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Improved Road Design for Future Maintenance – Analysis of Road Barrier Repair Costs

HAWZHEEN KARIM

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Preface

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The steering committee that was formed for this project included the following members:

Anders Wengelin	SRA
Bengt Holm	SRA
Björn Granqvist	Skanska Roads
Bo Skogwik	SRA
Hans Cedermark	SRA
Håkan Westerlund	CDU
Jan Moberg	SRA
Jan-Erik Elg	SRA
Karin Renström	SRA
Lars Fridh	SRA
Rolf Magnusson	Dalarna University
Rolf Svahn	SRA
Ulf Isacsson	KTH

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Abstract

The cost of a road construction over its service life is a function of the design, quality of construction, maintenance strategies and maintenance operations. Unfortunately, designers often neglect a very important aspect which is the possibility to perform future maintenance activities. The focus is mainly on other aspects such as investment costs, traffic safety, aesthetic appearance, regional development and environmental effects.

This licentiate thesis is a part of a Ph.D. project entitled "Road Design for lower maintenance costs" that aims to examine how the life-cycle costs can be optimized by selection of appropriate geometrical designs for the roads and their components. The result is expected to give a basis for a new method used in the road planning and design process using life-cycle cost analysis with particular emphasis on road maintenance.

The project started with a review of literature with the intention to study conditions causing increased needs for road maintenance, the efforts made by the road authorities to satisfy those needs and the improvement potential by consideration of maintenance aspects during planning and design.

An investigation was carried out to identify the problems which obstruct due consideration of maintenance aspects during the road planning and design process. This investigation focused mainly on the road planning and design process at the Swedish Road Administration. However, the road planning and design process in Denmark, Finland and Norway were also roughly evaluated to gain a broader knowledge about the research subject. The investigation was carried out in two phases: data collection and data analysis. Data was collected by semi-structured interviews with expert actors involved in planning, design and maintenance and by a review of design-related documents. Data analyses were carried out using a method called “Change Analysis”. This investigation revealed a complex combination of problems which result in inadequate consideration of maintenance aspects. Several urgent needs for changes to eliminate these problems were identified.

Another study was carried out to develop a model for calculation of the repair costs for damages of different road barrier types and to analyse how factors such as road type, speed limits, barrier types, barrier placement, type of road section, alignment and seasonal effects affect the barrier damages and the associated repair costs. This study was carried out using a method called the “Case Study Research Method”. Data was collected from 1087 barrier repairs in two regional offices of the Swedish Road Administration, the Central Region and the Western Region. A table was established for both regions containing the repair cost per vehicle kilometre for different combinations of barrier types, road types and speed limits. This table can be used by the designers in the calculation of the life-cycle costs for different road barrier types.

Keywords: highway maintenance, highway management, highway design, road planning, road design, highway engineering, road barrier, cable barrier, w-beam barrier, road barrier damages, barrier repair cost.

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SUMMARY

Introduction

The cost of a road construction over its service life is a function of its design, quality of construction, maintenance strategies and maintenance operations. An optimal life-cycle cost for a road construction requires estimations of the above mentioned components. Unfortunately, designers often neglect a very important aspect which is the possibility to perform future maintenance activities. The focus is mostly on other aspects such as investment costs, traffic safety, aesthetic appearance, regional development and environmental effects.

As the funding sources for road infrastructures are becoming less and less sufficient to insure implementations of new projects and maintenance of the existing roads, road authorities around the world are forced to increase the efficiency and reduce the costs (Parche 2007). Because of this, road authorities are continuously trying to increase the efficiency of road maintenance and reduce the related costs, as maintenance costs constitute a large share of the annual road infrastructure expenditures. Unfortunately, many of those efforts have resulted in reduced road maintenance standards. The focus has mainly been on the improvement of operating practises and maintenance procedures without consideration of the improvement potentials in the road planning and design process.

Objective

This licentiate thesis is a part of a Ph.D. project that aims to examine how the life-cycle costs can be optimized by selection of appropriate geometrical designs for the roads and their components. The result is expected to give a basis for a new method for the road planning and design process using life-cycle cost analysis with particular emphasis on road maintenance.

Scope of the study

The research focused on the planning and design processes at the Swedish Road Administration, SRA, which is in charge of both country and urban roads in Sweden. The SRA is also responsible for Swedish road planning and design specifications as well as maintenance specifications. Another reason for this delimitation is that the SRA is the initiator for this research. This means that the results of this research should be valid for Nordic construction traditions, design and climate. However, most of the results may also be applicable for road planning and design outside the Nordic countries.

The research is mainly limited to the geometrical design of paved roads within the planning and design process. The structural design of the roads is not included as this subject has already been included in several other research studies. These previous studies focused mainly on identifying the pavement type and thickness which gives an optimal life-cycle cost.

Problems taking maintenance aspects into account when designing roads

An investigation was carried out with the intention of identifying problems which prevent sufficient consideration of maintenance aspects. The purpose of this investigation was to

- Identify the problems obstructing due consideration of maintenance aspects during the road planning and design process.
- Identify the urgent needs for changes to eliminate these problems. This was done by analysing the problems, the planning and design activities and the goals which govern these activities. Measures to implement the identified changes were not included in this investigation.

The investigation focused mainly on the road planning and design process at the Swedish Road Administration, SRA. However, the road planning and design process in Denmark, Finland, and Norway were also roughly evaluated to gain a broader knowledge of the research subject.

Method

The investigation was carried out in two stages: Data collection and data analysis. Data was collected using interviews and by a review of planning and design related documents. The main objective of the interviews was to invent situations perceived as problems by the actors involved in maintenance activities or in the road planning and design process. The respondents were divided into four categories: consultants, maintenance contractors, persons involved in maintenance activities and in planning and design at the SRA.

The second part of the data collection was the review of documents which describe the processes of planning and design, construction and consignment (Vägverket 2004a, 2004b, 2004g, 2004f, 2004h, 2004i). Other reviewed documents were guidelines for road planning and design (Vägverket 2004c) and documents which describe the purchasing process (Vägverket 2004d). These documents were examined to identify planning and design activities, and the goals which govern the activities.

The method used for data analysis in this investigation is called “Change analysis” and is mostly used in the preliminary phases of investigations to develop organisations or activities. The method can be used for development of products/services, economical steering principles, employees, administrative working routines or data systems (Goldkuhl and Röstlinger 1998).

According to “Change analysis”, the collected data was analysed in four steps: analysis of problems, analysis of activities, analysis of goals and analysis of needs for change. The aim of the problem analysis was to obtain an overview of the situations identified as problems and to describe their causes and consequences. The analysis was carried out in four steps: formulation of problems, classification of problems, delimitation of problem areas, and analysis of the relations between the problems.

The aim of the activities analysis was to evaluate the activities included in the planning and design process in order to understand how the process was conducted and to identify problems not mentioned by the respondents. This was done by describing action patterns within each subprocess and by clarifying how different documents were treated and how administration activities were performed within the processes.

Analysis of goals aimed to identify the goals which the planning and design process has to fulfil, and to examine and evaluate correlations between them. This analysis was carried out in three steps: identification of goals, analysis of the relationship between goals and evaluation of goals.

The analysis of the needs for change was aimed at identifying the most urgent needs for change which are necessary for sufficient consideration of maintenance aspects in the road planning and design process. The needs were identified in order to find measures that satisfy those needs. Earlier analyses of problems, activities and goals constituted the basis for this analysis which was conducted in three steps: evaluation of the problems, analysis of possibilities and strengths, and formulation of the needs for change.

Results

During the interviews more than 100 situations, perceived as problems for sufficient consideration of maintenance aspects, were presented by the respondents. The analyses reduced that number to 46. Most of the problems were identified during the interviews. A few more were identified during the analysis phases. These problems are presented in the "Problem list" shown in appendix 1. The identified problems were classified into six different problem areas: insufficient consulting, insufficient knowledge, regulations without consideration of maintenance aspects, insufficient planning and design activities, inadequate organisation and demands from other authorities. The problem areas are presented in the "Problem-area document" shown in appendix 2. A structure in the form of graphs called "problem graphs" was established for the problems within each problem area (appendix 3). These graphs constituted an important basis for later evaluation of the problems and elaboration of the proposals considering the needs for changes.

On the basis of the analysis of problems, activities and goals the following needs for changes have been identified to eliminate insufficient consideration of maintenance aspects during the planning and design process:

- An urgent need for the establishment of well-defined long-term goals for maintenance, and methods to evaluate the fulfilment of these goals.
- Development of well-structured systems for experience exchange and consulting among actors involved in maintenance activities and in the planning and design process.
- Increased knowledge regarding road maintenance among actors involved in planning and design.
- Development of a systematic evaluation process with clear guidelines for examination of completed road projects to ensure adequate consideration of maintenance as a part of a quality assurance system.
- Addition of maintenance aspects in the planning and design related guidelines, regulations and other documents.
- Creation of guidelines and requirements for future maintenance considerations, which should be incorporated into procurement of requests for quotations and other purchasing related documents.

- Creation of incentives for consultants to consider maintenance aspects during the planning and design process to a sufficient extent.

A case study for analysis of road barrier repair costs

The majority of maintenance costs for road barriers are due to repairs of barrier damages caused by vehicle impacts. The number of repairs and the repair costs of barrier damages depend upon a number of factors including speed limit, traffic volume, road alignment, seasonal effects, barrier strength and the distance between the edge of the traffic lane and the barrier itself. According to road designers, limited data related to the maintenance costs of barrier repairs and the factors influencing these costs is the major obstacle preventing the total cost for barriers over their service life being taken into consideration during the road design phases. In addition, effects of the factors mentioned above are still unclear because so far research in this field has been very limited. For the designers, taking into consideration all the effects of all the factors during the selection of a barrier type is an almost impossible task in absence of a calculation model for repair costs which takes these factors into consideration. Therefore, the designers often assume that maintenance costs for all types of road barriers are the same and they mainly focus on performance requirements, initial costs and aesthetic aspects.

The purpose of this case study was to:

- Develop a model for calculation of annual repair costs for damages of different road barrier types.
- Analyse how factors such as road types, speed limits, road barrier types, road barrier placements, road section types, road alignments and seasonal effects affect the barrier damages and the related repair costs.

The road barrier types which were considered in this case study were cable barriers, w-beam barriers, Kohlswa-beam barriers and pipe-beam barriers. However, the analyses mainly focused on cable barriers and w-beam barriers as they are the most common barrier types in Sweden. Data collection regarding repair costs was limited to 1087 barrier repairs in two regional offices at the Swedish Road Administration. The investigation of the costs focused on costs for both roadside and median barriers but the model for calculation of the annual repair cost was established only for the median barriers due to limited availability of data for roadside barriers. Socio-economical costs were excluded in this case study. Nevertheless, some consideration was given to costs for vehicle damages due to collisions with road barriers. The study was limited to four road types: Motorway (MW), four-lane cross-section (4-Lane), collision-free arterial roads and collision-free country roads.

Method

Analysis was based on data collected from 402 barrier repairs carried out in the Central Region and 685 barrier repairs in the Western Region. The data sources were a mix of archived documents and contemporary information taken from several databases and interviews with involved actors.

The case study was the most significant research strategy for this study as it has the ability to deal with a full variety of evidence such as documents, archival records, interviews and observations. A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context especially when the boundaries between the phenomenon and the context are not clearly evident. The case study copes with the technically distinctive situation in which there will be many more variables of interest than data points (Yin 2003).

The design of a case study consists of defining the research question, formulation of the proposition, and selection of the unit of analysis and the logic of linking the data to the proposition (Yin 2003). As mentioned before, the research question for this case study was “how do factors such as road type, speed limit and road barrier type affect the repair cost of damaged road barriers?" The propositions were defined in the very beginning of this study in order to identify the necessary type of data to collect. Identification of the propositions was based on experiences of experts in the SRA and the information collected from the interviews conducted during the change analysis. The propositions were:

- The number of barrier damage repairs and the associated costs are higher along roads with speed limits of 110 km/hr than on roads with speed limits of 70 km/hr or 90 km/hr.
- The number of barrier repairs and the associated costs are higher along collision-free roads than on other road types.
- The number of barrier repairs and the associated costs are higher for cable barriers than for w-beam barriers.
- Cable barriers are the most profitable type of barrier for road authorities.
- The number of barrier damage repairs and the associated costs are higher during winter than during summer.
- The number of barrier repairs and the associated costs are inversely proportional to the distances between the barriers and edges of traffic lanes.
- The number of barrier repairs and the associated costs are higher for barriers installed along curves than for barriers installed along straight road sections.
- On collision-free roads, the number of barrier repairs is higher on lane shifts than on the single-lane sections and double- lane directions.

The most suitable units for analyses were the regional offices as the information about the barrier repairs within each region were archived separately. The type of case study selected for this research study was the multiple-case study consisting of two single-case studies, one for each of the two regional offices. As an appropriate logic to link the data to the propositions the pattern matching logic was used (Trochim 1989). The empirically based data pattern was linked to the propositions, which were the predicted based patterns. The findings from both single-case studies were compared to each other to see if they predict the same results or not. If the findings coincided, they were considered to be an actual empirical based pattern. Later, such findings were compared to the propositions to confirm or reject the propositions.

The necessary data for this case study was collected from the following sources: repair invoices for barrier damages, The Swedish National Road Database (NVDB)-Information about roads, insurance companies and interviews with experts. To analyse the influence of the studied factors on barrier repairs and the associated costs the following data regarding barrier repairs were collected:

- The reported date of the damage.
- The road number and location of the barrier damage.
- The road barrier type where the damage occurred.
- Barrier position, i.e. roadside barrier or median barrier.
- The position of the barrier damage, on a straight road section or in a curve.
- The distance between the road barrier and the edge of the traffic lane.
- The road section type where the damage occurred.
- The speed limit where the damage occurred.
- The position of the damage in relation to double-lane or single-lane sections or lane shifts.
- The total repair cost for the damage and the different cost items.
- The SRA’s actual costs for the barrier repairs.
- The number of replaced posts per barrier repair.
- The names of the insurance companies and the repair compensation for the vehicle damage.

Collection of data necessary for calculation of traffic work

For calculation of the traffic works the following data were collected:

- The types of median barriers along the studied roads.

- The road types and speed limits along the studied roads.
- The annual average daily traffic on the links.
- The traffic increase factors for the links.
- The length of the links.

Calculation and analyses

Barrier repair cost per vehicle kilometre (vkm) was used as a measure for comparing the influence of different factors such as road type, barrier type and speed limit, on barrier repairs and the associated costs.

In this case study, the following analyses were carried out:

- Analysis of the effects of speed limits on barrier repairs.
- Analysis of the effects of road types on barrier repairs.
- Analysis of the effects of barrier type on barrier repairs.
- Analyses of seasonal effects on barrier repairs.
- Analyses of the effects of barrier placement on barrier repairs.
- Analyses of the effects of road alignment on barrier repairs.
- Analyses of the effects of cross section types on barrier repairs.

Results and discussion

Analysis of the effects of speed limits on barrier repairs

According to the results, the repair costs per vkm for median barriers are generally lower along roads with speed limits of 110 km/hr than along roads with speed limits of 90 or 70 km/hr. This difference generally occurs because the number of repairs per vkm is lower along roads with speed limits of 110 km/hr than along roads with speed limits of 70 km/hr or 90 km/hr. A possible explanation for this phenomenon is that roads with 110 km/hr speed limits have a better geometrical design standard and better traffic safety properties than roads with speed limits of 90 km/hr or 70 km/hr. These factors probably contribute to a lower risk for damage along roads with a speed limit of 110 km/hr. Another factor probably contributing to a higher risk for damages of median barriers on roads with speed limits of 70 km/hr or 90 km/hr is that these kinds of roads are usually located within urban regions with a high traffic density and many connecting roads, with a higher accident risk as a consequence

Analysis of the effects of road types on barrier repairs

The results show that the repair costs per vkm and the number of repairs per vkm for barriers along collision-free roads are higher than for barriers along motorways and 4-lanes roads in both regions, even though the average cost per repair is almost the same for all barrier types. An explanation for these differences is that road barriers along collision-free roads are more exposed to damage because the distance between the barriers and the edge of the traffic lanes, according to Swedish specifications, is between 0.65 to 1.1 m compared to 1.75 m along normal standard motorways and 4-lane roads. Another explanation for the difference in repair costs per vkm is that the geometrical standard for motorways is higher than for collision-free roads.

Another explanation for the high number of repairs per vehicle per kilometre on collision-free roads is that these types of roads are mainly equipped with cable barriers. Cable barriers have to be repaired even after minor damages as the barriers are weaker than w-beam or Kohlswa-beam barriers.

Analysis of the effects of barrier type on barrier repairs

The repair cost per vkm for cable barriers is three times higher than for w-beam barriers, even though the average cost per repair for both types are almost the same. The weaker construction of cable barriers can be the major factor which contributes to a higher number of repairs per vkm for this type of barrier. Due to its weak construction, cable barriers lose all efficiency even after minor impacts and must be repaired. On the other hand, w-beam barriers retain some degree of efficacy after minor impacts due to the rigidity of their elements. Consequently, w-beam barriers are often not repaired after minor impacts.

The results also show that the average vehicle repair compensation from insurance companies due to impacts with w-beam barriers is higher than the average repair compensation due to impacts with cable barriers. This indicates that vehicle damages caused by w-beam barriers are greater than vehicle damages caused by cable barriers. This difference may occur because the w-beam barrier has a stronger construction and the impact surface is concentrated to a limited area. The combination of these two factors result in a strong redirecting force concentrated to a small area. This might lead to critical damage in the vehicle's main structure even if the surface damage is small. On the contrary, vehicle damage due to an impact with a cable barrier is mostly surface damage which is cheaper to repair than damage to the basic structure of the vehicle. Unfortunately, the data used in the analysis of vehicle repair compensations was uncertain, making reliable conclusions impossible.

Analyses of seasonal effects on barrier repairs

The number of repairs conducted during winter is higher than during summer in the Central Region. This result can be explained by bad road conditions and higher risks for collisions during the winter season. However the differences are very small and are less interesting as the number of barrier repairs can not be correlated to seasonal traffic works.

The results also show that to some extent the average cost per repair is higher during summer than during winter in both regions. This indicates that barrier damages are more extensive at collisions during summer than during winter.

The result of this analysis has to be interpreted carefully as the underlying data was to some extent uncertain due to the following factors:

- The repair costs per vkm and the number of repairs per vkm for the different seasons were not possible to calculate as the traffic works for the different seasons were not available. Therefore the effect of the traffic could not be neutralised.
- In many cases the damages occurred during the winter but the repairs were conducted during the summer or vice versa.
- It was also difficult to clarify the repair date because it was often not specified in the invoice. For those types of damages, it was assumed that the damages and repairs occurred during the same season. This assumption was based on the fact that barrier damages must be repaired within three weeks after the date of the reported damage.

Analyses of the effects of barrier placement on barrier repairs

The results show that the number of repairs of barriers placed 0.5-2 m from the traffic lane edges is higher than the number of repairs of barriers placed farther than 2 m from the traffic lane edges. The common assumption within the SRA is that most of the barriers in both regions are installed within 0.5-2 m from the edges of traffic lanes. This can be an explanation for the high proportion of damage to barriers placed 0.5-2 m from the edges of traffic lanes. In addition, these types of barriers are more exposed to damage caused by snow removal equipment. However, it is notable that damages of this kind were not found among the 1084 studied damage reports. An explanation for this can be that damage caused by snow removal equipment is concealed by maintenance contractors to avoid economical consequences.

The results also show that the average cost per repair for barriers installed farther away than two metres from the traffic lane edges to some extent is higher than the average cost per repair for barriers installed 0.5-2 m from the traffic lane edges. These differences might be due to greater impact angles for barriers placed further from the lane edges. However, the difference is marginal. The common supposition is that damages should be less serious for barriers farther away from the lane edges.

The results of this analysis should be interpreted very carefully as the number of repairs is not correlated to the traffic work. Unfortunately, calculation of the traffic work was not possible as the lengths of the barriers with a different placement are unknown in the studied regions. However, the analysis of the effect of road type indicates that the number of repairs per vkm and the repair costs per vkm for barriers along roads with wide medians are lower than for barriers along roads with narrow medians.

Analyses of the effects of road alignment on barrier repairs

The results show that most of the damages occurred on straight road sections in both regions. This is reasonable as straight road sections in both regions probably constitute a higher proportion of the road net compared to curved sections. Still, the results are less interesting as the number of barrier repairs is not correlated to the traffic work. Calculation of the traffic work was not possible as the exact lengths of the straight road sections and curves are unknown in the studied regions. However, the analysis of the effect of road types indicates that roads with high geometrical design standards, i.e. roads with smooth alignment, contributes to a lower number of repairs per vkm and low repair costs per vkm compared to roads with lower geometrical design standards.

Analyses of the effects of cross section types on barrier repairs

The results show that the number of barrier repairs along double-lane cross section directions is higher than along single-lane cross section directions, despite wider roadways along double-lane cross sections. An explanation for this might be that overtake manoeuvres are only possible along the double-lane cross section directions. In many cases the drivers try to overtake as fast as possible to avoid the lane shifts ahead. Under this pressure the risk for accidents and collisions with barriers increases. The drivers might feel that overtake manoeuvres on double-lane cross sections are complicated and the overtaken vehicles are considered to be more dangerous than road barriers. Therefore, the drivers often try to drive closer to the barrier than to the overtaken vehicles.

Contrary to the common opinion, the results also show that the number of repairs conducted on lane shifts is much lower than the number of repairs conducted on double-lane or single-lane cross section directions. An explanation for this could be that drivers are getting increasingly accustomed to driving on collision-free roads and are more aware of the accident risks while overtaking near lane shifts. Another explanation may be that the length of the lane shift sections constitutes approximately 30% of the total length of collision-free roads.

The results should be interpreted carefully as they are based on a limited number of repairs in both regions. The information about the precise location of the damages was often missing in the repair invoices. In addition, the results can not give a realistic picture about the effect of the road section on barrier repairs as the repairs are not correlated to the traffic work. Calculations of the traffic works were not possible since the lengths of the roads with the different cross sections are unknown.

Comparison of the repair costs between the studied regions

The results show that the repair costs per vkm for barrier damages for almost all the barriers types, regardless of road types and speed limits, are higher in the Central Region than in the Western Region. The underlying factors for this difference are:

- Tender prices in the Central Region are higher than in the Western Region.
- The majority of the roads in the Central Region are collision-free roads. The repair costs per vkm for barriers installed along collision-free roads are higher than for barriers installed along motorways or 4-lane roads.

- The frequent use of cable barriers in the Central Region. The repair cost per vkm for cable barrier is three times higher than for w-beam barriers.
- The number of repairs per vkm in the Central Region is higher than in the Western Region as the climate in the Central Region is distinguished by long, cold, and snowy winters with slippery road conditions as a consequence.

Concluding summary

The most important findings from this research project are:

- Road authorities have made a lot of effort to increase maintenance efficiency, focusing mainly on improving operating practises and maintenance activities. However, the improvement potentials in the planning and design process have been neglected. Some efforts are purely cost savings, as the main focus has been on reduction of the frequency of maintenance activities rather than on streamlining these activities. As a result, some of their efforts have, to some extent, depreciated the maintenance standard.
- Sufficient consideration of maintenance aspects during the planning and design process requires development of efficient models for analyses of life-cycle costs, including maintenance costs. However, existing models have been created according to requirements for specific road projects and have seldom been developed and used after that. Several models have been developed for selection of the most favourable pavement types and the related maintenance strategies. No models for calculation of life-cycle costs for road barriers, traffic signs and road geometry have been found. The maintenance costs used in the models are often unrealistic and roughly calculated.
- Although insufficient consideration of maintenance aspects during the road planning and design process is a well-known issue, the underlying causes

and consequences have, up to now, not been sufficiently studied and therefore improvements still remain to be made. The limited amount of literature pertaining to this subject confirms this fact.

- This research study has revealed a complex combination of problems which result in an insufficient consideration of maintenance aspects during the road planning and design process, se appendix 1. The identified problems can be divided into six problem areas: insufficient consulting, insufficient knowledge, regulations without consideration of maintenance aspects, insufficient planning and design activities, inadequate organisation, and demands from other authorities. The problem areas are closely linked to each other. None of the problem areas can be completely eliminated separately from the other areas. On the other hand, the elimination of a problem in one problem area can also contribute to the elimination of problems in other areas.
- To eliminate the problem of insufficient consideration of maintenance aspects during the planning and design process, the following needs for change have been identified:
    - An urgent need for the establishment of well-defined long-term goals for maintenance and methods to evaluate the fulfilment of these goals.
    - Development of well-structured systems for experience exchange and consulting among actors involved in maintenance activities and in the planning and design process.
    - Increased knowledge regarding road maintenance among actors involved in the planning and design process.
    - Development of a systematic evaluation process with clear guidelines for the examination of completed road projects to ensure adequate consideration of maintenance as a part of a quality assurance system.

  - Incorporation of maintenance aspects in the planning and design related guidelines, regulations and other documents.
  - Creation of guidelines and requirements for future maintenance considerations, which should be incorporated into requests for quotations and other purchasing related documents.
  - Creation of incentives for consultants to consider maintenance aspects during the planning and design process to a sufficient extent.
- Barrier repair costs per vkm and number of barrier repairs per vkm along roads with speed limits of 110 km/hr are lower than along roads with speed limits of 70 km/hr or 90 km/hr.
- The number of barrier repairs per vkm and repair costs per vkm for cable barriers are higher than for w-beam barriers.
- The number of barrier repairs per vkm and barrier repair costs per vkm for barriers installed along collision-free roads is higher than for barriers installed along motorways or 4-lane roads.
- It is not clear how the number of barrier repairs and the associated costs are influenced by seasonal effects. However, the analyses show that barrier damages are more extensive during summer than during winter.
- The number of repairs per vkm and the repair costs per vkm for barriers installed along roads with wide medians are lower than for barriers installed along roads with narrow medians.
- Roads with high geometrical design standards, i.e. roads with smooth alignments and wider road median and verge, contributes to a lower number of repairs per vkm and lower repair costs per vkm compared to roads with low geometrical design standard.
- The number of barrier repairs per vkm and barrier repair costs per vkm are higher in the Central Region than in the Western Region due to:

- High number of barrier repairs per vkm in the Central Region due to a colder climate distinguished by long, cold, and snowy winters with slippery road conditions as a consequence.
- High maintenance tender prices in the Central Region.
- Frequent use of cable barriers in the Central Region.

Sammanfattning

Introduktion

Kostnaden för en vägkonstruktion under dess livslängd beror på utformningen, kvaliteten av konstruktionen och drift- och underhållsstrategin. En optimal livscykelkostnad för en vägkonstruktion kräver att hänsyn tas till ovan nämnda faktorer. Tyvärr försummar projektörerna ofta vid utformningen av vägen att beakta behoven av att kunna utföra framtida underhållsåtgärder. Fokus ligger ofta på andra aspekter som investeringskostnader, trafiksäkerhet, estetik, regional utveckling och miljö. Detta leder ofta till svårigheter att utföra nödvändiga underhållsåtgärder. Försumning av drift- och underhållsaspekter under planerings- och projekteringsskeden leder också till onödiga drift- och underhållsåtgärder med höga kostnader som följd.

Eftersom resurserna till nya investeringar och väghållning är begränsade försöker väghållarna ständigt förbättra effektiviteten och minska kostnaderna. På grund av denna kostnadsjakt, har en del av dessa försök lett till försämrad kvalitet för drift och underhåll. Detta eftersom fokus främst har varit på att minska antalet utförda drift- och underhållsåtgärder istället för att utforma vägar så att drift och underhåll underlättas.

Syfte

Denna licentiatavhandling är en del av ett doktorandprojekt som syftar till att undersöka hur vägarnas livscykelkostnad kan optimeras genom val av lämplig utformning av vägarna och deras komponenter. Resultatet förväntas att leda till en ny metod för planering och projektering av vägar genom användning av livscykelkostnadsanalyser med särskilt perspektiv på drift- och underhållskostnader.

Den försköning som presenteras i denna skrift består av två delprojekt:

- Analys av de problem som förhindrar beaktande av drift- och underhållsaspekter. Syftet med detta delprojekt är att identifiera problemen samt att föreslå förändringsbehov för att avlägsna dessa problem genom att analysera de identifierade problemen, analysera verksamheten vid planering och projektering, analysera verksamhetens mål, identifiera möjligheter och styrkor inom verksamheten och fastställa de nödvändiga förändringsbehoven.

- Analys av reparationskostnader för vägbarriärer genom en typfallstudie. Syftet är utarbeta en metod för beräkning av hur kostnaderna för skadereparation av vägbarriär beror av faktorer som vägtyp, hastighet, linjeföring, typsektion barriärtyp och barriärplacering.

Begränsningar

Forskningen har tagit sin utgångspunkt i planerings- och projekteringsprocessen inom det svenska Vägverket. Anledningen till denna avgränsning är att forskningsprojektet tillkom på initiativ av Vägverket. Vägverket är också en stor väghållare med ansvar för både nationella vägar på landsbygden och i tätorter. Dessutom har Vägverket ett nationellt ansvar för de regelverk som styr vägbranschen.

