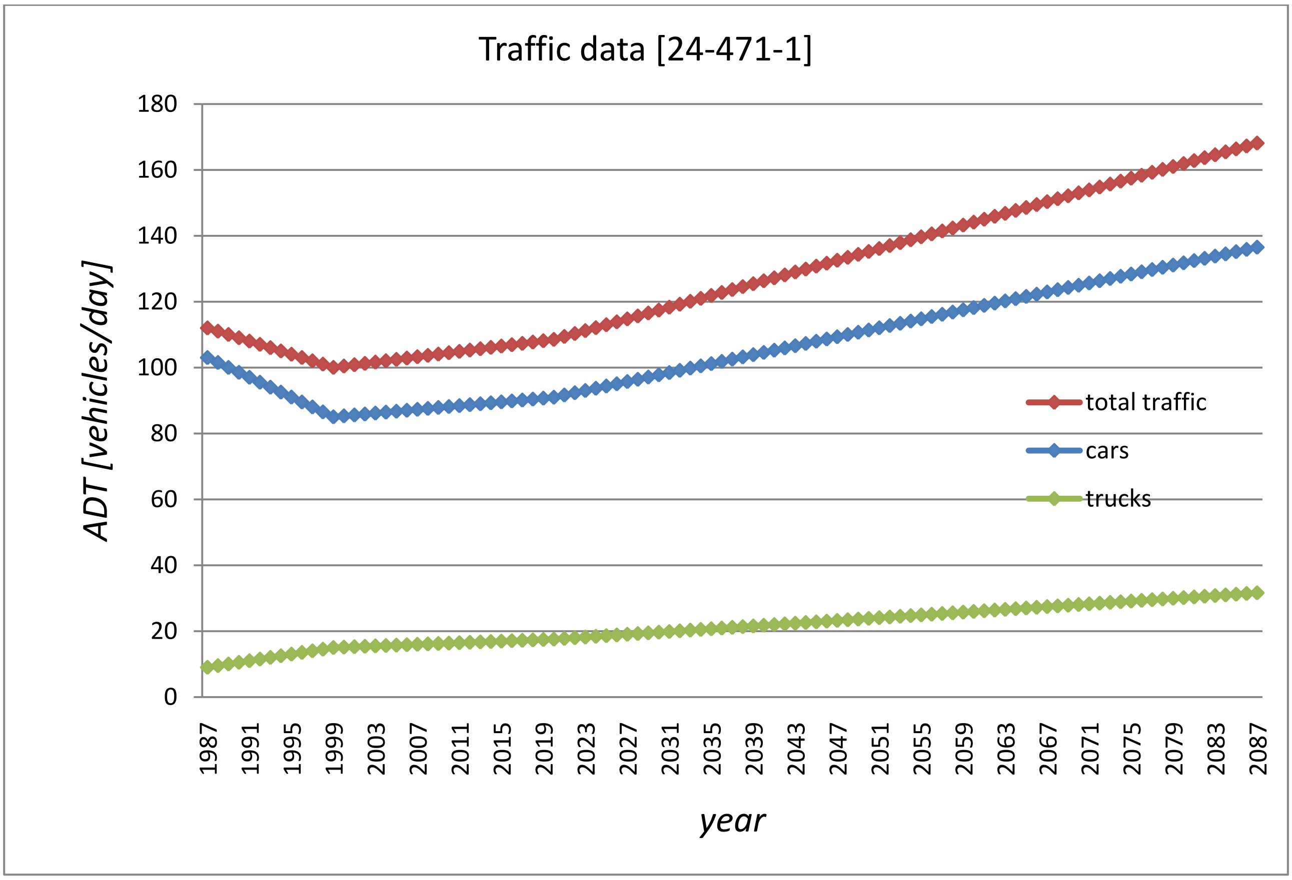


Bridge 24-471-1

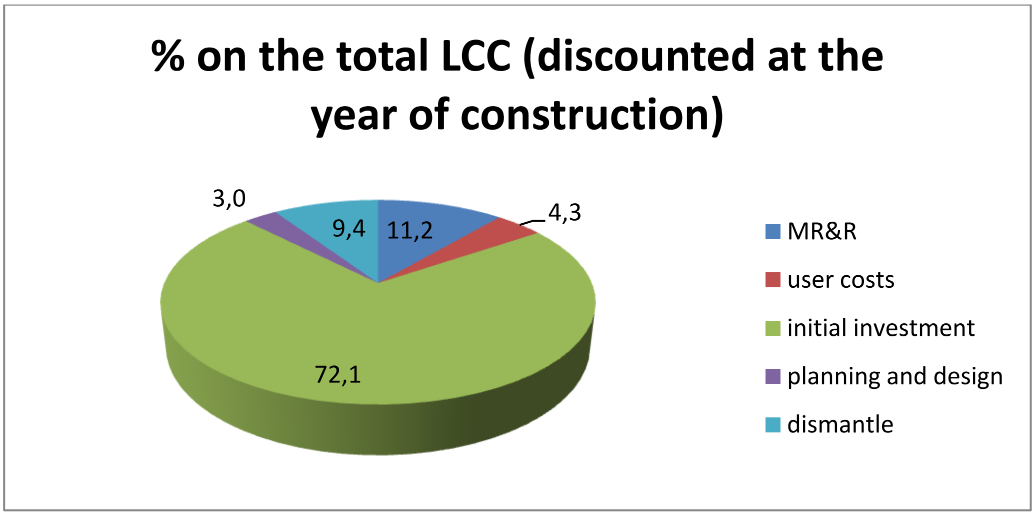
bridges information		economic information	
BaTMan code	24-471-1	interest rate	0.04
year of construction	1987	inflation rate	0.015
expected service life [years]	100	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	1987	100000.00	153295.60	354.40	100000.00	231.19
material and construction	1987	2400000.00	5687805.10	13149.52	2400000.00	5548.51
users cost	1987	49000.00	39697.67	91.78	49000.00	113.28
MR&R						
yearly inspection (10)	yearly	800.00	29291.28	67.72	29291.28	67.72
yearly maintenance (11)	yearly	2000.00	73228.21	169.29	73228.21	169.29
users cost for yearly op.	service life	2000.00	2614.55	6.04	3227.22	7.46
MR&R cost 1 (1+6)	2020	110000.00	84169.05	194.59	49280.13	113.93
users cost 1	2020	1000.00	1111.00	2.57	1371.34	3.17
MR&R cost 2 (1+3+4)	2040	744000.00	349934.47	809.01	204883.13	473.66
users cost 2	2040	26000.00	34979.06	80.87	43175.68	99.82
MR&R cost 3 (1+6)	2065	115000.00	29439.42	68.06	17236.48	39.85
users cost 3	2065	3000.00	5126.90	11.85	6328.29	14.63
dismantle						
Dismantle (5)	2087	820000.00	385937.44	892.24	312034.34	721.39
users cost	2087	15000.00	31641.43	73.15	39055.95	90.29
		total LCC	6908271.18	15971.08	3328112.06	7694.19

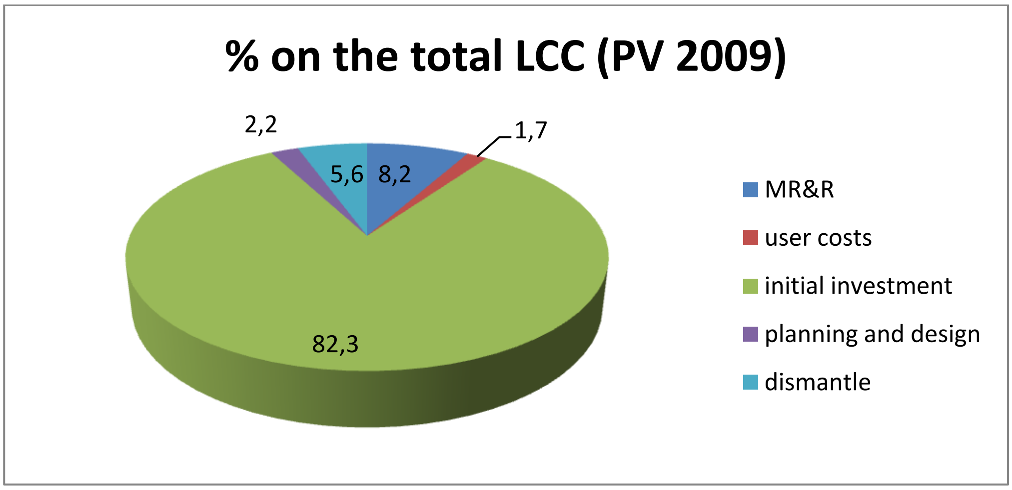

LCC [SEK]
6000000
5000000
4000000
3000000
2000000
1000000
0
expenditure [SEK]
MR&R
user cost
materials&construction
planning&design
dismantle
1987
2020
2040
2065
2090
year


Traffic data [24-471-1]
180
160
140
120
100
80
60
40
20
0
ADT [vehicles/day]
total traffic
cars
trucks
1987
1991
1995
1999
2003
2007
2011
2015
2019
2023
2027
2031
2035
2039
2043
2047
2051
2055
2059
2063
2067
2071
2075
2079
2083
2087
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	373919.24	11.2
user costs	142158.48	4.3
initial investment	2400000.00	72.1
planning and design	100000.00	3.0
dismantle	312034.34	9.4



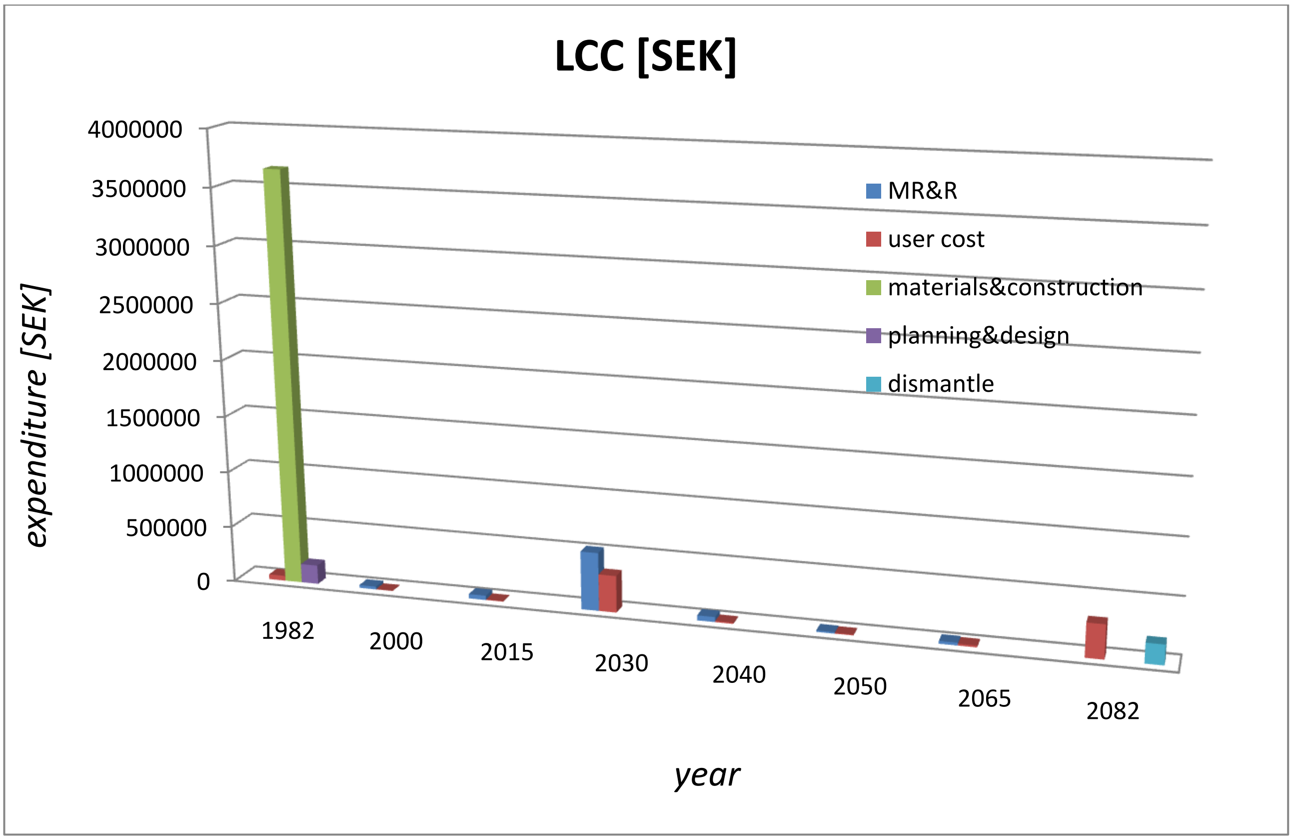
% on the total LCC (PV 2009)		
	costs	%
MR&R	566062.43	8.2
user costs	115170.61	1.7
initial investment	5687805.10	82.3
planning and design	153295.60	2.2
dismantle	385937.44	5.6



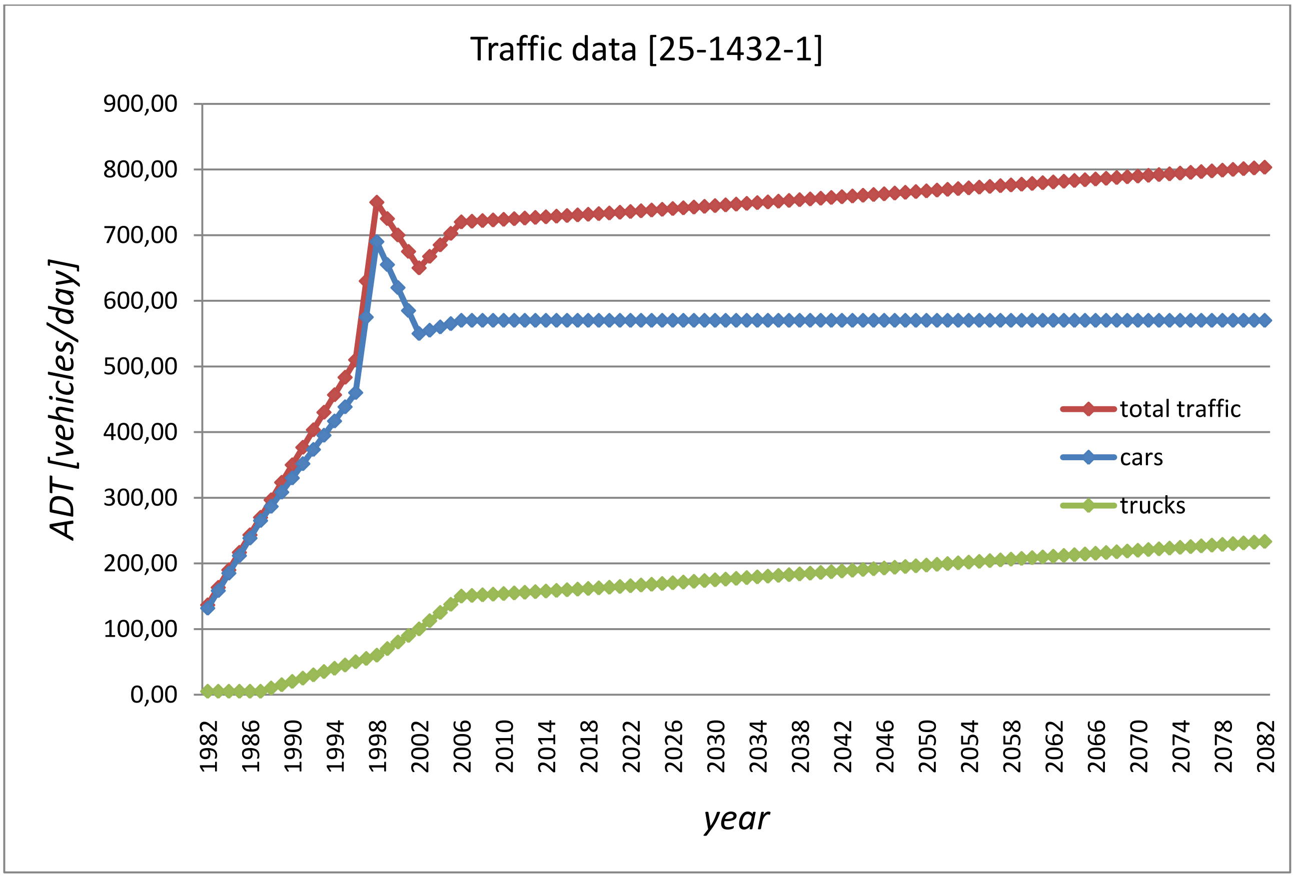
Bridge 25-1432-1

bridges information		economic information	
BaTMan code	25-1432-1	interest rate	0.04
year of construction	1982	inflation rate	0.015
expected service life [years]	100	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	1982	100000.00	168925.62	390.54	100000.00	231.19
material and construction	1982	1270000.00	3661878.09	8465.82	1270000.00	2936.09
users cost	1982	57000.00	44021.41	101.77	57000.00	131.78
MR&R						
yearly inspection (10)	yearly	800.00	29291.28	67.72	29291.28	67.72
yearly maintenance (11)	yearly	2500.00	91535.26	211.62	91535.26	211.62
users cost for yearly op.	service life	17000.00	21185.37	48.98	27431.33	63.42
MR&R cost 1 (6)	2000	20000.00	24896.35	57.56	12906.80	29.84
users cost 1	2000	2000.00	1834.96	4.24	2375.95	5.49
MR&R cost 2 (6+7)	2015	45000.00	38887.38	89.90	20160.05	46.61
users cost 2	2015	5000.00	5295.49	12.24	6856.72	15.85
MR&R cost 3 (1+3+4)	2030	863000.00	517723.12	1196.91	268398.78	620.51
users cost 3	2030	268000.00	327649.83	757.49	424249.03	980.81
MR&R cost 4 (1)	2040	95000.00	44682.49	103.30	23164.36	53.55
users cost 4	2040	8000.00	10762.79	24.88	13935.92	32.22
MR&R cost 5 (6)	2050	35000.00	12906.51	29.84	6691.01	15.47
users cost 5	2050	5000.00	7402.26	17.11	9584.63	22.16
MR&R cost 6 (6+7)	2065	95000.00	24319.52	56.22	12607.76	29.15
users cost 6	2065	9000.00	15380.71	35.56	19915.31	46.04
dismantle						
Dismantle (5)	2082	360000.00	177822.26	411.10	136990.69	316.71
users cost	2082	150000.00	301631.24	697.33	390559.53	902.93
		total LCC	5528031.94	12642.81	2923654.44	6759.13