Resultatet av forskningsprojektet kan emellertid också vara giltig för andra väghållare t.ex. kommuner som bedriver planerings- och projekteringsprocessen på liknande sätt som Vägverket. En anledning till detta är att kommunerna i Sverige i stor utsträckning använder samma tekniska standarder och regelverk som Vägverket, samt att konsultföretag och entreprenörer har båda dessa typer av väghållare som beställare.

Resultatet kan emellertid också vara giltigt i de andra nordiska länderna eftersom klimatet och byggnadstekniska traditionen ändå är relativt lika inom Norden Det finns egentligen heller ingen anledning att anta att resultatet inte skulle kunna tillämpas utanför Norden.

Projektet har främst begränsats till vägarnas geometriska utformningar. Den strukturella utformningen ingår inte i projektet, eftersom denna redan har varit ett ämne för flera andra forskningsstudier.

Analys av problem som förhindrar beaktande av drift- och underhållsaspekter vid planerings- och projekteringsprocessen

Forskningsprojektet inleddes med en utredning som genomfördes med avsikten att:

- Identifiera de problem som förhindrar att drift- och underhållsaspekterna beaktas under planerings- och projekteringsprocessen.
- Föreslå förändringsbehov för att eliminera dessa problem genom att analysera de identifierade problemen, analysera verksamheten vid planering och projektering, analysera verksamhetens mål, identifiera möjligheter och styrkor inom verksamheten och fastställa de nödvändiga förändringsbehoven.

Utredningen har främst fokuserats på planerings- och projekteringsprocessen vid det svenska Vägverket. Emellertid, har också planerings- och projektringsprocessen i Danmark, Finland och Norge utvärderats för att ge vidgade kunskaper om planerings- och projekteringsprocessen.

Metod

Utredningen genomfördes i två etapper; datainsamling och dataanalys. Datainsamlingen utfördes genom intervjuer och granskning av projekteringsrelaterade dokument. Intervjuarnas huvudsakliga mål var att inventera de situationer som ansågs vara problem som förhindrar att drift- och underhållsaspekterna beaktas i tillräcklig grad vid planerings- och projekteringsprocessen. Ett problem innebär en situation som av någon eller några aktörer upplevs som otillfredsställande i något avseende. Upplevelsen av situationen avviker från aktörens förväntningar eller önskade upplevelse av situationen. Situationen avviker från något mål eller från någon värdering som gäller för situationen. Den upplevda situationen kan vara en föreliggande eller en tänkt framtida situation (Goldkuhl and Röstlinger 1998).

Den typ av intervju som ansågs vara lämplig att användas i denna utredning var kvalitativa semistrukturerade intervjuer. Denna typ av intervju gör det möjligt för de tillfrågade att besvara frågorna med egna ord, vilket betyder att intervjuerna i stor utsträckning får formen av diskussioner. De intervjuade personerna delades in i fyra kategorier: konsulter, drift- och underhållsentreprenörer, personer involverade i drift- och underhållsprocessen och personer involverade i planerings- och projekteringsprocessen vid de studerade väghållarna.

Den andra delen av datasamlingen var granskningen av de dokument som beskriver och styr planerings- och projekteringsprocessen, vägbyggnadsprocessen, upphandlingsprocessen och processen för överlämnade av den färdiga vägförbindelsen. Dessa dokument granskades för att båda analysera planerings- och projekteringsprocessen och granska de mål som styr processen.

Insamlade data analyserades med hjälp av metoden ”Förändringsanalys”, som används i ett inledande skede vid utveckling av verksamheter och organisationer. Förändringsanalysen kan leda till olika typer av förändringsåtgärder. I förändringsanalysen ställer man diagnos på problem och verksamhet, föreslår lämpliga förändringsåtgärder samt bedömer åtgärdernas konsekvenser (Goldkuhl and Röstlinger 1998). Förändringsanalysen består av fem arbetsmoment: problemanalys, verksamhetsanalys, målanalys, analys av förändringsbehov och bestämning av förändringsåtgärder.

Syftet med problemanalysen är att utveckla kunskap kring problem inom valt verksamhetsområde. Arbetet med problemanalysen delades in i fyra arbetsmoment: identifiering och formulering av problemen, problemområdesindelning, problemområdesavgränsning och analys av problemsamband.

Verksamhetsanalysen syftade till att beskriva, analysera och utvärdera det verksamhetsområde inom vilket problemen identifierats. Verksamhetsanalysen i denna utredning begränsades till Vägverkets verksamhet för planering och projektering av vägar. Verksamheten bedrivs genom fyra delprocesser: ”Upprätta förstudie” (Vägverket 2004a), ”Upprätta vägutredning” (Vägverket 2004b), ”Upprätta arbetsplan” (Vägverket 2004h) och ”Upprätta bygghandling”(Vägverket 2004i). Dessa fyra delprocesser ligger inom ramen för en delprocess som kallas ”Utveckla förbindelse”(Vägverket 2004e) och som ingår i en större delprocess som kallas ”Förbättra transportvillkor”, vilken i sin tur är en del av huvudprocesserna ”Stödja näringslivets transporter” och ”Stödja medborgarnas transporter”. Tre andra delprocesser har också direkt anknytning till projekterings- och planeringsverksamheten: ”Genomföra upphandling” (Vägverket 2004d), ”Bygga” (Vägverket 2004f) och ”Överlämna” (Vägverket 2004g). Även dessa delprocesser ingick i verksamhetsanalysen.

Verksamhetsanalysen började med analys av verksamhetsstrukturen i form av en beskrivning av handlingsmönstret i planerings- och projekteringsverksamheten och olika verksamheters relationer till varandra. Behandlingen av olika dokument och olika administrativa aktiviteter inom de olika delprocesserna klargjordes. Dessutom beskrevs sambandet mellan olika aktiviteter med angivande av vem som utför dessa aktiviteter.

Syftet med målanalysen var att fastställa de mål som gäller för verksamheten, identifiera sambanden mellan de olika identifierade målen och värdera målen. Målanalysen delades in i tre arbetsmoment: målidentifiering, analys av målsamband och målvärdering.

Analysen av förändringsbehov syftade till att fastställa de mest akuta förändringsbehoven som var nödvändiga för att möjliggöra ett lämpligt övervägande av drift- och underhållsaspekter vid planerings- och projekteringsprocessen. Grunden för denna analys var problemanalysen, verksamhetsanalysen och målanalysen. Analysen av förändringsbehoven delades in i tre arbetsmoment: problemvärdering, analys av styrkor och möjligheter och formulering av förändringsbehoven.

Resultat

Under intervjuerna presenterades mer än 100 situationer som problem som förhindrar att underhållsaspekter beaktas i tillräcklig utsträckning under planerings- och projekteringsprocessen. Genom senare analyser förminskades antalet problem till 46. De flesta problemen identifierades under intervjuerna. Ytterligare några problem identifierades under senare analyser. De identifierade problemen presenteras i en ”problemlista” (appendix 1).

De identifierade problemen indelades i sex olika problemområden:

- Brist i samråd mellan olika delorganisationer.
- Kunskapsbrist avseende drift och underhåll.
- Brister i regelverk för planering och projektering.
- Brist i planerings- och projekteringsprocessen.
- Organisatoriska brister.
- Krav från externa aktörer.

Problemområdena finns beskrivna i ett ”Problemområdedokument” (appendix 2). En struktur i form av en graf som kallades ”problemgraf” upprättades för problemen inom varje problemområde (appendix 3). Dessa grafer utgjorde ett viktigt underlag för utvärdering av problemen och identifiering av förändringsbehoven.

Med hjälp av analyser av problem, aktiviteter och mål identifierades följande förändringsbehov, vilka är viktiga för ett effektivt övervägande av drift- och underhållsaspekter vid planerings- och projekteringsprocessen.

- Det finns ett stort behov av tydliga och mätbara mål för varje vägprojekt avseende drift- och underhåll. Sådana mål kommer att ge drift- och underhållsaspekterna mera tyngd vid avvägning mellan de olika aspekter som brukar beaktas vid planerings- och projekteringsprocessen. Uppfyllelse av dessa mål ska tillmätas stor betydelse vid utvärdering av färdiga vägprojekt. En minimering av livscykelkostnaden, inklusive drift- och underhållskostnaden, kan vara ett sådant mätbart mål. Dessa projektmål ska vara en del av ett långsiktigt huvudmål som också bör sättas upp för väghållaren avseende drift- och underhållskostnader.
- Det finns behov av att skapa ett strukturerat system för samråd mellan byggnadsavdelningen, konsultföretagen och drift- och underhållsavdelningen under planerings- och projekteringsprocessen. Samrådet bör ske i enlighet med framtagna riktlinjer. I detta system bör alla aktiviteter vara beskrivna och utförare av aktiviteterna skall vara identifierade. Kostnaderna för samrådet bör ingå som en specifik post i planerings- och projekteringsbudgeten.
- Behovet av ökad kunskap avseende drift och underhåll är stort både inom väghållarens organisation och hos konsultföretagen. Detta skapar behov av ett effektivt system för erfarenhetsåterföring mellan olika delorganisationer. Det är därmed också nödvändigt att följa upp de kostnader och andra

konsekvenser, som uppstår till följd av olämpliga vägutformningar med hänsyn till drift- och underhåll.

- En systematisk utvärderingsprocess med tydliga riktlinjer avseende drift- och underhållsaspekten bör ingå som en viktig del i ett system för kvalitetsuppföljning. Utvärderingsprocessen ska för varje vägprojekt säkerställa att möjligheten att utföra drift- och underhållsaktiviteter beaktas.
- Regelverk och andra styrande dokument, som Värgar och Gaturs Utformning, VGU 2004, (Vägverket 2004c), bör kompletteras med avseende på drift och underhåll för att dessa faktorer inte ska försummas vid planerings- och projekteringsprocessen.
- Förfrågningsunderlag och andra upphandlingsdokument bör innehålla tydliga riktlinjer med avseende på drift och underhåll, exempelvis genom krav på optimering av vägens livscykelkostnad. Detta leder också till behov av att utveckla modeller och andra hjälpmedel för att utföra sådana beräkningar. Ett annat exempel är krav på skötselplaner för drift- och underhålls eller s.k. drift- och underhållskonsekvenser för olika vägutformningar och vägkomponenter.
- Behovet är stort av att öka incitamentet hos konsultföretagen för att i projekteringsskedet beakta drift och underhåll. Detta kan göras t.ex. genom att skapa ett belöningssystem i form av bonuspoäng baserat på den systematiska utvärderingen, som är nämnd under punkt 4. Bonussystemet skulle kunna användas som en mjuk parameter vid upphandling av konsulttjänster.

Analys av reparationskostnader för vägbarriärer

En stor del av underhållkostnaderna för vägbarriärer är reparationskostnader för skador som orsakas av påkörningar. Emellertid beaktar man inte i tillräcklig grad möjligheten att reducera dessa kostnader genom lämplig utformning och val av barriärtyp. Reparationskostnaderna är beroende av ett antal faktorer, bl.a. hastighet, vägtyp, trafikflöde, linjeföring, säsong, barriärtyp och barriärplacering. Enligt vägprojektörerna, är begränsad kunskap om reparationskostnader och de faktorer som påverkar dessa kostnader den avgörande orsaken till att man inte tar tillräcklig hänsyn till drift- och underhållskostnaderna vid val barriärtyper. För vägprojektörer är det omöjligt att beakta alla ovannämnda faktorer vid val barriärtyper i frånvaron av en beräkningsmodell som tar hänsyn till alla nämnda faktorer. Därför antar projektörerna att drift- och underhållskostnaderna är lika stora för alla vägbarriärtyper och fokuserar därmed på istället på investeringskostnader, estetiska aspekter och funktionella krav som grund för val av barriärtyp.

Syftet med denna typfallstudie var att:

- Upprätta en metod för beräkning av de årliga reparationskostnaderna för vägbarriärskador. Metoden ska senare ingå i en modell för beräkningen av livscykelkostnader för olika vägbarriärtyper som ett exempel för en ny metod för övervägande av drift- och underhållsaspekter vid projektering och planering.
- Analysera hur faktorer, som vägtyp, hastighet, barriärtyp, vägbarriärplacering, vägens typsektion, säsong och linjeföring, påverkar reparationerna och de associerade kostnaderna för dessa.

De barriärtyper som studerades i typfallstudien var w-profilräcken, stållineräcken, Kohlswabalkräcken och rörräcken. Analyserna fokuserades dock främst på w-profilräcken och stållineräcken, vilka är de två mest använda räckestyper i Sverige. Data hämtades från 1084 reparationer av skador på barriärer utförda i två av Vägverkets regioner: Region Väst och Region Mitt. Både mitträcken och sidoräcken ingick i datainsamlingen. Utvecklingen av beräkningsmetoden och genomförande av analyserna var huvudsakligen begränsade till mitträcken. Samhällsekonomiska analyser ingick inte i studierna. Dock har reparationskostnaderna för skadade fordon ingått i en del av analyserna. Typfallstudien var begränsad till fyra vägtyper: motorvägar, fyrfältsvägar, mötesfria motortrafikleder och mötesfria landsvägar.

Metod

Datakällorna utgjordes av en blandning av arkiverade dokument, aktuell information som togs från flera databaser och intervjuer med aktörer involverade i drift- och underhållsprocessen samt i planerings- och projekteringsprocessen. Fallstudier valdes som den mest lämpliga forskningsstrategin, eftersom den har kapaciteten att behandla en mängd olika typer av informationskällor som dokument, arkiverad handlingar, intervjuer och observationer. En fallstudie är en empirisk undersökning som studerar ett fenomen inom dess kontext, speciellt när gränserna mellan fenomenet och kontexten inte är tydliga (Yin 2003).

Utformning av en typfallstudie består av identifiering av forskningsfrågan, utformning av forskningspåståenden, val av analysenheter och bestämning av logiken för att relatera data till påståendena (Yin 2003). Forskningsfrågan för denna fallstudie var ”Hur påverkar faktorer som vägtyp, hastighets och barriärtyp, barriär placering och linjeföring barriärreparationer och de associerade kostnaderna?”. Forskningspåståendena utformades i början av denna typfallstudie, baserade på erfarenheter hos experter inom Vägverket och de informationer som insamlades under de intervjuer som utfördes under tidigare beskriven förändringsanalys. Forskningspåståendena var:

- Antalet reparationer av barriär och kostnader för dessa är högre på vägar med hastighetsbegränsning 110 km/hr än på vägar med hastighetsbegränsning 90 km/hr.
- Antalet reparationer av barriär och kostnader för dessa är högre på mötesfria vägar än på andra vägtyper.
- Antalet reparationer av barriär och kostnaderna för reparation av stållineräcken är högre än för w-profilräcken.
- Stållineräcke är den mest lönsamma typen av räcke för Vägverket.
- Antalet reparationer av barriär och kostnader för dessa är högre under vintersäsongen än under sommarsäsongen.

- Antalet reparationer av barriär och kostnader för dessa är omvänt proportionell mot avståndet mellan körbanan och barriären.
- Antalet reparationer av barriär och kostnader för dessa är högre i vägkurvor än på raka vägsträckor.
- De flesta påkörningar av barriär på mötesfria vägar sker på övergångssträckorna.

De lämpligaste analysenheterna för denna fallstudie var Vägverkets regioner, eftersom informationen om reparationerna av skador på barriärerna är arkiverad separat inom varje region. För denna studie valdes en multipel-fallstudie där två olika fall studerades med ett fall i varje region.

Mönstermatchning (Trochim 1989) valdes som lämplig logik för att relatera insamlade data till påståendena. Insamlade data som utgjorde det empiriska mönstret relaterades till påståendena som representerade det teoretiska baserade mönstren. Rönen från de båda regionerna jämfördes med varandra för att se om samma resultat erhållits i de båda fallen. Om resultaten sammanfalls, ansågs rönen utgöra ett verkligt empiriskt baserat mönster. Därefter jämfördes rönen med påståendena för att avgöra om påståendena skulle antas eller förkastas.

Data samlades in från följande källor: Reparationsfakturor, Vägdatabanken (NVDB) (Vägverket 2005), databasen ”Info om vägar”, berörda försäkringsbolag och genom intervjuer med experter. Insamlade data bestod av följande:

- Datum när skadan upptäcktes.
- Typ av skadad barriär.
- Plats och vägnummer där skadan inträffade.
- Barriärposition, dvs. mittbarriär eller sidobarriär.
- Barriärplaceringen, dvs. avståndet mellan skadade barriären och körbanan (dvs. barriärplacering i relation till körbanekant).

- Vägens linjeföring där skadan inträffade, dvs. vägkurva eller raksträcka.
- Vägens typsektion där skadan inträffades.
- Hastighetsbegränsningen där skadan inträffade.
- Den totala kostnaden för varje reparation och uppdelningen av denna kostnad i delposter.
- Vägverkets del av den totala reparationskostnaden
- Antalet skadade bärriärståndare.
- Namn på det berörda försäkringsbolaget och summan som betaldes ut i ersättning för reparationen av skadade barriären och det skadade fordonet.

Följande data insamlades för beräkning av trafikarbeten:

- Barriärtyper längs de studerade vägarna.
- Vägtyper och hastighetsbegränsningar längs de studerade vägarna.
- Årsmedeldygnstrafik ÅDT.
- Trafikökningsfaktorer för studerade väglänkar.
- Längden av studerade väglänkar.

Beräkningar och analyser

Reparationskostnaden per miljon fordon kilometer (Mfkm) valdes som mått för att värdera inverkan av studerade faktorer på barriärskadorna och på kostnaderna för att reparera dessa.

Följande analyser utfördes i typfallstudien:

- Analys av hur de hastighetsbegränsningarna påverkar barriärskadorna och tillhörande kostnader.
- Analys av hur de olika vägtyperna påverkar barriärskadorna och kostnaderna för reparation av dessa.
- Analys av hur säsonger påverkar barriärskadorna och reparationskostnaderna.

- Analys av hur barriärplaceringar påverkar barriärskadorna och reparationskostnaderna. Ambitionen var att finna det avstånd mellan barriärer och körbanor som ger den lägsta skaderisken och reparationskostnaden.
- Analys av hur linjeföringen påverkar barriärskadorna och reparationskostnaderna.
- Analys av hur vägens typsektion påverkar barriärskadorna och reparationskostnaderna.

Resultat och diskussion

Analys av inverkan av hastighetsbegränsningar på barriärskadorna

Enligt resultaten är reparationskostnaden per miljoner fordonskilometer (Mfkm) för mittbarriär på vägar med hastighetsbegränsningen 110 km/hr lägre än på vägar med hastighetsbegränsningen 90 km/hr och 70 km/hr. Denna skillnad beror främst på att antalet reparationer per miljoner fordonskilometer är mindre på vägar med hastighetsbegränsningen 110 km/hr än på vägar med hastighetsbegränsningen 70 km/hr och 90 km/hr. En möjlig förklaring till detta är att vägar med hastighetsbegränsningen 110 km/hr är utformade med hög geometrisk standard och hög trafiksäkerhet jämfört med vägar med hastighetsbegränsningen 90 km/hr eller 70 km/hr. Dessa två faktorer bidrar troligen till att risken för skador är låg för vägbarriärer på vägar med hastighetsbegränsningar 110 km/hr. En annan faktor som troligen bidrar till högre skaderisk för barriärer på vägar med 70 km/hr och 90 km/hr är att dessa vägtyper oftast förekommer i tätorter med höga trafikflöden och många anslutningsvägar.

Analys av inverkan av vägtyper på barriärskadorna

Reparationskostnaden per Mfkm för barriärer på mötesfria vägar är högre än på motorvägar och fyrfältsvägar, trots att medelkostnaderna per reparation är ungefär lika höga för alla vägtyper. Orsaken till denna skillnad är att antalet reparationer per miljoner fordonskilometer för mötesfria vägar är högre än för andra vägtyper. En trolig förklaring för denna skillnad är att mötesfria vägar är utformade med låg geometrisk standard jämfört med motorvägar och fyrfältsvägar. Till exempel; avståndet mellan barriärerna och körbanorna på mötesfria vägar brukar vara mellan 0.65 m och 1.1 m jämfört med 1.75 m längs motorvägar och fyrfältsvägar med normal standard. Detta innebär att skaderisken är stor för barriärer längs mötesfria vägar jämfört med barriärer längs andra vägtyper.

En annan förklaring till att antalet skador per miljoner fordonskilometer för barriär längs mötesfria vägar är högre är att dessa vägtyper oftast är utrustade med stållineräcken som har en svag konstruktion jämfört med andra barriärtyper. Den svaga konstruktionen gör att stållineräcke tappar sin funktion även efter mindre skador och därför måste repareras oftare.

Analys av påverkan av barriärtyper på barriärskadorna

Reparationskostnaden per Mfkm för stållineräcken är tre gångar högre än för w-profilräcken, trots att medelkostnaden per reparation för båda typerna är ungefär lika höga. Huvudorsaken till denna skillnad är att antalet skador per miljoner fordonskilometer är högre för stållineräcken än för w-profilräcken. Detta beror på att stållineräcken har en svag konstruktion som tappar sina funktioner även efter mindre skador och därför måste repareras oftare än w-profilräcken.

Resultaten visar också att medelreparationskostnaderna för de fordon som kolliderade med w-profilräcken är högre än medelreparationskostnaderna för de fordon som kolliderade med stållineräcken. Detta tyder på att fordonsskadorna vid kollision med w-profilräcken blir större än fordonsskadorna som vid kollision med stållineräcken. Den troliga förklaringen för denna skillnad är att w-profilräcken har starkare konstruktion och att kollisionsytan vid kollision med w-profilräcken är mindre. Kombination av dessa två faktorer medför att kraften vid en kollision är koncentrerad till en liten yta. Detta leder till stora skador i fordonets grundkonstruktion, som ofta är kostsamma att reparera. Fordonsskador som orsakas av kollisioner med stållineräcken är mestadels ytliga och är billigare att reparera. Det är dock svårt att dra några bestämda slutsatser, eftersom analysen är baserad på relativt begränsad information om ersättningar för fordonsreparationerna.

Analys av säsongernas påverkan på barriärskadorna

Antalet utförda reparationer var högre under vintersäsongen än under sommarsäsongen i Region Mitt. En trolig förklaring till denna skillnad är det hala väglaget som ofta råder under vintern med en hög risk för barriärskador som följd. Skillnaden som endast syns i Region Mitt är dock relativt liten.

Resultaten visar också att medelkostnaden per reparation är något högre under sommarsäsongen än under vintersäsongen i båda regionerna. Detta tyder på att barriärskadorna är mer omfattande under sommarsäsongen än under vintersäsongen. Resultatet av denna analys är dock osäkert på grund av att:

- Reparationskostnaderna per miljoner fordonskilometer och antalet reparationer per miljoner fordonskilometer reparationskvoten för säsongerna kunde inte beräknas eftersom trafikarbetet för de olika säsongerna inte var möjlig att beräkna.
- I många fall skede skadorna under en säsong medan reparationerna utfördes under en annan säsong.
- Reparationsdatumen saknades ofta på reparationsfrakturerna. För dessa typer av skador antogs det att skadorna och reparationerna uppstod under samma säsong. Detta antagande baserades på det faktum att barriärskadorna måste repareras inom tre veckor efter att skadorna var upptäckta.

Analys av inverkan av barriärplaceringar på barriärskadorna

Antalet reparationer som utfördes på barriärer som var placerade 0,5 - 2 m från körbanekanten var större än antalet reparationer som var utförda för barriärer som var placerade längre än 2 m från körbanekanten. Enligt den allmänna uppfattningen i Vägverket är de flesta vägbarriärer som är installerade i båda regionerna placerade inom 0.5 - 2 m från körbanekanten. Detta kan vara en förklaring till den höga andelen av reparationer på barriärer placerade inom 0.5 - 2 m från körbanekant. Dessa barriärer är mer utsatta för skador vilket orsakas av snöröjningsutrustningar. Emellertid är det anmärkningsvärt att skador av denna typ inte kunde hittas bland de 1084 skador som undersöktes. En förklaring till denna kan vara att skador som orsakas av snöröjningsutrustningar inte avrapporteras av underhållsentreprenörerna för att undvika eventuella ekonomiska konsekvenser.

Resultaten visar också att medelkostnaden per reparation av barriärer placerade längre än 2 m från vägbanakanten, i någon grad är högre än medelkostnaden per reparation av barriärer placerade inom 0.5 - 2 m från körbanekanten. Skillnaden kan bero på att påkörningsvinkeln blir större ju längre avståndet mellan barriären och körbanekanten blir. Större påkörningsvinkel innebär större påkörningskraft med större skador som följd. Skillnaden är dock liten. Enligt den allmänna uppfattningen bör skadorna dock vara mindre allvarliga ju längre barriären är placerad från körbanekanten. Detta verkar inte vara fallet.

Resultaten av denna analys bör tolkas med försiktighet eftersom reparationskostnaderna inte är korrelerade till trafikarbetet. Det var inte möjligt att beräkna trafikerarbetet eftersom längderna för barriärer med olika placeringar var okända. Analysen av inverkan av vägtyper på barriärskadorna visar dock att reparationskostnaderna per miljoner fordonskilometer och antalet reparationer per miljoner fordonskilometer för barriärer längs vägar med breda mittremsor, är lägre än för barriärer längs vägar med smala mittremsor.

Analys av inverkan av linjeföringen på barriärskadorna

Resultaten visar att de flesta skadorna har förekommit på raka vägsträckor i båda regionerna. Detta är rimligt eftersom raka vägsträckor sannolikt utgör den största delen av det undersökta vägnätet. Resultatet är dock mindre intressant eftersom reparationerna inte kan relateras till trafikarbetet. Beräkningen av trafikarbeten var inte möjligt eftersom längderna varken för raksträckor eller kurvor var kända. Trots detta indikerar analysen av inverkan av vägtyper på barriärskadorna att vägar med hög geometrisk standard, dvs. vägar med mjuka kurvor, bidrar till mindre antal av barriärskador per miljoner fordonskilometer och lägre reparationskostnader per miljoner fordonskilometer, jämfört med vägar med lägre geometrisk standard.

Analys av inverkan av typsektionen på barriärskadorna

Resultaten visar att de flesta skadereparationer som skede på de studerade mötesfria vägarna har skett längs de dubbelfältiga sträckorna. En förklaring är att omkörningsmanövrer endast är möjliga på dubbelfältiga sträckor. I många fall försöker förarna göra omkörningen så fort som möjligt för att undvika övergångssträckan. Samtidigt upplever förarna omkörningsmanövern som ett komplicerat moment och anser att den omkörda bilen är farligare än vägbarriären. Därför försöker de köra närmare vägbarriären än den omkörda bilen. Under dessa förhållanden blir risken för sammanstötningar med vägbarriären större. Till skillnad mot den allmänna uppfattningen, visar resultatet att antalet skadereparationer på övergångssträckorna var betydligt lägre än på de dubbelfältiga eller enkelfältiga sträckorna. Denna skillnad är logisk eftersom övergångsträckorna utgör endast en liten andel av den totala längden för en mötesfri väg. En annan förklaring kan vara att bilisterna blir allt mer vana vid att köra på mötesfria vägar och är allt mer medvetna om riskerna vid omkörningar nära övergångssträckorna.

Även denna analys bör tolkas försiktigt eftersom analysen är baserad på ett begränsat antal reparationer. Detta beror främst på att i reparationsfakturorna aldrig nämns typsektionen där skadan har inträffat. Dessutom har reparationerna inte kunnat relateras till trafikarbetet eftersom det inte har gått att beräkna trafikarbetet med anledning av att längderna för de olika sträckorna inte var kända.

Jämförelse av reparationskostnaderna mellan regionerna

Analyserna visar att reparationskostnaderna per miljoner fordonskilometer för alla barriärtyper var högre inom Region Mitt än inom Region Väst, oavsett hastighetsbegränsningar eller vägtyper. De underliggande faktorerna är troligen följande:

- Anbudspriserna är högre i Region Mitt än i Region Väst.
- Mötesfria vägar utgör en stor andel av vägnätet i Region Mitt. Reparationskostnaderna per miljoner fordonskilometer är högre på mötesfria vägar än på motorvägar eller fyrfältiga vägar.
- Stållineräcken används i stor utsträckning i Region Mitt. Antalet reparationer per miljoner fordonskilometer är högre för stållineräcken än för w-profilräcken som är mer vanliga i Region Väst.
- Antalet reparationer per miljoner fordonskilometer är högre i Region Mitt än i Region Väst. Detta kan bero på att vinterförhållanden råder under en längre tidsperiod i Region Mitt än i Region Väst.

Slutsatsar

De viktigaste slutsatserna av detta forskningsprojekt är följande:

- Olika åtgärder har utförts av väghållarna för att öka effektiviteten vid utförande av drift- och underhåll. Fokus har dock varit på att förbättra drift- och underhållsmetoderna utan att betrakta förbättringspotentialer som finns i planerings- och projekteringsskedet. Detta har i många fall lett till en försämrat drift- och underhållsstandard.
- Ett hänsynstagande till drift- och underhållsaspekter under planerings- och projekteringsprocessen skulle underlättas av en modell för analys av

vägarnas livscykelkostnad med särskilt perspektiv på drift- och underhållskostnaderna. De modeller som finns är i allmänhet framtagna efter särskilda krav för specifika projekt och är sällan vidareutvecklade. De flesta modellerna är utvecklade för val av beläggningstyper och underhållsstrategier för beläggningar. Enligt de allmänna uppfattningarna i Vägverket är de drift- och underhållskostnader som används i dessa modeller grovt beräknade och orealistiska jämfört med dagens kostnader.