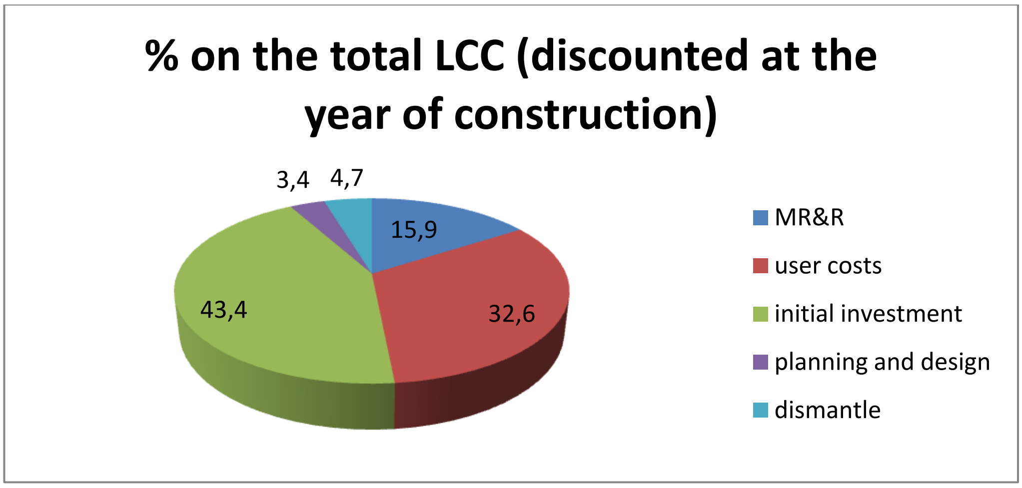


LCC [SEK]
expenditure [SEK]
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
1982
2000
2015
2030
2040
2050
2065
2082
year
MR&R
user cost
materials&construction
planning&design
dismantle

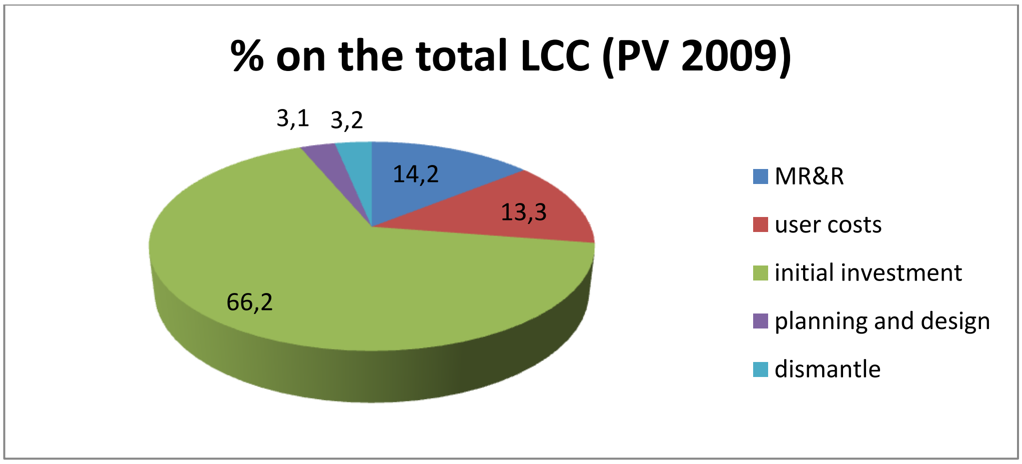


Traffic data [25-1432-1]
ADT [vehicles/day]
900,00
800,00
700,00
600,00
500,00
400,00
300,00
200,00
100,00
0,00
1982
1986
1990
1994
1998
2002
2006
2010
2014
2018
2022
2026
2030
2034
2038
2042
2046
2050
2054
2058
2062
2066
2070
2074
2078
2082
year
total traffic
cars
trucks

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	464755.32	15.9
user costs	951908.43	32.6
initial investment	1270000.00	43.4
planning and design	100000.00	3.4
dismantle	136990.69	4.7



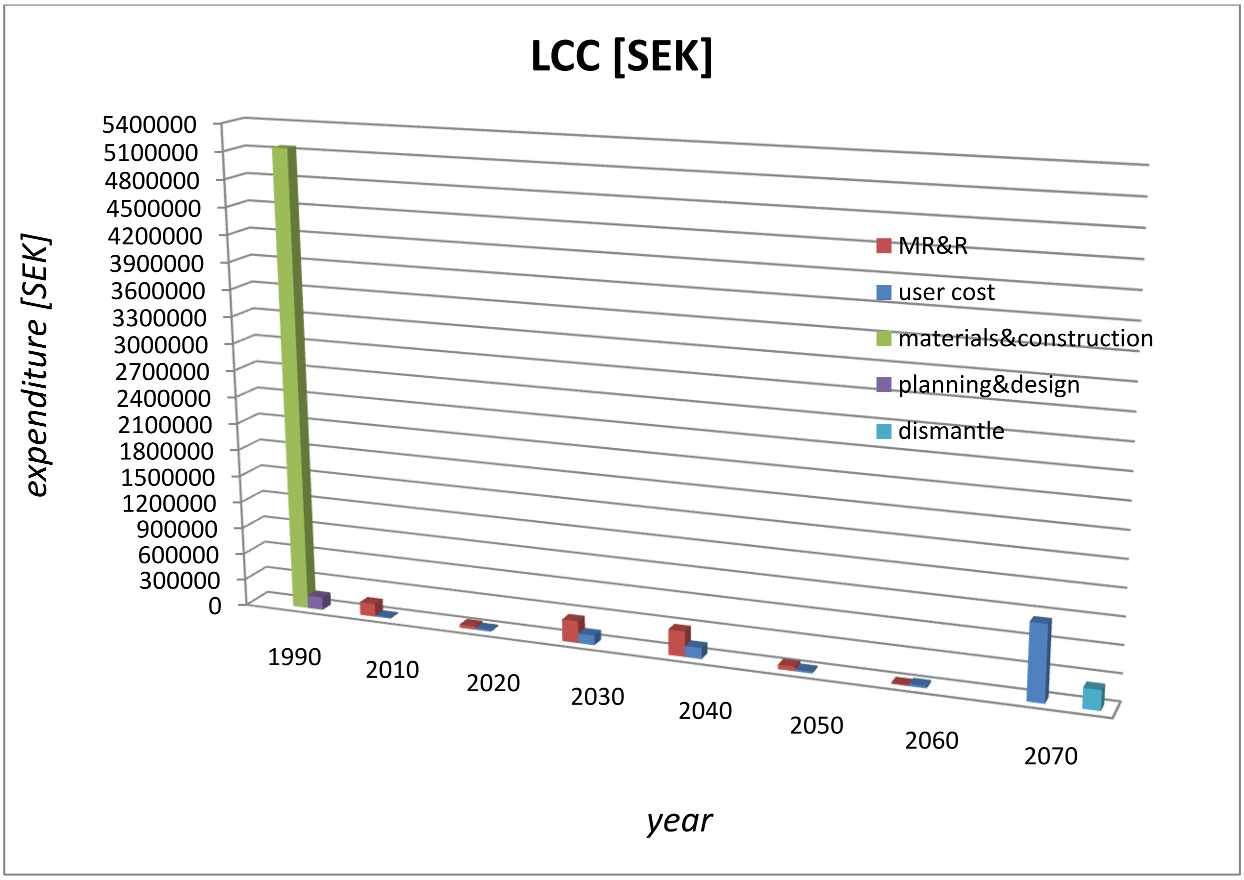
% on the total LCC (PV 2009)		
	costs	%
MR&R	784241.92	14.2
user costs	735164.05	13.3
initial investment	3661878.09	66.2
planning and design	168925.62	3.1
dismantle	177822.26	3.2



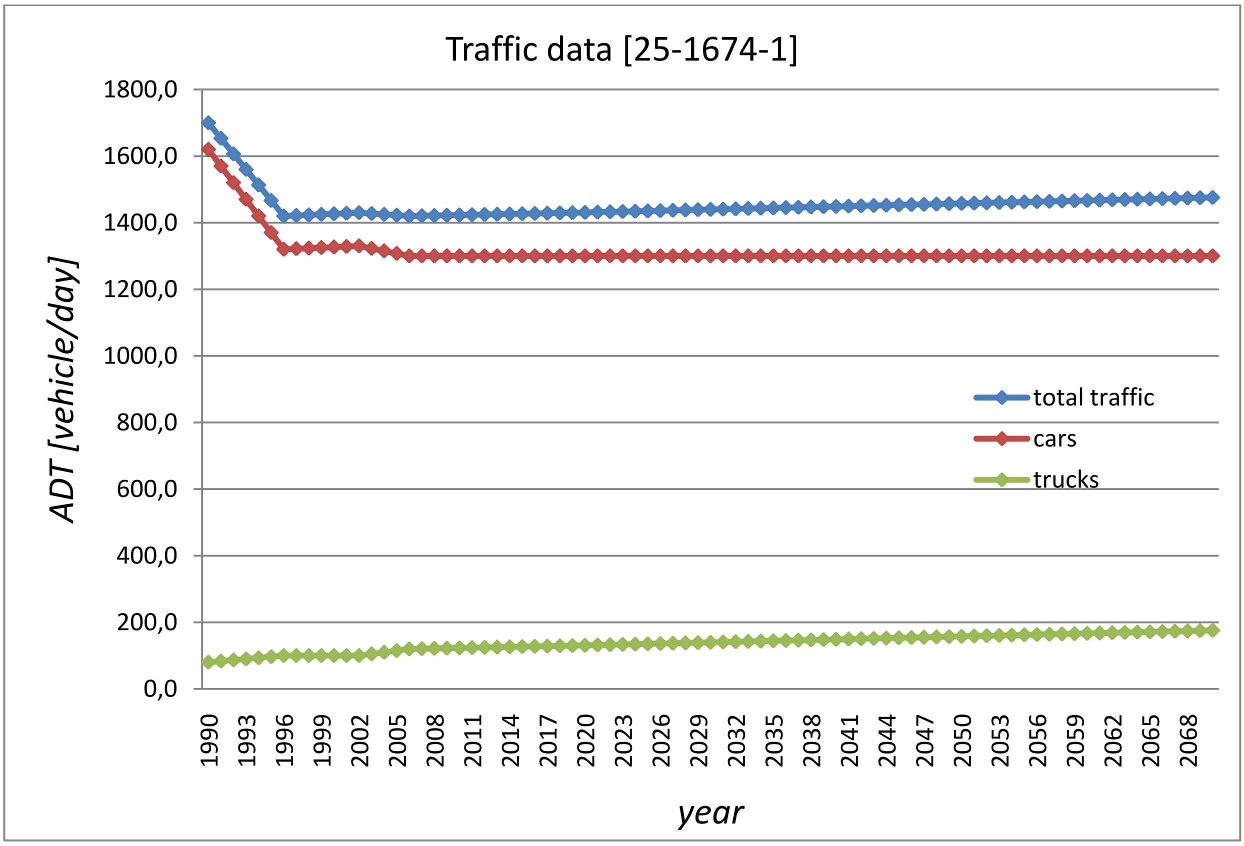
Bridge 25-1674-1

bridges information		economic information	
BaTMan code	25-1674-1	interest rate	0.04
year of construction	1990	inflation rate	0.015
expected service life [years]	80	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	1990	100000.00	144620.61	582.25	100000.00	402.60
material and construction	1990	2444000.00	5149139.39	20730.67	2444000.00	9839.65
user costs	1990	713000.00	594465.01	2393.34	713000.00	2870.57
MR&R						
yearly inspection (10)	yearly	500.00	17225.91	69.35	17225.91	69.35
yearly maintenance(11)	yearly	2000.00	68903.63	277.41	68903.63	277.41
users cost for yearly op.	service life	22000.00	13198.04	53.14	8312.48	33.47
MR&R cost 1 (1)	2010	150000.00	146394.23	589.39	92203.06	371.21
users cost 1	2010	13000.00	13125.00	52.84	15742.10	63.38
MR&R cost 2 (6)	2020	50000.00	38258.66	154.03	24096.34	97.01
users cost 2	2020	17000.00	18887.07	76.04	22653.10	91.20
MR&R cost 3 (3+6)	2030	410000.00	245963.47	990.26	154914.47	623.69
users cost 3	2030	89000.00	108809.09	438.07	130505.37	525.42
MR&R cost 4 (1+4)	2040	605000.00	284556.93	1145.64	179221.67	721.55
users cost 4	2040	91000.00	122426.70	492.90	146838.31	591.18
MR&R cost 5 (1+6)	2050	135000.00	49782.26	200.43	31354.22	126.23
users cost 5	2050	14000.00	20726.33	83.45	24859.11	100.08
MR&R cost 6 (3)	2060	35000.00	10118.96	40.74	6373.20	25.66
users cost 6	2060	14000.00	22807.73	91.82	27355.54	110.13
dismantle						
Dismantle (5)	2070	400000.00	221869.19	893.26	184659.15	743.45
users cost	2070	471000.00	844373.22	3399.48	1012739.36	4077.33
		total LCC	8135651.42	30361.16	5404957.01	21760.60

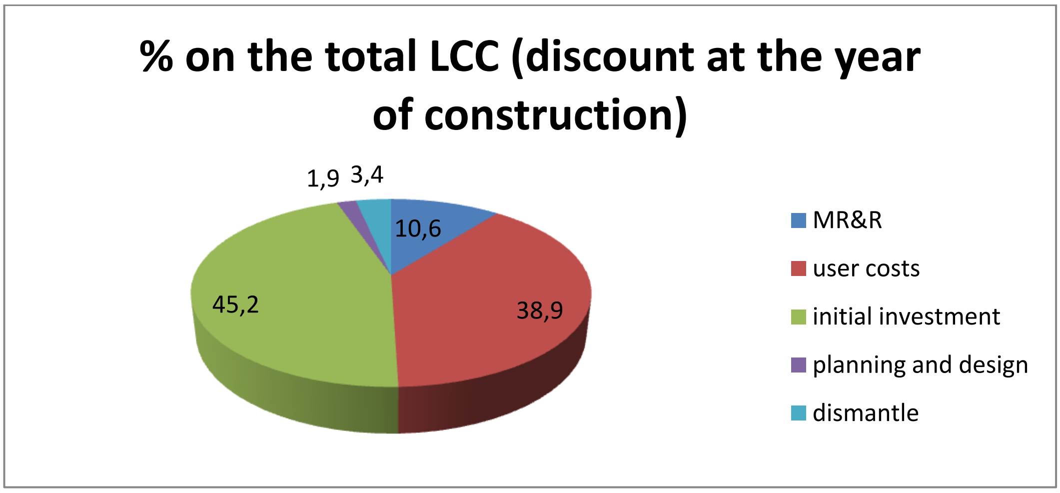


LCC [SEK]
5400000
5100000
4800000
4500000
4200000
3900000
3600000
3300000
3000000
2700000
2400000
2100000
1800000
1500000
1200000
900000
600000
300000
0
expenditure [SEK]
MR&R
user cost
materials&construction
planning&design
dismantle
1990
2010
2020
2030
2040
2050
2060
2070
year

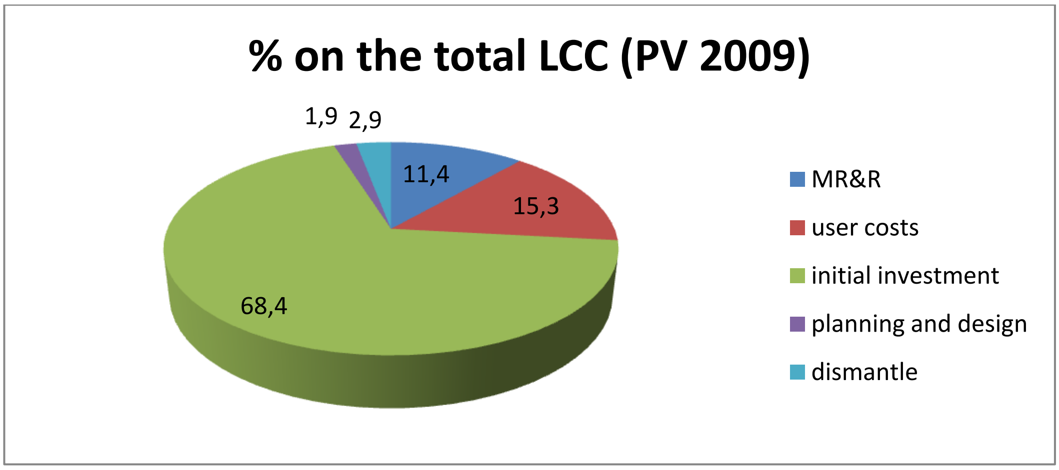


Traffic data [25-1674-1]
1800,0
1600,0
1400,0
1200,0
1000,0
800,0
600,0
400,0
200,0
0,0
ADT [vehicle/day]
total traffic
cars
trucks
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
2020
2023
2026
2029
2032
2035
2038
2041
2044
2047
2050
2053
2056
2059
2062
2065
2068
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	574292.49	10.6
user costs	2102005.38	38.9
initial investment	2444000.00	45.2
planning and design	100000.00	1.9
dismantle	184659.15	3.4