- Även om det är välkänt att drift- och underhållsaspekterna inte betraktas i nämnvärd grad under planerings- och projekteringsprocessen, är de bakomliggande orsakerna och konsekvenserna av detta inte tillräckligt studerade. Den begränsade litteratur som finns inom ämnesområdet bekräftar detta faktum.
- Detta forskningsprojekt har identifierat en mängd problem som hindrar tillräckligt beaktande av underhållsaspekter under planerings- och projekteringsprocessen. De identifierade problemen kan delas in i sex problemområden:
  - Brist i samråd mellan olika delorganisationer.
  - Kunskapsbrist avseende drift och underhåll.
  - Brister i regelverket för planering och projektering.
  - Brist i planerings- och projekteringsprocessen.
  - Organisatoriska brister.
  - Krav från externa aktörer.
- Problemområdena är inte oberoende av varandra. Elimineringen av ett problem inom ett problemområde kan också bidra till elimineringen av problem inom andra problemområden.
- För att bidra till att drift- och underhållsaspekter betraktas i högre grad under planerings- och projekteringsprocessen, är följande förändringsbehov identifierade:

  - Det finns ett stort behov av tydliga och mätbara mål för varje vägprojekt avseende drift- och underhållsaspekter.
  - Det finns behov av att skapa ett strukturerat system för samråd mellan byggnadsavdelningen, konsultföretagen och drift- och underhållsavdelningen vid planerings- och projekteringsprocessen.
  - Behovet av ökad kunskap avseende drift och underhåll är stort både inom väghållarens organisation och hos konsultföretagen. Detta skapar behov av ett effektivt system för erfarenhetsåterföring.
  - En systematisk utvärderingsprocess med tydliga riktlinjer avseende drift- och underhållsaspekter, bör ingå som en viktig del i ett system för kvalitetsuppföljning.
  - Regelverken för planering och projektering och andra styrande dokument bör kompletteras med avseende på drift- och underhållaspekter för att dessa aspekter inte ska försummas vid planerings- och projekteringsprocessen.
  - Förfrågningsunderlag och andra upphandlingsdokument bör innehålla tydliga riktlinjer med avseende på drift och underhåll.
  - Behovet är stort av att öka incitamentet hos konsultföretagen för att i projekteringsskedet beakta drift- och underhållsaspekter.
- Reparationskostnaderna per miljoner fordonskilometer och antalet reparationer per miljoner fordonskilometer för mittbarriärer är lägre längs vägar med hastighetsbegränsningen 110 km/hr än längs vägar med hastighetsbegränsningen 90 km/hr och 70 km/hr.
- Reparationskostnaderna per miljoner fordonskilometer och antalet reparationer per miljoner fordonskilometer är högre längs mötesfria vägar än längs med motorvägar och fyrfältsvägar.
- Det är i övrigt inte klarlagt i vilken grad barriärskadorna påverkas av säsongerna. Barriärskador är dock mer omfattande under sommaren än under vintern.

- Reparationskostnaderna per miljoner fordonskilometer och antalet reparationer per miljoner fordonskilometer är lägre längs vägar med bredda mittremsor än längs vägar med smala mittremsor.
- Vägar med hög geometrisk standard har lägre reparationskostnaderna per miljoner fordonskilometer och lägre antal reparationer per miljoner fordonskilometer.
- Reparationskostnaderna per miljoner fordonskilometer och antalet reparationer per miljoner fordonskilometer för mittbarriärer är större i Region Mitt än i Region Väst.

1 Introduction

1.1 Background

The cost of a road construction over its service life is a function of the design, quality of construction, maintenance strategies and maintenance operations. An optimal life-cycle cost for a road construction requires estimations of the above mentioned components. Unfortunately, designers often neglect a very important aspect which is the possibility to perform future maintenance activities. The focus is mainly aimed towards other aspects such as investment costs, traffic safety, aesthetic appearance, regional development and environmental effects.

In some cases, the construction documents are sent to the maintenance department for revision. Unfortunately, the limited resources in the maintenance departments often obstruct sufficient revision of these documents. As a result the need for specific maintenance measures often arises during the service life of the road due to problems in certain locations along the road.

During the road planning and design process, the number of hours devoted to analyse the future maintenance activities and the associated costs, is negligible compared to the hours devoted to structural technical calculations, technical descriptions and quantity calculations. This occurs despite the fact that construction usually takes only a few years while the maintenance period lasts for thirty to forty years. In some cases, the annual maintenance costs for road construction have been equal to the initial costs for the construction (Olsson 1983).

Often, the insignificant considerations of the maintenance aspects during the planning and design process are on purpose. For example, due to limited investment budgets, designers are often forced to select road equipment which has low initial costs; even if they are aware of the high maintenance costs which this equipment will generate in the future. For instance, the designers prefer cable barriers which are distinguished by a low initial cost but a high maintenance costs.

In other cases the maintenance aspects are neglected for aesthetics reasons. This often occurs in urban regions with high aesthetic requirements. For example, in Sweden there are specific aesthetic requirements for the design of the motorway approaches to cities. Designers have to follow these requirements even if they are aware of the high future maintenance costs associated with the selected designs. One example is the use of pipe barriers in urban regions. Other examples include the selection of certain types of vegetation that result in increased maintenance costs and the use of glass noise barriers, despite the high maintenance costs associated with these types of noise barriers. Figure 1.1 shows a noise barrier which is installed along road E6.20 in the city of Gothenburg, Sweden. The glass elements are repeatedly vandalized or damaged by flying stones from the road. According to the maintenance contractor there, the repair cost of each glass element is 8000 SEK.

Figure 1.1 *Damaged noise barrier along road E6.20 in the city of Gothenburg in Sweden*

In some cases the maintenance aspects are neglected because the designers do not have enough experience regarding road maintenance. Figure 1.2 shows a design proposal for a new road for which the designers have proposed to have a concrete roadside barrier very close to the road. The designers have not considered how to get rid of the snow piles along the verges left by the snowploughs, because they have falsely presumed that the snow heaps do not need to be removed. However, the verge must be free from snow and ice according to the maintenance regulations (Vägverket 2006b). For the mentioned design, this means that the snow heaps have to be loaded onto trucks and transported away from the road after each snowfall at both considerable cost and likely traffic disruptions.

Figure 1.2 *Design proposal for a new road section (Source: SRA)*

1.2 The need to consider the maintenance aspects during the road planning and design process

As the funding sources for road infrastructures are becoming less and less sufficient to insure implementations of new projects and maintenance of existing roads, road authorities around the world are forced to increase efficiency and reduce costs (Prarche 2007). For this reason, the road authorities are continuously trying to increase the efficiency of road maintenance and reduce the related costs, as the maintenance costs constitute a large portion of the annual expenditure on road infrastructures. Unfortunately, many of those efforts have resulted in reduced maintenance standards and impaired road conditions. The focus has mainly been on the improvement of the operating practises and maintenance procedures without consideration of the improvement potential in the road planning and design process.

Consideration of maintenance aspects during the road planning and design process is an area where improvement is possible in increasing the road maintenance efficiency and reducing the need of costly maintenance measures. Beside that the efficient road maintenance does mean efficient use of the road funding sources, it also results in:

- Better road management and actions to preserve the existing road infrastructure.
- Reduced socio-economic costs as a result of decreased traffic disturbances and accidents related to maintenance measures.
- Reduced negative effects on the environment.

1.3 Objective

This licentiate thesis is a part of a Ph.D. project that aims to examine the optimisation of the road life-cycle costs through the selection of appropriate designs for roads and their components. The result is expected to give a basis for a new method for the road planning and design process using life-cycle cost analysis with particular emphasis on road maintenance. The objective of this project is to:

- Identify the problems which obstruct due consideration of the maintenance aspects during the road planning and design process.
- Identify the urgent needs for changes to eliminate these problems through analyses of problems, activities, objectives, possibilities and strengths within the process of road planning and design.
- Establish a model for calculating the annual repair costs for damages to different road barrier types. This will be used in life-cycle cost analysis as an example of a method for proper consideration of maintenance aspects.

- Analyse how parameters such as road types, speed limits, road barrier types, road barrier placements, road section types, seasonal effects and road alignment affect barrier damages and the related repair costs.

1.4 Scope of the study

The research was focused on planning and design processes at the Swedish Road Administration, SRA, which is in charge of both country and urban roads in Sweden. The SRA is also responsible for Swedish road planning and design as well as maintenance specifications. Another reason for this delimitation is that the SRA is the initiator for this research. This means that the results of the research are valid for Nordic construction traditions, design and climate. However, most of the results may also be applicable for road planning and design outside the Nordic countries.

The research is mainly limited to the geometrical design of paved roads within the planning and design process. The structural design of the roads is not included as this subject has already been included in several other research studies. These previous studies focused mainly on identifying the pavement type and thickness which gives an optimal life-cycle cost.

1.5 Research method

The project started with a review of previous research which took into consideration maintenance aspects during the road planning and design process. Very few references were found in the literature regarding this research subject. This led to the second stage of the research which was an investigation with the intention to identify the problems and difficulties which prevent satisfactory consideration of the maintenance aspects during the road planning and design process. This investigation started with an inventory of circumstances which were experienced as obstacles to consideration of the maintenance aspects. For this purpose, actors involved with both the road maintenance process and road planning and design were interviewed using semi-structured interviews.

The third stage of the research was the identification of the most urgent needs for changes which would contribute to increased consideration of the maintenance aspect during the road planning and design process. This was done by analysing the identified problems, the planning and design activities and the goals which govern the activities. The method used for this purpose was the “Change Analyses” (Goldkuhl and Röstlinger 1998).

The fourth stage was an analysis of repair costs for damage to various road barrier types. This part of the research was carried out for two purposes: Firstly to establish a model for calculation of annual barrier repair costs. Secondly, to analyse how parameters such as road types, speed limits, road barrier types, road barrier placement, road section types, alignment and road climate affect barrier damages and associated repair costs. The analysis of the repair costs were based on data collected from repairs of 1086 road barriers in Sweden. The method used for this proposes was the Case Study Research Method (Yin 2003).

2 Definitions

This chapter contains descriptions and definitions of some of the terms which are used in this licentiate thesis.

2.1 Road planning and design

The construction of new roads or the improvement of existing ones always starts with a planning and design process. Road planning includes investigations of conditions relevant to the building of new roads or the improvement of old ones, such as: transportation demands, climate, topography, geology and material supplies. It also includes evaluation of the consequences for society, the environment, transportability, traffic safety, and economic development.

Road design means selecting the dimensions of the road and its components, e.g. width of traffic lanes, road profile and type of road equipment. The process of road planning and design is very complicated due to the numerous components which the road consists of and other aspects which have to be considered for an optimal solution.

The road planning and design process consists of four subprocesses: the feasibility study, the road survey, creation of the work plan and creation of the construction documents. The first two subprocesses are called road planning and the third and fourth subprocesses are called road design.

2.1.1 Feasibility study (Vägverket 2004a)

The planning and design process starts with the establishment of a feasibility study which intends to:

- Describe the problems which have to be solved, e.g. problems concerning accessibility, traffic safety and environmental issues.

- Highlight existing conditions and their important values as well as the goals of the road project.
- Identify all the conceivable options to solve the problems.

The feasibility study gives explanations to all the conceivable options, the proposals for solutions and the relevant costs. However, any decision about the appropriate option is not taken in this stage.

The feasibility study starts with a formulation of the problems, the strategies and the goals of the project initiators. A consultation regarding the environmental issues, the demands as well as the plans for the forthcoming subprocesses, takes place between all the concerned parties, such as municipalities and county administrations. Afterwards, an Environmental Impact Assessment (EIA) will be issued based on the collected facts, the delimitations, the analyses of the consequences and effects. The EIA describes the possible environmental effects of the road project on nature, culture, landscape, health, safety and public transport. Later, the county administration decides whether the environmental effects of the road project are significant or not. If the environmental effects are expected to be significant, then the road authority has to make an in-depth consultation during the next subprocess. Afterwards, the road authority decides if the project should be carried out or not.

The feasibility study is expected to answer the following questions:

- What are the problems and the possibilities?
- What happens if nothing is done?
- What are the alternative ways to solve the problems?
- How large will the concerned geographical area be?
- Is there any need to carry on the project?
- If there is a need for a new road or improvement of an existing one, where should the new road section or the improvement start and end?

2.1.2 Road survey (Vägverket 2004b)

This subprocess is carried out only if the need to study a new road corridor, instead of the existing one, has been stated in the feasibility study. The aim of this subprocess is to determine the most suitable road corridor option and the traffic standard. This subprocess is carried out in consultation with the parties concerned such as county administrations, various organisations, associations and the public.

The road survey begins with complementary studies concerning the terrain and the environmental conditions followed by descriptions of applicable traffic conditions, the environment, safety and availability. Later, the proposed corridor options for the new road are studied and compared to each other and to the option of retaining the existing road with necessary improvements. The consequences and the effects are described and analysed. All the options are then discussed with the concerned parties. An EIA is carried out for each proposed road corridor option. All the options are then studied to determine the most suitable corridor for the surroundings as well as the implementation of the road. Afterwards, the EIA of the most suitable road corridor is approved by the concerned county administration. At this phase, the road authority decides to select the most suitable road corridor option and the road standard. The decision of the road authorities can not be appealed at this phase.

2.1.3 Creation of the work plan (Vägverket 2004h)

This subprocess is carried out in order to:

- Show more details about the location of the new road in the selected corridor.
- Issue the documents which are required from the road authorities in order to receive the “Right of Way” (The Swedish ministry of Enterprise 1971). The right of way is necessary for the expropriation of the land required for the road construction.
- Make a more comprehensive EIA.
- Carry out meetings with the concerned landowners.

- Estimate the costs of the road project.

The subprocess starts with consultations or in-depth consultations with the concerned parties and landowners. An in-depth consultation is only required if the environmental effects are expected to be significant. Later, the most suitable road location in the selected corridor is identified. Afterwards, suitable measures for the adoption of the road as well as the surroundings are identified and presented in a work plan with the intention to get the standpoints from all concerned parts.

The road authority sets the work plan, i.e. decides to select the proposed road location and presents the conditions which are valid to accomplish the road project. In this phase the decision of the road authorities can be appealed.

2.1.4 Creation of the construction documents (Vägverket 2004i)

Creation of the construction documents is the last subprocess in the planning and design process. The purpose of this subprocess is to:

- Create the technical documents required for construction of the proposed road.
- Apply for the permission required for the construction phases.
- Make the agreements required during the construction phases.

The construction documents contain all the technical details required for the construction of the road, including the design details about the road as well as the components and equipment needed to be installed. The construction documents also contain instructions regarding:

- The temporary traffic arrangements required during the construction period.
- The design of connections with private roads.
- The place required for the remaining soil masses after construction.

2.2 Road maintenance

Road maintenance includes all activities carried out with the intention of maintaining the functions for which the road was designed. Proper road maintenance contributes to reliable transportation at reduced costs, as there is a direct link between road condition and vehicle operating costs (VOC) (The World Bank Group 2001).

The maintenance of road infrastructures has traditionally been funded by tax revenues or road usage fees. The recent years have witnessed development of new funding forms for road infrastructure such as Public Private Partnership Projects which cover maintenance as well as construction costs (Arnek et al. 2007).

In general, road maintenance activities can be broken down into four categories (The World Bank Group 2001):

- **Routine works**: These works include activities which are undertaken each year and funded from the recurrent budget. These activities are grouped into cyclic and reactive work types. Cyclic works are those undertaken where the maintenance standard indicates the frequency at which activities should be undertaken. Examples are verge cutting and culvert cleaning, both of which are dependent on the environmental effects rather than on the traffic levels. Reactive works are those undertaken where intervention levels, defined in the maintenance standard, are used to determine when maintenance is needed. An example is patching, which is carried out in response to the appearance of cracks or pot-holes.
- **Periodic works:** These works include activities undertaken at intervals of several years to preserve the structural integrity of the road, or to enable the road to carry increased axle loadings. The category normally excludes those works that change the geometry of a road by widening or realignment. Periodic works can be grouped into the work types of preventive, resurfacing, overlay and pavement reconstruction. Examples are resealing

and overlay works, which are carried out in response to measured deteriorations in road conditions. Periodic works are expected at regular, but relatively long, intervals. As such, they can be budgeted on a regular basis and can be included in the recurrent budget. However, many countries consider these activities as discrete projects and fund them from the capital budget.

- **Special works.** These works include activities whose needs cannot be estimated with any certainty in advance. The activities include emergency works to repair landslides and washouts that result in the road being cut or made impassable. Winter maintenance works of snow removal or salting are also included under this heading. A contingency allowance is normally included within the recurrent budget to fund these works, although separate special contingency funds may also be provided.
- **Development works.** These works are construction works that are identified as part of the national development planning activity. As such, they are funded from the capital budget. Examples are the construction of by-passes, or the paving of unpaved roads in villages.

In some countries, including Sweden, the routine works and the special works are called operation activities or services.

2.3 Collision-free roads

Collision-free roads are a specific category of three-lane roads, consisting of two lanes in one direction and a single lane in the opposite direction, alternating every few kilometres. The opposite directions are separated with road barriers, mainly steel cable barriers, to prevent cross-over collisions (Vägverket 2004c). Traditional roads of at least 13 metres width can be converted to collision-free roads with a safety level close to motorways at a much lower cost than an actual conversion to motorways. In Sweden, the collision-free roads are also called 2+1 roads.

2.4 Damage excess

Damage excess is the amount of money which the owner of the insured property has to pay in case of any damages to the property. In the case of barrier damages, the owner of the impacting vehicle has to pay for the damage excess for the barrier repair. In the case where the impacting vehicle is unknown, the SRA pays for the damage excess which is limited to 5% of the price base amount (Johansson 2002).

2.5 Environmental Impact Assessment (EIA)

The Environmental Impact Assessment is a document which is issued during the planning and design process according to the Swedish Environmental Code (The Swedish Ministry of the Environment 1998). This document describes the possible environmental impact of new road projects on nature, culture, landscape, health, safety and public transport.

2.6 Price base amount

The price base amount is a figure expressed in SEK which shows how prices have changed in Sweden. Through the development of the price base amount, one gets a perspective regarding how the cost of living costs has changed. The price base amount is dependent on the consumer price index, CPI, and set by the Government each year. The price base amount has various uses, including ensuring that sickness, benefits, study grants and other allowances do not decline in value because of an increase in the general price level.

2.7 Right of way (The Swedish Ministry of Enterprise 1971)

Right of way includes the right of the owner of road to, without hindrance of anybody with other rights to the land, utilise land needed for the road and, unless otherwise stated in the work plan or in the decision to transfer a road from private to public use, also otherwise in lieu of the landowner decide over the utilisation of the land during the time of the right of way and to profit from the utilisation of the road. Right of way is created when the owner of a road claims land for the construction of the road based on approved work plan. Right of way is also created when lands is transferred in connection with the transfer of a road from private use to public. Lands is considered utilized

2.8 Swedish Road Administration (SRA)

The Swedish Road Administration is the national authority assigned responsibility to oversee the entire road transport system. SRA's task is to co-operate with others to develop an efficient road transport system in the direction stipulated by the Swedish Government and Parliament.

2.9 Swedish Motor Insurers (SMI)

Swedish Motor Insurers is the organization that represents Sweden's motor third-party liability (MTPL) insurance companies. The role of this organisation is mainly to collect charges from owners of uninsured motor vehicles and to settle third-party motor liability claims caused by untraced, uninsured or foreign vehicles.

2.10 Road equipment

Road equipment can be seen as the furniture of the road, improving safety, comfort and accessibility for road users (Lundkvist 2008). The European committee for standardisation (European Committee for Standardization 2000) has divided road equipment into the following groups:

- Road restraint systems, e.g. crash barriers, safety fences and guardrails.
- Horizontal signs, e.g. road markings.
- Vertical signs, e.g. road signs and anti-glare systems.
- Traffic control, e.g. traffic signs.
- Noise protection devices, noise barriers.
- Clockwork parking meters and automatic car park ticket dispensers.

3 Literature review

Problems faced while conducting maintenance activities often trigger debates about the road planning and design process, because design is one of those crucial factors which control the maintenance workload of the roads over its service life. Insufficient consideration of maintenance aspects during the road planning and design process is a well-known problem for the road authorities and other concerned actors. Opinions regarding the underlying causes and their possible solutions are often numerous. This chapter presents a review of the literature and the previous research data regarding consideration of maintenance aspects during the road planning and design process.

The aim of the literature review was to:

- Study the conditions causing the increased needs for efficient road maintenance.
- Study the efforts made by the road authorities to satisfy those needs.
- Study the importance of consideration of maintenance aspects during the road planning and design process as an improvement potential for maintenance efficiency.
- Identify the problems and the difficulties which prevent sufficient consideration of maintenance aspects during the road planning and design process.

3.1 Road maintenance related issues

The cost of a road project over its service life is, among other, a function of design standards, construction quality, maintenance strategies and maintenance operation. These components control the rate of road deterioration and dictate the maintenance workload throughout the life of the road (figure 3.1). However, there has been very little work on the interrelationship between the above mentioned components (Freer-Hewish 1986).

Figure 3.1 Development of maintenance workload (Freer-Hewish 1986)

Road maintenance costs constitute 50% of the annul road infrastructure financing (Prarche 2007). These costs have constantly increased around the world (table 3.1). The increase is a result of construction of new road infrastructures (table 3.2), insufficient improvements in working methods, insufficient knowledge sharing, improper support functions for designers, governmental monopoly and inefficient competition in passive maintenance markets (Thorman and Magnusson 2004).

Table 3.1 Annual road maintenance expenditure forecasts as examples of increased demands for maintenance funding, US $ billion (Prarche 2007)

	2000	2000-2010	2010-2020	2020-2030
USA	89,50	106,1	11,5	117,8
Canda	7,60	12,6	13,1	13,8
Combined	97,1	118,7	24,6	131,6

Table 3.2 Annual road construction expenditures forecast for USA and Canada as examples of increased demands for road infrastructure funding, US $ billion (Prarche 2007)

	2000	2000-2010	2010-2020	2020-2030
USA	105,20	124,8	131,2	138,6
Canda	9,00	14,8	15,4	16,2
Combined	114,2	139,6	146,6	154,8

In addition to increased costs, improper maintenance activities result in increased safety hazards for road users and maintenance staff. During the last five years approximately 600 maintenance-related traffic accidents occurred in Sweden. According to the Swedish Road Administration, these accidents resulted in 20 fatalities, including two road workers (Liljegren 2008).

Improper road maintenance leads to the deterioration of road transportation quality and the environment. However, the quantification of these costs, which are considered as socio-economic costs, is very difficult. Therefore these costs are usually not stated when the road authorities declare their annual maintenance costs.

3.2 Road maintenance in Sweden

The governmental road net in Sweden, which is a total of 98 300 km, is managed by the SRA. The SRA is divided into seven regions: the Northern Region, the Central Region, the Stockholm Region, the Mälardalen Region, the South-eastern Region, the Western Region and the Skåne Region (figure 3.2). Each region has a separate department responsible for the road maintenance.

Figure 3.2 SRA regional divisions

Each region is divided into several geographical areas called “Maintenance areas”. The maintenance activities within these areas are outsourced to one or more maintenance contractors. The contracts are usually four years-long with a possibility for a few years extension depending on the type of the contract.

According to SRA’s annual report for 2006, the annual maintenance expenditures between 2002 and 2006 have been lower than the annual road investment expenditure (tables 3.3 and 3.4). Road investment expenditures significantly decreased in 2006 compared to 2002-2005 as the SRA was facing a funding gap during those years.

Table 3.3 Cost for road investment in Sweden, MSEK (Vägverket 2007a)

	2002	2003	2004	2005	2006
Motorway	3 177	3 868	4 133	2 952	3 638
Collision-free road	2 273	2 694	2 319	2 016	1 638
Non collision-free road	991	1 269	710	449	342
Bearing capacity improvements, roads/ bridges, frost protection	724	523	1 477	1 322	1 269
Paving, gravel roads	163	120	57	25	23
Environment and safety prioritised roads/streets	134	138	121	69	48
Pedestrian and cycle routes, bus routes	174	202	150	153	177
Level crossings	329	276	260	216	106
Grade-separated cross-ings	108	154	254	171	171
Rest areas etc.	26	26	63	49	33
Bus stops	24	43	40	52	29
Environmental measures, noise and water protec-tion etc.	89	124	196	182	188
Guard rails	187	260	302	209	160
Other protective instal-lations	21	18	38	30	18
Traffic guidance instal-lations	123	274	182	117	64
Other	11	1	13	87	1
Total investments	**8 551**	**9 990**	**10 315**	**8 099**	**7 905**
Price level 2006	**9 819**	**11 134**	**11 270**	**8 476**	**7 905**

Table 3.4 Cost for maintenance and operation, MSEK, (Vägverket 2007a)

	2002	2003	2004	2005	2006
Maintenance services					
Maintenance, paved roads*	2 682	2 223	2 114	2 291	2 393
Maintenance, gravel roads	236	233	221	205	238
Maintenance, bridges, tunnels and ferry routes	553	596	569	642	704
Maintenance, road furniture	431	439	440	432	470
Maintenance, roadsides and roadside facilities	50	48	64	74	95
Total maintenance services	**3 951**	**3 538**	**3 408**	**3 644**	**3 900**
Operational services					
Winter operations	1 796	1 748	1 867	1 925	1 979
Operation of paved roads	379	358	353	351	243
Operation of gravel roads	197	187	166	165	134
Operation of roadsides and roadside facilities	256	271	367	408	384
Operation of road furniture	320	357	301	320	312
Operation of bridges and tunnels	63	57	60	82	92
Operation of ferry routes	411	381	398	415	445
Total operational services	**3 422**	**3 359**	**3 512**	**3 666**	**3 590**
Total operation and maintenance	**7 373**	**6 898**	**6 920**	**7 310**	**7 490**
Total, price level 2006	**8 360**	**7 585**	**7 532**	**7 620**	**7 490**

The table has used the SRA's operational index. This index reflects cost developments for necessary components.

* *Variations between 2000 and 2003 are partly because the service has also been financed via regional plans.*

However, the report shows that maintenance expenditures was constant from 2002 to 2006, with the exception of 2005 when the winter storm “Gudrun” required significant expenditures in order to keep the roads open and repair the damages. These steady maintenance expenditures probably occurred because the operation activities, i.e. routine maintenance activities, have been prioritised by the SRA at the expense of periodic maintenance, since the funds have not been sufficient to cover both (Vägverket 2007a). The SRA has also made savings in the maintenance activities through greater efficiency. At the same time, the costs have risen and the savings have not kept pace with the cost increases.

According to the SRA, the winter maintenance expenditures have risen continually since 2002 (Vägverket 2006a). More than 50% of the annual maintenance expenditures have been expenditures for the winter maintenance activities, especially snow removal and anti-skid measures. However, the salt consumption per winter has been reduced since 2003 due to an increased number of salt-free roads and use of an efficient model to compensate the contractors for anti-skid measures (Möller 2003).

Sometimes due to a limited budget, the SRA has prioritized road maintenance over road investments. For example, in 2007 the Swedish government decided to increase the road maintenance funds by 100 MSEK without any significant increase in the total road infrastructure funds. According to the Swedish government, this decision was necessary since the condition of the road infrastructure deteriorated during 2005 (The Swedish Ministry of Finance 2006).

In 2008 the Swedish government again prioritized road maintenance at the expense of road investments. Thus, the government decided to assign 815 MSEK for road maintenance and only 385 MSEK for new road investments (The Swedish Ministry of Finance 2006).

3.3 Increased efficiency as a solution for funding gaps

To deal with future funding challenges, different strategies are established by the SRA to improve efficiency and reduce costs, including maintenance expenses (Vägverket 2007b). The strategies which are expected to improve the efficiency of road maintenance are:

- Development of new forms of contracts and cooperation as well as performance-based requirements for purchased products and services. This will stimulate innovations and promote productivity growth within the road infrastructure.

- Development of a well-functioning supplier market through the use of SRA's own operational units. This will improve capacity and quality and stimulate lower prices.
- Exploit SRA's purchasing volume to guarantee a competitive market for road infrastructure.
- Harmonisation of the Swedish guidelines and requirements with adjacent countries in order to increase the number of international as well as domestic bidders.
- Focus on applied research in order to improve road management efficiency.
- Wider use of road life-cycle cost analyses to achieve a lower total cost for road infrastructure.
- Development of new road funding forms, such as Public Private Partnership projects, road usage fee or short-term loans, to increase flexibility and efficiency.

In the SRA's strategic plan for 2007-2017 (Vägverket 2007b), it is stated that the efficiency of maintenance and operation activities will be increased by one percent per year. It is also stated that the possibilities to make any savings concerning operational activities, i.e. routine maintenance activities, are very limited. When it comes to maintenance, i.e. periodic works, it is stated that SRA will prioritise the maintenance of road information systems, tunnels, bridges and road equipment over traffic safety. These statements indicate that the possibility of improved maintenance efficiency improvement is limited when the focus is mainly on operating practises and maintenance procedures, without proper attention being paid to the improvement potential in planning and design.