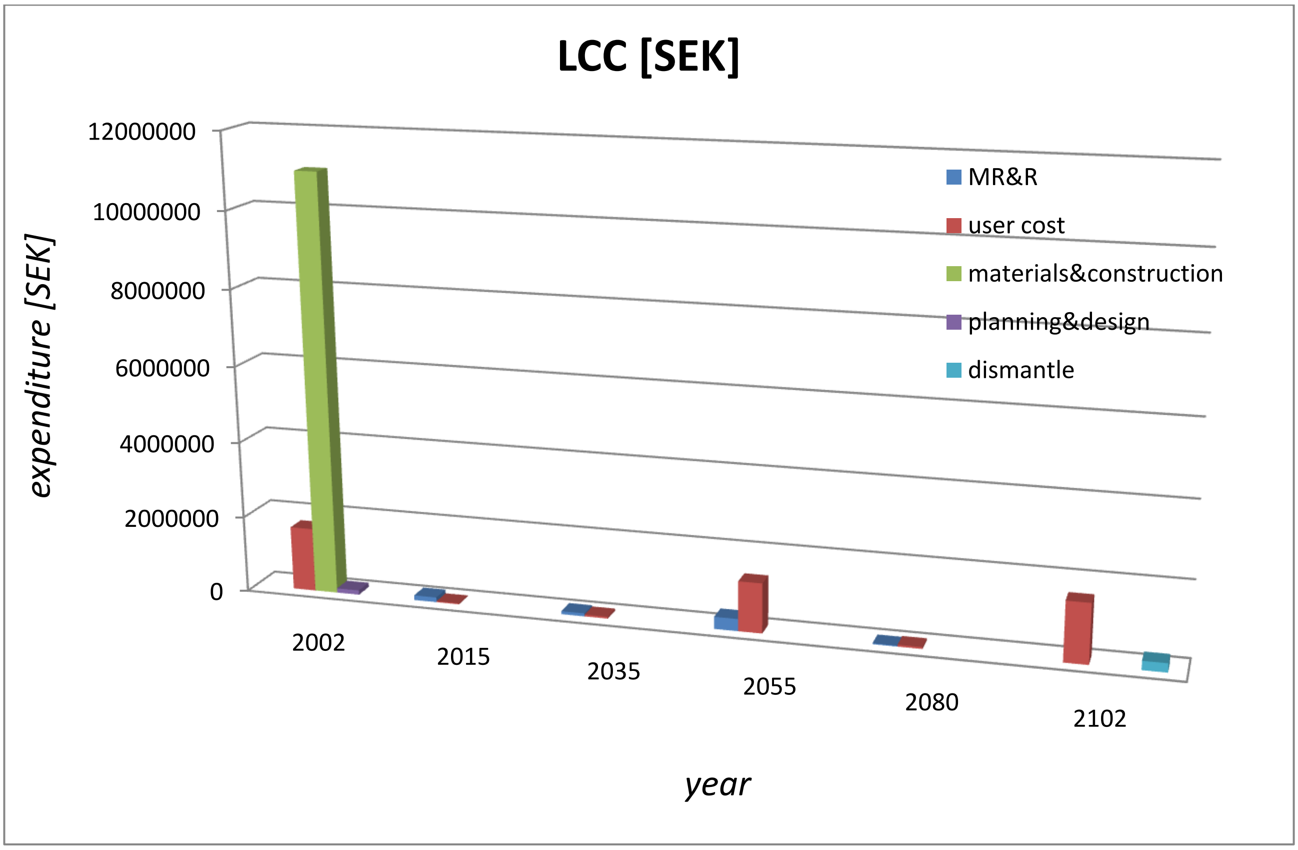
% on the total LCC (PV 2009)		
	costs	%
MR&R	861204.05	10.6
user costs	1758818.18	21.6
initial investment	5149139.39	63.3
planning and design	144620.61	1.8
dismantle	221869.19	2.7

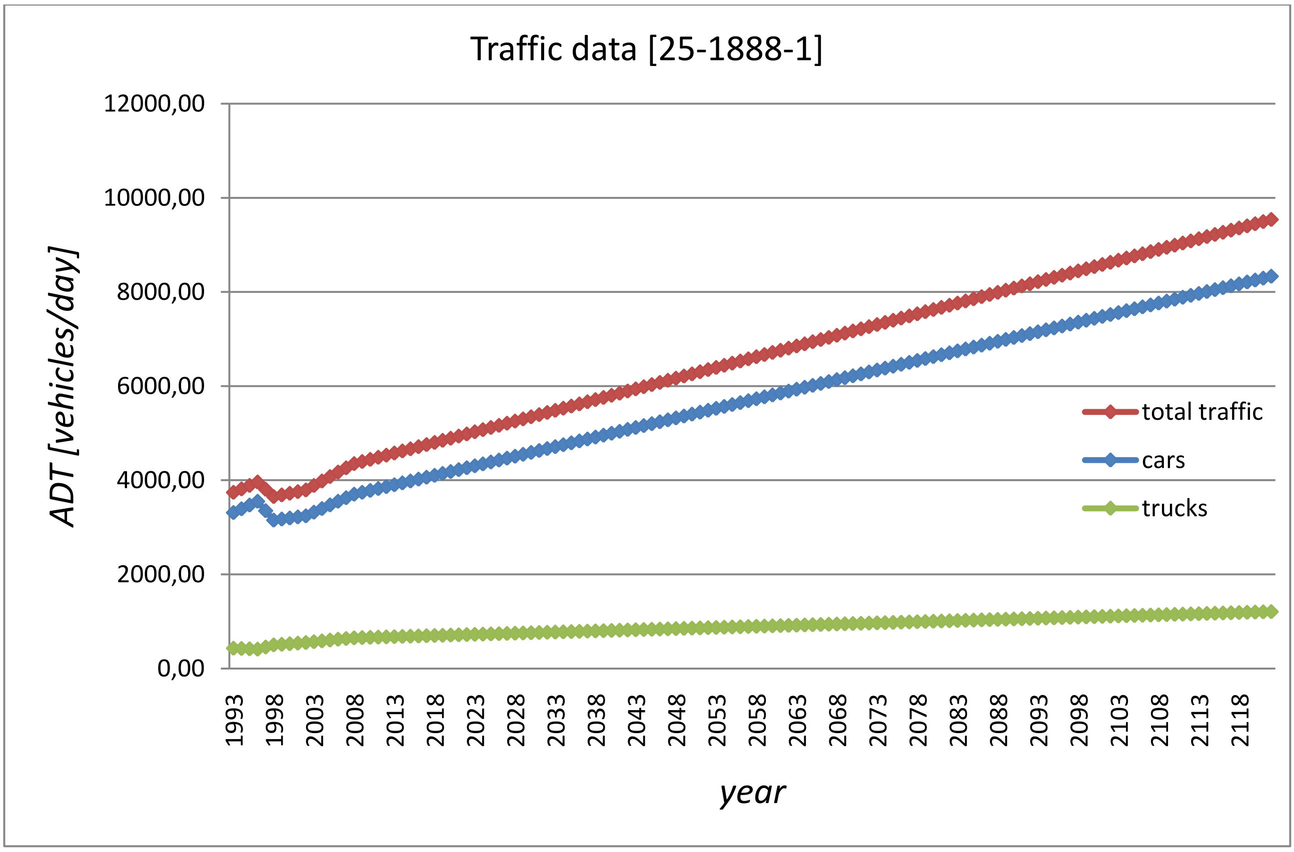


Bridge 25-1888-1

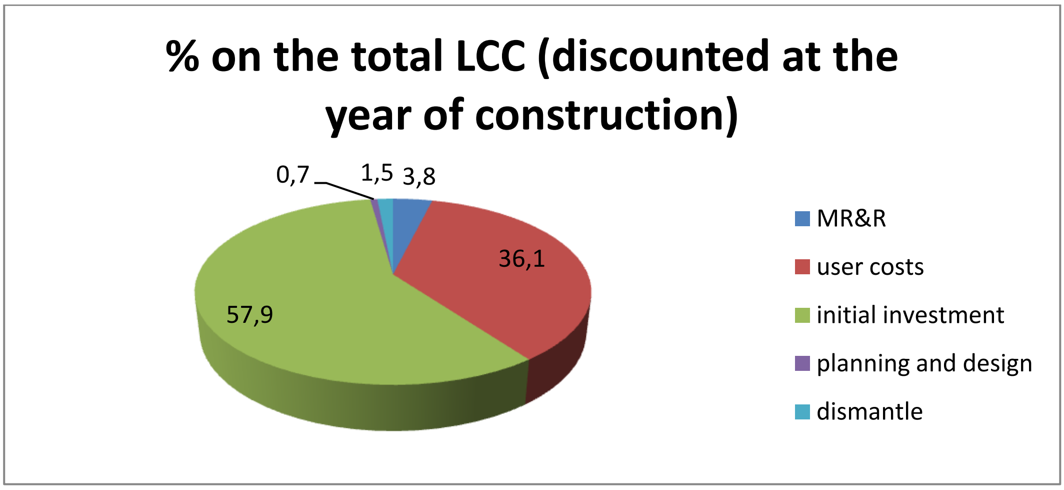
bridges information		economic information	
BaTMan code	25-1888-1	interest rate	0.04
year of construction	2002	inflation rate	0.015
expected service life [years]	100	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	2002	100000.00	114559.78	264.85	100000.00	231.19
material and construction	2002	8363000.00	11005137.47	25442.54	8363000.00	19334.24
users cost	2002	1795000.00	1678698.62	3880.95	1795000.00	4149.82
MR&R						
yearly inspection (10)	yearly	500.00	18307.05	42.32	18307.05	42.32
yearly maintenance(11)	yearly	2000.00	73228.21	169.29	73228.21	169.29
users cost for yearly op.	service life	134000.00	202213.93	467.49	216223.45	499.88
MR&R cost 1 (1)	2015	145000.00	125303.79	289.69	105680.08	244.32
users cost 1	2015	23000.00	24359.23	56.32	26046.86	60.22
MR&R cost 2 (6)	2035	150000.00	79678.57	184.21	67200.18	155.36
users cost 2	2035	37000.00	47452.24	109.70	50739.76	117.30
MR&R cost 3 (1+3+4)	2055	978000.00	319332.55	738.26	269322.17	622.64
users cost 3	2055	842000.00	1307634.11	3023.09	1398227.89	3232.53
MR&R cost 4 (1)	2080	135000.00	23991.40	55.47	20234.13	46.78
users cost 4	2080	24000.00	47346.12	109.46	50626.29	117.04
dismantle						
Dismantle (5)	2102	580000.00	236150.75	545.95	220707.22	510.25
users cost	2102	643000.00	1565724.08	3619.76	1674198.51	3870.54
		total LCC	16869117.92	38999.35	14448741.80	33403.74

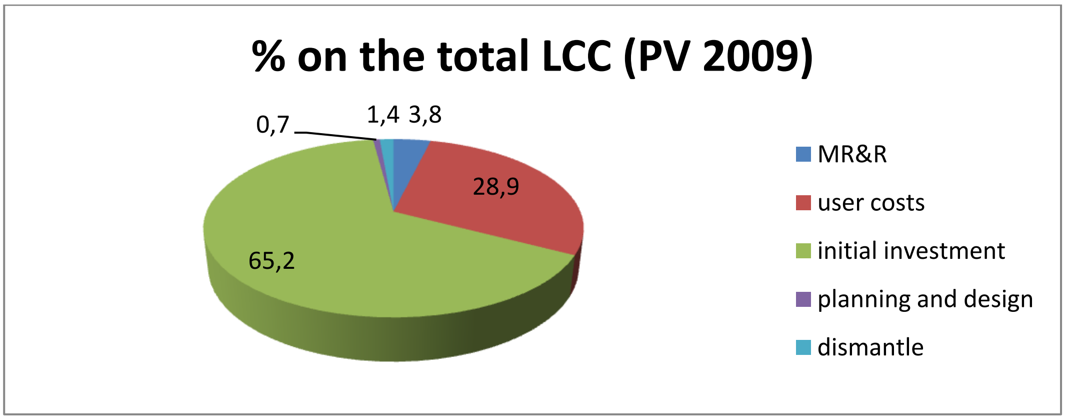

LCC [SEK]
12000000
10000000
8000000
6000000
4000000
2000000
0
expenditure [SEK]
MR&R
user cost
materials&construction
planning&design
dismantle
2002
2015
2035
2055
2080
2102
year


Traffic data [25-1888-1]
12000,00
10000,00
8000,00
6000,00
4000,00
2000,00
0,00
ADT [vehicles/day]
total traffic
cars
trucks
1993
1998
2003
2008
2013
2018
2023
2028
2033
2038
2043
2048
2053
2058
2063
2068
2073
2078
2083
2088
2093
2098
2103
2108
2113
2118
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	553971.83	3.8
user costs	5211062.74	36.1
initial investment	8363000.00	57.9
planning and design	100000.00	0.7
dismantle	220707.22	1.5



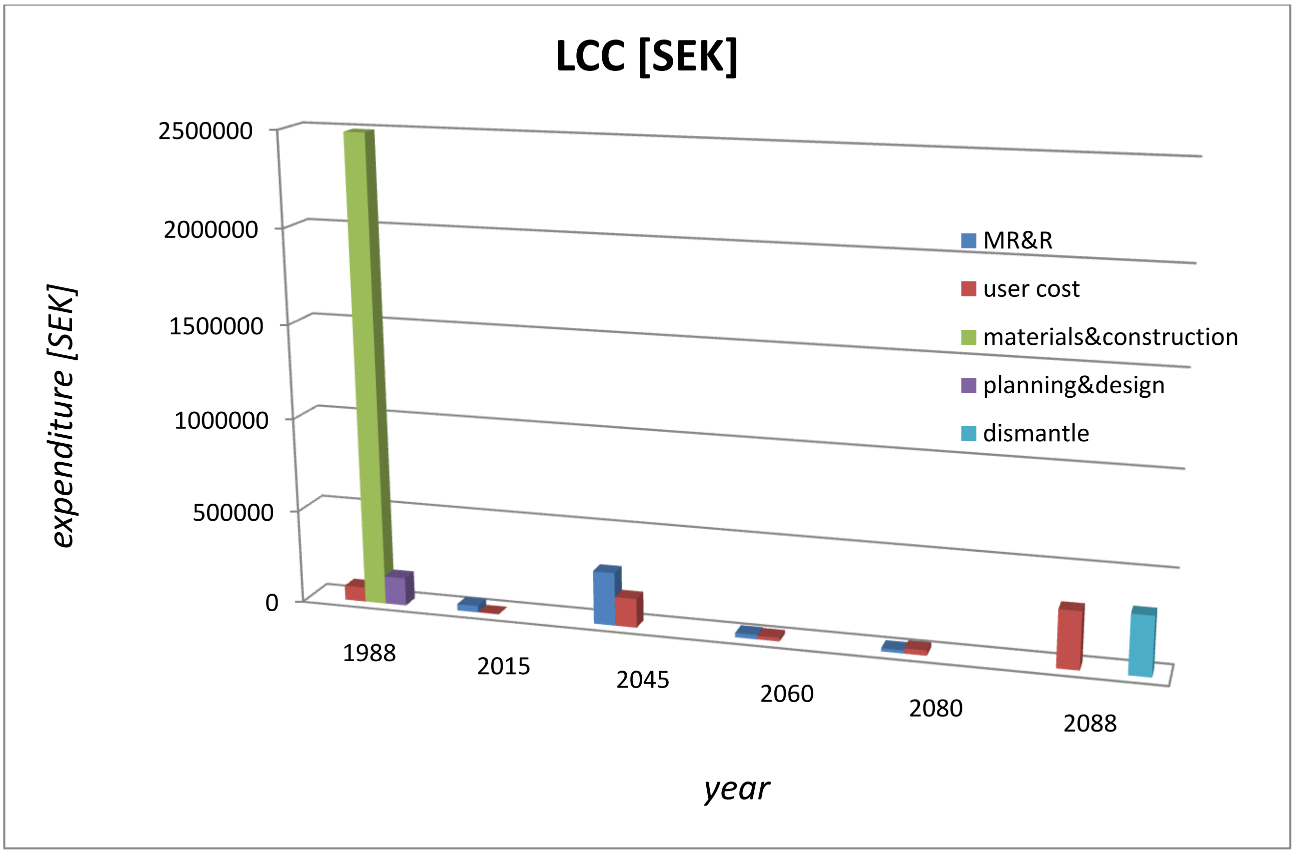
% on the total LCC (PV 2009)		
	costs	%
MR&R	639841.58	3.8
user costs	4873428.33	28.9
initial investment	11005137.47	65.2
planning and design	114559.78	0.7
dismantle	236150.75	1.4