These statements also indicate that the efforts which the SRA makes to increase maintenance efficiency are mainly cost saving efforts rather than stimulation of maintenance activates. The focus is on the reduction of the rate of recurrence of maintenance activities and the prioritisation of some maintenance activities over others. Therefore many of these efforts will probably deteriorate the road maintenance standards. For example, developmental project “Review of Maintenance Activities (GAD)” has been carried out by the SRA with the intention of increasing maintenance efficiency. Some of the measures proposed by GAD have resulted in lower maintenance standards. For instance, visibility along the roads is decreased due to reduction of the mowing width from seven meters to three meters and due to the reduced of cleaning frequency of road reflexes. GAD and other similar projects are expected to give the SRA 70 million SEK in cost savings. However, the consequences regarding socio-economic costs are not stated.

3.4 Practical efforts to increase the efficiency of maintenance

Funding resources for infrastructure are seldom sufficient to insure the implementation of new projects as well as proper management, maintenance and rehabilitation of existing projects (table 3.5).

Table 3.5 Infrastructure funding gaps around the world (The World Bank 2008)

Canada	Closing Canada's infrastructure gap requires an investment of six to ten times the current annual governmnet infrastructure spending. Canada's local govenments face an annual infrastructure deficit of $ 60 billion
USA	The US infrastructure deficit totals about $ 40 billion a year in the road sector alone. The toatal US infrastructure investment need over the next five years is estimated to be up to $ 1.6 trillion.
Europe	The infrastructure need for the EU is estimatesd to be significant higher than $ 1 trillion. Germany alone requires infrastracture investments of about $90 billion each year
East Asia	The developing countries in East Asia need to invest about $ 165 billion per year over the next five years. China is estimated to acount for up to 80 percent of all regional infrastructure expenditures
South Asia	India is estimated to need about $ 250 billion of the infrustracture investment over the next five years
South Pacific	Australia's infrastructure deficit is estimated to be about $ 19 billion. New Zealand has an infrastructure gap of about $ 4 billion

Du to this fact, governments around the world are continuously searching for ways to improve efficiency and reduce expenditures. For this reason, the road authorities try to find other measures to increase maintenance efficiency, because a large share of the total expenditure for road infrastructure is maintenance costs.

3.4.1 Outsourcing of maintenance activities

According to the SRA, outsourcing of maintenance activities in competitive markets has been a successful option to increase the efficiency of maintenance and also to reduce the costs. However, the exact amount of the cost reductions is difficult to estimate. A study of maintenance outsourcing in Sweden between 1992 and 2001 has shown that the transaction costs for maintenance contracts for the outsourced maintenance areas are estimated to be at least 5% lower than for the non-outsourced maintenance areas (Liljegren 2003). Unfortunately, the effect of the outsourcing on innovation and technology improvements has been very limited, as the SRA has tried to engage the contractors in those kinds of improvements instead of having that function internally in the SRA (Thorman and Magnusson 2004). The interest for development among the contractors has been very limited as the development costs are often high compared with the benefits. In addition, the contractors have often refused to share their knowledge with others in order to maintain competitiveness.

3.4.2 Development of models for life-cycle cost analyses

Road authorities have developed models for life-cycle cost analyses with the intention to reduce the total costs for road infrastructures. These models have been mainly used for the selection of road construction types or pavement types. The Nordic Road Forum (NVF) has performed a study to survey the use of life-cycle assessments, annual costs, and life-cycle costs in road construction in the Nordic countries (Holmvik and Wallin 2007). The study has shown, that the models developed for analyses of life-cycle costs often consider the road authority’s costs such as investment costs and maintenance costs and sometimes, to some extent, user costs and other environmental costs. The study has also shown that none of the models can be used as a standard model since they are developed according to requirements for particular road projects. The disadvantages of the studied models include the use of unrealistic and roughly calculated maintenance costs and insufficient consideration of how the road design affects the maintenance costs.

3.4.3 New funding forms for road infrastructures

The road authorities aspire to develop new funding forms to bridge the infrastructure funding gaps. Public Private Partnership Project is one of those new funding forms, which are used to deal with the increasing demands for new road infrastructures. In the Public Privet Partnership projects, governments or road authorities assign the obligation to finance, design, build, operate, maintain and rehabilitate an infrastructure project to a private sector partner. As the contract is awarded to the bidder who provides the highest value, often the lowest cost over the term of the concession, the bidders strive to minimize the overall cost of the project, not only the initial cost for design and construction, but also the costs for operation, maintenance and rehabilitation. This leads to a solution that is not derived from the availability or non-availability of funds, but is determined by what is most cost efficient (Prarche 2007). Unfortunately, the influence of the road design on the road maintenance has been ignored in most of the Public Privet Partnership Projects which have been carried out up to now, especially in the Nordic countries.

3.5 Preformed studies concerning maintenance consideration during planning and design phases

Thorsman and Magnusson (2004) have identified some of the problems occurring during maintenance activities on the collision-free roads. The study has shown that the high maintenance costs for those types of roads are one of the problems which have been faced by the road authorities. According to the study, insufficient consideration of maintenance aspects and inadequate support for the designers during the planning and design process are the two major factors underlying the high maintenance costs. The study has suggested the following improvements:

- Improvement in the methods and technologies for maintenance activities to reduce the maintenance costs through reduction in intervention time and use of efficient tools.
- Creation of support functions, which will support designers and coordinate maintenance-related consulting between the parties involved.
- Improvement of the coordination and information sharing between contractors concerning the technologies and the methods used for the road maintenance.

Another study has been preformed to compile the factors in road design which decrease the needs for future road maintenance (Gaffeny and Gane 1970). Based on experience from the United States, some general advice has been given concerning the design of cuttings, embankments, bridges, bridge abutments, steelworks, street lightings, pavement types, pavement thicknesses and surface types. Calculations to confirm the statements and to quantify the positive effects on future maintenance have not been performed in the study.

A study by Olsson (1983) has described a new methodology for road construction design using annual cost calculations. In this study, it has been shown that the major factors that prevent the consideration of road management costs, including maintenance cost, during road design are difficulty of quantifying administration costs, time shortage and improper inexperience of the road designers regarding road maintenance. The study recommends a model for road design, which consists of the following three steps:

I. To choose the optimal design alternative, work with different design alternatives and calculate the annual cost, including the investment and maintenance costs.

II. Clarify the calculation presuppositions to offer enough information for the decision makers concerning the calculations and the included cost elements.
III. Estimate calculation accuracy statically or based on practical experiences.

Besides the costs for investment and maintenance, any other costs have not been considered in the model. Therefore, the model is very simple to apply, especially for small road projects which do not require calculation of socio-economic benefits.

Another study has examined economic and asset management implementation in the choice of a design life for the urban residential road pavements (Howard 1991). Life-cycle costs for 20, 50 and 100 years design life of road pavements have been analysed. According to the study, a 100-years design life gives the lowest life-cycle cost for urban residential roads.

Other studies concerning the design of pavements, bridges and specific roadside components have also indirectly considered maintenance aspects. For example, a study made by (Neuzil and Peet 1970) has determined the fill height of embankments whereby flattening of the slope proved to be cheaper than the installation of guardrails. Based on the cost-benefit analysis, maintenance costs have been considered in simplified graphs to determine the needs for road barrier installations (Wolford and Sicking 1997).

Another study has compared road barrier end terminals from a maintenance point of view in order to identify those types of terminals which are most profitable to use in order to decrease the future maintenance needs and costs (Mattingly and Ma 2002). This study has been based on practical experiences without any analyses of life-cycle costs or any evaluation of the factors which would affect the maintenance costs of the end terminals.

3.6 Conclusion

Based on the reviewed literature, the following calculation can be drawn:

- Maintenance costs around the world are continually increasing while the funding gaps in road infrastructure are getting greater and greater. As the maintenance costs constitute a large share of the annual expenditure for road infrastructure, the efficiency of maintenance activities is crucial for the reduction of annual expenditures. Increased maintenance efficiency requires sufficient considerations of the maintenance aspects during the planning and design process, since the maintenance workloads and the related costs among other things are a function of the design standard.
- In order to increase maintenance efficiency, the road authorities have made various efforts focusing mainly on the improvement of operating practises and maintenance activities. However, the improvement potentials in the planning and design process have been neglected. Some efforts are purely cost savings, as the main focus was on reducing the rate of recurrence of maintenance activities rather than on streamlining of those activities. Therefore, some of the efforts have, to some extent, depreciated the maintenance standard.
- Sufficient consideration of maintenance aspects during the planning and design process requires development of efficient models for analysis of life-cycle costs, including the maintenance costs.
- No standard model for analyses of the life-cycle costs of road infrastructures in the Nordic countries has been found in the studied literature. Existing models have been created according to requirements of particular road projects and have seldom been developed and used after that. Several models have been developed for selection of the pavement types and the related maintenance strategies. No models for calculation of life-cycle costs for road barriers, traffic signs and road geometry have been found. The

maintenance costs used in the models, are unrealistic and calculated rather roughly

- Proper implementation of the Public Privet Private Partnership Projects for increased maintenance efficiency would benefit from consideration of the improvement potentials of the road design and planning, as the maintenance costs are dependent on the design.
- Although insufficient consideration of the maintenance aspects during the road planning and design process is a well-known issue, the underlying causes and consequences have up until now, not been studied adequately and therefore improvements still remain to be made. The limited literature concerning the subject confirms this fact.

4 Problems taking maintenance issues into account when designing roads

This chapter presents the result of an investigation which was conducted in order to identify the problems which prevent appropriate consideration of maintenance aspects during the road planning and design process.

4.1 Introduction

Insufficient consideration of maintenance aspects during road planning and design has been a well-known issue in recent years within the road infrastructure sector, particularly among road maintenance contractors. There are different opinions regarding the underlying causes for this issue. According to maintenance contractors, this ignorance of maintenance aspects is due to poor knowledge among consultants and project managers, concerning road maintenance. They also believe that the absence of adequate coordination between maintenance contractors, consultants and project managers is another factor.

According to the consulting firms, the inadequate consideration of maintenance aspects is mainly due to the meagre interest that road authorities have for road maintenance. For instance, quotation requests usually do not contain any requirements relating to the maintenance aspects. Therefore, consultants do not have any reason to consider the maintenance aspects during the road design process. Another factor which contributes to inadequate consideration of maintenance aspects is the absence of a systematic feedback process between the actors involved in maintenance activities on one side and the consultants on the other.

Despite all of these different opinions and despite how serious this issue is, there are limited research studies concerning the importance of taking road maintenance into consideration during the planning and design process. Traditionally, activities regarding road investments are more interesting than road maintenance because new roads are given higher status than maintenance activities. Therefore, road authorities as well as governments have often prioritised new road construction over road maintenance.

Knowing all these facts, this research study started with an investigation to identify the problems which prevent adequate consideration of maintenance aspects during the road planning and design process. For this reason an evaluation of the process was of great importance. This investigation started with the collection of data to activities within this process; the actors involved, the goals which govern the process and the problems which are experienced by those involved. Later the collected data was analysed in order to identify the most urgent needs for changes to ensure due consideration of maintenance aspects during the road planning and design process.

4.2 The purpose of the investigation

The aim of this investigation was to:

- Identify the problems which obstruct due consideration of maintenance aspects during the road planning and design process.
- Identify the urgent need for changes to eliminate these problems. This was done by analysing the problems, analysing the planning and design activities and analysing the goals which govern the activities. However, any measures to implement the identified changes were not included in this investigation.

Implementation of the results of this investigation will contribute to the design of roads which will not require unnecessary and costly maintenance measures. This will increase the efficiency of maintenance activities dealing with future challenges regarding funding gaps.

4.3 Scope of the investigation

This investigation focused mainly on the road planning and design process at the Swedish Road Administration, SRA, which is in charge of both country and urban roads in Sweden. The SRA is also responsible for Swedish road design and maintenance specifications. However, the road planning and design process in Denmark, Finland and Norway were also roughly evaluated to gain a broader knowledge about the research subject.

4.4 Method

To identify the problems which obstruct due consideration of maintenance aspects during the road planning and design process, Activities carried out, the actor's experiences and situations that were perceived as problematic were analysed. The analyses also identified several needs for changes. However, any measures to implement the identified changes were not included in this investigation.

The investigation not only covered road planning and design but also other processes which in some way were related to the planning and design process. This gave a comprehensive overview of the road authority's organisation and led to identification of several problems and difficulties in other processes which could influence the planning and design process.

The investigation was carried out in two stages: Data collection and data analysis

4.4.1 Data collection

For identification and elimination of the problems which obstruct sufficient consideration of maintainability during the road planning and design process, it was necessary to evaluate the organization and its processes, its goals and regulations. For this reason the investigation started with collecting data pertaining to the following areas:

- Activities included in road planning and design.

- Actors involved in the activities.
- Goals and regulations which govern the activities.
- Documents which are created during the planning and design process.
- Organizational structure of the SRA.

The data was collected using interviews and a review of design-related documents. Interviews are an effective method of data collection as they give a good insight into the human beings' experiences, ideas, behaviour and feelings (May 2001). The main objective of the interviews was to invent situations perceived as problematic by the actors involved in planning and design or maintenance activities. A problem is defined as a situation which is experienced as unsatisfactory by the actors involved. Experiences from the situation deviate from the expected results or specific goals valid for the situation (Goldkuhl and Röstlinger 1998).

The objective of the study established the basis for the selection of the type of interviews. For this investigation semi-structured interviews were chosen which gave the respondents the possibility to answer in their own words which means that the interviews took the form of a discussion (Trost 2005).

The questionnaire used during the interviews consisted of two types of questions: general questions and specific questions (appendix 9). The general questions were designed to cover areas such as the road authority's organisational structure, goals for process, communication between actors, coordination of the activities, knowledge, and the guidelines and regulations which govern the working process within the road authority. The specific questions focused on problems associated with such road elements as roadside areas, road alignment, circulation places, road barriers, speed reductions measures and buss stops. The design of these features often results in unnecessary and costly maintenance measures due to insufficient consideration of maintenance aspects during design phases.

The respondents were divided into four categories: consultants, maintenance contractors, persons involved in maintenance activities and in planning and design at the SRA. Experience, organisational role, and geographical locations were the main criteria for the choice of respondents. The aim of having many categories of respondents was to see the problems from different perspectives and to collect as much information about the problems as possible. The respondents were also selected from different regions of Sweden to analyse how the geographical conditions affect road planning and design.

In total, 45 interviews were carried out with 53 persons. Some of the interviews were group interviews made with two to three respondents. The advantage of group interviews is the interaction within the group which stimulates interaction between the respondents and reveals different aspects. Using group interviews, the researcher is able to focus on those norms and dynamics which exist within the group in relation to the subject being discussed (May 2001). In addition, group interviews save time and resources. Unfortunately, the number of group interviews was very limited in this investigation. It was difficult to find a convenient opportunity for some respondents to participate in a group.

The interviews were recorded and saved as digital files in order to have the material available for later analyse. By recording the interviews the interviewer was able to focus on the discussions instead of writing notes.

The second part of the data collection was the review of documents which describe the processes of planning and design, construction and consignment (Vägverket 2004a, 2004b, 2004g, 2004f, 2004h, 2004i). Other reviewed documents were guidelines for road planning and design (Vägverket 2004c) and documents which describe the purchasing process (Vägverket 2004d). These documents were examined to identify planning and design activities, and the goals which govern the activities.

4.4.2 Data analysis

The second stage in the investigation was analysis of the collected data. As previously stated, the aim of this investigation was to identify those problems and difficulties which prevent due consideration of maintenance aspects during the planning and design phases. The most important part in this stage of the research was to identify the problems as well as their causes and effects. Another part was to examine the actions of the various actors involved in the planning and design process. The rate of recurrence of the problems and the related costs was also analysed in this part. A qualitative research method was chosen for the analyses of the collected data.

The method used for the data analyses in this investigation is called “Change analysis” and it is mostly used in the preliminary phases of investigations intended to develop organisations or activities. The method can be used for development of products/services, principles of economical management, employees, administrative working routines or data systems. The method can also be used in connection with reorganisations (Goldkuhl and Röstlinger 1998). Through “Change analysis” one can diagnose problems and activities and suggest necessary and suitable measures for change. In “Change analysis” the following questions are gone through and answered:

- What are the problems?
- What are the activities?
- What are the goals to be fulfilled?
- What are the problems to be eliminated?
- What measures are taken to fulfil the goals and eliminate the problems?
- What consequences can be expected if the measures are undertaken?

- Which combination of measures are the most optimal for the overall problem situation?

“Change analysis” consists of four areas: analysis of problems, analysis of activities, analysis of goals and analysis of needs for change.

4.4.2.1 Analysis of problems

The aim of this analysis was to obtain an overview of the situations identified as problems and to describe their causes and consequences. The analysis was carried out in four steps: formulation of problems, classification of problems, delimitation of problem areas, and analysis of the relations between the problems.

Formulation of the problems

In the interviews, the problems were often described in many words and explained with a lot of examples. Some problems described in different ways proved to be more or less the same problem. The problem description was then reformulated to combine several descriptions into one. The formulation of the problems was carried out without any restriction concerning type or origin of the problems in order to create a realistic and comprehensive picture. The problem formulation was conducted gradually until the descriptions became distinctive, understandable, unique, descriptive, well based and less complicated.

Classification of problems

The previous activity resulted in a list of problems covering many different problem areas. To avoid working with all the problems simultaneously and to create a basis for further analysis a structure was created by classifying the problems into problem areas. Similarities between the problems were identified, e.g. similar subjects, causes or effects. Problems related to the same subjects, causes or consequences were included in the same problem area.

Delimitation of problem areas

In the beginning of the investigation, there was an understanding regarding the kinds of problems to be included in the investigation but that was vague and insufficiently described. The aim of the delimitation was to specify those problem areas which would be included in the "Change analysis". Owing to time and resource restrictions, it was necessary to concentrate the investigation on the most urgent problem areas. Some problems were also excluded as they were considered to be beyond the scope of this investigation.

Analysis of relations between problems

The intention of the analysis of the relationship between problems was to find any connection between them in order to understand the problematic situation as a whole. The relationships between the problems were analysed through studying each problem individually to find its connection to the other problems. This analysis was a cause/consequence correlation (figure 4.1).

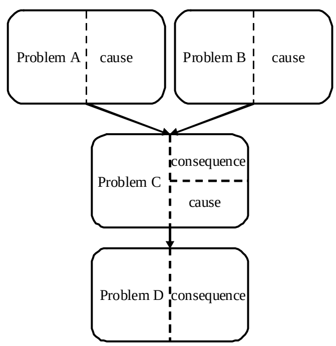

Figure 4.1 Principle for analysis of relations between the identified problems

Problem C is caused by factors A and B (cause correlation). Problem C results in problem D (consequence correlation). Factors A and B have to be considered as problems as they are the underlying causes for problems C and D. To eliminate problems C and D both problems A and B should be eliminated. For each problem area, this principle was used to illustrate the connection between the problems in the form of a graph called problem graph. These graphs were the basis for the evaluation of the problems during the analysis of needs for change. This gave a structure to each problem area. In some cases, the analyses of the relationships were interrupted when it came to causes which were too unrealistic to be included in this investigation.

4.4.2.2 Analysis of activities

The aim of this analysis was to evaluate the activities included in the planning and design process in order to understand how the process was conducted and to identify problems not mentioned by the respondents. The planning and design process at SRA consists of four subprocesses: a feasibility study, road survey, creation of work plan, and creation of construction documents. In addition, this analysis also covered three other subprocesses: Purchasing, Construction, and Consignment. The latter three are not part of the planning and design process but they still have a direct influence on that process (figure 4.2).

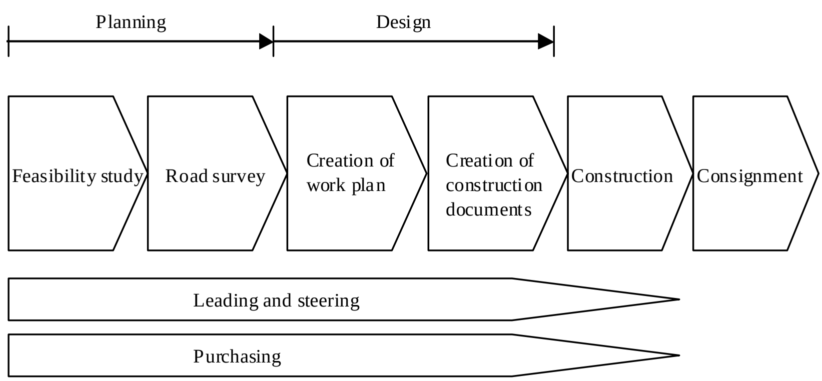

Figure 4.2 the processes which were included in the activity analysis

Analysis of the activities began by describing action patterns within each subprocess to clarify how different documents were treated and how administration activities were performed within the processes. The sequence of activities, the results and the responsible actors were identified. The correlation between the activities and between the actors responsible for conducting the activities were illustrated by describing the flow of documents between different activities, methods of consulting and cooperation as well as the relationship between actors.

4.4.2.3 Analysis of goals govern the road planning and design process

This analysis aimed to identify the goals which the planning and design process has to fulfil, and to examine and evaluate correlations between them. The analysis was carried out in three steps: identification of goals, analysis of the relation between goals and evaluation of goals.

Identification of goals

The aim here was to identify the goals which govern the planning and design process. These were identified both by reviewing documents in which the goals are stated and by analysing the recorded interviews. Efforts were taken to differentiate between the overall goal and the sub-goals.

Analysis of the relation between goals

This analysis aimed at determining in which way sub-goals contribute to the fulfilment of each other and to the overall goal. The fulfilment of each goal was examined to determine if it had negative or positive contributions to the fulfilment of other goals.

Evaluation of goals

The intention of this phase was to identify goals relevant to maintenance aspects during planning and design. This was done by examining how the existing goals can have an influence on how the maintenance aspects must be considered during planning and design.

4.4.2.4 Analysis of needs for change

The purpose of this analysis was to identify the most urgent needs for change which are necessary for adequate consideration of maintenance aspects during the road planning and design process. The needs were analysed in order to find measures to satisfy those needs. The earlier analyses of problems, activities and goals constituted the basis for this analysis which was conducted in three steps: evaluation of the problems, analysis of possibilities and strengths, and formulation of the needs for change.

Evaluation of problems

The objective of the evaluation of problems was to identify the most important problems to be solved and to find the problems pertinent to the needs for change. The analysis of problems was the basis for this evaluation, see subsection 4.4.2.1.

During this phase the problems were divided into three different statuses according to the following criteria:

- No solution to the problem (NSP): if the problem has no solution or has a solution outside the scope of this investigation.
- Solved problem (SP): if the identified problem was already solved or in the process of being solved.
- Needs for change (NC): these problems seem urgent to eliminate and they can be eliminated by changes within the planning and design process and the other related subprocesses.

For the last category of problems, priority was set according to the following criteria presented without priority:

- A problem which was the cause for several other problems
- A problem which was connected to high costs or which could result in serious consequences
- A problem which was crucial to the solution of another problem
- A problem which was stressed during the interviews
- A problem which was relatively simple to eliminate, thus generating a large positive effect for little effort.

Generally, a low priority was given to problems which could be solved entirely by solving another problem. The problems given the status NC were all given a priority according the above mentioned criteria. The sum of priorities from all criteria gave each problem the priority high or low. In the problem graphs the problems given high priority were then analyzed further by combining them and analyzing the consequences of changes. Based on this the most urgent needs for change were formulated. The aim of this activity was to indicate needs for changes which could contribute to the elimination of the identified problems. The changes were identified without specifying any measures to fulfill them. In this phase of the investigation it was important to focus on the problems and also to study strengths and possibilities which the road authority and others involved in planning and design have.

The analysis of possibilities and strengths

The aim of this analysis was to generate ideas for changes by focusing on different possibilities and strengths, for example: better utilization of research results and experiences among the staff at road authorities, consultants and contractors as well as experiences from other countries and other industrial sectors. To a large extent, this phase was based on the results of the literature review presented in chapter 3.

Formulation of needs for change

The evaluation of problems and the analysis of possibilities and strengths formed the basis for the formulation of the needs for change. Here the goal was to identify the most urgent changes which could contribute to the elimination of the identified problems. The changes were identified without specifying any measures to fulfil them.

4.4.3 Comparison of the Swedish condition to other Nordic countries

Insufficient consideration of maintenance aspects during the planning and design process is not a unique phenomenon for Sweden. Regarding road maintenance as a low priority is an international phenomenon. The degree of consideration of maintenance aspects seems to differ between countries depending on variations in the planning and design processes as well as in the forms of road infrastructure funding. To gain a broader knowledge about maintenance aspects, an investigation was conducted focusing on the Nordic countries. The aim of this investigation was to:

- Identify the problems which obstruct sufficient consideration of maintenance aspects during the planning and design process in the Nordic countries.
- Compare the problems earlier identified in Sweden to the problems identified in the other Nordic countries.

The investigation started in the same way as in Sweden with an inventory of the situations experienced as obstacles for due consideration of maintenance aspects by the involved parties in both the road design and road maintenance process. Semi-structured interviews were used (Trost 2005). As a basis for the interviews, a questionnaire was used which included two types of questions (appendix 10). The first type was generall questions concerning the planning and design process as well as the organisational structures and related goals. The objective with this type of question was to give the respondents a chance to describe the phenomenon, the underlying causes and the related consequences in their own words without any restrictions. The second type was specific questions formulated and based on the problems previously identified in the investigation conducted in Sweden. The main objective with these questions was to study similarities and differences between the problems identified in Sweden and the problems identified in the other Nordic countries. The interviews were recorded and saved as digital files in order to have the material available for later analyses.

Like the investigation conducted in Sweden, the problems identified in this investigation were also described in many words and in several different ways. Therefore the problems were reformulated and analysed using the principles described in subsection 4.4.2.1. The problems were then compared.

The most difficult task in this investigation was to find people who were aware of the phenomenon and willing to take part in the interviews. Over 20 persons from the Nordic countries were asked to take part in the interviews and propose other persons suitable to be interviewed. They were either members of the Nordic Road Forum (NVF), or recommended by other members of NVF. Despite three months of effort, only seven persons were willing to be interviewed: four respondents from Norway, two from Denmark and one from Finland. The explanation for this low response was probably a combination of limited knowledge concerning the subject and a feeling that the subject could be sensitive. Maintenance experts were underrepresented in the investigation as three respondents were road designers and three were project managers.

4.5 Results

This subsection presents the result of each analysis separately following the same structure in which the method of “change analyses” was presented in the method subsection.

4.5.1 Analysis of problems

As mentioned before, this phase was carried out in four steps: formulation of problems, classification of problems, delimitation of problems, and analysis of the correlation between the problems.

4.5.1.1 Formulation of the problems

During the interviews the respondents presented more than 100 situations perceived as problems preventing sufficient consideration of maintainability. Most of the problems were identified during the interviews. A few more were identified during the analysis phase. The analyses reduced that number to 46 problems shown in the “Problems list” presented in appendix 1.

4.5.1.2 Classification of problems

The problems identified and formulated in the previous phases were classified into six different problem areas: insufficient consulting, insufficient knowledge, regulations without consideration of maintenance aspects, insufficient planning and design activities, inadequate organisation and demands from other authorities. The classification was carried out by analysing similarities between the problems, e.g. similar subject, similar activity, similar causes or effects. This classification is illustrated in figure 4.3 and in the "Problem-area document" which are presented in appendix 2.

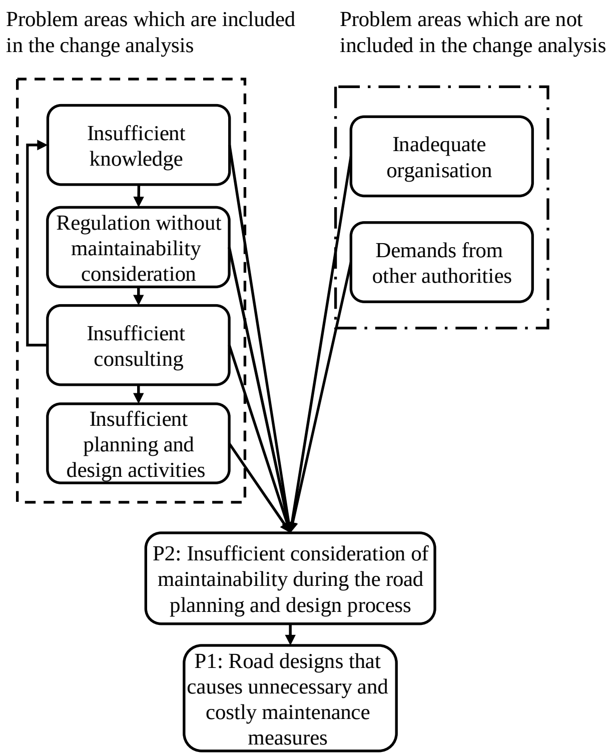

Figure 4.3 Classification and delimitation of the problem areas

Insufficient Consulting: This problem area consists of problems related to insufficient consulting between actors involved in maintenance activities and in planning and design. Consultation between those actors is mostly unsystematic and limited to only a few meetings; several of those are arranged during the construction phase. Any design correction during these late phases will be difficult and costly.

Insufficient knowledge: This problem area contains problems related to knowledge regarding road planning and design as well as road maintenance. Insufficient consideration of maintenance aspects often depends on the fact that project managers or consultants do not have sufficient knowledge about the costs and performance of maintenance activities.