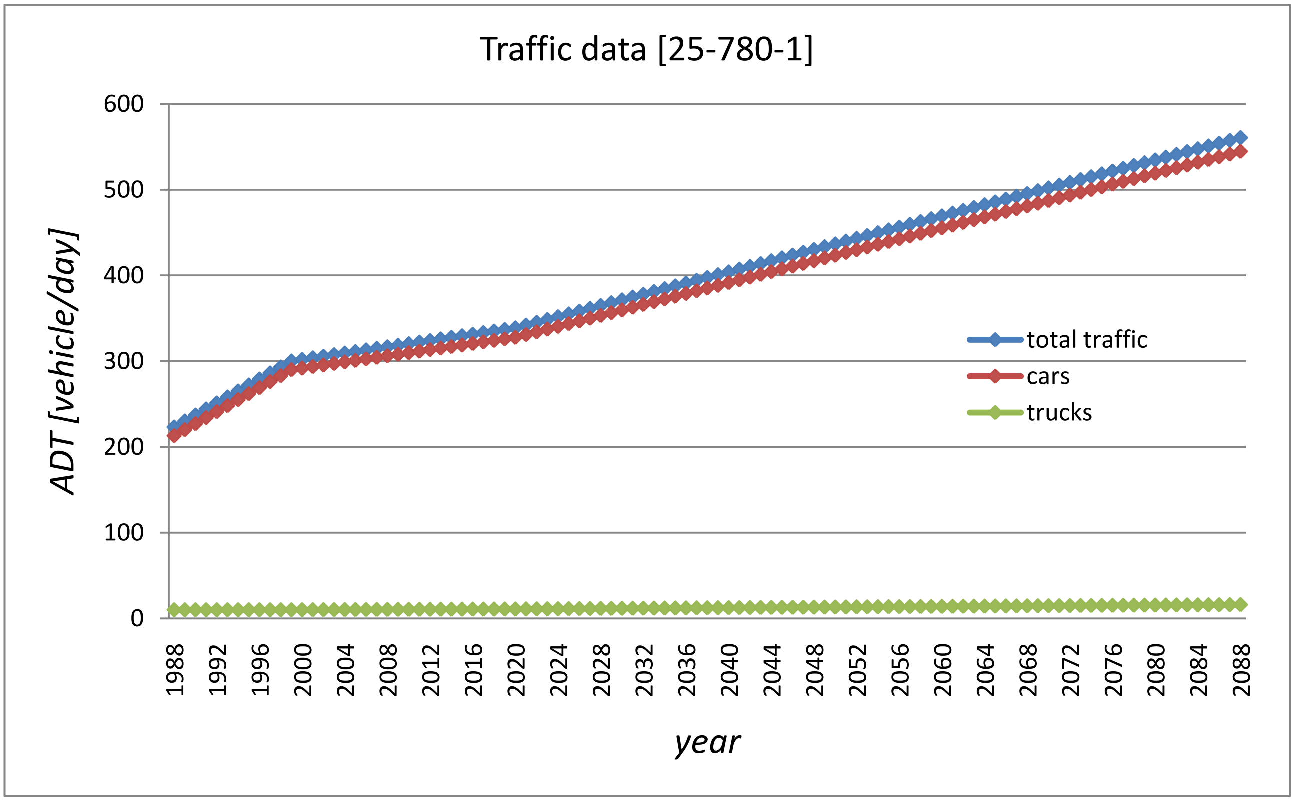


Bridge 25-780-1

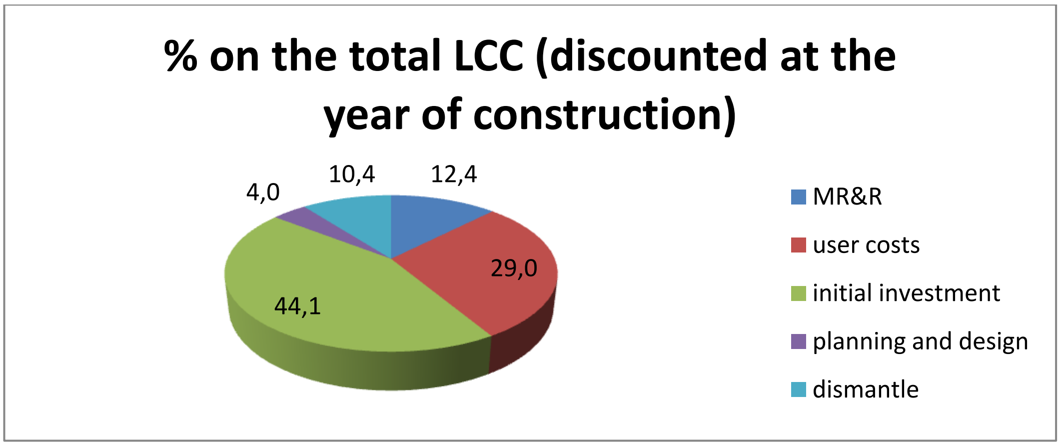
bridges information		economic information	
BaTMan code	25-780-1	interest rate	0.04
year of construction	1988	inflation rate	0.015
expected service life [years]	100	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]	discount value (year of construction) [SEK]	annuity cost (year of cons.) [SEK]
initial investment						
planning and design	1988	100000.00	150347.61	347.59	100000.00	231.19
material and construction	1988	1093000.00	2490693.50	5758.18	1093000.00	2526.88
users cost	1988	95000.00	77704.91	179.64	95000.00	219.63
MR&R						
yearly inspection (10)	yearly	500.00	18307.05	42.32	18307.05	42.32
yearly maintenance(11)	yearly	2000.00	73228.21	169.29	73228.21	169.29
users cost for yearly op.	service life	7000.00	9238.91	21.36	11295.25	26.11
MR&R cost 1 (6)	2015	40000.00	34566.56	79.91	20736.86	47.94
users cost 1	2015	1000.00	1059.10	2.45	1294.82	2.99
MR&R cost 2 (1+3+4)	2045	682000.00	284028.34	656.64	170391.70	393.92
users cost 2	2045	110000.00	155241.29	358.90	189793.96	438.78
MR&R cost 3 (1+6)	2060	80000.00	23129.05	53.47	13875.37	32.08
users cost 3	2060	12000.00	19549.48	45.20	23900.69	55.26
MR&R cost 4 (1)	2080	95000.00	16882.84	39.03	10128.20	23.42
users cost 4	2080	14000.00	27618.57	63.85	33765.74	78.06
dismantle						
Dismantle (5)	2088	680000.00	316968.32	732.79	258760.19	598.22
users cost	2088	144000.00	306678.49	709.00	374937.15	866.81
		total LCC	4005242.23	9259.63	2488415.20	5752.91

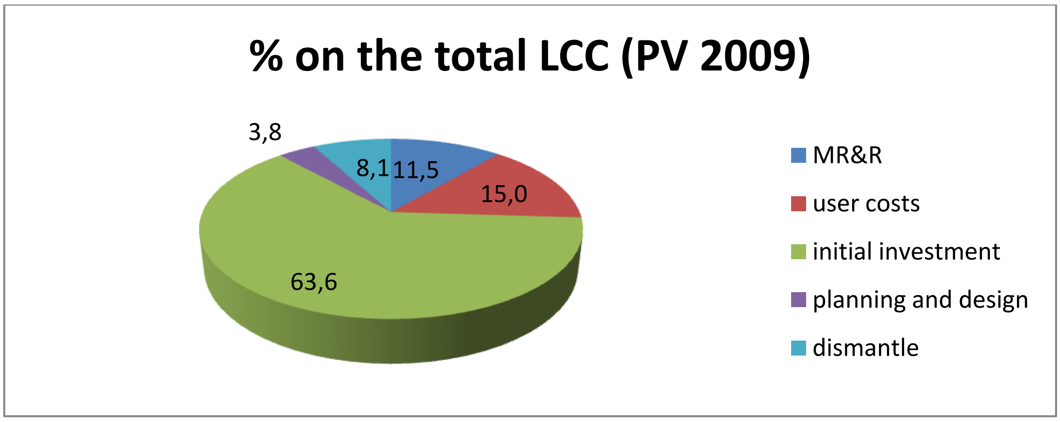

LCC [SEK]
2500000
2000000
1500000
1000000
500000
0
expenditure [SEK]
1988
2015
2045
2060
2080
2088
year
MR&R
user cost
materials&construction
planning&design
dismantle


Traffic data [25-780-1]
600
500
400
300
200
100
0
ADT [vehicle/day]
total traffic
cars
trucks
1988
1992
1996
2000
2004
2008
2012
2016
2020
2024
2028
2032
2036
2040
2044
2048
2052
2056
2060
2064
2068
2072
2076
2080
2084
2088
year

% on the total LCC (discount at the year of construction)		
	costs	%
MR&R	306667.40	12.3
user costs	729987.62	29.3
initial investment	1093000.00	43.9
planning and design	100000.00	4.0
dismantle	258760.19	10.4

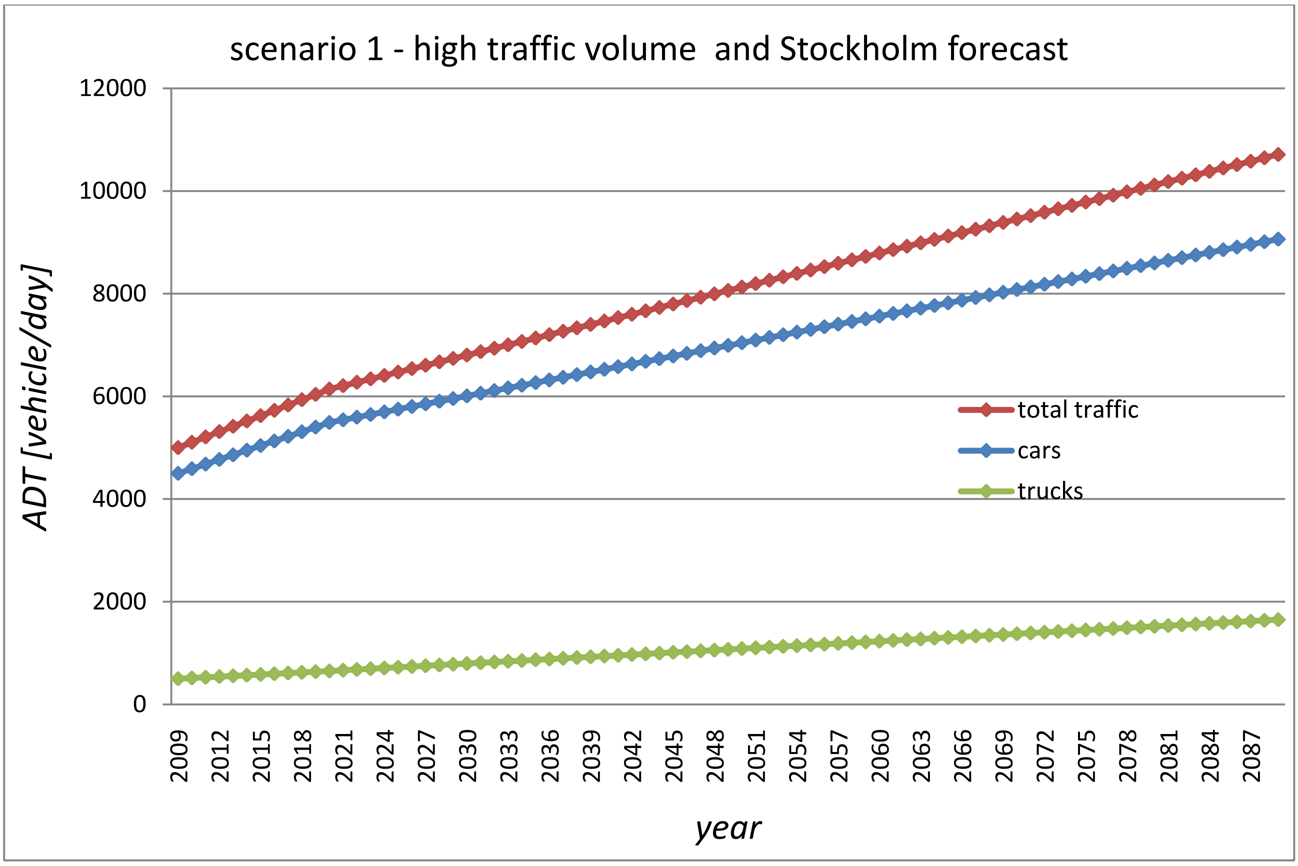


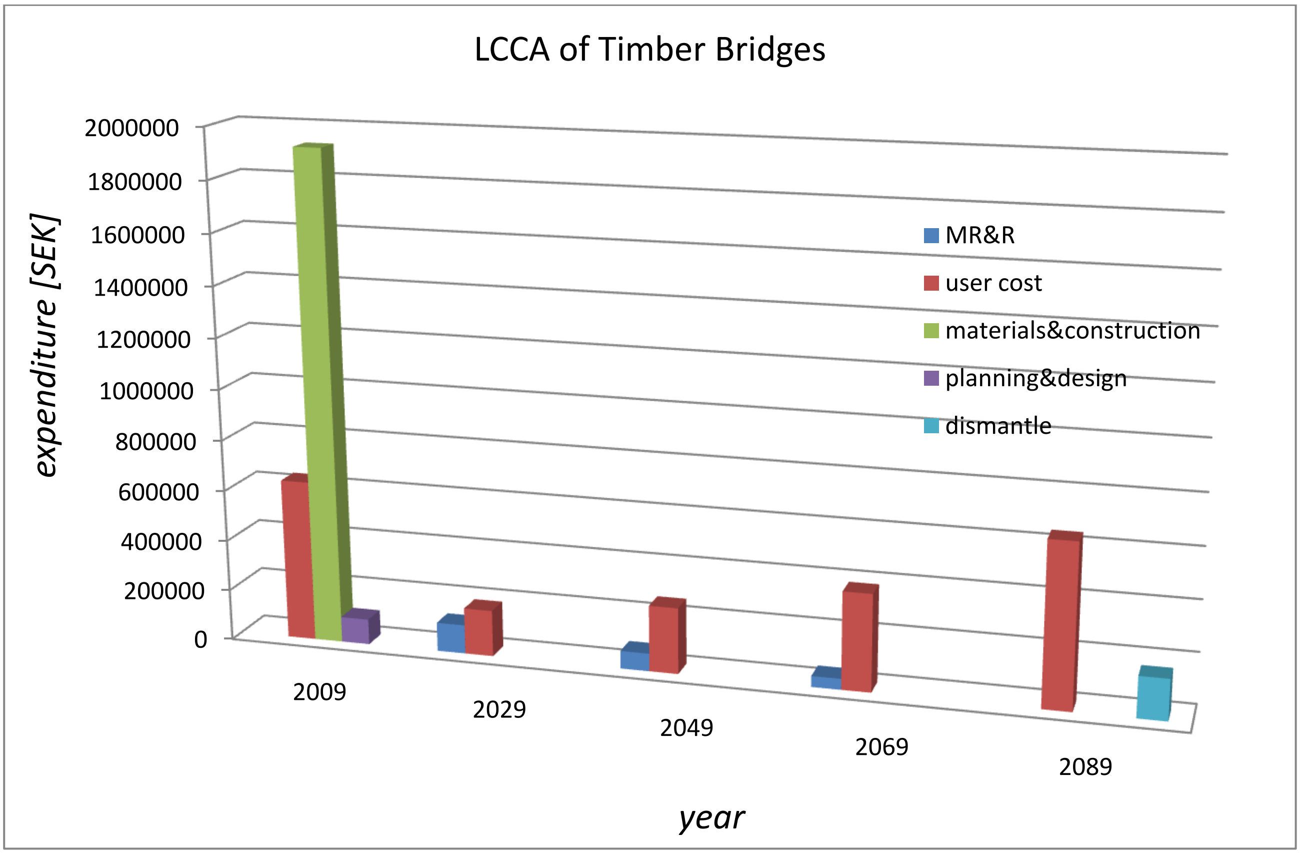
% on the total LCC (PV 2009)		
	costs	%
MR&R	450142.06	11.2
user costs	597090.74	14.9
initial investment	2490693.50	62.2
planning and design	150347.61	3.8
dismantle	316968.32	7.9



APPENDIX A2 – Life-Cycle Cost Calculations of Timber Bridges

n°	***Operation***	***Description***
1	Exchange isolation	Remove the asphalt/concrete and the waterproofing and replace it with concrete or new waterproof and asphalt
2	Exchange panels	Remove the old panels at the sides of the bridge and mount new ones
3	Exchange of dripping plates	Remove the old dripping plates at the sides of the bridge and mount new ones
4	Exchange expansion joints	Remove the old expansion joints at the sides of the bridge and mount new ones
5	Paint the lower surface of the deck	Take away the old paint and replace with new paint
6	Yearly inspection	Check from a distance inferior than arm-length all part of the bridge
7	Periodical maintenance	remove vegetation around and on the bridge, change some parts on the fence, mainly small repairing that do not have so much affect on the traffic, adjust/strengthen the slope with filling with material (rocks)
8	Demolition	Take down the old bridge, separate different parts and disposal it

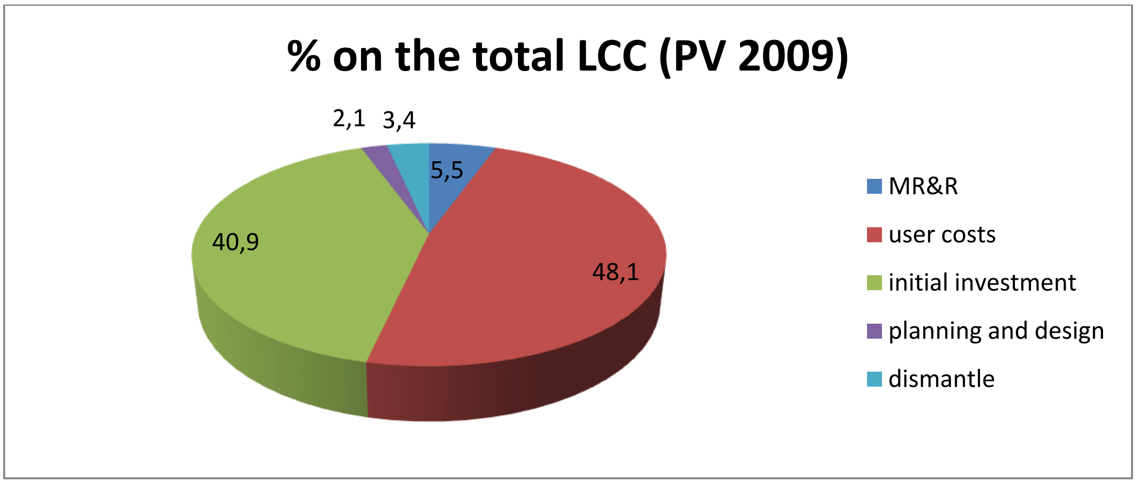

scenario 1 - high traffic volume and Stockholm forecast
ADT [vehicle/day]
12000
10000
8000
6000
4000
2000
0
2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048 2051 2054 2057 2060 2063 2066 2069 2072 2075 2078 2081 2084 2087
year
total traffic
cars
trucks

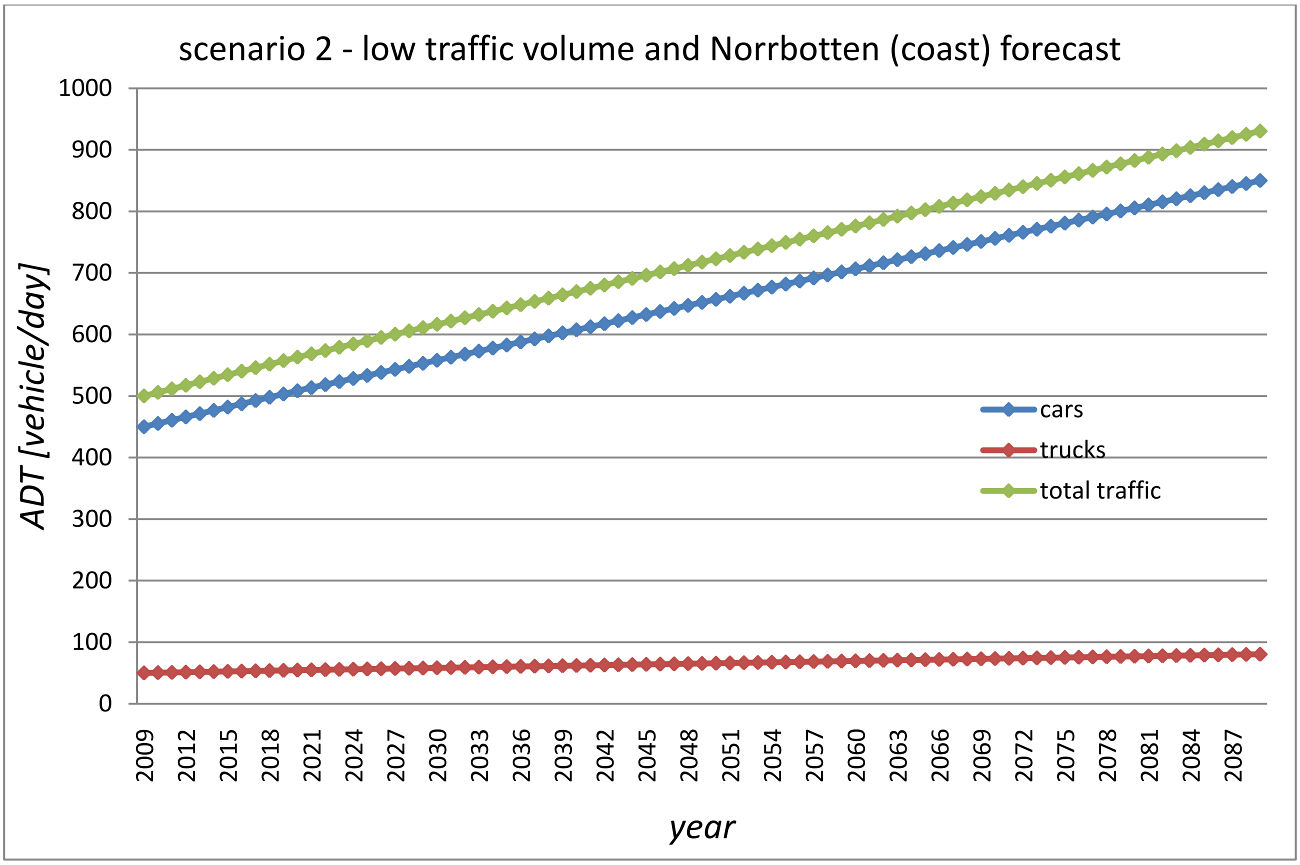

LCCA of Timber Bridges
expenditure [SEK]
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
2009
2029
2049
2069
2089
year
MR&R
user cost
materials&construction
planning&design
dismantle