Regulations without consideration of maintenance aspects: In this problem area the problems are associated with regulations regarding the planning and design process. These regulations are often created without sufficient consideration of maintenance aspects, something which the consultants seldom are aware of. As a result road designs according to these regulations will not cover maintenance aspects.

Insufficient planning and design activities: This deficiency results in the selection of road designs which require costly and unnecessary maintenance activities. For example, a limited investment budget forces project managers and consultants to select cheaper road designs which require costly maintenance measures.

Inadequate organisation: Problems which belong to this area are related to the organisational structure of road authorities. A linear organisation often leads to poor coordination between different processes and activities within the road authorities which results in poor exchange of knowledge and experience.

Demands from other authorities: Problems in this area are related to the requirements from authorities, such as municipalities and county administrations. These requirements have in some cases negative effect on maintenance aspects. Some requirements can force road authorities to choose road designs for aesthetic or regional development reasons which are uneconomical to maintain.

4.5.1.3 Delimitation of problems

Subjects for further analysis were four problem areas: insufficient consulting, insufficient knowledge, regulations disregarding maintenance aspects, and insufficient planning and design activities. These problem areas have a direct connection to the planning and design process.

The problem area regarding inadequate organisation was excluded in this investigation because organisations are frequently changed and differ considerably among road authorities. The problem area related to demands from other authorities was also excluded. Examination of these problems requires an in-depth analysis of authorities such as municipalities, other county administrations and EU organisations which requires a lot of work but with probably minimal benefits. The delimitation of problem areas is illustrated in figure 4.3 which also describes the relations between problem areas.

4.5.1.4 Analysis of relations between problems

This analysis revealed the causes and consequences of each problem. A structure in the form of graphs called "problem graphs" was established for the problems within each problem area. These graphs constituted an important basis for identifying problems which caused other problems or were consequences of other problems and crucial for elimination of other problems according to the priority criteria. The result of this activity was presented in the "Problem graph" which is shown in appendix 3.

4.5.2 Analysis of activities

The analysis of activities made the correlation between planning and design activities more understandable. The divisions responsible for planning and design were identified together with other involved divisions at the SRA and other involved organizations. In addition, the input and output for each activity were illustrated. A few more problems mentioned in the problem list were identified during this analysis. This analysis also revealed in which activity a particular problem originated and also how difficult it could be to solve it. The result of this activity was presented in the "Action graphs" which are illustrated in appendix 4.

4.5.3 Analysis of goals that govern the planning and design process

The SRA controls its activities through demands for established goals and results formed on the basis of society's needs. The basis for these goals is the overall transportation-related policy goal which was established by the Swedish Parliament in 1998.

4.5.3.1 Identification of goals

The overall transport-related policy goal in Sweden is a socio-economically efficient and long-term sustainable transport system for individuals and business communities throughout the country (Vägverket 2006a). This comprehensive goal is clarified in six sub-goals. For each secondary goal one or more long- term stage goals are established. Each stage goal is broken down into one or more operational goals which are short-term goals formulated during the annual activity planning. The operational goals constitute the basis for the creation of several specific project goals for each road construction or road improvement project. These project goals, which are unique for each project, are formulated during the subprocesses of the road investigation. Figure 4.4 shows the goal structure for SRA. In addition to the above mentioned goals, which are considered documented goals, there are other important aspects which also control planning and design, e.g. budget or time restrictions. These aspects can be considered as non-documented goals and they are just as important as the documented goals. This activity results in the "List of goals" which is presented in appendix 5.

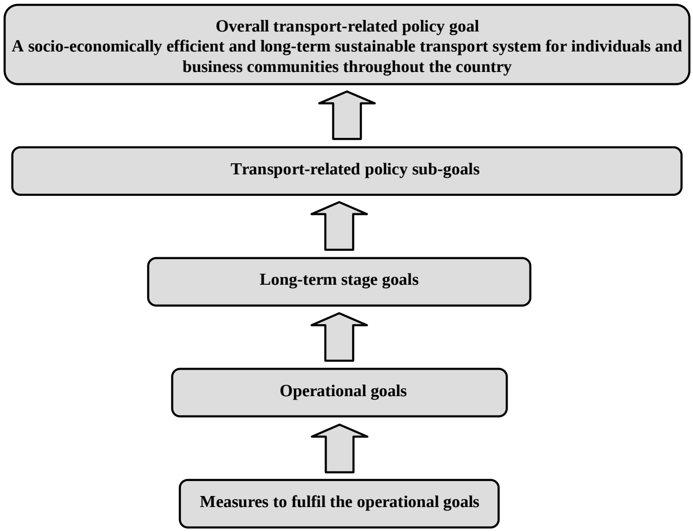

Figure 4.4 Goal structure within SRA's organisation

4.5.3.2 Analysis of the relation between goals

To achieve the project goals for each road construction project, several measures are chosen. An important basis for the selection of a particular measure is SRA's document "New construction and improvement – influence correlations" (Vägverket 2001) which describes the consequences of the different measures taken within the road transportation system. For example, to increase traffic safety on a specific road section, a reduction of the number of fatalities and severe injuries by a certain percentage can be formulated as a specific project goal. To achieve this project goal, measures such as separation of conflict points, level-separated intersections, safety barriers and wildlife fences can be taken.

Usually, a selected measure which aims to achieve a specific project goal has a negative effect on other specific project goals for the same project, and thus conflicts between goals arise. An example of such a conflict is the selection of speed-reduction measures which increase traffic safety at the expense of traffic quality and accessibility. Other conflicts appear due to the restricted budget frame which sets a limit for the selection of efficient measures. To reduce goal conflicts, measures are selected after balancing the different project goals. This balancing is often performed by using socio-economic cost-benefit calculations. A specific measure seldom leads to achieving all the goals. This analysis resulted in the "Goal Graph" which is shown in appendix 6.

4.5.3.3 Evaluation of goals

The analyses of goals revealed that the SRA has not established any clearly defined long-term goals concerning future maintenance and confirmed that this is a problem and a source for other problems. None of the stage goals or operational goals covers maintainability even if the overall transportation-related policy goal indicates a cost efficient transportation system. Absence of well-defined goals concerning maintainability leads to insufficient consideration of these aspects. Due to this fact, requirements to fulfill existing operational goals concerning other aspects often direct planning and design towards the selection of road designs which may require costly and unnecessary maintenance measures.

Non-documented goals, e.g. the budget frame, also dictate planning and design. For each project, a budget is established during the sub-process of road investigation. This budget is often set many years before the construction work begins. The presuppositions and calculations made in that budget can subsequently be out of date which means that the costs may be underestimated. This can force road authorities to select designs with low acquisition costs which later may incur high maintenance costs.

4.5.4 Analysis of needs for change

This analysis resulted in the identification of several genuine needs for changes to eliminate identified problems regarding sufficient consideration of maintenance aspects during planning and design. This analysis consisted of three activities: evaluation of problems, analysis of possibilities and strength and formulation of needs for change.

4.5.4.1 Evaluation of problems

Based on the problem graphs, the identified problems were classified into four different status groups: 37 problems with “needs for change” status (NC), seven problems with “no solution to the problem” status (NSP) and two problems with “solved problem” status (SP). Prioritizing the NC problems in accordance with the five criteria, mentioned in the methodology paragraph, resulted in 24 problems with high priority and 13 problems with lower priority (appendix 1). More details about this activity are presented in the “Problem status” which is shown in appendix 7.

4.5.4.2 Analysis of possibilities and strength

Analysis of possibilities and strengths was base on a formulation of the needs for change. As a result of this analysis the following possibilities and strengths were pointed out:

Extensive maintenance experience: Road authorities have substantial and often excellent, but seldom properly documented, experience regarding road maintenance. This experience is useful to ensure an adequate consideration of maintenance aspects in the design related guidelines and regulations and during the planning and design process.

Research studies and developments in the road technology fields: There are many maintenance related studies which are preformed by road authorities or other institutes in Sweden and abroad. For example, there are many internal investigations made by SRA’s regional offices focusing on maintenance issues. These studies contain a large amount of well documented information that should be valuable when considering maintenance aspects during the road planning and design process. One problem is that the results often are documented in scientific reports, which can be hard to adopt and utilize in practice.

Available technical means: There is a wide range of technical means and IT-tools which can be useful when considering maintenance aspects during the planning and design process. For example, there are computer-based calculation programs used by maintenance contractors to calculate the costs of new maintenance contracts. With some adaptations, those programs also can be used to calculate future maintenance costs for different proposed road designs. Another example is a computer-based application which is used to determine road alignments or corridors which have the lowest temperature divergences (Gustavsson et al. 1998). Road alignment with a low temperature divergence is expected to contribute to lower winter maintenance costs through decreased needs for anti-skid measures.

Research studies and developments in other fields: Design with focus on future maintenance needs has been the subject for developments in many other fields. For example, within the industrial fields there are two principles developed for design or formation. The first principle is “Design for maintenance” which means design of components that have optimal live cycle cost and are easy to replace, e.g. car components. The second principle is “Design out maintenance” which means design of components that do not need any future maintenance, e.g. satellite components (Markeset and Kumar 2001). The road authorities should examine the possibility to adopt these principles in the road infrastructures sector.

4.5.4.3 Formulation of needs for change

On the basis of the problem and goal evaluations, several needs for change were identified. The most urgent need is the establishment of well-defined and long-term stage goals for road maintenance. These stage goals should be possible to break down into operational goals which give maintenance aspects significance in the planning and design process. It must also be possible to evaluate the fulfilment of the operational goals at the end of each road project. An optimal life-cycle cost including maintenance costs can be such an operational goal.

During the planning and design process, there is a great need for well-structured systems for consulting and knowledge exchange between the actors involved in maintenance and planning and design activities. The consulting process has to be carried out by designated actors and through well-defined activities in accordance with the established guidelines. Consulting expenses should be a specified part of the planning and design budget.

Increased knowledge regarding road designs which include support for future maintenance is needed for road authorities, contractors and consultant firms. This knowledge is the basis for adequate consideration of maintenance aspects. This requires an efficient feedback system from the maintenance process to the planning and design process and vice versa. A part of such a system is registration of expenses for maintenance measures which had to be performed due to inappropriate road design.

It is recommended that an evaluation process with clear guidelines be carried out for each completed road project as a part of the quality assurance system. This process should ensure that the possibilities of performing maintenance measures are considered to a satisfactory extent for each road project. Experiences from such evaluations should be registered in data bases in order to be readily accessible to avoid improper road design in future projects.

There is a great need to complete guidelines, legislation and other documents governing planning and design with focus on maintenance aspects. This can ensure an automatic consideration of maintenance aspects during the planning and design process.

Requests for quotations and other purchasing related documents should contain clear guidelines concerning maintenance aspects. For example: requirements for maintenance management plans or requirements for optimisation of life-cycle costs have to be considered in requests for quotations. Coordination and consultation concerning maintenance aspects has to be another requirement in the requests for quotations.

There is a need for increased incentives for the consulting firms in order to get them to pay more attention to maintenance aspects during planning and design. Compensation in the form of bonus points during the evaluation of quotations can be an option for consultants proven to consider maintenance aspects.

The result of this activity is presented in the “List of Needs for Change” which is shown in appendix 8. This document also shows the problems which can be eliminated with each proposed change.

4.5.5 Problems which prevent sufficient consideration of maintenance aspects in the Nordic countries

Based on the interviews which were conducted with experts involved in the planning and design process as well as in the maintenance process in the Nordic countries, the following problems were identified:

1. Traditionally, the interest in road maintenance has a low priority among politicians. The construction of new roads is considered to be more important than their maintenance. An explanation for this is that a new bridge or new highway section often are noticeable landmarks whereas maintenance measures are usually only noticed if the work is not done properly.

2. Insufficient consideration of maintenance aspects during planning and design is partly connected to the lack of interest of road authorities' management to give road maintenance a high priority. The focus is mostly on other aspects, such as environment, traffic safety and investment costs. This lack of interest in maintenance is a logical result of insufficient knowledge regarding the consequences of neglecting maintenance and the politicians' lack of interest in road maintenance.

3. The absence of clear goals concerning road maintenance in the Nordic countries has resulted in insufficient consideration of that aspect during planning and design. The absence of such goals is a result of limited interest from politicians and road management authorities to give maintenance a higher priority.

4. Limited funding for road infrastructure results in limited investment budgets. To deal with this problem, project mangers are forced to select cheaper material at the expense of durability. They are also forced to reduce the cost of the planning and design process which gives limited opportunities for discussion of alternative solutions and consideration of life cycle costs. Public Private Partnership Projects are exceptions to the rule where the designer and the bidders are forced to focus on the maintenance aspects in order to reduce the total life-cycle costs of the road construction over its service life.

5. Limited knowledge regarding road maintenance and its associated costs as well as the negative consequences due to inadequate designs are other factors which underlie the ignorance of maintenance aspects during the road planning and design process. The factors which contribute to this knowledge deficiency are:
   - The costs of the maintenance activities and the related economic consequences resulting from inadequate consideration of maintenance aspects are not properly pursued.

- In some of the Nordic countries, systematic consultation between the maintenance department and the construction department is limited which prevents exchanges of knowledge. Limited resources, insufficient organisational structure and the absence of clear consultation guidelines are major factors underlying this limited consulting.
- Road authorities seldom have an appropriate feedback process between the maintenance departments and the departments responsible for road planning and design or construction. Therefore, knowledge about maintenance aspects can hardly be spread within the organisation. Some of the road authorities have established networks which are responsible for knowledge transfer within the organisation. Unfortunately, those networks are often established within the same department and do not involve experts from other departments.
- Maintenance aspects are very seldom included in the evaluations of the projects when the construction work is completed.

6. Road designers do not have sufficient knowledge or experiences concerning road maintenance. The major factors which underlie this are:
   - Road designers often begin their careers directly after graduation. Experience with maintenance work is not an essential requirement during the recruitment of the designers as the road authorities only require consultants with relevant construction experience.
   - Maintenance knowledge is usually not considered in road engineering education programs.
   - The status of construction experts has traditionally been higher than the status of maintenance experts. Therefore, road design has been more attractive for newly graduated engineers than road maintenance. Another factor which makes road design more attractive is that salaries paid by

consulting firms normally are higher than salaries paid by maintenance contractors.

7. Inadequate consideration of the maintenance aspects in planning and design related regulations and guidelines.

8. When requesting a quotation, road authorities do not require maintenance aspects to be considered or the involvement of maintenance experts during the planning and design process. Therefore consulting firms also ignore this aspect to reduce the design costs and retain competitiveness.

9. The consideration of safety or aesthetic aspects during the planning and design process often requires selection of road designs or road components which require costly maintenance measures. Such designs can not be prevented as those aspects are given high priority compared to the maintenance aspects. In some other cases, curiosity or the ambition to stimulate technical development makes designers select new road designs or components which require costly maintenance measures. The designers are not required to think about future maintenance needs as long as road authorities do not require any maintenance plan descriptions.

10. Road designers do not strive for road designs which give an optimal life-cycle cost. Normally, analyses of life-cycle costs are not conducted because:
    - Road authorities do not require any life-cycle cost analyses for the selected road designs or components during the planning and design process.
    - A standard model for calculation of life-cycle cost does not exist.
    - Accurate data relating to maintenance costs are not available as those costs are not appropriately registered.

11. The parties involved in the planning and design process normally do not have any incentives which encourage consideration of maintenance aspects during the road planning and design process. The Public Private Partnership Projects are exceptions where low future maintenance cost is a strong incentive.

It is obvious that the problems can be divided into five problem areas: inadequate organisation, insufficient planning and design process, insufficient knowledge, insufficient consulting and regulation for planning and design without consideration of the maintenance aspects. Despite this classification, the problems are strongly related to each other. Therefore, many of the problems can not be solved independently from the others. However, elimination of some of the problems can be prioritised above others, depending of how the solutions affect the phenomenon as a whole.

It is also obvious that the problems which prevent sufficient consideration of maintenance in the Nordic countries, including Sweden, are very similar. An explanation for this similarity is that the principles of planning and design are to some extent similar in all Nordic countries. However, the implementation of new forms of road funding or contracts, e.g. The Public Private Partnership Projects and implementation of performance-based contracts in Finland and Denmark, has forced the road authorities in those countries to consider maintenance aspects to a greater extent. However, in neither of those two countries are maintenance aspects given adequate consideration in the traditional forms of contracts or road funding.

4.6 Conclusion

This investigation has indicated a complex combination of problems which result in inadequate consideration of maintenance aspects during the road planning and design process. The problem areas which contribute to the main problem are also affected by the existence of related problems found in other problem areas. For example, inadequate consulting leads to a lack of knowledge concerning maintenance aspects which in turn leads to regulations lacking consideration of these maintenance aspects and inadequate planning and design activities. On the other hand regulations without consideration of these maintenance aspects result in inadequate consulting as illustrated in figure 4.2. This indicates that the problem areas are closely related. None of the problem areas can be isolated and eliminated from the others. On the other hand, the elimination of one problem area may contribute to the elimination of problems in other areas.

The absence of a well defined goal concerning maintenance is a fundamental basis for the inadequate consideration of maintenance aspects. This is also the reason why insufficient consideration of maintenance aspects is not considered as a problem. The non-existence of such goals makes road authorities more concerned about the fulfilment of goals concerning other aspects which often results in road designs with costly and unnecessary maintenance requirements.

The analysis of the activities confirms the respondents assertions regarding poor consultation or communication between the actors involved in maintenance activities and in the road planning and design process. One reason for this can be an inadequate organisational structure within the road authorities.

On the basis of the analysis of the problems, activities and goals the following needs for changes have been identified in order to eliminate the inadequate consideration of maintenance aspects during the planning and design process:

- An urgent need for the establishment of well-defined long-term goals for maintenance, and methods to evaluate the fulfilment of these goals.
- Development of well-structured systems for experience exchange and consulting between the actors involved in maintenance activities and in the planning and design process.

- Increased knowledge regarding road maintenance among actors involved in planning and design.
- Development of a systematic evaluation process with clear guidelines for examination of completed road projects to ensure adequate consideration of maintenance as a part of a quality assurance system.
- Addition of maintenance aspects in the planning and design related guidelines, regulations and other documents.
- Creation of guidelines and requirements for future maintenance considerations, which should be incorporated into requests for quotations and other purchasing related documents.
- Creation of incentives for consultants to consider maintenance aspects during the planning and design process to a satisfactory extent.

The implementation of these changes requires further studies to establish effective and long-term solutions. Avoidance of measures which require a lot of resources is important. At the same time, it must be realised that efforts aimed towards change and development always require new resources. The optimal solution may be to select measures which can solve several problems at the same time. It is also important to study all the possible positive and negative consequences of the measures for the actors involved in planning and design.

A life-cycle cost model will contribute to sufficient consideration of maintenance aspects during the road design. Such a model will constitute a basis to select the design which gives the optimal life-cycle cost. The next step in this project is to collect information relating to maintenance costs. These studies will be conducted as case studies, initially including only road barriers. Together with data about acquisition, the maintenance costs will be applied to a life-cycle cost model. This model will then be expanded to include other road components.

5 A case study for analysis of road barrier repairs and associated costs

This chapter presents a study which was conducted with the purpose of analyzing the repair costs of road barrier damage and the factors influencing these costs. The types of barriers, roads, speed limits, barrier placement and seasonal effects were all taken into account. The study was carried out using a method called “Case Study Research Method”. Data was collected from 1087 barrier repairs. Data relating to roads, traffic and barriers was collected from different sources. For each regional office, repair costs for different combinations of barrier types, road types and speed limits were correlated to the traffic works in order to measure the influence of the these factors. The data for each region was analysed separately. A comparison between the two regions was conducted to generalize the findings. Figure 5.1 shows the steps which were followed to carry out the study. Each step is described in this chapter.

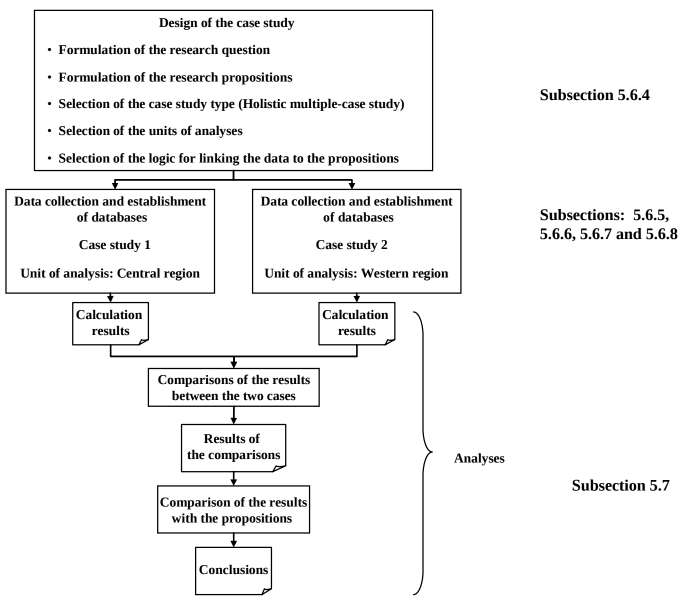

Figure 5.1 Structure of the case study

5.1 Background

The majority of maintenance costs for road barriers are due to repairing damage caused by vehicle impacts. Therefore repair costs should be the prime consideration, especially in areas where traffic volume is extremely high and vehicle impacts with barriers are frequent. This usually occurs along roads in urban regions, where repairs are difficult for maintenance staff to perform without interfering with traffic.

The number of repairs and the repair costs for barrier damage depend upon a number of factors including speed limit, traffic volume, road alignment, seasonal effects, barrier strength and the distance between the edge of the traffic lane and the barrier itself.

According to road designers, limited data pertaining to maintenance costs for barrier repairs is the major obstacle, in the road design phase, preventing due consideration of the total costs for barriers throughout their service life. In addition, consequences of the influencing factors mentioned above are still unclear as research in this field so far has been very limited. For the designers, consideration of the consequences of these previously mentioned factors during the selection of the barrier type is an impossible task in absence of a calculation model for repair costs taking these factors into consideration. Therefore, the designers often assume that the maintenance costs for all types of road barriers are the same and they therefore focus mainly on performance requirements, initial costs and aesthetic aspects.

5.2 Objective

The purpose of this case study was to:

- Develop a model for calculation of annual repair costs for damages of different road barrier types.
- Analyse how factors such as road type, speed limits, barrier types, barrier placement, type of road section, alignment and seasonal effects affect barrier damage and the related repair costs.

5.3 Delimitation of the Case Study

The types of road barriers which were considered in this case study were cable, w-beam barrier, Kohlswa-beam barriers and pipe-beam barriers. However, the analyses focused mainly on cable and w-beam barriers as they are the most common barrier types in Sweden. Data collection regarding repair costs was limited to 1087 barrier repairs in two of the regional offices of the Swedish Road Administration. The investigation into the costs focused on the costs of both roadside and median barriers but the model for calculation of the annual repair cost was established only for the median barriers due to limited data available for roadside barriers. The socio-economic costs were excluded in this case study. Still, some consideration was given to costs for vehicle damages due to impacts with road barriers. The study was limited to four road types: motorway (MW), four-lane roads (4-Lane), collision-free arterial roads and collision-free country roads (table 5.1).

Table 5.1 Lengths of different road types in the studied regions during 2006

		Road length (km)						
		Motorways	**%**	**Collision-free roads**	**%**	**4-Lanes**	**%**	**Total**
Central Region	**All roads**	199	22.0%	652	72.2%	52	5.8%	903
	Studied roads	199	25.6%	527	67.7%	52	6.7%	778
Western Region	**All roads**	969	63.5%	343	22.5%	213	14.0%	1525
	Studied roads	773	72.4%	89	8.3%	206	19.3%	1068

5.4 Geographical area of the research

The geographical area which was covered in this research was two regional offices of the SRA: the Central Region and the Western Region. This choice was based on the fact that the two regions differ regarding traffic volume, climate and to some extent routines for carrying out maintenance. Despite the differences it was expected that the effects of the influencing factors on barrier repairs would follow the same pattern in both regions. Table 5.2 shows some distinguishing characteristics for the regions.

Table 5.2 Characteristics of the studied regions

		Central region	Western region
Road network (km)*		20 218 580	20 454 675
Roads in urban regions (km)*		778 895	1 086 000
Road types (km)*			
	Motorways	198 056	935 177
	Arterial roads	9 632	24 686
	Collosion-free arterial road	146 710	96 126
	4-lane roads	51 877	230 033
	Country road	19 293 338	1 890 533
	Collosion-free country road	505 592	252 886
Annual traffic work (Mvkm)*		6 625	13 802
Population**		941 296	2 038 846
Climate , see figure 5.2**	Climate Zones	3, 4 and 5	1, 2 and 3
	Average annual tep. C°	(-2) - 4	4 - 8
	Max snow depth (cm)	20 - 50	50 - 70
Forest area (kha)**		7 900	1 953
Length of median barriers (km)*		611 186	329 952
Median barrier types*		Concrete	Concrete
		Kohlswa-beam	Kohlswa-beam
		Pipe	Pipe
		Cable	Cable
			W-beam

* Source: SRA

** Source: Sveriges Atlas

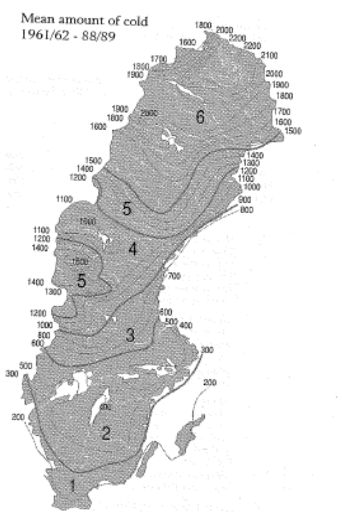

Figure 5.2 Climate zones, mean amount of cold (days times – ºC) (Vägverket 1994)

5.5 Road barriers

Road barriers are used to prevent vehicles from veering off the roadway into oncoming traffic, crashing into solid roadside objects or falling into ravines. Road barriers are also used to protect pedestrians and cyclists from the vehicular traffic (ASHTO 1996).

Conditions that warrant shielding by roadside barriers are the height of the embankment, the side slope and the presence of roadside obstacles within the clear zone. The need for median barriers is determined by width of road medians, types of roads, speed limits and obstacles. For Swedish conditions, these criteria are specified by the Road Design Manual (Vägverket 2004c).

Performance requirements for road barriers are characterised by containment level, impact severity and deformation or level of working width. The containment level is the ability of road barriers to contain and redirect errant vehicles safely for the benefit of the occupants and other road users. For Swedish conditions, these criteria are specified by Swedish standard SS-EN 1317-2 (Swedish Institute for Standards 1998) which is adjusted to European standards for road restrain systems.

5.5.1 Road barrier types

Road barriers are usually categorized as flexible, semi rigid or rigid, depending on their deflection characteristics on impacts. Flexible systems, such as cable barriers, generally impose lower impact forces upon vehicles than the other categories since more of the impact energy is dissipated by the deflection of the barrier (ASHTO 1996).

There are many types of road barriers used around the world. Some of these barrier types consist of steel or are a mix of wood and steel constructions with a high deflection capacity. Some other types consist of rigid reinforced concrete elements with very limited or no deflection capacity at all. Design characteristics for barrier categories are basically the same around the world, with the exception of some limited modifications due to different conditions and requirements for each country.

Cable barriers, w-profile barriers, pipe barriers, Kohlswa-beam barriers and concrete barriers are the common barrier types in Sweden. However, there are some other types which, for aesthetic reasons, are specifically designed for use on bridges or along specific road sections in urban regions.

W-beam barriers

This barrier system consists of a steel beam with a w-shaped guard rail profile, mounted on steel posts (figure 5.3). The w-beams redirect the impacting vehicle as tension forces are imposed at impact. The posts primarily hold the beams at the proper elevation. The posts and the beams separate readily when struck.

Figure 5.3 Figure W-beam barriers

W-beam barriers retain some degree of efficiency after minor impacts due to the rigidity of the w-beams (ASHTO 2006) (figure 5.4). An advantage of this system is the ability to bend the beams to make smooth radiuses along curves. Another advantage is the low sensitivity for impacts caused by snow removal equipment compared to cable barriers.

Figure 5.4 A damaged w-beam barrier which still retains some degree of efficiency

The disadvantages of the w-beam barriers include the high risk for vehicle vaulting or underride in the case of incorrect beam height or irregularities in the approach terrain, high deceleration forces upon vehicle occupants, somewhat reduced visibility through the barrier and high risk for snow accumulation at snowdrifts.

Cable barriers

This barrier system consists of steel cables mounted on weak steel posts (figure 5.5). The number of cables as well as type and shape of the posts differ depending on the manufacturer. The posts can be installed in sleeves or concrete foundations in the ground for easier removal and replacement. The cable barriers redirect the impacting vehicle when sufficient tension is developed in the cable. The posts in the impact area offer only slight resistance. Proper anchorage of the cables at the ends is crucial for the performance of cable barriers.

The primary advantages of cable barriers include low initial installation costs, effective vehicle containment, and redirection over a wide range of the vehicle surface and low deceleration forces upon the vehicle occupants. The open design of cable barriers prevents snow accumulation on roads and enables a good visibility through the barrier. The ability to remove the cables in emergency situations is another positive character of the cable barrier. The major disadvantage of the cable barrier is the need for repairs to maintain its efficiency even after small impacts. Therefore the use of cable barriers is not recommended along road sections likely to be hit frequently. Cable barriers are also less efficient along sharp curves.