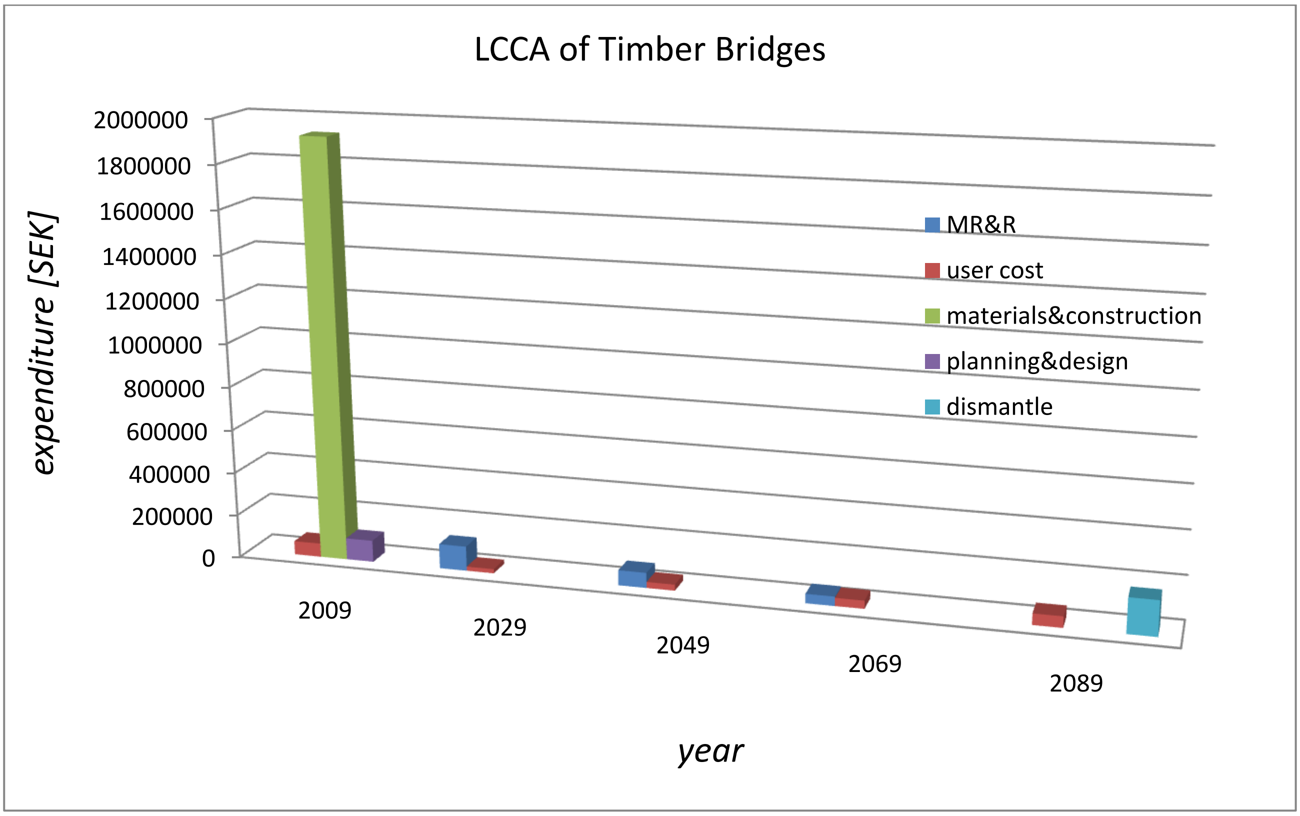
bridges information		economic information	
Timber Bridge 1		interest rate	0.04
year of construction	2009	inflation rate	0.015
expected service life [years]	80	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]
initial investment				
planning and design	2009	100000.00	100000.00	402.60
material and construction	2009	1925000.00	1925000.00	7750.14
user costs	2009	634000.00	634000.00	2552.51
MR&R				
yearly inspection (6)	yearly	500.00	17225.91	69.35
periodical maintenance (7)	6 years	2500.00	13687.80	55.11
users cost for yearly op.	service life	429000.00	162093.43	652.60
MR&R cost 1 (1+2+3+4+5)	2029	184800.00	113594.17	457.34
users cost 1	2029	150000.00	181639.57	731.29
MR&R cost 2 (1+2+3+4+5)	2049	184800.00	69824.86	281.12
users cost 2	2049	177000.00	259544.40	1044.94
MR&R cost 3 (1+2+3+4+5)	2069	184800.00	42920.44	172.80
users cost 3	2069	215000.00	381764.94	1537.00
dismantle				
Dismantle (8)	2089	350000.00	161576.75	650.52
users cost	2089	299000.00	642906.73	2588.37
		total LCC	4705778.99	18945.68

% on the total LCC (PV 2009)		
	costs	%
MR&R	257253.17	5.5
user costs	2261949.06	48.1
initial investment	1925000.00	40.9
planning and design	100000.00	2.1
dismantle	161576.75	3.4



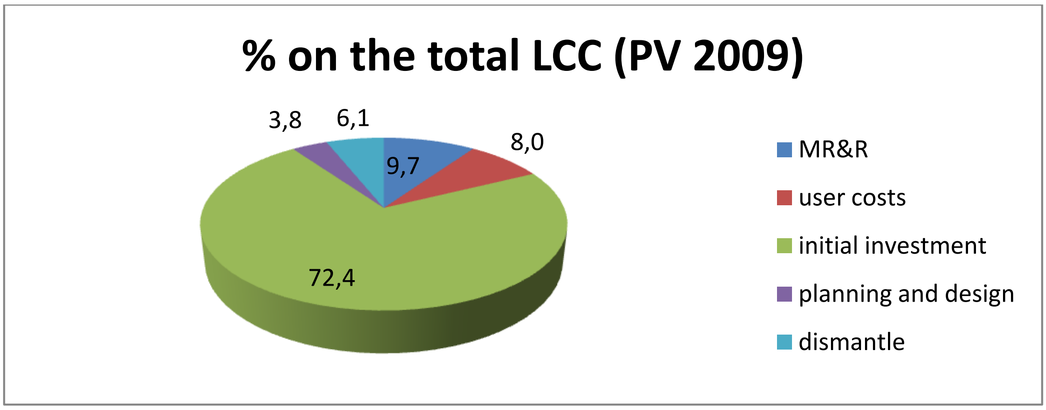

scenario 2 - low traffic volume and Norrbotten (coast) forecast
ADT [vehicle/day]
1000
900
800
700
600
500
400
300
200
100
0
cars
trucks
total traffic
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
2051
2054
2057
2060
2063
2066
2069
2072
2075
2078
2081
2084
2087
year

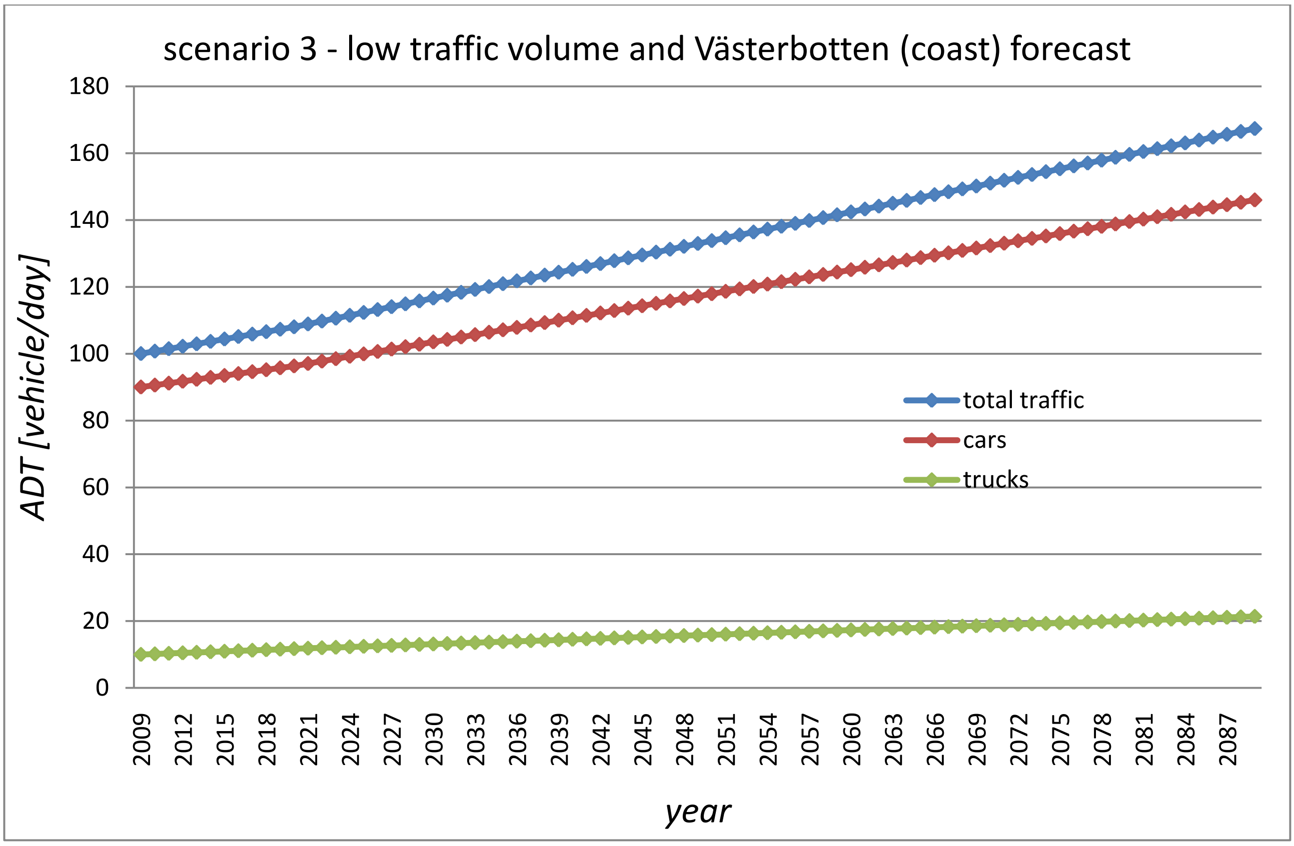

LCCA of Timber Bridges
expenditure [SEK]
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
MR&R
user cost
materials&construction
planning&design
dismantle
2009
2029
2049
2069
2089
year

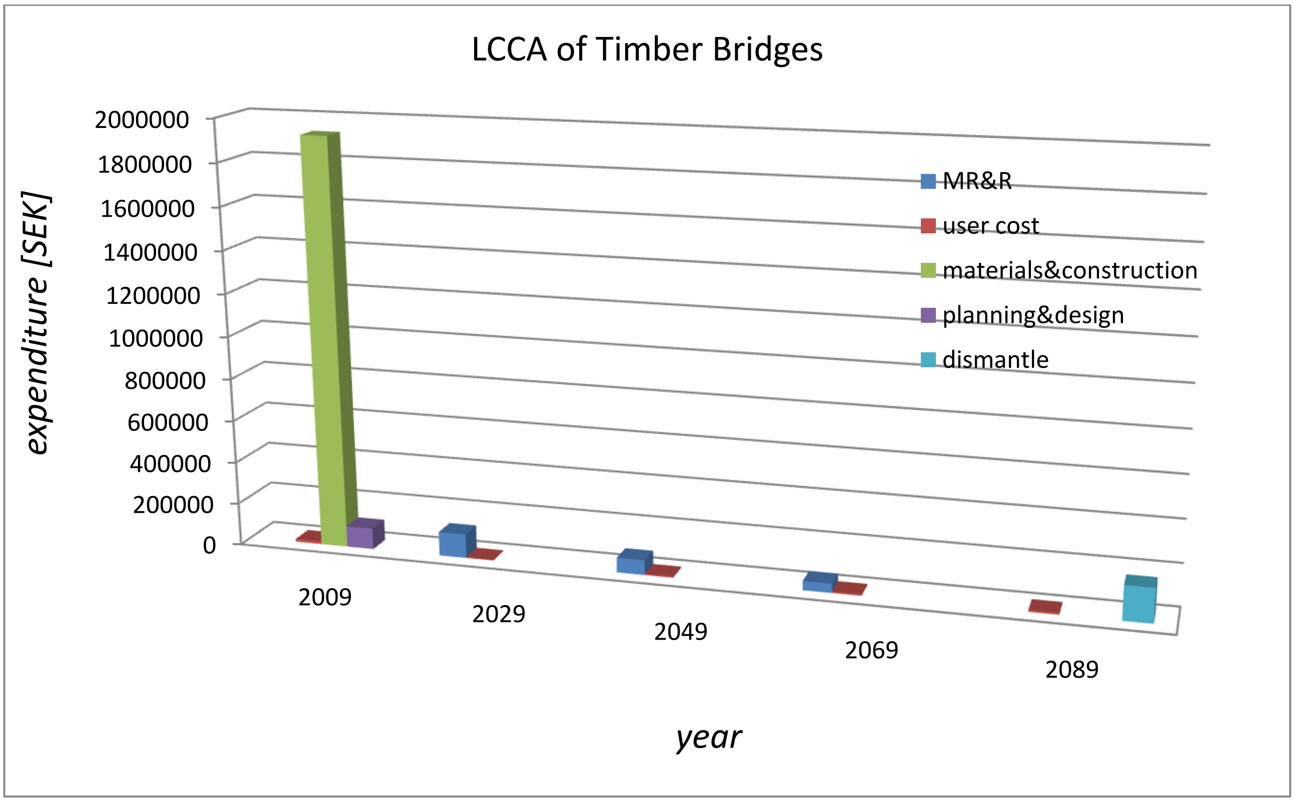
bridges information		economic information	
Timber Bridge 2		interest rate	0.04
year of construction	2009	inflation rate	0.015
expected service life [years]	80	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]
initial investment				
planning and design	2009	100000.00	100000.00	402.60
material and construction	2009	1925000.00	1925000.00	7750.14
user costs	2009	63000.00	63000.00	253.64
MR&R				
yearly inspection (6)	yearly	500.00	17225.91	69.35
periodical maintenance (7)	6 years	2500.00	13687.80	55.11
users cost for yearly op.	service life	38000.00	14357.93	57.81
MR&R cost 1 (1+2+3+4+5)	2029	184800.00	113594.17	457.34
users cost 1	2029	16000.00	19374.89	78.00
MR&R cost 2 (1+2+3+4+5)	2049	184800.00	69824.86	281.12
users cost 2	2049	19000.00	27860.70	112.17
MR&R cost 3 (1+2+3+4+5)	2069	184800.00	42920.44	172.80
users cost 3	2069	21000.00	37288.67	150.13
dismantle				
Dismantle (8)	2089	350000.00	161576.75	650.52
users cost	2089	24000.00	51604.55	207.76
		total LCC	2657316.66	10698.48

% on the total LCC (PV 2009)		
	costs	%
MR&R	257253.17	9.7
user costs	213486.73	8.0
initial investment	1925000.00	72.4
planning and design	100000.00	3.8
dismantle	161576.75	6.1



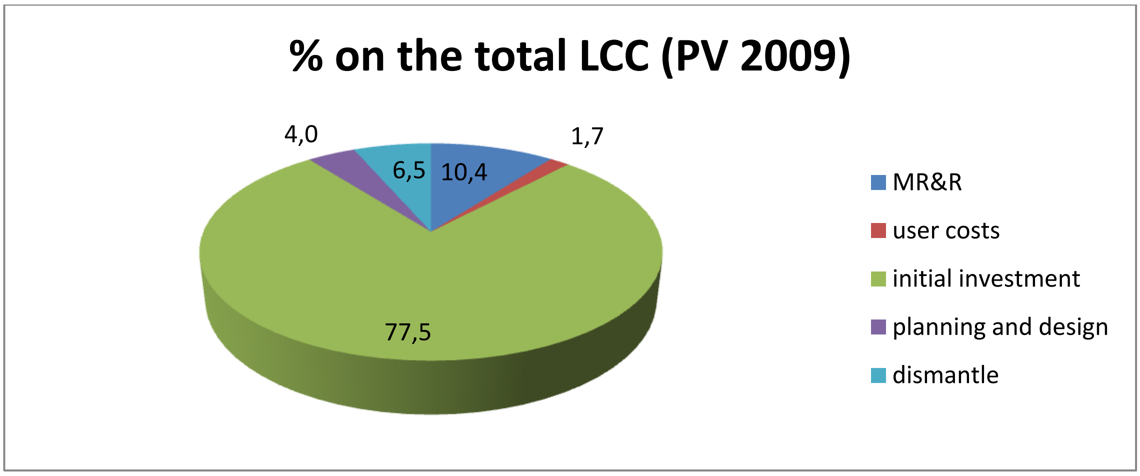

scenario 3 - low traffic volume and Västerbotten (coast) forecast
ADT [vehicle/day]
180
160
140
120
100
80
60
40
20
0
total traffic
cars
trucks
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
2051
2054
2057
2060
2063
2066
2069
2072
2075
2078
2081
2084
2087
year


LCCA of Timber Bridges
expenditure [SEK]
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
MR&R
user cost
materials&construction
planning&design
dismantle
2009
2029
2049
2069
2089
year

bridges information		economic information	
Timber Bridge 3		interest rate	0.04
year of construction	2009	inflation rate	0.015
expected service life [years]	80	year update costs	2009
		currency [SEK]	1