Figure 5.5 Cable barriers

In Sweden, cable barriers are preferred compared to w-beam barriers on account of low initial cost and low impact severity. In addition, cable barriers occupy less space as it has a thinner profile. However, no scientific reports have been found which confirm that the impact forces upon vehicle occupants are less during the collisions with cable barriers than with w-beam barriers.

Kohlswa-beam barrier

This barrier system behaves pretty much like w-beam barriers. It consists of a steel beam mounted on steel posts (figure 5.6). The Kohlswa-beam redirects the impacting vehicle as tension forces are imposed at impacts. The posts primarily hold the beams at the proper elevation. The posts and the beams separate readily when struck. In the snow-rich regions, this type of barrier is better than the w-beam barriers as it is even less sensitive to snow accumulation. Due to its compact shape and strength, the

Kohlswa-beams stand the impacts caused by snow removal equipment better than the w-beams.

Figure 5.6 Kohlswa beam barriers

Concrete barriers

Concrete barriers are the most common rigid median barrier type owing to efficient performance and low maintenance costs. However, the use of concrete barriers in Sweden is very limited as their initial costs are very high compared to other barrier types. Concrete barriers differ in construction, shape and reinforcement. Based on their surface slope, concrete barriers are divided into three types: safety shape barriers, single-slope and vertical slope barriers.

Safety shape barriers are designed with two different surface slopes, one at the bottom and one at the top of the barrier. This minimizes damage to vehicles and reduces the impact forces on the occupants as a result of low-angle impacts (figure 5.7). The intention is that the bottom slope shall redirect the wheels and prevent damages to the vehicle or at least reduce the impact. The crucial factor for these barriers is the height of the break point between the slopes from the road surface. If this break point is higher than 330 mm the chances of a vehicle overturning are increased. The height of the break point must be adjusted when it is reduced by pavement layer adjustments. New Jersey and F-shape barriers are the two most common types of safety shape barriers (ASHTO 2006).

Figure 5.7 Safety shape barriers

The single-slope barriers (figure 5.8) can be a good alternative as the pavement adjacent to it can be overlaid several times without affecting the performance of the barrier (ASHTO 2006). The Texas Constant-Slope Barrier is an example of a single-slope barriers, it is 1070 mm high and has a constant-slope face that makes an angle of 10.8 degrees with respect to the vertical.

Figure 5.8 Single slope barriers

The vertical slope barriers (figure 5.9) are primarily used as a protection for construction works along roads to keep errant vehicles from hitting construction workers along the roads. When a concrete safety shape lifts a vehicle, some of the kinetic energy of the vehicle is converted to potential energy. This potential energy reverts to kinetic energy as the vehicle returns to the ground. Vertical concrete parapet walls do not have this energy management feature. All of the energy absorption in an impact with a rigid vertical wall is due to crushing of the vehicle. A common type of vertical concrete barriers in Sweden is the GP-LINK (figure 5.9) which is 870 mm high and 240 mm wide.

Figure 5.9 Vertical concrete barrier (GP-LINK)

The primary advantage of the concrete barrier is low maintenance costs, as the barriers often do not get damaged by impacts (figure 5.10). In addition to its low installation cost, the lower deflection level makes concrete barriers suitable as temporary protection for construction work along the roads. The disadvantages of concrete barriers include high acquisition costs, high redirection forces on the impacting vehicle, increased risks for snowdrift and the need for sweeping and snow removal.

Figure 5.10 A concrete barrier with obvious traces of the impacting vehicle without any damage to the barrier

Pipe barriers

This type of barrier is mostly designed for aesthetic reasons appealing to areas with natural beauty and urban areas with high aesthetic requirements (figure 5.11). This barrier type consists of two longitudinal steel beams, which have an ellipse-shaped or a C-shaped profile mounted parallel on steel posts. The open design of this kind of barrier reduces snowdrift risks.

Figure 5.11 Pipe barriers

The disadvantages of this type include high sensitivity to damages by snow removal equipment due to protruding joints and bolts. The ability to bend the beams in a curve to make radiuses is very limited. Therefore, beams for sharp curves have to be remanufactured after damages which results in delayed repairs and high costs.

5.5.2 Selection of road barrier type

In Sweden, the selection of road barrier type is done during creation of the construction documents according to several criteria stated in the Road Design Manual (Vägverket 2004c). Those criteria are:

- **Performance requirements**: Containment level, impact severity, level of deflection, possibility to modify the deflection level, possibilities for connection of the barrier to other barrier types and to the barrier end terminals.
- **Other safety requirements**: Visibility of the surrounding areas.
- **Maintenance costs**: Easy to repair, available spare parts and possibility to reuse the foundation without need for straightening measures. In snow-rich regions, snowdrifts have to be taken into account as well.

The initial cost is another crucial factor affecting the selection of barrier type. Between two barrier types both fulfilling the same performance requirements, the designers usually select the one with a lower initial cost. However, there are exceptions where the designers select an expensive barrier type for aesthetic reasons. This is usually the case in urban regions where aesthetic requirements are frequently more pronounced.

5.5.3 Barrier maintenance measures

The most frequent maintenance measure for road barriers is damage repairs, mostly caused by vehicle collisions or impacts by snow removal equipment (figure 5.12). Barrier damage due to vehicle collisions usually require immediate repairs as the damaged barriers usually lose their efficiency after the impact. In some cases, the damaged parts of the barriers, such as damaged posts or beams at the road surface or protruding in the traffic area, constitute additional hazards for road users. These parts have to be removed as fast as possible. However, some kinds of barriers, e.g. w-beam barriers and Kohlswa-beam barriers retain some degree of efficiency after minor impacts due to the rigidity of their elements (ASHTO 2006). Therefore repair of those barriers after minor impacts sometimes has a low priority.

Figure 5.12 Damaged road barriers due to vehicle collision

Barrier damage caused by snow removal equipment is another maintenance issue. However, this kind of damage often does not require immediate repair because many barrier types, such as w-beam barriers and Kohlwa-beam barriers, retain a high degree of efficiency even after such damage (figure 5.13).

Maintenance costs related to barrier damage differs depending on the type of road barrier. For instance, repair costs for concrete barriers are very low compared to other barrier types due to their rigidity and strong construction.

Figure 5.13 Damaged w-beam barriers due to impact by snow removal equipment

For the same types of barriers the repair costs differ depending on the design. For instance, repair costs for cable barriers made by different manufacturers differ considerably as they use different structures and different components for their products. Unfortunately, due to procurement regulations road authorities can only specify performance requirements for the barriers and may not specify certain products which are known for their low maintenance costs.

Road type is another factor which probably influences barrier damage and repair costs. For instance, the number of barriers damaged along motorways is less than along collision-free roads because motorways normally have broader lanes and better road standard. This claim is only verified by opinions expressed by road authorities and has not been verified by any scientific studies or surveys.

Also speed limits influence repair costs for barrier damage. In a study made by the Swedish National Road and the Swedish Transport Research Institute to evaluate the performance of collision-free roads, it has been stated that the damage risk for barriers along roads with a speed limit of 110 km/hr is 20% higher than on roads with a speed limit of 90 km/hr (Carlsson and Brüde 2005). Due to this fact, the annual repair costs for barrier damages are probably also higher for barriers along roads with a speed limit of 110 km/hr.

Another factor which likely affects repair costs for barrier damage is seasonal effects. Repair costs for barrier damage seem to be higher during winter. This is based on experiences regarding difficulties in conducting repair measures for some specific barrier type during the winter months. For example, replacement of cable barrier posts is difficult and time-consuming during the winter due to frozen water inside the post sleeves or at concrete foundations. It has also been proven that the damage risks for barriers along the collision-free roads in the northern regions of Sweden are 20% higher than in the southern regions (Carlsson and Brüde 2006). This difference depends on poor road conditions due to colder winters in the northern regions. Therefore the repair costs are probably higher in northern Sweden as the number of barrier damages is higher.

Road alignment is another factor which might affect barrier damage and the related repair costs. Maintenance contractors believe that barrier damage is more frequent in curves than at straight road sections. The risk of sliding is higher in curves, especially during the winter. This is not confirmed by any scientific study or survey. However, there is a trend towards the use of stronger barrier types, such as concrete barriers, along curves to reduce barrier damage and the related costs.

The common opinion is that the distance between the edge of the traffic lane and the barrier itself affects barrier damage and repair costs. Damage due to snow removal equipment, can probably be prevented if the barriers are installed some distance away from lane edges. Studies have shown that the number of barrier repairs along 13 meter wide collision-free roads is higher than along the 14 meter wide collision-free roads (Carlsson and Brüde 2004; 2005; 2006). However, any ideal distance has not been identified which may reduce the number of damages and repair costs.

The common opinion is that the type of road cross section affects the number of barrier collisions. For example, barrier damage along collision-free roads occurs when the road section shifts from a double-lane a to single-lane section. Overtakes on these roads sometimes end up with accidents as the drivers misjudge the distance to lane shifts.

Besides the repair measures, road barriers require several other maintenance measures such as:

- Periodic washing of reflexes mounted on the barriers for visibility purpose.
- Periodic sweeping of accumulated sand or other rubbish around barriers, especially concrete barriers, to sustain a clean and neat appearance.
- Height adjustment measures to restore barrier height after pavement maintenance.
- Repair of damages due to frost damage which raises and bends the posts.

5.5.4 Other issues related to road barriers

The presence of road barriers indirectly increases the costs for other maintenance measures. For instance, snow removal measures take more time along roads equipped with road barriers. Another example is trimming at road barrier locations which is the most difficult, time consuming and costly single operation involved in grass mowing (O'brien 1963).

Repair costs for vehicles damaged by collisions with road barriers are another cost which occurs because of the presence of barriers. The barrier type is one of the factors affecting the extent of vehicle damages. During collisions with flexible barriers, such as w-beam barriers and cable barriers, much of the impact energy is dissipated by the deflection of the barrier and lower impact forces are imposed upon the vehicle (ASHTO 1996). However, this does not mean that flexible barrier types cause less damage to vehicles. For example, according to the experience of maintenance contractors, cable barriers cause greater vehicle damage compared to w-beam barriers. Cable barriers redirect the impacting vehicle very smoothly. This redirection occurs over a wide area of the vehicle's surface (ASHTO 1996). These redirections cause great damage to vehicles because of the large contact surface between the barrier and the vehicle. Based on this explanation, the w-beam barriers could cause less damage to the impacting vehicles as the redirections often occur over a limited surface of the vehicle. On the other hand, collisions with rigid barriers often cause severe damage to the vehicle's chassis.

The effects of the type of barrier on the extent of vehicle damages are seldom considered during the selection of barrier types even if repair of vehicle damages can be an important socio-economic cost in the end. Opinions regarding which type of barrier is least harmful to vehicles differ and the issue has not yet been properly investigated. The focus has mostly been on how harmful the different barrier types are for the vehicle's occupants. Because of this, information concerning the correlation between barrier types and vehicle damage is limited and might be inadequate. Therefore this aspect is often ignored during the selection of barrier types.

In addition, there are also other issues related to barrier maintenance. For instance, barrier maintenance measures disturb traffic, impair accessibility and expose the repair staff to a risky work environment (Thorman and Magnusson 2004).

There have been numerous accidents around the world where a road barrier has contributed to the severity of crashes involving motorcycles. Motorcyclists have been killed or seriously injured after impacting with the road barrier beams or the edge of posts. Some European countries have attempted to reduce this risk by using motorcycle protection measures. The most efficient protection is the use of additional appliance, made of plate or textile cloth, mounted longitudinally under the barrier beams to cover the posts. Another type of protection is padding of the posts with expanded plastic foam. These protection measures are mainly used at locations with both high motorcycle use and a high number of accidents (Perandones et al. 2008). However, no systematic approach to handling this issue has been developed because motorcycle crashes have random characteristics. Some countries, such as Norway and Holland, have decided not to use cable barriers any more as this type of barrier is considered to be more harmful for motorcyclists than other types. However, these decisions are political and not based on any scientific facts (Turbell 2008).

5.5.5 Compensation for barrier damages

After the detecting barrier damages, the responsible maintenance contractor has two to three weeks to repair the damage. For each completed repair, the maintenance contractor sends an invoice to the road authority listing the total amount of repair costs and other details regarding the repair see subsection 5.6.5.

If the vehicle is known, the road authority receives compensation from the insurance company of the vehicle involved. If the vehicle is unknown, the road authority receives compensation from the Swedish Motor Insurers. In both cases the compensation is paid according to an agreement between SRA and the Swedish Motor Insurers (Johansson 2002). Therefore SRA’s costs are much lower than the actual repair cost of the damaged barrier. The amount of compensation depends on the type of road barrier. For example in the case of cable barriers, the SRA receives compensation for the entire repair cost. For other barrier types, the SRA receives compensation for the repair staff and machinery used for the repair and for 50% of the expenses for replaced parts. Based on this, the cable barrier is considered to be the most profitable barrier type for SRA.

5.6 Method

This subsection describes the method chosen to carry out the study. It starts with a description of the efforts made in deciding an optimal research strategy. The subsection presents the different research strategies which were evaluated as alternatives for conducting the study. It also presents the reasons for selecting the case study method as the research strategy. The subsection describes how the case study was designed, i.e. formulation of the research questions and propositions, selection of the units of analysis, description of the data and data sources as well as the models for calculations and analyses of the collected data.

5.6.1 Research strategies

The following five different research strategies were evaluated as alternatives for this study: experiment, survey, archival analysis, history and case study (Yin 2003).

An experiment research strategy includes conducting laboratorial or field experiments to study a phenomenon. This type of strategy is usually used when researchers have the possibility to manipulate the events in order to study only the variables of interest. Experiments require control over behavioural events and focus on contemporary events.

Survey research strategies are used with the intention of producing statistics, i.e. quantitative or numerical descriptions about some aspects of the studied population. The main method of collecting information is by way of questionnaires where the answers constitute the data to be analysed. Generally, information is collected about only a fraction of the population rather than every member of the population (Fowler 2003). A survey requires focus on contemporary events but not control over the behavioural events.

Archival analysis is similar to survey research with the exception that archival records are usually used as the source of evidence instead of interviews. This strategy is often used for conducting medical research. Archival analysis does not require control over behavioural events but in some cases focus on contemporary events is required.

The historical research strategy is preferred when there is virtually no control over or access to actual behavioural. The distinctive contribution of the historical method is in dealing with "dead" past when no relevant persons are alive to report, even retrospectively, what occurred (Yin 2003).

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context especially when the boundaries between the phenomenon and the context are not clearly evident. The case study copes with the technically distinctive situation in which there will be many more variables of interest than data points. One of the case study's distinctive characteristics is its ability to deal with a full variety of evidence such as documents, archival records, interviews and observations (Yin 2003). Case studies can be based on a mix of quantitative and qualitative evidence or be limited to either quantitative or qualitative evidence. The case study research strategy is preferred in examining contemporary events when the relevant behaviour can not be manipulated.

Both history and case study strategies rely on the same techniques but the case study adds two sources of evidence not usually included in the historical studies: direct observation of the events being studied and interviews with persons involved in the events (Yin 2003).

5.6.2 Conditions for selecting a research strategy

There are three basic conditions which are suggested to determine an optimal research strategy (Yin 2003): the research question, the extent of control over behavioural events and the degree of focus on contemporary events.

The research question

Usually, research questions are categorized according to the familiar series: "who", "where", "what", "how" and "why". Questions starting with "what" require carrying out exploratory research. However, another type of “what” question, which actually is a “how much” or “how many” question, requires conducting a survey or archival analysis research.

“Who” and “where” questions or their derivatives “how many” and “how much” are likely to favour survey or archival analyses, and tend to describe incidents or phenomena with the goal of predicting outcomes.

In contrast, “how” and “why” questions are explanatory and probably lead to the use of a research strategy such as case study, history or experiment. These questions tend to deal with operational links which occur during a span of time, rather than incidents or phenomena which occur at intervals over time (Yin 2003).

The research question in this study was “how do factors such as road type, speed limit, road barrier placement, alignment, road cross-section, road barrier type and seasonal effects affect the repair costs of damaged road barriers?”

The extent of control over behavioural events

By the extent of control over behavioural events means the possibility for the researcher to control actual behavioural events. For example, through laboratorial experiments or field studies researchers can focus on one or two isolated variables and control the other variables which are not interesting.

In this study, the focus was on collection of data concerning barrier repairs which had already occurred, i.e. focus on past events. Therefore it was no longer possible to control behaviour directly, precisely and systematically as can be done in the case of laboratorial experiments. A laboratory experiment concerning the repair cost of barrier damages is almost impossible to conduct due to the difficulty of reconstructing conditions in a laboratory which can be equivalent to realty.

The degree of focus on contemporary events

The degree of focus on contemporary events means the possibility of having actual access to contemporary events. For example, when researchers try to study a phenomenon which occurred during 19th century, they do not have any actual access to contemporary events. Therefore they need to relay on primary documents and secondary documents as the main sources of evidence.

In this study, the data sources were a mixture of archived documents and contemporary information taken from several databases and interviews with involved actors. For example, information about repair costs was taken from repair invoices saved in SRA's archives while interviews with involved experts was used to collect information about repair costs, difficulties at repair works and possibilities to improve barrier designs and maintenance measures.

5.6.3 Selection of case study method as research strategy

In order to decide an optimal research strategy, the three basic conditions mentioned above were analysed according to table 5.3. It was obvious that neither survey nor archival analyses were suitable for this study as the research question for this study was a "how" question.

Table 5.3 Relevant situations for different research strategies (Yin 2003)

Research Strategys	Type of Research Question	Requires Control of Behavioural Events?	Focuses on Contemporary Events?
Experiment	How, Why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case Study	How, why?	No	Yes

According to table 5.3 three types of research strategies were possible in the case of a "how" question: the experimental, historical or case study. Therefore the choice for this study so far was one of these three strategies.

For this study, it was not possible to use an experimental research strategy because it was not possible to conduct experiments to study the effect of factors such as road types, speed limits, barrier types, seasonal effect and traffic volume on barrier damages. The number and combination of factors was too high and it would be very hard to simulate so many accidents to study the effect of each factor or combinations. Therefore the choice was either historical or case study.

As mentioned in the previous subsection, the focus in this study was on the collection of data concerning barrier repairs which already had been carried out i.e. focus on past events. Therefore it was no longer possible to control behaviour. According to table 5.3, neither the historical nor case study requires control of behavioural events so both could be suitable for this research.

At this point it became necessary to use the third condition, i.e. the degree of focus on contemporary events, to distinguish between the historical and case study strategy. As mentioned before, there was a need for interviews with the experts involved in order to collect information concerning difficulties at repair works and possibilities to improve barrier designs and maintenance measures. Therefore, it was obvious that the case study was the best strategy for this research study as the historical study did not have the possibility of dealing with contemporary events such as interviews and direct observations (table 5.3). In addition, data was collected from different sources such as documents, archival records and observations. Therefore the best strategy to use was the case study as this it had the possibility of combining all these features.

5.6.4 Design of the Case Study

The design of a case study consists of defining the research question, the proposition, the units of analyses and the logic of linking the data to the proposition (Yin 2003).

Research question

As mentioned before, the research question for this case study was "how do factors such as road type, speed limit, road barrier placement, alignment, road cross-section, road barrier type and seasonal effects affect the repair costs of damaged road barriers?"

Proposition of the research

The research propositions are important to be defined as each proposition direct the attention to something that should be examined within the scope of the study (Yin 2003). Therefore the propositions were defined in the very beginning of this research in order to identify the necessary data to be collected. Identified propositions were of great importance for saving time and resources by focusing only on the data which was needed for the case study.

The following propositions were formulated based on experiences of experts in the SRA and the information collected from the interviews conducted during the change analyses:

- The number of barrier repairs and the associated costs are higher along roads with speed limit of 110 km/hr than on roads with speed limits of 70 km/hr or 90 km/hr.
- The number of barrier repairs and the associated costs are higher along collision-free roads than on other road types.
- The number of barrier repairs and the associated costs are higher for cable barriers than for w-beam barriers.
- Cable barriers are the most profitable type of barrier for the road authorities.

- The number of barrier repairs and the associated costs are higher during winter than during summer.
- The number of barrier repairs and the associated costs are inversely proportional to the distance between the barriers and the edges of traffic lanes.
- The number of barrier repairs and the associated costs are higher for barriers installed along curves than for barriers installed along straight road sections.
- On the collision-free roads, the number of barrier repairs is higher on the lane shifts than on the single-lane and double- lane directions.

Based on these propositions, it was obvious that data concerning repair costs, road types, speed limits, road barrier types, barrier placement, climate and traffic volumes had to be collected. In addition, through the propositions it became clear which sources of evidence were important to use in the case study.

Units of analyses

The third step in the design of this case study was the identification of the units of analysis. The unit of analysis in a case study could be an individual, a community, an organization, a nation-state, an empire, or a civilization (Sjöberg et al. 1991). For this case study, the most appropriate units for analysis were the regional offices because information about barrier repairs within each region was archived separately. Each region is unique regarding costs, subsidiary prices, climate and to some extent regulations. The Western Region and the Central Region were the two units of analysis used in this case study.

When the units of analysis were selected, the type of case study was decided. The choice was between a single-case study and a multiple-case study (figure 5.14). Multiple-case studies have distinct advantages compared to single-case studies. The evidence from multiple case studies is often considered more compelling, and the overall study is therefore regarded as being more robust (Herriott and Firestone 1983).

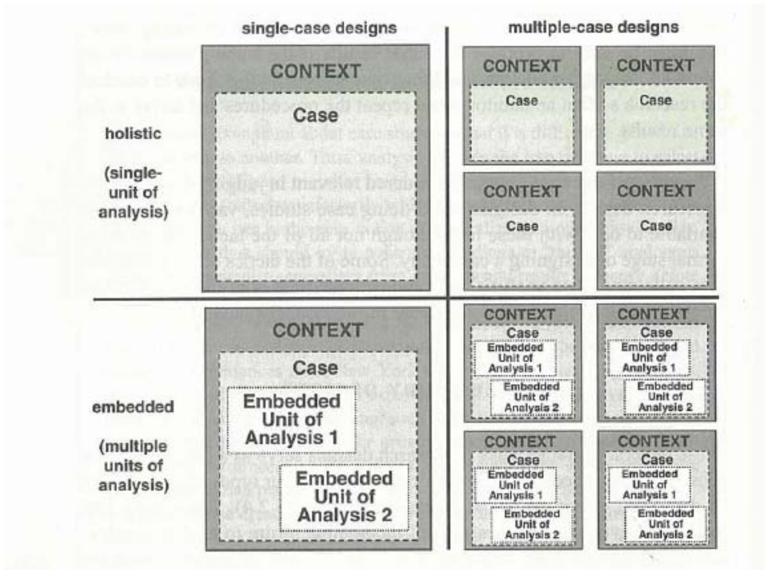

Figure 5.14 Basic types of design of case studies (Yin 2003)

Analytical conclusions arising independently from two cases, as with two experiments, will be more powerful than those coming from one single case or a single experiment (Yin 2003). In addition, the contexts of the two cases are likely to differ to some extent. If, under these varied circumstances the researchers can still arrive at some common conclusions (same or similar results) from both cases, they will have immeasurably expanded the external ability to generalize those findings, compared to those from a single case.

The logic underlying the use of multiple-case studies is the replication logic. When a significant finding is uncovered from a single case, the finding will be replicated by conducting second, third and even more cases. The logic underlying the multiple-case studies must be carefully selected so that it either predicts the similar results (a literal replication) or predicts contrasting results but for predictable reasons (a theoretical replication) (Yin 2003).

The type of case study selected for this research was the multiple-case study consisting of two single-case studies, one for each of the two regional offices. The chosen regions have different traffic volumes, climate conditions and routines in conducting maintenance measures. Despite these differences it was expected that the effect of the variables on the barrier repairs would follow approximately the same pattern. Therefore it was important to investigate more than one region in order to establish a strong base for the analyses and generalization of the findings.

As shown in figure 5.14, a multiple-case study could be either holistic or embedded. The holistic multiple-case study consists of several single case studies containing one unit of analysis each. The embedded multiple-case study consists of several single case studies containing several units of analysis each. The findings from the units of analysis will contribute to the final findings of the case study.

For this research study, the choice was between either a holistic multiple-case study consisting of one regional office as a unit of analysis or an embedded multiple-case study consisting of several maintenance areas within each region as units of analysis (figure 5.14). The embedded type requires a lot of analysis work as all units of analysis must be evaluated. In addition, the data concerning barrier repairs within each maintenance area was limited due to a limited number of barrier repairs within most of the maintenance areas. Analyses or conclusions based on such limited data would be very vague. Based on this a holistic multiple-case study for the research study was preferred. This study consisted of two cases, one for each region.

The first case study started at the end of 2006 within the Western Region. Data about barrier repairs was collected from ten maintenance areas within the region. For each maintenance area, data about repair costs for barrier damages during 2005 was collected.

The second case study started one year later within the Central Region. The barrier repairs covered in this case were carried out during 2006. The selection of two different years for the case studies was due to a limited number of barrier damage reported in the Central Region during 2005 as the existence of road barriers was limited that year. In both regions, maintenance areas with high traffic volumes were selected as road barriers usually are installed on such roads. The data about barrier repairs was collected from seven maintenance areas.

Linking the data to the propositions

The fourth step in the design of the case study was identification of an appropriate logic linking the data to the propositions. This step has been the least well developed in the design of the case study. There are many ways of linking data to propositions but the most promising way for the case study is "pattern matching" logic (Trochim 1989). Such logic compares an empirically based pattern with a predicted one (Yin 2003).

In this case study, pattern matching logic was used. The empirically based data pattern was linked to the propositions, which were predicted based patterns. The findings from each case were compared to each other to see if they predicted the same results or not. If the findings coincided, they were considered as an actual empirical based pattern. Later, such findings were compared to the propositions to support or reject the propositions.

5.6.5 Sources for data collection

For this study data had to be collected from different sources. It was obvious form the beginning that the data which was needed was a mix between old and new data. Due to insufficient data storage within SRA concerning road barrier related costs, it was also obvious that a mix of many types of data sources had to be utilized, such as interviews with maintenance experts, documentations, archival records and databases which contained information about barrier repairs and the Swedish road network. This approach, called data triangulation, is considered to be one of the major strengths of case study research. Data triangulation increases the reliability of the data and the process of gathering it. In the context of data collection, triangulation serves to corroborate the data gathered from different sources (Tellis 1997). Findings or conclusions in case studies are likely to be much more convincing and accurate if they are based on different sources of information (Yin 2003).

The data necessary for this case study was mainly collected from the following five data sources:

Invoices for repair of barrier damages and damage notifications

Data necessary for this case study were mostly collected from the repair invoices and the attached repair notifications, photos and police reports. The invoices are usually issued and sent by the maintenance constructors to SRA's regional offices after each barrier repair. The invoices contained the following details:

- Expenses for the repair staff
- Expenses for vehicles and machinery used for the repair, e.g. lorries or cranes.
- Expenses for replaced barrier parts, e.g. posts, foundations, beams, etc.
- Costs for replaced material around the road barrier, e.g. gravel and asphalt.
- Costs for material used for temporary traffic arrangements.

With each invoice a damage notification was attached with the following information:

- The date when the damage was noticed.
- The actor who observed the damage.
- The number and the name of the road.

- The location of the damage.
- The type and registration number of the vehicles involved in the collision if the vehicles have been known.

The road authority requires photos of the damages, taken before and after the repair, from the maintenance contractor. These photos must be attached to the invoices. Otherwise the contractors will not get paid for the repair. The photos are important later when the road authority requires compensation from the insurance companies or Swedish Motor Insurers.

In cases of serious traffic accidents and injuries, a copy of the police report will also be attached to the invoices.

For each maintenance area, invoices which were issued during the same year were collected in folders and saved in the archives of SRA’s regional offices. Access to the folders was easy to acquire. However, it was difficult to find the barrier repair invoices in the folders as they were mixed with repair invoices for other road components such as lighting posts, fences, road signs. A satisfactory system for filing the invoices was also missing in the folders. The invoice forms and the attached notifications differed between maintenance contractors as the SRA does not require a standard form. All these factors made the data search a time-consuming process.

The information taken from the photos attached to the invoices was frequently based on subjective judgments. Sometimes the photos were taken at night and in such cases it was very hard to obtain reliable information.

The Swedish National Road Database (NVDB)

The Swedish National Road Database (NVDB) is a nationwide road database, containing up-to-date information that fulfils particular quality standards (Vägverket 2005). The aim of this database is to meet the immediate and long-term need for fundamental road information, and to give both the public and the private sectors access to such information. The purpose is to create the right conditions for a breakthrough of intelligent transport system (ITS). The database contains geometrical and topographical description of the Swedish road network. It also contains information about other road related characteristics such as speed limits, road numbers, road classes, road bearing capacity, etc. In addition, it is possible to get information about distances between locations on the roads. The data is presented on the web in form of digital maps. Unfortunately, this database does not contain any information about the length or type of median barriers, nor the existence or the length of roadside barriers.