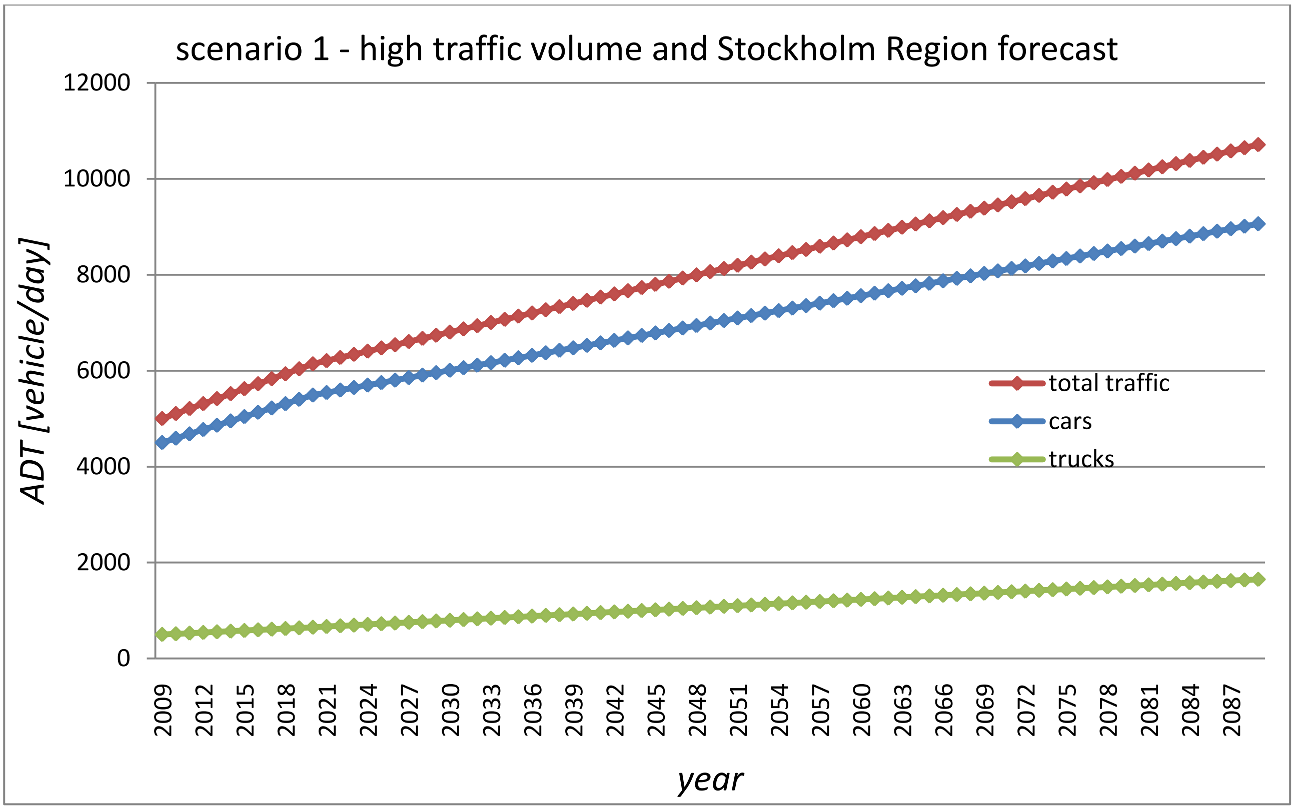
	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]
initial investment				
planning and design	2009	100000.00	100000.00	402.60
material and construction	2009	1925000.00	1925000.00	7750.14
user costs	2009	13000.00	13000.00	52.34
MR&R				
yearly inspection (6)	yearly	500.00	17225.91	69.35
periodical maintenance (7)	6 years	2500.00	13687.80	55.11
users cost for yearly op.	service life	8000.00	3022.72	12.17
MR&R cost 1 (1+2+3+4+5)	2029	184800.00	113594.17	457.34
users cost 1	2029	3000.00	3632.79	14.63
MR&R cost 2 (1+2+3+4+5)	2049	184800.00	69824.86	281.12
users cost 2	2049	4000.00	5865.41	23.61
MR&R cost 3 (1+2+3+4+5)	2069	184800.00	42920.44	172.80
users cost 3	2069	4000.00	7102.60	28.60
dismantle				
Dismantle (8)	2089	350000.00	161576.75	650.52
users cost	2089	4000.00	8600.76	34.63
		total LCC	2485054.21	10004.94

% on the total LCC (PV 2009)		
	costs	%
MR&R	257253.17	10.4
user costs	41224.29	1.7
initial investment	1925000.00	77.5
planning and design	100000.00	4.0
dismantle	161576.75	6.5

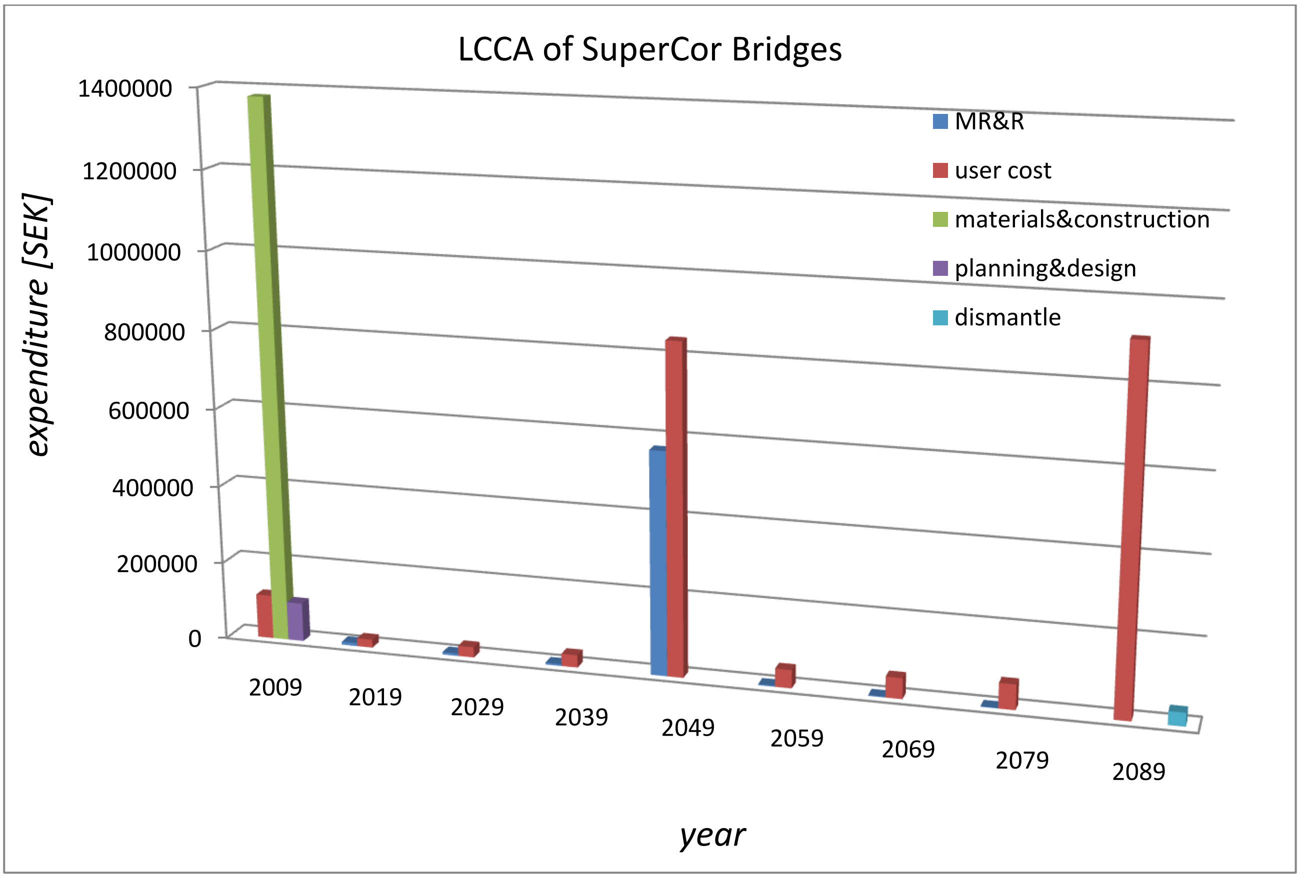


APPENDIX A3 – Life-Cycle Cost Calculations of Super Cor Bridges

n°	***Operation***	***Description***
1	Washing	Wash the steel culvert and gabions
2	Repaint steel	Take away all paint that loose and replace the several layers with new paint
3	Yearly inspection	Check from a distance inferior than arm-length all part of the bridge
4	Periodical maintenance	Remove the asphalt/concrete and the waterproofing and replace it with concrete or new waterproof and asphalt, remove vegetation around and on the bridge, change some parts on the fence, mainly small repairing that do not have so much affect on the traffic, adjust/strengthen the slope with filling with material (rocks)
5	Demolition	Take down the old bridge, separate different parts and disposal it



scenario 1 - high traffic volume and Stockholm Region forecast
ADT [vehicle/day]
12000
10000
8000
6000
4000
2000
0
total traffic
cars
trucks
2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048 2051 2054 2057 2060 2063 2066 2069 2072 2075 2078 2081 2084 2087
year

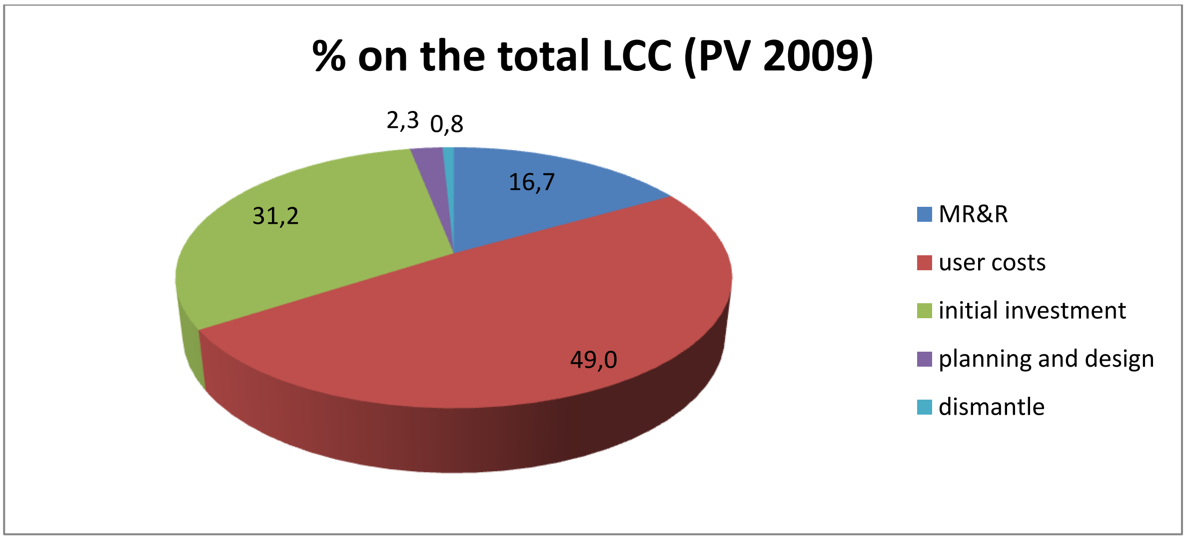


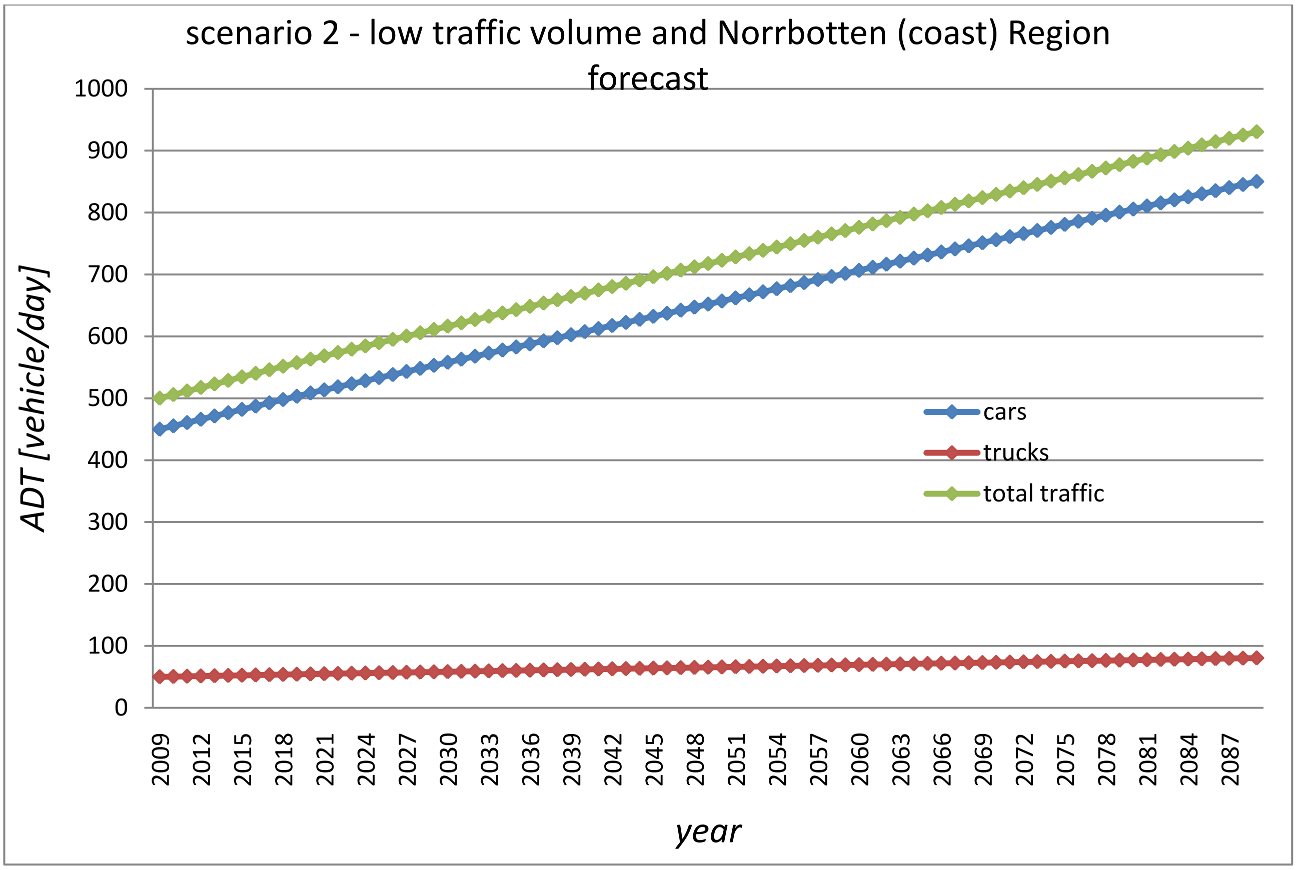
LCCA of SuperCor Bridges
expenditure [SEK]
1400000
1200000
1000000
800000
600000
400000
200000
0
MR&R
user cost
materials&construction
planning&design
dismantle
2009 2019 2029 2039 2049 2059 2069 2079 2089
year

bridges information		economic information	
SuperCor 1		interest rate	0.04
year of construction	2009	inflation rate	0.015
expected service life [years]	80	year update costs	2009
		currency [SEK]	1

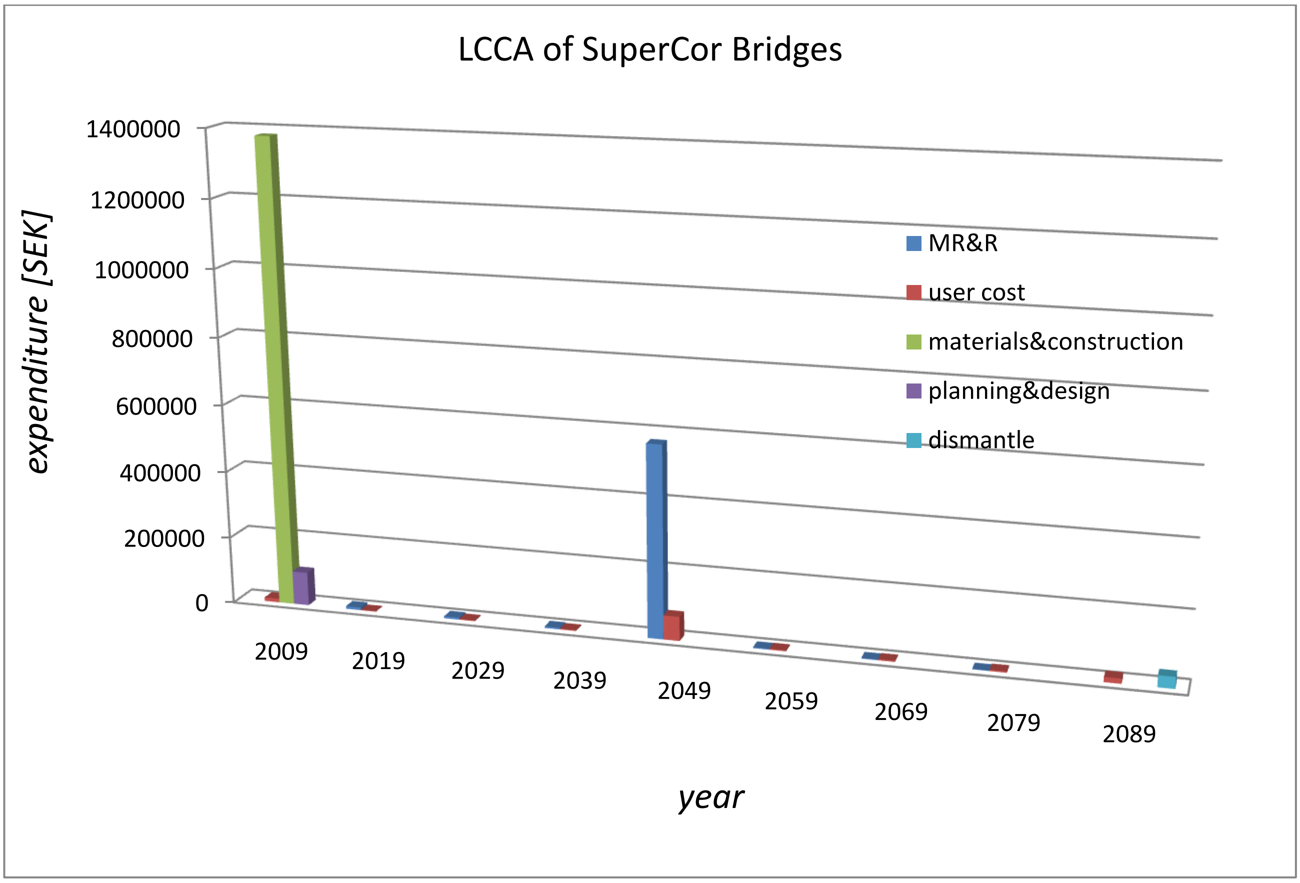
	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]
initial investment				
planning and design	2009	100000.00	100000.00	402.60
material and construction	2009	1379000.00	1379000.00	5551.92
user costs	2009	113000.00	113000.00	454.94
MR&R				
yearly inspection (3)	yearly	1000.00	34451.82	138.70
periodical maintenance (4)	6 years	20000.00	109502.38	440.86
users cost for yearly op.	service life	157000.00	59320.91	238.83
MR&R cost 1 (1)	2019	10000.00	7840.20	31.56
users cost 1	2019	19000.00	20908.03	84.18
MR&R cost 2 (1)	2029	10000.00	6146.87	24.75
users cost 2	2029	22000.00	26640.47	107.26
MR&R cost 3 (1)	2039	10000.00	4819.27	19.40
users cost 3	2039	24000.00	31980.85	128.76
MR&R cost 4 (1)	2049	10000.00	3778.40	15.21
users cost 4	2049	26000.00	38125.17	153.49
MR&R cost 5 (2)	2049	1500000.00	566760.24	2281.80
users cost 5	2049	548000.00	803561.18	3235.17
MR&R cost 6 (1)	2059	10000.00	2962.34	11.93
users cost 6	2059	29000.00	46794.63	188.40
MR&R cost 7 (1)	2069	10000.00	2322.53	9.35
users cost 7	2069	30000.00	53269.53	214.47
MR&R cost 8 (1)	2079	10000.00	1820.91	7.33
users cost 8	2079	33000.00	64480.90	259.60
dismantle				
Dismantle (5)	2089	75000.00	34623.59	139.40
users cost	2089	424000.00	911680.44	3670.47
		total LCC	4423790.67	17095.83