Information about Roads

Another source for information about road types and geometry is a web-based database called Information about Roads. This database is developed mostly for internal use within SRA and it is similar to NVDB but contains more information. In this application the Swedish road network is divided into several homogeneous traffic sections and presented on a digital map. The lengths of the sections are given as well as the lengths of sections with a specific speed limit, road width or road type. Another advantage of this application is the possibility to collect different items of data at the same time by marking a section on the map. However, as with the NVDB, this data base does not contain any information about the length of the road barriers, nor the existence or the length of the roadside barriers.

Annual Average Daily Traffic Map

Daily Traffic Map (ÅDT-karta) is a web-based database containing information about the roads for which the SRA is responsible. In this application the Swedish road network is categorized into homogeneous sections. For each section the traffic volume is measured regularly using temporary or permanent traffic measuring stations. The annual average daily traffic for each section is then calculated and shown on digital maps or in tables. The advantage with the tables compared to maps is the possibility of showing different combinations of data at the same time such as combinations of annual average daily traffic, type of roads, road length, etc.

Insurance companies

The databases of the different insurance companies were also used as data sources in this case study. These databases were mainly used to obtain information about repair compensations paid by the insurance companies for the damaged vehicles. The repair compensations were used as indicators of the extent of vehicular damage. Data was collected in two steps. The registration numbers of the damaged vehicles were collected in one list for each insurance company. The amounts of repair compensations for the vehicles were collected through telephone contacts with the insurance companies. In some other cases the process was more complicated and time-consuming as some of the insurance companies were not willing to hand over this kind of information without an official request. In these cases, the lists were attached with an official request for the information and sent to the insurance companies.

Interviews with experts

The interviews were mainly carried out with the maintenance contractors or the maintenance project leaders to identify the types of median barriers along the studied road sections. However, the data collected in interviews carried out for the change analyses in chapter 4 was also very useful for this case study. In those interviews, four specific questions were included concerning road barriers and related maintenance issues and costs (appendix 9). The information collected from those interviews was mainly based on experience of barrier design and installation issues, barrier maintenance costs and effects of barriers on other road maintenance measures.

5.6.6 Collection of data concerning barrier damage repairs

In order to analyse how different factors affect barrier damages and the associated repair costs, the following data regarding barrier repairs was collected:

The observation date of the damage

This information was taken from the damage notifications. Since the repair dates were seldom given in the invoices, the observation dates of the damages were used to decide in which season the repairs occurred. Barrier repairs are mostly conducted two or three week after the observation date according to the maintenance works contract.

Damages observed between 15 October and 15 April were considered as winter damages and damages in the other months were considered summer damages. The season in which the repairs occurred was necessary in order to analyse the seasonal effects on barrier damages and the repair costs.

The road number and the location of the barrier damage

This information was given in the damage notifications. The road number and the location of the barrier damage were necessary in order to find other data necessary for the analyses, e.g. speed limits, road cross-section, road type, etc.

In many cases, the location of the damage was poorly described. An incorrect location could result in incorrect registration of other factors such as speed limits.

The road barrier type where the damage occurred

Information about the barrier types was collected with the intention of distinguishing between repair costs for the different barrier types. This information was given in the invoices or in the photos attached to the invoices. In some cases, it was difficult to identify the barrier type due to poor quality photos or missing information in the invoices. In those cases, the maintenance contractor involved was contacted for more information about the barrier type.

Barrier position, i.e. roadside barrier or median barrier

This information was taken from the photos in order to distinguish between repair costs for the median barriers and the roadside barriers and to conduct a separate analysis for each of these barrier positions.

The location of the barrier damage, on a straight road section or in a curve

This information was taken from the photos with the intention of identifying the effect of the road alignment on the damages and repair costs. The classification was based on subjective judgments. Unfortunately, the poor quality of the photos made judgment a difficult task in some cases. In addition, most of the roads included in the case study were major roads with good geometrical standard. Due to the large radius of such roads, sometimes it was impossible to identify the transition points between straight sections and curves from the photos. These cases were excluded from the analysis.

The distance between the road barrier and the edge of the traffic lane

The photos were used to classify the distance between the road barriers and the edge of the traffic lanes into two classes:

- 0.5 to 2 m from the edge of the traffic lane.
- 2 m or more from the edge of the traffic lane.

The road section type where the damage occurred

This information was mainly taken from the photos. In cases where the photo quality was bad, the information was taken from the Swedish National Road Database.

The speed limit where the damage occurred

Information about speed limits was taken from the Swedish National Road Database.

In some cases, the Swedish National Road Database contained information not valid for the year of the damage. For example, the speed limits given in the database were in some cases not the same as those speed limits which were valid during the year of the damage. In cases of doubts these kinds of data further investigated, for example by consulting the maintenance contractors.

Position of the damage in relation to double-lane or single-lane sections or lane shifts

This information was collected only for the collision-free roads. Photos were the source of this information. Sometimes, it was difficult to identify the road section type as it was not visible in the photos or the photo quality was poor. In such cases these repairs were not included in the analysis.

The total repair cost for the damage and the different cost items

The total repair cost is defined as the amount of money required by the maintenance contractor after each barrier repair. Each repair cost consists of several cost items: costs for replaced barrier parts, hired tools used for repairs, materials used for temporary traffic arrangements and working costs. Information about the repair costs was taken from invoices with the intention of correlating the repair costs with the traffic works and obtaining the repair cost per vehicle kilometres (vkm). This correlation was important in order to neutralize the effect of the traffic volume on the barrier repairs and the associated costs. The repair cost per vkm was used as a measure of the effects of the studied factors such as road types, barrier types and speed limits.

The SRA's actual barrier repair cost

SRA's actual barrier repair cost is the part of barrier repair cost which the SRA pays. The purpose of collecting this information was to identify the barrier type which gave SRA the lowest barrier repair costs. This information was taken from the invoices on which SRA's part of the repair cost for each barrier repair is calculated and noted by the finance departments in the regional offices.

The number of replaced posts per barrier repair

The number of replaced posts can be considered as a measure of the extent of barrier damage. The purpose of collecting this information was primarily to investigate the seasonal effect on the extent of barrier damages and repair costs. This information was taken from the invoices. Unfortunately, the number of replaced posts was only known for cable barrier repairs.

Names of the insurance companies and the repair compensation for vehicle damage

In order to identify the insurance company involved, it was necessary to know the registration numbers of the damaged vehicles. This information was given in the damage notifications or in the police reports attached to the invoices.

The insurance companies were contacted to obtain information about the amount of repair compensation paid for the damaged vehicles. This information was taken from the insurance companies' record archives. The amount of compensation was used as an indication of the extent of damage to impacting vehicle in order to compare the effects of the different barrier types on the damaged vehicle. The purpose of this comparison was to identify the barrier type which causes minimum damage to vehicles.

In some cases, it was impossible to get information about repair compensations as the registration numbers turned out to be incorrect or unregistered with the insurance companies which were given in the notifications. These cases were not included in the analyses.

5.6.7 Collection of data necessary for calculation of the traffic work

To calculate the repair cost per vkm, it was necessary to calculate the traffic work. Calculation of the traffic work started by dividing the roads which were included in this case study into road links. A road link is a road section with the same road type, median barrier type, speed limit and annual average daily traffic. A new link starts at the point where one of these factors changes. The starting point for each link was the same as the end point for the previous link. These points gave the lengths of the links. The traffic work for each link was calculated by multiplying the length by the annual average daily traffic volume (AADT). For this calculation the following data was collected:

The types of median barriers along the studied roads

For identification of the barrier types, two different data sources were used: photos attached to the invoices and interviews with the maintenance contractors. The information was often taken from the photos if a barrier repair was carried out on a road section. When a specific type of median barrier was found in the photos at the location of the damage, the type of median barrier past that location was assumed to be the same until further information was found. This assumption was based on the fact that median barriers are usually designed with the same barrier type being used continuously for long distances. Unfortunately, a similar assumption was not possible in the case of roadside barriers. These types of barriers exist intermittently for rather short distances with the purpose of protecting road users from roadside hazards. Therefore it was not possible to estimate the length of the roadside barriers in the same way.

At sections where photographs were not available, the type of median barrier was identified through further investigation such as interviews with the maintenance contractors involved.

Road types and speed limits along the studied roads

Information regarding speed limits and type of the road studied was necessary in order to identify and establish the road links. This information was taken from the Swedish National Road Database.

The annual average daily traffic on the links

This information was found in the Annual Average Daily Traffic Map. The annual average daily traffic recorded in the database was often not valid for the year when the damage occurred as traffic measurements are not done each year. Therefore traffic increase factors were used to transform the annual average daily traffic to the year of repair.

The traffic increase factors for the links

The traffic increase factor for each link was taken from the Annual Average Daily Traffic Map. If such information was missing, the factor was estimated to be 2% per year.

The length of the links

The lengths of the links were measured using a specific function in the Swedish National Road Database which is used to measure the distances between locations on roads.

5.6.8 Established databases for the collected data

Due to the number of variables and factors included in this case study and for more practical data handling, the collected data was saved in more than one database. As the data for each of the studied regions was collected and analysed separately, the collected data for each region was also saved separately. For each region two databases were established: the damage repair database and the traffic works database.

The damage repair database

A database, in the form of an excel sheet, was established for each regional office to save all collected data, except the data for the calculation of the traffic work. This database was useful for the analyses of different combinations of the studied factors. The structure of this database is shown in appendix 11.

The traffic works database

The data collected for the calculation of the traffic works was also saved in a database consisting of an excel sheet. This database was used to summarize traffic works for the different road links. The structure of this database is shown in appendix 12.

5.7 Equations for calculation of repair cost per vkm

Barrier repair cost per vkm was used as a measure for comparing the influence of different factors, such road types, barrier types and speed limits, on barrier repairs and associated costs. The correlations between the repair costs and the traffic works were also necessary to neutralize the effect of traffic volume and barrier lengths on barrier damage.

For this reason, the repair cost per vkm for different combinations of road types, barrier types and speed limits was calculated. For each combination the calculation was carried out in the following steps: calculation of the traffic works, calculation of the total repair costs, calculation of average cost per repair and calculation of the repair cost per vkm.

The repair cost per vkm was only calculated for median barriers. For the roadside barrier, the calculation of the traffic works was not possible as the lengths for the roadside barriers were unknown.

5.7.1 Calculation of traffic works

Calculation of the repair cost per vkm started by calculating the total annual traffic works for the different combinations of the studied road types, barrier types and speed limits. For this reason, the annual traffic works for each road link was calculated separately using the following equations:

$$ATW_{(l,r,b,s)} = AADT_{(l,r,b,s)} * LL_{(l,r,b,s)} * 365$$

$$AADT_{(l,r,b,s)} = AADT^{o}_{(l,r,b,s)} * C$$

ATW: the annual traffic work for the link in vehicle kilometre (vkm).

AADT: the annual average daily traffic in vehicles per day for the studied year.

$AADT^{o}$: the annual average daily traffic in vehicles per day for the year of the measurement.

LL : the link length in kilometres.

C : the traffic increase factor for the link.

l : the road link.

r : the road type.

b : the barrier typ

s : the speed limit.

The total annual traffic works for the different combinations of studied road types, barrier types and speed limits were calculated using the following equation:

$$TATW_{(r,b,s)} = \sum_{l=1}^{l=n} ATW_{(l,r,b,s)}$$

TATW: the total annual traffic work in vehicle kilometres (vkm).

5.7.2 Calculation of the total repair cost and the average cost per repair

Calculation of the average cost per repair started by calculating the total annual repair cost for the different combinations of studied road types, barrier types and speed limits in the region using the following equations:

$$TARC_{(r,b,s)} = \sum_{BR=1}^{BR=n} RC_{BR\,(r,b,s)}$$

$$AVCR_{(r,b,s)} = TARC_{(r,b,s)} \div NR_{(r,b,s)}$$

TARC: the total annual repair cost.

AVCR: the average cost per repair.

NR: the number of the damage repairs during the studied year.

RC_{BR}: the cost for the single barrier repair (*BR*).

5.7.3 Calculation of the repair cost per vkm

The average repair cost per vkm for the different combinations of the studied road types, barrier types and speed limits was calculated using the following equations:

$$ARC_{(r,b,s)} = TARC_{(r,b,s)} \div TATW_{(r,b,s)}$$

or

$$ARC_{(r,b,s)} = RQ_{(r,b,s)} * AVCR_{(r,b,s)}$$

$$RQ_{(r,b,s)} = NR_{(r,b,s)} \div TATW_{(r,b,s)}$$

ARC: the repair cost per vkm.

RQ: the number of repairs per vkm.

The model for calculation of design annual repair cost for barriers

To calculate the annual repair costs for the different studied barrier types in this case study the following equation was established:

$$DARC_{(r,b,s)} = (ARC_{(r,b,s)} * 365 * AADT)$$

DARC: the design annual repair cost for the barrier per kilometre of road.

AADT: the annual average daily traffic which is expected for the new roads in vehicle per day.

Based on the results of this case study, a table was established for the Western Region and the Central Region containing the calculated values of repair cost per vkm for different combinations of barrier types, road types and speed limits. This table can be used by the designers for calculation of the design annual repair cost per kilometre as a crucial cost item in the calculations of the life-cycle costs for different road barrier types (appendix 13)

5.8 The analyses of the effects of the studied factors

This subsection presents the analyses conducted in this case study to identify the influence of the studied factors on the barrier damage repairs and the associated costs. Table 5.4 includes the basic conditions for the analyses of the studied factors.

5.8.1 Analysis of the effects of speed limits on barrier damage repairs

The aim of this analysis was to identify how different speed limits affect barrier repairs and their associated costs. In these analyses the focus was mainly on w-beam barriers and cable barriers as the data regarding other barrier types was very limited. The speed limits which were studied were 70 km/hr, 90 km/hr and 110 km/hr. For each road type the effect of the speed limits on the barrier repairs was analysed separately. The road types which were included in these analyses were motorways, collision-free arterial roads, collision free country roads and 4-lane roads.

In this analysis, the barrier repair cost per vkm was used as a measure for comparing the effects of different speed limits on barrier repairs and the associated costs. Correlations between the repair costs and the traffic works were also necessary to neutralize the effect of the traffic volume and the barrier lengths on the barrier damages.

Table 5.4 Basic conditions for analyses of the studied factors

Analyses	Road types	Speed limit km/hr	Barrier types	Barrier position	Barrier placement	Season
	Basic conditions considerd in the analyses					
5.8.1 Analysis of effects of the speed limits on barrier damage repairs	Motorways, Collision-free roads and 4-lane roads	70, 90 and 110	Cable barriers and w-beam barriers	Median barriers	-	-
5.8.2 Analysis of effects of road types on barrier damage repairs	Motorways, Collision-free roads and 4-lane roads	-	Cable barriers, w-beam barriers and Kohlswa beam barrier	Median barriers	-	-
5.8.3 Analysis of the effects of barrier type on the barrier damage repairs and on vehicle damage repairs	Motorways, Collision-free roads and 4-lane roads	-	Cable barriers and w-beam barriers	Median barriers Roadside barrier	-	-
5.8.4 Analyses of seasonal effects on barrier damage repairs	-	-	-	Median barriers Roadside barrier	-	Winter and summer
5.8.5 Analyses of effects of barrier placements on barrier damage repairs	-	-	-	Median barriers Roadside barrier	Placment classes 0.5-2 m > 2 m	-
5.8.6 Analyses of effects of road alignment on barrier damage repairs	-	-	-	Median barriers Roadside barrier	Along curves Along straight road sections	-
5.8.7 Analyses of effects of cross-section types on barrier damage repairs	Collision-free roads	-	Cable barriers	Median barriers Roadside barrier	Along single lanes Along dubble lanes Along lane shiftes	-

This analysis was made only for median barriers as calculation of traffic works for roadside barriers was not possible.

5.8.2 Analysis of the effects of road types on barrier damage repairs

The intention of this analysis was to clarify how the different road types affect barrier damage repair and the associated costs. The road types which were included in these analyses were motorways, collision-free arterial roads, collision free country roads and 4-lane roads.

In this analysis, the barrier repair cost per vkm was used as a measure to compare the effect of different road types. The correlations between the repair costs and the traffic works were necessary to neutralize the effect of the traffic volume and the barrier lengths on barrier damage. For the calculation of the barrier repair cost per vkm, the equations mentioned in subsection 5.7 were used.

This analysis was only made for the median barriers as the calculation of traffic works for roadside barriers was not possible.

5.8.3 Analysis of the effects of barrier type on barrier repairs and on vehicle damages

The aim of this analysis was to identify the effect of the barrier types on barrier damage repairs in order to identify the type barrier which is most profitable to use. In this analysis the focus was on three aspects:

- The repair cost per vkm
- The SRA’s actual repair cost per vkm
- The extent of damage to vehicles caused by collision with different barrier types

This analysis began by calculating the average cost per repair of different barrier types, regardless of road types, speed limits and barrier positions. For this reason the following equations were used:

$$\boldsymbol{TARC_{(b)} = \sum_{BR=1}^{BR=n} RC_{BR\,(b)}}$$

$$\boldsymbol{AVCR_{(b)} = TARC_{(b)} \div NR_{(b)}}$$

‘

TARC: the total annual repair cost.

AVCR: the average cost per repair.

NR: the number of the damage repairs.

$\boldsymbol{RC_{BR}}$: the cost for the single repair (BR).

b: the barrier type.

Later, the barrier repair costs per vkm were calculated as another basis for the comparison between barrier types. During this part of the analyses, the focus was mainly on median barriers, as the calculation of the traffic works was only possible for the median barriers. The repair cost per vkm for each barrier type was calculated using the following equations:

$$\boldsymbol{TATW_{(b)} = \sum_{l=1}^{l=n} ATW_{(b)}}$$

$$\boldsymbol{ARC_{(b)} = TARC_{(b)} \div TATW_{(b)}}$$

or

$$\boldsymbol{ARC_{(b)} = RQ_{(b)} * AVCR_{(b)}}$$

$$\boldsymbol{RQ_{(b)} = NR_{(b)} \div TATW_{(b)}}$$

TATW: the total annual traffic work in vehicles kilometre.

ARC: the repair cost per vkm.

RQ: the number of repairs per vkm.

b: the barrier type.

In order to identify the most profitable median barrier type, the analysis focused on w-beam barriers and cable barriers. These two barrier types are the most common types in Sweden and in many other countries. This analysis compared the repair costs per vkm between w-beam barriers and cable barriers using the equations mentioned in subsection 5.7.

The SRA's actual repair cost per vkm was also used as another basis a comparison between w-beam barrier and the cable barriers. The SRA's actual repair cost is the part of barrier repair cost which the SRA stands for. As the SRA receives compensation for the entire repair cost for repairs of cable barriers, the common belief is that cable barriers are more profitable for the SRA than w-beam barriers. SRA's actual repair cost per vkm was calculated using the same equations mentioned in subsection 5.7.

These two comparisons of the repair costs between barrier types were only possible to do in the Western Region, as w-beam barriers did not exist as median barriers in the Central Region. Motorways were the only road type included in this comparison, as w-beam barriers only exist along motorways. The comparison was done regardless of the speed limits. Roadside barriers were excluded from the comparisons as calculation of traffic works for this barrier type was not possible.

The extent of vehicle damage, caused by w-beam barriers and cable barriers, was used for comparison between these two barrier types. The aim of these comparisons was to identify which barrier type was less harmful for impacting vehicles. Vehicle repair compensations from insurance companies were used as indicators for the extent of vehicle damage. For damages which occurred due to impact with the same barrier type, an average value for vehicle repair compensation was calculated. This value was used to compare the extent of vehicle damages caused by both median barriers and roadside barriers, regardless of speed limits or road types. For these comparisons the following equations were used:

$$AVCVD_{(b)} = TCVD_{(b)} \div NDV_{(b)}$$

$$TCVD = \sum_{DV=1}^{DV=n} CVD_{DV\,(b)}$$

AVCVD: the average repair compensation per vehicle damage.

TCVD: the total annual repair compensation for vehicle damages.

NVD: number of compensated vehicle damages during the studied year.

CVD: the repair compensation for the single damaged vehicle (*DV*).

b: the barrier type.

5.8.4 Analyses of the seasonal effects on barrier damage repairs

To verify the seasonal effect on barrier repairs and their associated costs, efforts were made to analyse the differences in repair costs between summer repairs and winter repairs. Efforts were also made to analyse the differences in repair costs between the regions, as each region had different climate characteristics. This analysis covered both roadside barriers and median barriers. Unfortunately, it was not possible to correlate the repair costs to the traffic works as the traffic volume was not measured separately for each season. Barrier types, road types, barrier position, barrier placements and speed limits were not considered in the comparisons. For this analysis the following equations were used:

$$AVCR_{(rg,se)} = TARC_{(rg,se)} \div NR_{(rg,se)}$$

$$TARC_{(rg,se)} = \sum_{BR=1}^{BR=n} RC_{BR\,(rg,se)}$$

AVCR: the average cost per repair.

TARC: the total annual repair cost

NR: the number of the damage repairs during the studied year.

RC_{BR} : the cost for the single repair (*BR*).

rg: the region.

se: the season.

5.8.5 Analyses of the effects of barrier placements on barrier damage repairs

The aim of this analysis was to verify the effect of barrier placement on barrier repairs and the associated costs. The objective was to find the distance between the barriers and the edge of traffic lanes which gave minimal damage risks and repair costs. For this reason, the road barriers were classified into two classes depending on the distances between the road barriers and the traffic lanes. The classes were:

Class A: the distance between the road barrier and the edge of the traffic lane was within the range of 0.5 to 2 metres.

Class B: the distance between the road barrier and the edge of the traffic lane was more than 2 metres.

The number of repairs and the repair cost per barrier repair were compared between the two classes, regardless of road types, barrier type and speed limits. The following equations were used for these comparisons:

$$AVCR_{(c)} = TARC_{(c)} \div NR_{(c)}$$

$$TARC_{(c)} = \sum_{BR=1}^{BR=n} RC_{BR\,(c)}$$

AVCR: the average cost per repair.

TARC: the total annual repair cost.

NR: the number of damage repairs during the studied year

RC_{BR}: the cost for a single repair (*BR*).

c: the barrier class (A or B).

Both median barriers and roadside barriers were included in this analysis. However, it was not possible to correlate the number of barrier repairs and the associated costs to traffic works. The calculation for traffic works was not possible as the lengths of the barriers with different placement were unknown in the studied regions.

5.8.6 Analyses of the effect of road alignment on barrier repairs

The aim of this analysis was to verify the effect of road alignment on barrier repairs. This was done by analysing the difference in the number of repairs between barriers installed along straight road sections and barriers installed along curves. Differences between barrier types, road types and speed limits were not considered in this analysis. Both roadside barriers and median barriers were covered in this analysis. However, it was not possible to correlate the number of barrier repairs to the traffic works as the lengths of barriers with a different placement were unknown in the studied regions.

5.8.7 Analyses of the effects of cross section types on barrier repairs

In order to identify how the type of road cross section along collision-free roads affects the number of barrier repairs, the repairs along the collision-free roads were divided into four categories:

- Repairs conducted along the single-lane directions.
- Repairs conducted along the double-lane directions.
- Repairs conducted along the lane shifts, from single to double lanes.
- Repairs conducted along the lane shifts, from double to single shifts.

For each of these categories, the ratio between the number of barrier repairs within each category and the total number of repairs on collision-free roads were calculated, regardless of speed limits, barrier types and barrier positions, etc. These ratios were used to identify the type of road cross section which generates the lowest number of barrier repairs.

Both roadside barriers and median barriers were included in this analysis. Unfortunately, it was not possible to correlate the number of barrier repairs to the traffic works as the lengths of the barriers along the mentioned categories were unknown.

5.9 Results

This subsection presents the results of the calculations and analyses. It starts with a presentation of barrier repair expenses in both regions as well as the distribution of repair costs and cost items included in each barrier repair. Later, the results of the different analyses are presented separately. These results are discussed in subsection 5.10 in the same structure in which the results are presented in 5.9.

Table 5.5 shows the total annual repair costs in both regions for roadside barriers and median barriers regardless of barrier types, road types or speed limits.

Table 5.5 Repair costs for barrier damages, including both roadside and median barriers

Region	Number of annual damage repairs	Total annual repair cost (SEK)	Average cost per repair (SEK/Rep)	Average working-cost per repair (SEK/Rep)	%	Average cost for replaced parts per repair (SEK/Rep)	%	Aaverage cost for material for temporary traffic arrangements per repair (SEK/Rep)	%	Other costs (SEK/Rep)	%
Central	402	6 425 800	15 985	6 144	38%	5 534	35%	3 211	20%	1 095	7%
Western	683	7 729 875	11 318	5 269	47%	3 221	28%	2 726	24%	102	1%

The distribution of repair costs in figures 5.15 and 5.16 show that 76% of repair costs in both regions are within the interval of 5000 to 20000 SEK. Despite that similarity, the average cost per repair in the Central Region is 41% higher than the average cost per repair in the Western Region.

Each repair cost consists of four different items: Working-costs (cost for staff and machinery), cost for replaced parts, cost for material required for temporary traffic arrangements and other repair related costs. According to table 5.5, working-cost is the highest cost item for the repair of barrier damages. Costs for replaced parts is the second highest cost item and the third highest is the cost of materials required for temporary traffic measures. The lowest cost item is other costs. The costs included in this cost item differ between regions. This probably explains why this cost item differs so much between the regions. Unfortunately, it was not possible to calculate the installation costs for temporary traffic measures separately as these costs are not specified as an individual cost item in the repair invoices but included in the working- costs.

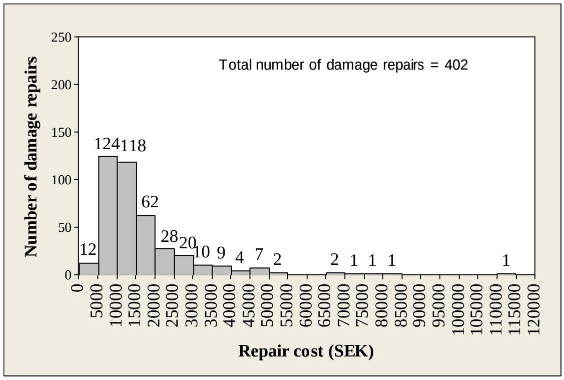

Figure 5.15 Distribution of repair costs for barrier damages in the Central Region regardless of barrier types, road types, speed limits and traffic volumes

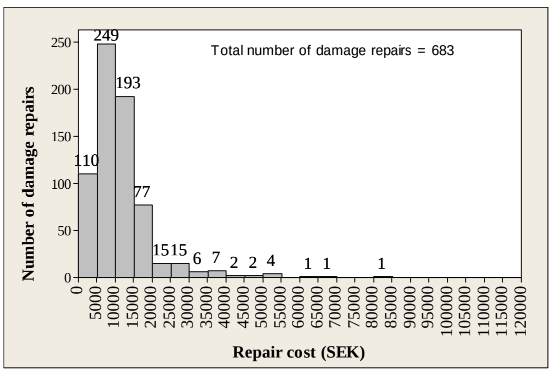

Figure 5.16 Distribution of repair costs for barrier damages in the Western Region regardless of barrier types, road types, speed limits and traffic volumes

The proportion of these cost items differ between the two regions. For example working-costs in the Western Region constitute 47% of the total repair cost compared to 38% in the Central Region (table 5.5). An explanation for this difference is that the cost for installation of temporary traffic arrangements in the Western

Region is higher due to a higher traffic volume and roads which are more sensitive to traffic disturbances. This requires complicated temporary traffic arrangement measures which are usually conducted at night. This is also indicated by the difference between the material costs required for temporary traffic arrangements in the regions (table 5.5).

Table 5.5 also shows that the costs for replaced parts in the Central Region constitute 35% of the total repair cost compared to 28% in the Western Region. Factors explaining this difference are described in subsection 5.10.8.

As mentioned before, the SRA receives compensation for expenses for each barrier repair from either the insurance companies involved or the Swedish Motor Insurers. Table 5.6 shows that in the Central Region, the SRA pays 11% of the total repair expenses compared to 22% in the Western Region. A possible factor underlying this difference could be the frequent use of cable barriers in the Central Region. The SRA usually receives compensation for the entire repair expenses for cable barriers. In contrast, the most used barrier type in the Western Region is the w-beam barrier. For this barrier type, the SRA receives compensation for the entire working-cost and for 50% of the costs for replaced parts (Johansson 2002). In addition, the amount of excess paid by the Central Region is 8% of the total annual repair cost compared to 13% paid by the Western Region.

Table 5.6 Distribution of the annual repair costs for road barriers between SRA, Swedish Motor Insurers and the insurance companies.

	Total annual repair cost (SEK)	Compensation from the Swedish Motor Insurers (SEK)	%	Compensation from insurance companies (SEK)	%	SRA's costs for barrier repairs excluding excess (SEK)	Excess paid by SRA (SEK)	SRA's share of the total annual repair cost (SEK)
Central Region*	5 269 120	2 273 524	43%	2 424 427	46%	158 289	412 880	11%
Western Region	7 729 875	3 753 587	49%	2 243 580	29%	713 306	1 019 403	22%

The costs of 68 repairs are excluded from the annual repair cost in the Central Region as the information about the compensation is missing for those repairs.

5.9.1 Analyses of effects of speed limits on barrier repair costs

This subsection presents the results of the analyses of repair costs for cable barriers and w-beam barriers depending on different speed limits.