% on the total LCC (PV 2009)		
	costs	%
MR&R	740404.97	16.7
user costs	2169762.11	49.0
initial investment	1379000.00	31.2
planning and design	100000.00	2.3
dismantle	34623.59	0.8





scenario 2 - low traffic volume and Norrbotten (coast) Region forecast
ADT [vehicle/day]
1000
900
800
700
600
500
400
300
200
100
0
cars
trucks
total traffic
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
2051
2054
2057
2060
2063
2066
2069
2072
2075
2078
2081
2084
2087
year

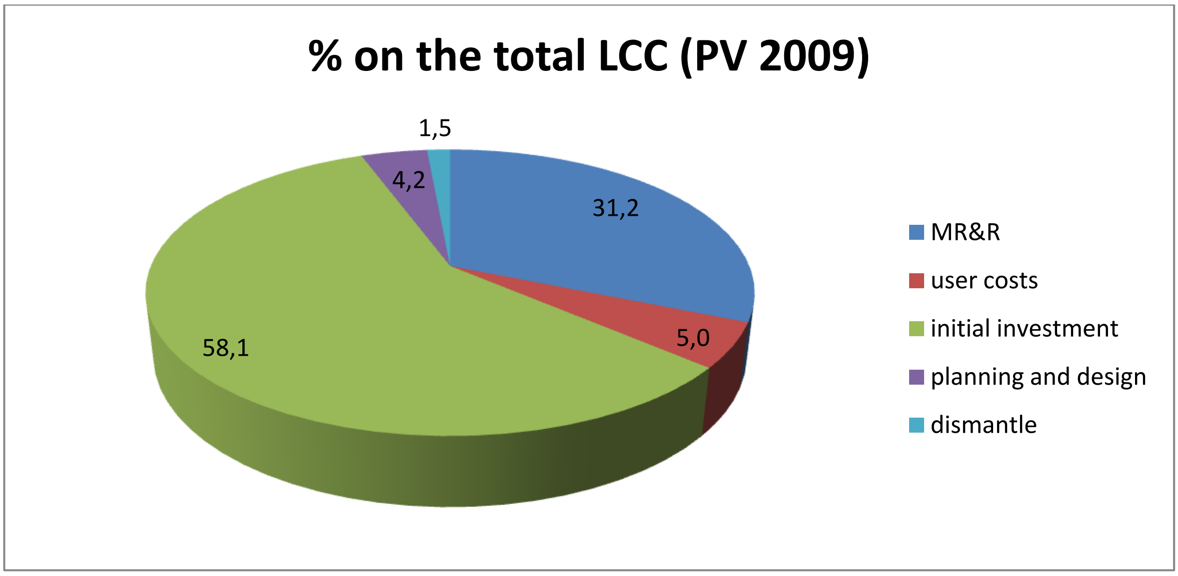


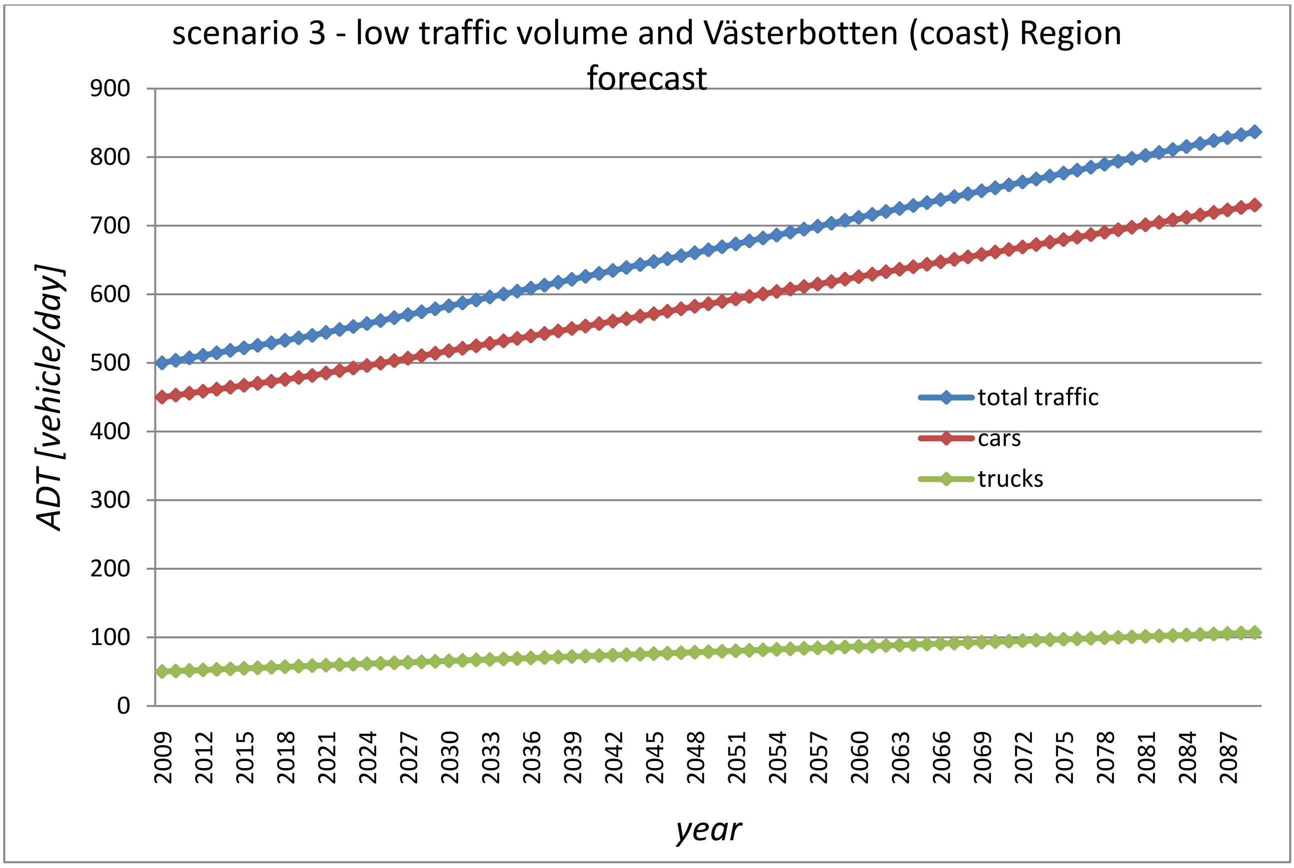
LCCA of SuperCor Bridges
expenditure [SEK]
1400000
1200000
1000000
800000
600000
400000
200000
0
MR&R
user cost
materials&construction
planning&design
dismantle
2009
2019
2029
2039
2049
2059
2069
2079
2089
year

bridges information		economic information	
SuperCor 2		interest rate	0.04
year of construction	2009	inflation rate	0.015
expected service life [years]	80	year update costs	2009
		currency [SEK]	1

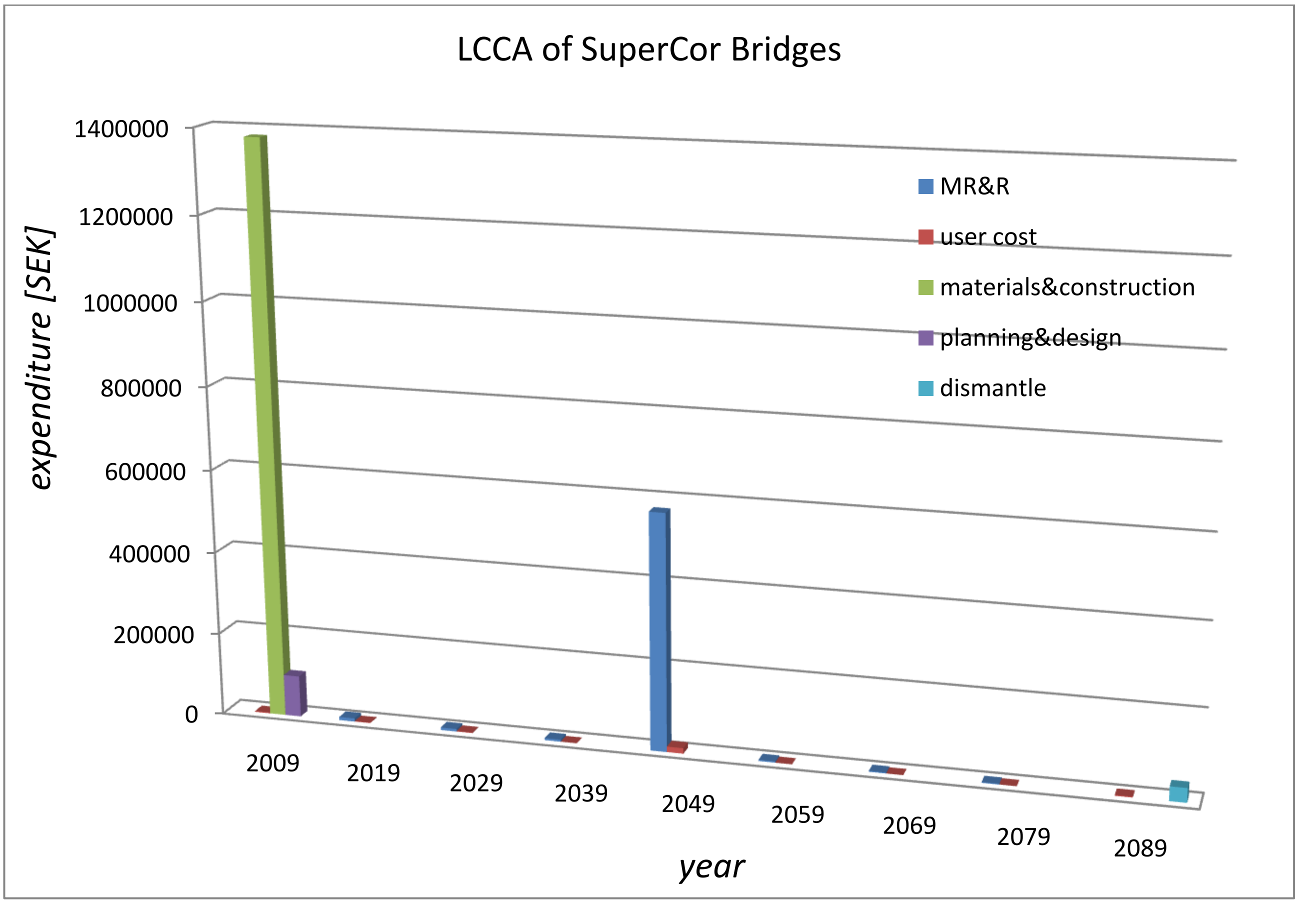
	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]
initial investment				
planning and design	2009	100000.00	100000.00	402.60
material and construction	2009	1379000.00	1379000.00	5551.92
user costs	2009	11000.00	11000.00	44.29
MR&R				
yearly inspection (3)	yearly	1000.00	34451.82	138.70
periodical maintenance (4)	6 years	20000.00	109502.38	440.86
users cost for yearly op.	service life	13000.00	4911.92	19.78
MR&R cost 1 (1)	2019	10000.00	7840.20	31.56
users cost 1	2019	1000.00	1100.42	4.43
MR&R cost 2 (1)	2029	10000.00	6146.87	24.75
users cost 2	2029	2000.00	2421.86	9.75
MR&R cost 3 (1)	2039	10000.00	4819.27	19.40
users cost 3	2039	2000.00	2665.07	10.73
MR&R cost 4 (1)	2049	10000.00	3778.40	15.21
users cost 4	2049	2000.00	2932.71	11.81
MR&R cost 5 (2)	2049	1500000.00	566760.24	2281.80
users cost 5	2049	47000.00	68918.57	277.47
MR&R cost 6 (1)	2059	10000.00	2962.34	11.93
users cost 6	2059	2000.00	3227.22	12.99
MR&R cost 7 (1)	2069	10000.00	2322.53	9.35
users cost 7	2069	2000.00	3551.30	14.30
MR&R cost 8 (1)	2079	10000.00	1820.91	7.33
users cost 8	2079	2000.00	3907.93	15.73
dismantle				
Dismantle (5)	2089	75000.00	34623.59	139.40
users cost	2089	7000.00	15051.33	60.60
		total LCC	2373716.89	9496.67

% on the total LCC (PV 2009)		
	costs	%
MR&R	740404.97	31.2
user costs	119688.33	5.0
initial investment	1379000.00	58.1
planning and design	100000.00	4.2
Dismantle	34623.59	1.5





scenario 3 - low traffic volume and Västerbotten (coast) Region forecast
900
800
700
600
500
400
300
200
100
0
ADT [vehicle/day]
total traffic
cars
trucks
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
2051
2054
2057
2060
2063
2066
2069
2072
2075
2078
2081
2084
2087
year

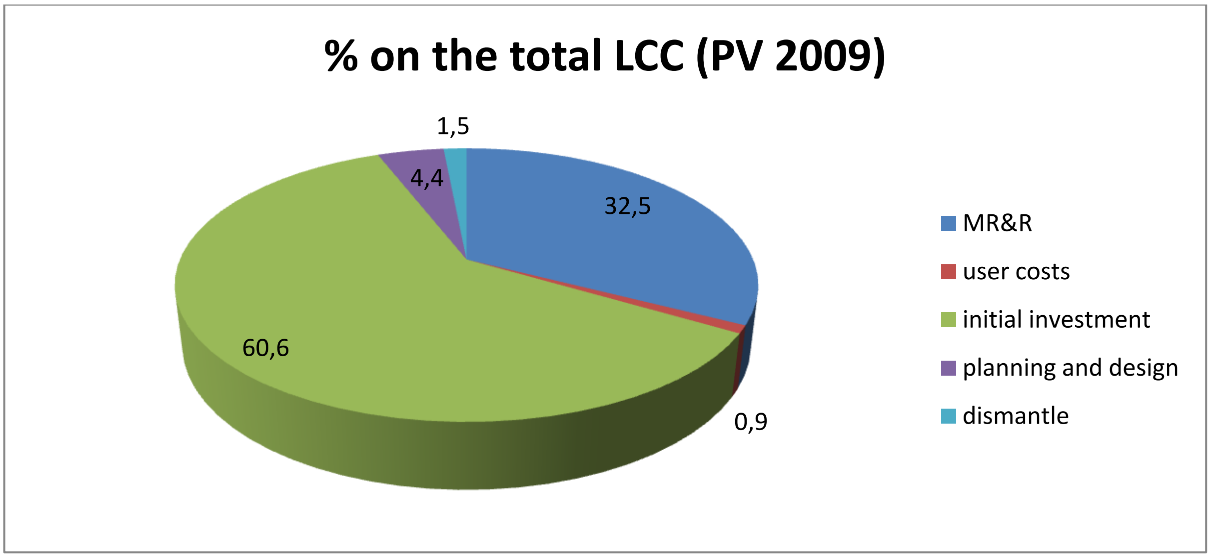


LCCA of SuperCor Bridges
1400000
1200000
1000000
800000
600000
400000
200000
0
expenditure [SEK]
MR&R
user cost
materials&construction
planning&design
dismantle
2009
2019
2029
2039
2049
2059
2069
2079
2089
year

bridges information		economic information	
SuperCor 3		interest rate	0.04
year of construction	2009	inflation rate	0.015
expected service life [years]	80	year update costs	2009
		currency [SEK]	1

	date	cost [SEK]	discount value (Present Value 2009) [sek]	annuity cost [SEK]
initial investment				
planning and design	2009	100000.00	100000.00	402.60
material and construction	2009	1379000.00	1379000.00	5551.92
user costs	2009	2000.00	2000.00	8.05
MR&R				
yearly inspection (3)	yearly	1000.00	34451.82	138.70
periodical maintenance (4)	6 years	20000.00	109502.38	440.86
users cost for yearly op.	service life	3000.00	1133.52	4.56
MR&R cost 1 (1)	2019	10000.00	7840.20	31.56
users cost 1	2019	1000.00	1100.42	4.43
MR&R cost 2 (1)	2029	10000.00	6146.87	24.75
users cost 2	2029	1000.00	1210.93	4.88
MR&R cost 3 (1)	2039	10000.00	4819.27	19.40
users cost 3	2039	0.00	0.00	0.00
MR&R cost 4 (1)	2049	10000.00	3778.40	15.21
users cost 4	2049	0.00	0.00	0.00
MR&R cost 5 (2)	2049	1500000.00	566760.24	2281.80
users cost 5	2049	9000.00	13197.17	53.13
MR&R cost 6 (1)	2059	10000.00	2962.34	11.93
users cost 6	2059	0.00	0.00	0.00
MR&R cost 7 (1)	2069	10000.00	2322.53	9.35
users cost 7	2069	0.00	0.00	0.00
MR&R cost 8 (1)	2079	10000.00	1820.91	7.33
users cost 8	2079	0.00	0.00	0.00
Dismantle				
Dismantle (5)	2089	75000.00	34623.59	139.40
users cost	2089	1000.00	2150.19	8.66
		total LCC	2274820.80	9150.48

% on the total LCC (PV 2009)		
	costs	%
MR&R	740404.97	32.5
user costs	20792.24	0.9
initial investment	1379000.00	60.6
planning and design	100000.00	4.4
Dismantle	34623.59	1.5



APPENDIX B1 – Statistical Analysis Calculations

PV 2009 [SEK]			
n°	***Bridge code***	***Total LCC [SEK]***	***Annuity Cost [SEK]***
1	24-1790-1	8629534	11752
2	24-1861-1	4989279	6777
3	24-1497-1	5204830	12033
4	24-1753-1	9628595	11712
5	24-1876-1	19951560	27170
6	24-417-1	6705193	20371
7	24-471-1	6908271	15971
8	25-1432-1	5528032	12643
9	25-1674-1	8135651	30361
10	25-1888-1	16869118	38999
11	25-780-1	4005242	9260
	SUM	96555305	197049

annuity cost		***total LCC***	
Bridge n°	Deviation from the mean squared	Bridge n°	Deviation from the mean squared
1	37964642	1	21969464841
2	124022645	2	14352550402576
3	34580815	3	12765793055625
4	38459166	4	723928705600
5	85681951	5	124853918178025
6	6039083	6	4295513243844
7	3773483	7	3494970426256
8	27778649	8	10560699576729
9	154939125	9	412297546816
10	444596393	10	65470155197769
11	74883849	11	22776880335169
variation	93883618	Variation	23611697830296
Standard deviation	9689	Standard deviation	4859187
mean	17914	mean	8777755

PV 2009 [SEK]				covariance total LCC - initial investment		
n°	***Bridge Type***	***Initial investment***	***Deviation from the mean squared***	***Deviation from the mean - initial investment***	***Deviation from the mean - total LCC***	***Product deviation from the mean***
1	Beam and Slab Bridge	6787171	1.71557E+12	1309797	-148221	-1.94139E+11
2	Slab Bridge	4201102	1.62887E+12	-1276272	-3788476	4.83513E+12
3	Slab Bridge	3872389	2.57598E+12	-1604985	-3572925	5.73449E+12
4	Slab Bridge	4892634	3.41921E+11	-584740	850840	-4.9752E+11
5	Slab Bridge	9439589	1.56991E+13	3962215	11173805	4.4273E+13
6	Slab Frame Bridge	3063579	5.82641E+12	-2413795	-2072562	5.00274E+12
7	Slab Frame Bridge	5687805	44281129241	210431	-1869484	-3.93397E+11
8	Slab Frame Bridge	3661878	3.29603E+12	-1815496	-3249723	5.89986E+12
9	Slab Frame Bridge	5149139	1.07738E+11	-328235	-642104	2.10761E+11
10	Slab Frame Bridge	11005137	3.05562E+13	5527763	8091363	4.47271E+13
11	Slab Frame Bridge	2490693	8.92026E+12	-2986681	-4772513	1.4254E+13
		variance	6.4284E+12		covariance	1.12593E+13
		standard deviation	2535428.285		pearson's correlation index	0.91389346
		mean	5477374.182			

PV 2009 [SEK]				covariance total LCC - MR&R		
n°	***Bridge Type***	***MR&R***	***Deviation from the mean squared***	***Deviation from the mean – MR&R***	***Deviation from the mean - total LCC***	***Product deviation from the mean***
1	Beam and Slab Bridge	1137440	1.70812E+11	413293.5455	-148221	-61258782601
2	Slab Bridge	498110	51092478783	-226036.4545	-3788476	8.56334E+11
3	Slab Bridge	671110	2812865511	-53036.45455	-3572925	1.89495E+11
4	Slab Bridge	624851	9859587293	-99295.45455	850840	-84484544545
5	Slab Bridge	800880	5888036998	76733.54545	11173805	8.57406E+11
6	Slab Frame Bridge	931728	43090098013	207581.5455	-2072562	-4.30226E+11
7	Slab Frame Bridge	566062	24990694769	-158084.4545	-1869484	2.95536E+11
8	Slab Frame Bridge	784242	3611474583	60095.54545	-3249723	-1.95294E+11
9	Slab Frame Bridge	861204	18784770766	137057.5455	-642104	-88005198167
10	Slab Frame Bridge	639842	7107241056	-84304.45455	8091363	-6.82138E+11
11	Slab Frame Bridge	450142	75078441111	-274004.4545	-4772513	1.30769E+12
		variance	37557022145		covariance	1.78641E+11
		standard deviation	193796.3419		pearson's correlation index	0.189702392
		mean	724146.4545			

PV 2009 [SEK]				covariance total LCC - users cost		
n°	***Bridge Type***	***User costs***	***Deviation from the mean squared***	***Deviation from the mean – user costs***	***Deviation from the mean - total LCC***	***Product deviation from the mean***
1	Beam and Slab Bridge	446316	3.0531E+12	-1747312.273	-148221	2.58988E+11
2	Slab Bridge	28443	4.68803E+12	-2165185.273	-3788476	8.20275E+12
3	Slab Bridge	301823	3.57893E+12	-1891805.273	-3572925	6.75928E+12
4	Slab Bridge	3733373	2.37081E+12	1539744.727	850840	1.31008E+12
5	Slab Bridge	9319372	5.07762E+13	7125743.727	11173805	7.96217E+13
6	Slab Frame Bridge	2220913	744456342.3	27284.72727	-2072562	-56549288926
7	Slab Frame Bridge	115171	4.31998E+12	-2078457.273	-1869484	3.88564E+12
8	Slab Frame Bridge	735164	2.12712E+12	-1458464.273	-3249723	4.7396E+12
9	Slab Frame Bridge	1758818	1.8906E+11	-434810.2727	-642104	2.79193E+11
10	Slab Frame Bridge	4873428	7.18133E+12	2679799.727	8091363	2.16832E+13
11	Slab Frame Bridge	597090	2.54893E+12	-1596538.273	-4772513	7.6195E+12
		variance	7.34857E+12		covariance	1.22094E+13
		standard deviation	2710824.434		pearson's correlation index	0.926892334
		mean	2193628.273			

PV 2009 [SEK]				covariance total LCC - planning and design		
n°	***Bridge Type***	***Planning & design***	***Deviation from the mean squared***	***Deviation from the mean – planning and design***	***Deviation from the mean - total LCC***	***Product deviation from the mean***
1	Beam and Slab Bridge	112357	531315072.8	-23050	-148221	3416534474
2	Slab Bridge	110196	635608272.5	-25211	-3788476	95512301657
3	Slab Bridge	144621	84892770.26	9214	-3572925	-32919956516
4	Slab Bridge	116806	346007347.1	-18601	850840	-15826706887
5	Slab Bridge	108077	746943807.3	-27330	11173805	-3.05383E+11
6	Slab Frame Bridge	165677	916256389.2	30270	-2072562	-62735886496
7	Slab Frame Bridge	153291	319827701.2	17884	-1869484	-33433341997
8	Slab Frame Bridge	168926	1123505078	33519	-3249723	-1.08927E+11
9	Slab Frame Bridge	144621	84892770.26	9214	-642104	-5916171137
10	Slab Frame Bridge	114560	434608780.2	-20847	8091363	-1.68683E+11
11	Slab Frame Bridge	150348	223225331.4	14941	-4772513	-71304815139
		variance	495189392.7		Covariance	-64200055476
		standard deviation	22252.85134		pearson's correlation index	-0.593726083
		mean	135407.2727			

PV 2009 [SEK]				covariance total LCC - dismantle		
n°	***Bridge Type***	***Dismantle***	***Deviation from the mean squared***	***Deviation from the mean – dismantle***	***Deviation from the mean - total LCC***	***Product deviation from the mean***
1	Beam and Slab Bridge	146250	10190553767	-100948.2727	-148221	14962653932
2	Slab Bridge	151427	9172136680	-95771.27273	-3788476	3.62827E+11
3	Slab Bridge	214888	1043953724	-32310.27273	-3572925	1.15442E+11
4	Slab Bridge	260931	188587798.3	13732.72727	850840	11684353673
5	Slab Bridge	283642	1328145258	36443.72727	11173805	4.07215E+11
6	Slab Frame Bridge	323296	5790864096	76097.72727	-2072562	-1.57717E+11
7	Slab Frame Bridge	385937	19248434445	138738.7273	-1869484	-2.5937E+11
8	Slab Frame Bridge	177822	4813067218	-69376.27273	-3249723	2.25454E+11
9	Slab Frame Bridge	221869	641572056.9	-25329.27273	-642104	16264027335
10	Slab Frame Bridge	236151	122042234.7	-11047.27273	8091363	-89387493796
11	Slab Frame Bridge	316968	4867814844	69769.72727	-4772513	-3.32977E+11
		variance	5218833829		Covariance	28581603876
		standard deviation	72241.49659		pearson's correlation index	0.081420966
		mean	247198.2727			

PV 2009 [SEK]				covariance total LCC - service life		
n°	***Bridge Type***	***Service Life [years]***	***Deviation from the mean squared***	***Deviation from the mean – material***	***Deviation from the mean - total LCC***	***Product deviation from the mean***
1	Beam and Slab Bridge	120	238.8429752	15.45454545	-148221	-2290688.182
2	Slab Bridge	120	238.8429752	15.45454545	-3788476	-58549174.55
3	Slab Bridge	100	20.66115702	-4.545454545	-3572925	16240568.18
4	Slab Bridge	120	238.8429752	15.45454545	850840	13149345.45
5	Slab Bridge	120	238.8429752	15.45454545	11173805	172686077.3
6	Slab Frame Bridge	90	211.5702479	-14.54545455	-2072562	30146356.36
7	Slab Frame Bridge	100	20.66115702	-4.545454545	-1869484	8497654.545
8	Slab Frame Bridge	100	20.66115702	-4.545454545	-3249723	14771468.18
9	Slab Frame Bridge	80	602.4793388	-24.54545455	-642104	15760734.55
10	Slab Frame Bridge	100	20.66115702	-4.545454545	8091363	-36778922.73
11	Slab Frame Bridge	100	20.66115702	-4.545454545	-4772513	21693240.91
		variance	170.2479339		covariance	17756969.09
		standard deviation	13.04790918		pearson's correlation index	0.280068526
		mean	104.5454545			

PV 2009 [SEK]				covariance annuity cost - initial investment		
n°	***Bridge Type***	***Initial investment***	***Deviation from the mean, squared***	***Deviation from the mean - initial investment***	***Deviation from the mean - annuity cost***	***Product deviation from the mean***
1	Beam and Slab Bridge	6787171	1.71557E+12	1309797	-6162	-8070372631
2	Slab Bridge	4201102	1.62887E+12	-1276272	-11137	14213263165
3	Slab Bridge	3872389	2.57598E+12	-1604985	-5881	9438188316
4	Slab Bridge	4892634	3.41921E+11	-584740	-6202	3626292817
5	Slab Bridge	9439589	1.56991E+13	3962215	9256	36676061364
6	Slab Frame Bridge	3063579	5.82641E+12	-2413795	2457	-5931791941
7	Slab Frame Bridge	5687805	44281129241	210431	-1943	-408771429.4
8	Slab Frame Bridge	3661878	3.29603E+12	-1815496	-5271	9568655149
9	Slab Frame Bridge	5149139	1.07738E+11	-328235	12447	-4085692506
10	Slab Frame Bridge	11005137	3.05562E+13	5527763	21085	1.16555E+11
11	Slab Frame Bridge	2490693	8.92026E+12	-2986681	-8654	25845381365
		variance	6.4284E+12		covariance	17947873210
		standard deviation	2535428.285		pearson's correlation index	0.730578273
		mean	5477374.182			

PV 2009 [SEK]				covariance annuity cost - MR&R		
n°	***Bridge Type***	***MR&R***	***Deviation from the mean, squared***	***Deviation from the mean - MR&R***	***Deviation from the mean - annuity cost***	***Product deviation from the mean***
1	Beam and Slab Bridge	1137440	1.70812E+11	413294	-6162	-2546526966
2	Slab Bridge	498110	51092478783	-226036	-11137	2517265250
3	Slab Bridge	671110	2812865511	-53036	-5881	311883281.7
4	Slab Bridge	624851	9859587293	-99295	-6202	615785274.8
5	Slab Bridge	800880	5888036998	76734	9256	710280575.6
6	Slab Frame Bridge	931728	43090098013	207582	2457	510122212.4
7	Slab Frame Bridge	566062	24990694769	-158084	-1943	307086238.6
8	Slab Frame Bridge	784242	3611474583	60096	-5271	-316736303.9
9	Slab Frame Bridge	861204	18784770766	137058	12447	1706017567
10	Slab Frame Bridge	639842	7107241056	-84304	21085	-1777597744
11	Slab Frame Bridge	450142	75078441111	-274004	-8654	2371110002
		variance	37557022145		Covariance	400789944.4
		standard deviation	193796.3419		pearson's correlation index	0.213440256
		mean	724146.4545			

PV 2009 [SEK]				covariance annuity cost - users cost		
n°	***Bridge Type***	***User costs***	***Deviation from the mean, squared***	***Deviation from the mean -users cost***	***Deviation from the mean - annuity cost***	***Product deviation from the mean***
1	Beam and Slab Bridge	446316	3.0531E+12	-1747312	-6162	10766143992
2	Slab Bridge	28443	4.68803E+12	-2165185	-11137	24112684207
3	Slab Bridge	301823	3.57893E+12	-1891805	-5881	11124846897
4	Slab Bridge	3733373	2.37081E+12	1539745	-6202	-9548796915
5	Slab Bridge	9319372	5.07762E+13	7125744	9256	65959122914
6	Slab Frame Bridge	2220913	744456342.3	27285	2457	67050977.06
7	Slab Frame Bridge	115171	4.31998E+12	-2078457	-1943	4037497728
8	Slab Frame Bridge	735164	2.12712E+12	-1458464	-5271	7686902243
9	Slab Frame Bridge	1758818	1.8906E+11	-434810	12447	-5412281106
10	Slab Frame Bridge	4873428	7.18133E+12	2679800	21085	56504795340
11	Slab Frame Bridge	597090	2.54893E+12	-1596538	-8654	13815716513
		variance	7.34857E+12		Covariance	16283062072
		standard deviation	2710824.434		pearson's correlation index	0.619925895
		mean	2193628.273			

PV 2009 [SEK]				covariance annuity cost - planning and design		
n°	***Bridge Type***	***Planning & design***	***Deviation from the mean, squared***	***Deviation from the mean - planning and design***	***Deviation from the mean - annuity cost***	***Product deviation from the mean***
1	Beam and Slab Bridge	112357	531315072.8	-23050	-6162	142025303.1
2	Slab Bridge	110196	635608272.5	-25211	-11137	280766484.7
3	Slab Bridge	144621	84892770.26	9214	-5881	-54181742.03
4	Slab Bridge	116806	346007347.1	-18601	-6202	115356638.3
5	Slab Bridge	108077	746943807.3	-27330	9256	-252981427.2
6	Slab Frame Bridge	165677	916256389.2	30270	2457	74386478.88
7	Slab Frame Bridge	153291	319827701.2	17884	-1943	-34739953.12
8	Slab Frame Bridge	168926	1123505078	33519	-5271	-176661975.7
9	Slab Frame Bridge	144621	84892770.26	9214	12447	114687451.4
10	Slab Frame Bridge	114560	434608780.2	-20847	21085	-439574221.5
11	Slab Frame Bridge	150348	223225331.4	14941	-8654	-129290262.6
		variance	495189392.7		covariance	-32746111.42
		standard deviation	22252.85134		pearson's correlation index	-0.151872506
		mean	135407.2727			

PV 2009 [SEK]				covariance annuity cost - dismantle		
n°	***Bridge Type***	***Dismantle***	***Deviation from the mean, squared***	***Deviation from the mean - dismantle***	***Deviation from the eman - annuity cost***	***Product deviation from the mean***
1	Beam and Slab Bridge	146250	10190553767	-100948	-6162	621997371
2	Slab Bridge	151427	9172136680	-95771	-11137	1066561132
3	Slab Bridge	214888	1043953724	-32310	-5881	190002027.4
4	Slab Bridge	260931	188587798.3	13733	-6202	-85164132.4
5	Slab Bridge	283642	1328145258	36444	9256	337339705
6	Slab Frame Bridge	323296	5790864096	76098	2457	187006705.8
7	Slab Frame Bridge	385937	19248434445	138739	-1943	-269506284
8	Slab Frame Bridge	177822	4813067218	-69376	-5271	365650798.9
9	Slab Frame Bridge	221869	641572056.9	-25329	12447	-315284970.9
10	Slab Frame Bridge	236151	122042234.7	-11047	21085	-232936766.9
11	Slab Frame Bridge	316968	4867814844	69770	-8654	-603755506.3
		variance	5218833829		covariance	114719098.1
		standard deviation	72241.49659		pearson's correlation index	0.163890613
		mean	247198.2727			

PV 2009 [SEK]				covariance annuity cost - service life		
n°	***Bridge Type***	***Service Life [years]***	***Deviation from the mean, squared***	***Deviation from the mean - service life***	***Deviation from the mean - total LCC***	***Product deviation from the mean***
1	Beam and Slab Bridge	120	238.8429752	15	-6162	-95223.8843
2	Slab Bridge	120	238.8429752	15	-11137	-172110.2479
3	Slab Bridge	100	20.66115702	-5	-5881	26729.75207
4	Slab Bridge	120	238.8429752	15	-6202	-95842.06612
5	Slab Bridge	120	238.8429752	15	9256	143054.2975
6	Slab Frame Bridge	90	211.5702479	-15	2457	-35744.79339
7	Slab Frame Bridge	100	20.66115702	-5	-1943	8829.752066
8	Slab Frame Bridge	100	20.66115702	-5	-5271	23957.02479
9	Slab Frame Bridge	80	602.4793388	-25	12447	-305528.4298
10	Slab Frame Bridge	100	20.66115702	-5	21085	-95842.97521
11	Slab Frame Bridge	100	20.66115702	-5	-8654	39334.29752
		variance	170.2479339		covariance	-50762.47934
		standard deviation	13.04790918		pearson's correlation index	-0.401519823
		mean	104.5454545			

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- *Load and Resistance Assessment of Railway Bridges* (SB-LRA), 428 pp;
- *Guideline for Monitoring of Railway Bridges* (SB-MON), 93 pp; and
- *Guide for use of Repair and Strengthening Methods for Railway Bridges (*SB-STR), 139 pp.