5.9.1.1 Cable barriers along motorways

Table 5.7 shows that the repair cost per vkm for median cable barriers along motorways in the Central Region is higher for a speed limit of 90 km/hr than for a speed limit of 110 km/hr. Both the number of repairs per vkm and the average cost per repair of median cable barriers on motorways are higher at speed limit of 90 km/hr than at 110 km/hr. A high average cost per barrier repair along roads with a speed limit of 90 km/hr indicates that barrier damages are greater on roads with that speed limit than on roads with a speed limit of 110 km/hr. This is confirmed by the average number of replaced barrier posts in the Central Region which is 9.8 posts per repair on roads with a speed limit of 90 km/hr compared to 4 posts per repair on roads with 110 km/hr.

Table 5.7 Repair cost for cable barriers installed as median barriers along motorways

Central Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs	None existing	6	68
Annual traffic work (Mvkm)		14.5	255
Number of repairs per vkm (Rep/Mvkm)		0.41	0.27
Total annual repair cost (SEK)		115 303	1 088 787
Average cost per repair (SEK)		19 217	16 012
Repair cost per vkm (kSEK/Mvkm)		7.952	4.270
Western Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs	None existing	None existing	105
Annual traffic work (Mvkm)			514
Number of repairs per vkm (Rep/Mvkm)			0.20
Total annual repair cost (SEK)			1 117 101
Average cost per repair (SEK)			10 639
Repair cost per vkm (kSEK/Mvkm)			2.173

The distribution of repair costs for median cable barriers in the Central Region is illustrated in figures 5.17, 5.18 and 5.19. It is worth noting that the high average cost per repair of cable barriers along roads with 90 km/hr speed limits in the Central

Region occur sporadically due to a limited number of repairs and one single repair cost of 83 000 SEK. Therefore the results have to be interpreted carefully.

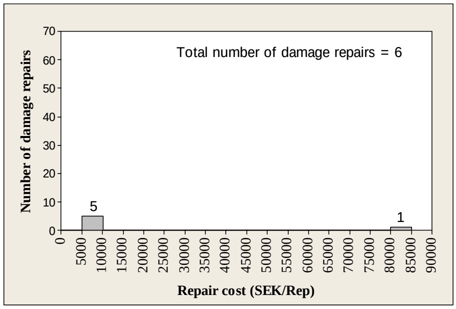

Figure 5.17 Distribution of the repair costs for cable barriers installed as median barriers along motorways with a speed limit of 90 km/hr in the Central Region

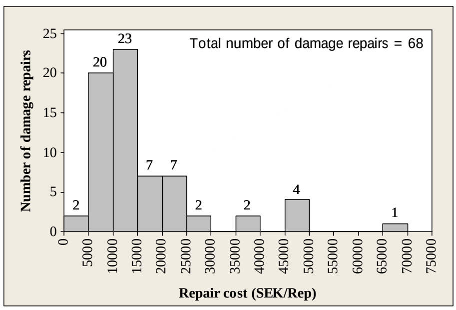

Figure 5.18 Distribution of repair costs for cable barriers installed as median barriers along motorways with a speed limit of 110 km/hr in the Central Region

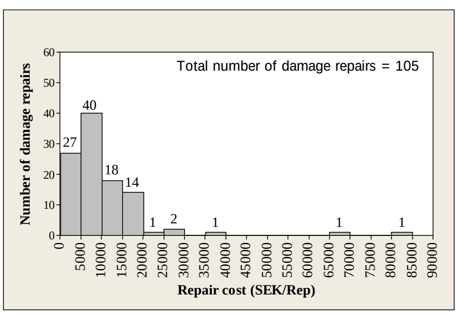

Figure 5.19 Distribution of repair costs for cable barriers installed as median barriers along motorways with a speed limit of 110 km/hr in the Western Region

5.9.1.2 Cable barriers along collision-free arterial roads

Table 5.8 shows that the repair cost per vkm for cable barriers along collision-free arterial roads is higher at speed limits of 90 km/hr than at 110 km/hr in the Central Region and higher for 90 km/hr than for 70 km/hr in the Western Region. This occurs because both the number of repairs per vkm and the average cost per barrier repair along the collision-free arterial roads are higher at a speed limit of 90 km/hr than at 110 km/hr un the Central Region, respectively higher at a speed limit of 70 km/hr than 90 km/hr in the Western Region.

Table 5.8 also shows that the number of repairs per vkm for cable barriers along collision-free arterial roads with 90 km/hr speed limits in the Central Region is unusually high. This is due to the fact that all six barrier repairs occurred along a two kilometre long road section which includes a sharp curve. The road barrier on this section was very exposed to vehicle impact. The distribution of the repair costs in both regions is described in figures 5.20, 5.21, 5.22 and 5.23.

Table 5.8 Repair costs for cable barriers installed as median barrier along collision-free arterial roads

Central Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs	None existing	6	137
Annual traffic work (Mvkm)	2.1	8	221
Number of repairs per vkm (Rep/Mvkm)		0.75	0.62
Total annual repair cost (SEK)		102 760	1 764 018
Average cost per repair (SEK)		17 127	12 876
Repair cost per vkm (kSEK/Mvkm)		12.845	7.982

Western Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs	7	21	None existing
Annual traffic work (Mvkm)	15.3	50.7	
Number of repairs per vkm (Rep/Mvkm)	0.46	0.41	
Total annual repair cost (SEK)	84 721	238 455	
Average cost per repair (SEK)	12 103	11 355	
Repair cost per vkm (kSEK/Mvkm)	5.537	4.703	

It is important to mention that the limited number of damage repairs on the collision-free arterial roads with speed limits of 70 or 90 km/hr contribute to a high degree of uncertainty in interpreting the results (figure 5.20 and 5.21).

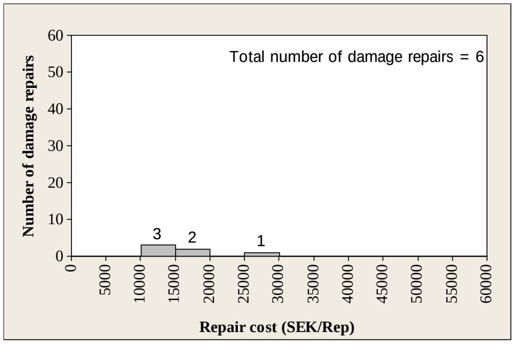

Figure 5.20 Distribution of the repair costs for cable barriers installed as median barriers along collision-free arterial roads with a speed limit of 90 km/hr in the Central Region

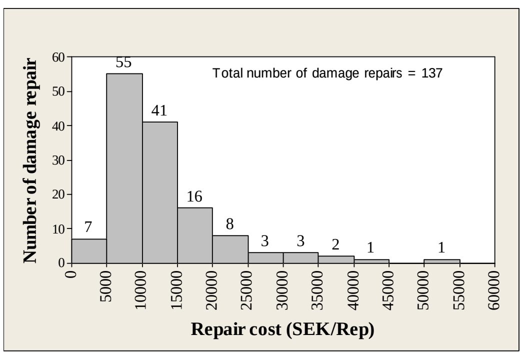

Figure 5.21 Distribution of the repair costs for cable barriers installed as median barriers along collision-free arterial roads with a speed limit of 110 km/hr in the Central Region

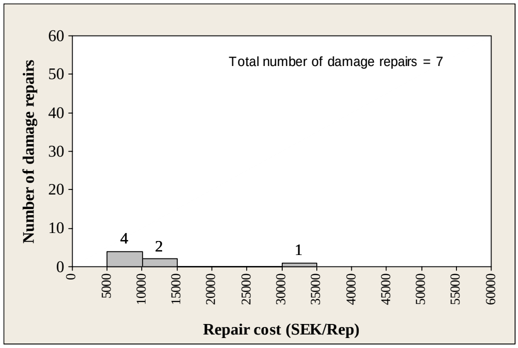

Figure 5.22 Distribution of the repair costs for cable barriers installed as median barriers along collision-free arterial roads with a speed limit of 70 km/hr in the Western Region

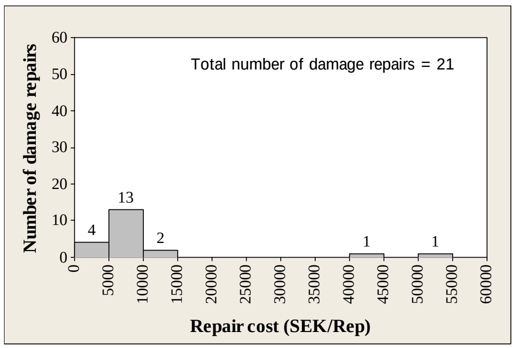

Figure 5.23 Distribution of the repair costs for cable barriers installed as median barriers along collision-free arterial roads with a speed limit of 90 km/hr in the Western Region

5.9.1.3 Cable barriers along collision-free country roads

Table 5.9 shows that the repair costs per vkm for cable barriers along the collision-free country roads are higher at speed limits of 90 km/hr than at 110 km/hr. The number of repairs per vkm along the collision-free country roads is three times higher at a speed limit of 90 km/hr than at 110 km/hr. However, the average cost per repair for median cable barriers along collision-free country roads are lower at a 90 km/hr speed limit than at 110 km/hr. It is worth noting that all the barrier repairs on the collision-free country roads with a 90 km/hr speed limit in the Central Region are conducted along a nine kilometre long road section, which is very exposed for accidents.

Table 5.9 Repair costs for cable barriers installed as median barriers along collision-free country roads

Central Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs		19	73
Annual traffic work (Mvkm)	2	25	299
Number of repairs per vkm (Rep/Mvkm)		0.76	0.24
Total annual repair cost (SEK)		272 211	1 197 917
Average cost per repair (SEK)		14 327	16 410
Repair cost per vkm (kSEK/Mvkm)		10.888	4.006

Western Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs	7	25	None existing
Annual traffic work (Mvkm)	32.4	100.2	
Number of repairs per vkm (Rep/Mvkm)	0.22	0.25	
Total annual repair cost (SEK)	94 290	255 715	
Average cost per repair (SEK)	13 470	10 229	
Repair cost per vkm (kSEK/Mvkm)	2.910	2.552	

Table 5.9 also shows that, the repair costs per vkm for the median cable barriers along collision-free country roads are higher at a speed limit of 70 km/hr than at 90 km/hr. The table also shows that the average cost per repair of median cable barriers along the collision-free country roads are higher at a speed limit of 70 km/hr than at 90 km/hr. However, the difference in the number of repairs per vkm is very small. At the same time, one has to be aware that the small number of repairs which are studied make the comparison of differences in average cost uncertain (figures 5.24 and 5.25).

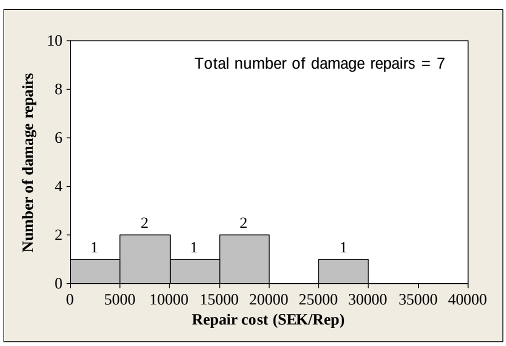

Figure 5.24 Distribution of the repair costs for cable barriers installed as median barriers along collision-free country roads with a speed limit of 70 km/hr in the Western Region

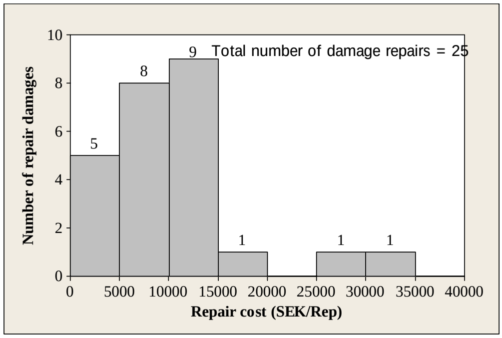

Figure 5.25 Distribution of the repair costs for cable barriers installed as median barriers along the collision-free country roads with a speed limit of 90 km/hr in the Western Region

Based on the results presented in this subsection it is obvious that the repair costs per repair as well as the number of repairs per vkm and the average cost per repair of median cable barrier damage generally are lower along roads with speed limit of 110 km/hr than along roads with speed limits of 70 km/hr or 90 km/hr, regardless of the road types (table 5.10).

Table 5.10 Repair cost for cable barriers installed as median barriers, regardless of road types

Central Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs	None existing	50	279
Annual traffic work (Mvkm)	5.9	96	776
Number of repairs per vkm (Rep/Mvkm)		0.52	0.36
Total annual repair cost (SEK)		828 047	4 057 150
Average cost per repair (SEK)		16 561	14 542
Repair cost per vkm (kSEK/Mvkm)		8.625	5.228
Western Region	**70 km/hr**	**90 km/hr**	**110 km/hr**
Number of damage repairs	14	46	105
Annual traffic work (Mvkm)	48	151	514
Number of repairs per vkm (Rep/Mvkm)	0.29	0.30	0.20
Total annual repair cost (SEK)	179 011	494 170	1 117 101
Average cost per repair (SEK)	12 787	10 743	10 639
Repair cost per vkm (kSEK/Mvkm)	3.729	3.273	2.173

5.9.1.4 W-beam barriers along motorways

In the Central Region w-beam barriers are not installed as median barriers. In the Western Region such barriers are installed along motorways and 4-lane roads. This is the reason why the w-beam barriers could only be studied in the Western Region. Table 5.11 shows that the differences in repair costs per vkm, number of repairs per vkm and average cost per repair for median w-beam barriers along motorways are very small between speed limits of 70 km/hr and 90 km/hr.

Table 5.11 Repair costs for w-beam barriers installed as median barriers along motorways in the Western Region

	70 km/hr	90 km/hr	110 km/hr
Number of damage repairs	16	42	149
Annual traffic work (Mvkm)	210	637.4	1605.7
Number of repairs per vkm (Rep/Mvkm)	0.08	0.07	0.09
Total annual repair cost (SEK)	162 343	422 067	1 665 549
Average cost per repair (SEK)	10 146	10 049	11 178
Repair cost per vkm (kSEK/Mvkm)	0.773	0.662	1.037

Table 5.11 also shows that the repair cost per vkm for w-beam barriers along motorways are higher at a speed limit of 110 km/hr than at 90 km/hr. Both the number or repairs per vkm and the average cost per repair of w-beam barriers along motorways are higher at a speed limit of 110 km/hr than at 90 km/hr or 70km/hr.

It is also important to observe that the number of repairs was particularly limited at a speed limit of 70 (figures 5.26, 5.27 and 5.28). This made the comparison uncertain.

5.9.1.5 W-beam barriers along 4-lane roads

Table 5.12 shows that the repair cost per vkm for w-beam barriers along 4-lane roads is higher at a 70 km/hr speed limit than at 90 km/hr. Both the number of repairs per vkm and the average cost per repair along 4-lane roads are higher at a speed limit of 70 km/hr than at 90 km/hr.

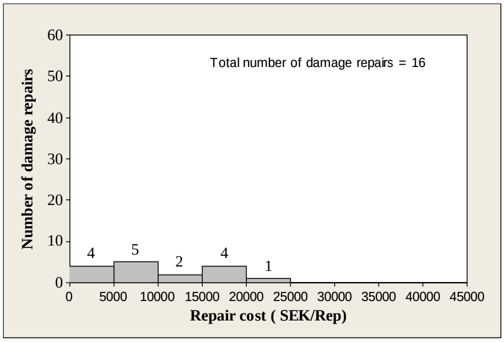

Figure 5.26 Distribution of the repair costs for w-beam barriers installed as median barriers along motorways with a speed limit of 70 km/hr in the Western Region

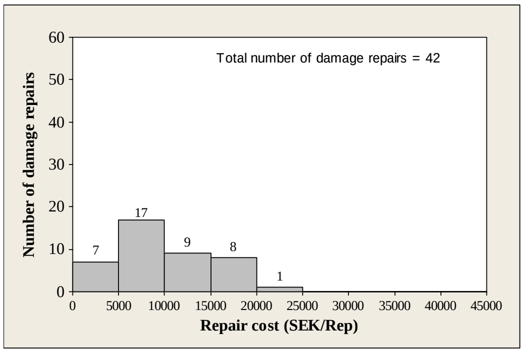

Figure 5.27 Distribution of the repair costs for w-beam barriers installed as median barriers along motorways with a speed limit of 90 km/hr in the Western Region

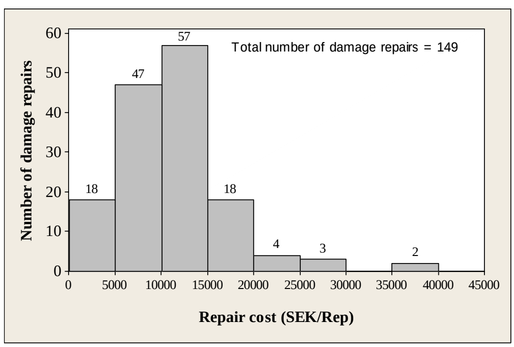

Figure 5.28 Distribution of the repair costs for w-beam barriers installed as median barriers along motorways with a speed limit of 110 km/hr in the Western Region

Table 5.12 Repair cost for w-beam barriers installed as median barriers along 4-lane roads in the Western Region

	70 km/hr	90 km/hr	110 km/hr
Number of damage repairs	26	10	None existing
Annual traffic work (Mvkm)	335.5	258.1	21.9
Number of repairs per vkm (Rep/Mvkm)	0.08	0.04	
Total annual repair cost (SEK)	228 714	53 029	
Average cost per repair (SEK)	8 797	5 303	
Repair cost per vkm (kSEK/Mvkm)	0.682	0.205	

Figures 5.29 and 5.30 clearly show that the repair costs of many of the barrier damages on 4-lane roads with speed limits of 70 km/hr or 90 km/hr are within the interval of 5000 to 10000 SEK.

In some cases the repair costs for barrier damages on 4-lane roads with a speed limit of 70 km/hr exceeded 10000 SEK. Those repairs were conducted in the city of Gothenburg where repairs are costly as they usually took place at night with complicated temporary traffic arrangement measures. This is probably one of the reasons why the average repair cost for barrier damage along 4-lane roads was higher at a speed limit of 70 km/hr than at 90 km/hr.

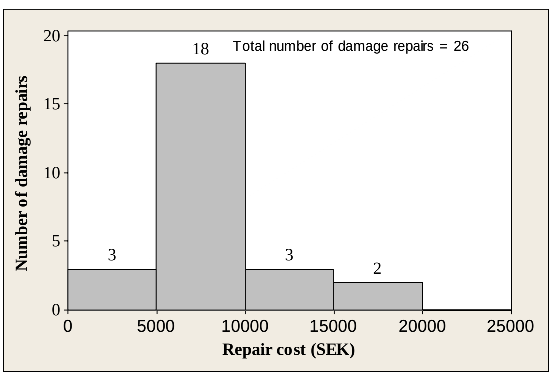

Figure 5.29 Distribution of the repair costs for w-beam barriers installed as median barriers along 4-lane roads with a speed limit of 70 km/hr in the Western Region

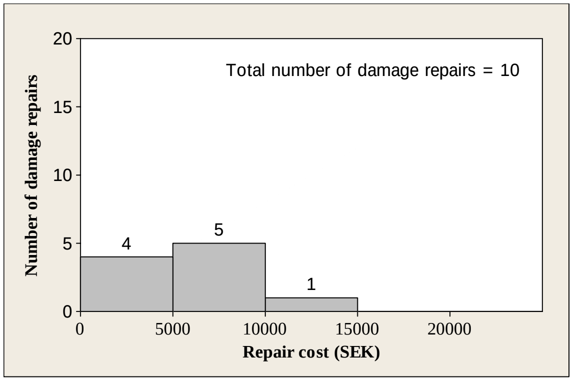

Figure 5.30 Distribution of the repair costs for w-beam barriers installed as median barriers along 4-lane roads with a speed limit of 90 km/hr in the Western Region

5.9.2 Analysis of effects of road types on barrier damage repairs

Table 5.13 shows that the repair costs per vkm in both regions are higher for barriers along collision-free roads than for barriers along motorways and 4-lane roads. This mainly occurs due to a higher number of barrier repairs per vkm along collision-free roads than along motorways and 4-lane roads.

Table 5.13 also shows that the repair costs per vkm for barriers along the studied roads are higher in the Central Region than in the Western Region. However, the biggest difference was noted along 4-lane roads. This difference mainly occurred because of the low number of repairs per vkm for barriers installed along 4-lane roads in the Western Region. The average cost per repair along 4-lane roads is also lower in the Western Region than in the Central Region. Also for other road types the number of repairs per vkm and the average cost per repair are lower in the Western Region than in the Central Region.

Table 5.13 Repair costs for median barriers along different road types regardless of speed limits and barrier types

Central Region*	**Motorways**	**Collision-free country roads + collision-free arterial roads**	**4-Lane roads**
Number of damage repairs	74	235	19
Annual traffic work (Mvkm)	269.6	555	78.5
Number of repairs per vkm (Rep/Mvkm)	0.27	0.42	0.24
Total annual repair cost (SEK)	1 204 090	3 336 907	337 773
Average cost per repair (SEK)	16 271	14200	17 778
Repair cost per vkm (kSEK/Mvkm)	4.466	6.012	4.303
Western Region	**Motorways**	**Collision-free country roads + collision-free arterial roads**	**4-Lane roads**
Number of damage repairs	315	60	40
Annual traffic work (Mvkm)	2980	199	649
Number of repairs per vkm (Rep/Mvkm)	0.11	0.30	0.06
Total annual repair cost (SEK)	3 387 036	673 181	334 030
Average cost per repair (SEK)	10752	11220	8351
Repair cost per vkm (kSEK/Mvkm)	1.137	3.383	0.515

*A repair in the Central region is excluded as the damages was on a 2-lane road section

5.9.3 Analyses of the effects of barrier type on the barrier repairs and on the vehicle damages

Table 5.14 shows the average cost per repair calculated for four barrier types installed as roadside barriers and median barriers. The costs are calculated regardless of road types, traffic volumes and speed limits. The Average cost per repair of w-beam barriers and Kohlswa-beam barrier are slightly the same in both regions.

Table 5.14 Repair costs for different road barrier types installed as median barriers and roadside barriers, regardless of road types and speed limits

Central Region	**Pipe barrier**	**Kohlswa-beam barrier**	**Cable barrier**	**W-beam barrier**
Number of damage repairs	5	9	341	47
Total annual repairs cost (SEK)	111 762	177 840	5 196 868	939 329
Average cost per repair (SEK)	22 352	19 760	15 240	19 986
Western Region	**Pipe barrier**	**Kohlswa-beam barrier**	**Cable barrier**	**W-beam barrier**
Number of damage repairs	4	52	172	455
Total annual repair cost (SEK)	73 221	623 377	1 954 721	5 078 557
Average cost per repair (SEK)	18 305	11 988	11 365	11 162

Table 5.14 also shows that the average cost per repair of pipe barriers in both regions is higher than the average cost per repair of other barrier types. According to maintenance contractors, pipe barriers require more time to repair. However the result has to be interpreted carefully as the number of repairs are very limited compared to the other barrier types. Table 5.12 also shows that the average cost per repair for cable barriers is lower than the average cost per repair of other barrier types.

These results are different when the repair costs are correlated to the traffic work and the focus is only on the median barriers as it is shown in table 5.15. The repair cost per vkm for cable barriers installed as median barriers in the Western Region is three times higher than for w-beam barriers, even if the average cost per repair for both types are almost the same. This difference is explained by the fact that the number of repairs per vkm for cable barriers is three times higher than for the w-beam barriers.

Table 5.15 Repair costs for median barrier damages regardless of road types and speed limits

Central Region	Cable barriers	W-beam barriers	Kohlswa-beam barriers	Pipe-barriers
Number of damage repairs	329	None existing	None existing	None existing
Annual traffic work (Mvkm)	878			
Number of repairs per vkm (Rep/Mvkm)	0.37			
Total annual repair cost (SEK)	4 885 197			
Average cost per repair (SEK)	14 849			
Repair cost per vkm (kSEK/Mvkm)	5.564			
Western Region	**Cable barriers**	**W-beam barriers**	**Kohlswa-beam barriers**	**Pipe-barriers**
Number of damage repairs	165	243	7	None existing
Annual traffic work (Mvkm)	713	3095	21	
Number of repairs per vkm (Rep/Mvkm)	0.23	0.08	0.34	
Total annual repair cost (SEK)	1 790 282	2 531 702	72 262	
Average cost per repair (SEK)	10 850	10 419	10 323	
Repair cost per vkm (kSEK/Mvkm)	2.511	0.818	3.491	

Table 5.15 also shows a higher repair cost per vkm for Kohlswa-beam barriers compared to the repair cost per vkm for cable barriers and w-beam barriers: even if

the average cost per repair of Kohlswa-beam barriers are slightly lower than for other barrier types. This low number of damage repairs for Kohlswa-beam barriers makes this result uncertain.

Table 5.16 shows that the average cost per repair of w-beam barriers and cable barriers installed as median barriers along motorways is almost the same. Despite that, the repair cost per vkm for cable barriers is more than two times higher than for w-beam barriers. This difference is due to the fact that the number of repairs per vkm for cable barriers is two times higher than for w-beam barriers.

Table 5.16 Comparison between cable barriers and w-beam barriers installed as median barrier in the Western Region, regardless of speed limits

Cable barrier	**Motorways**
Number of damage repairs	105
Annual traffic work (Mvkm)	514
Number of repairs per vkm (Rep/Mvkm)	0.20
Total annual repair cost (SEK)	1 117 101
Average cost per repair (SEK)	10 639
Repair cost per vkm (kSEK/Mvkm)	2.173
W-beam barrier	**Motorways**
Number of damage repairs	207
Annual traffic work (Mvkm)	2453
Number of repairs per vkm (Rep/Mvkm)	0.08
Total annual repair cost (SEK)	2 249 959
Average cost per repair (SEK)	10 869
Repair cost per vkm (kSEK/Mvkm)	0.917

Figure 5.31 shows how the cost items differ between w-beam barriers and cable barriers. The costs of temporary traffic arrangements for all three types of median barriers are similar and constitute approximately 25% of the total annual repair costs. This similarity is reasonable as costs for temporary traffic arrangements do not depend on the type of barrier but mostly on the road type and traffic volume.

Figure 5.31 also shows that the working-costs for w-beam barriers constitute 50% of the total annual repair cost for w-beam barrier damages, while the working-costs for cable barriers constitute 30% of the total annual repair cost for cable barrier damages. This difference is also reasonable because the replacement of the damaged components for w-beam barriers requires more time than cable barriers. This factor also contributes to higher installation costs for w-beam barriers compared to cable barriers.

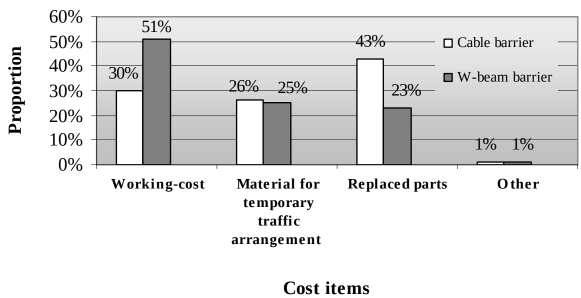

Figure 5.31 Figure Proportion of the cost items of the repair costs for w-barriers and cable barriers installed as median barriers in the Western Region regardless of the road types and speed limits.

Figure 5.31 also shows that the costs for replaced parts constitute 43% of the total annual repair cost for cable barriers and 23% of the total annual repair cost for w-beam barriers. This difference confirms a common opinion held by road authorities that there is a marketing policy used by the manufacturers of cable barriers; low initial prices compensated by higher spare part prices (Vägverket 2006c, 2006d, 2006e, 2006f, 2006g, 2006h, 2006i,) This is another factor contributing to a higher cost per repair of cable barriers compared to w-beam barriers.

Table 5.17 shows that SRA's actual average cost per repair of damages to w-beam barriers is more than two times higher than for cable barriers. This is reasonable as the SRA receives compensation for the entire repair expenses for cable barrier damages from the Swedish Motor Insurers or from the insurance companies. Despite that fact, SRA's actual repair cost per vkm is a little higher for cable barrier repairs than for w-beam barriers. The factor underling this difference is the number of repairs per vkm for cable barriers is approximately three times higher than for w-beam barriers.

Table 5.17 The SRA's actual repair cost for median barrier regardless of speed limits or road types

Central Region	Cable barriers	W-beam barriers
Number of damage repairs	329	None existing
Annual traffic work (Mvkm)	878	
Number of repairs per vkm (Rep/Mvkm)	0.37	
Total annual repair cost (SEK)	4 885 197	
Average cost per repair (SEK)	14 849	
Repair cost per vkm (kSEK/Mvkm)	5.564	
Western Region	**Cable barriers**	**W-beam barriers**
Number of damage repairs	165	243
Annual traffic work (Mvkm)	713	3095
Number of repairs per vkm (Rep/Mvkm)	0.23	0.08
Total annual repair cost (SEK)	1 790 282	2 531 702
Average cost per repair (SEK)	10 850	10 419
Repair cost per vkm (kSEK/Mvkm)	2.511	0.818

The analysis of vehicle damage compensation shows that the average vehicle repair compensation is 82 000 SEK in the Central Region compared to 86 000 SEK in the Western Region, regardless of barrier types. This means that the average vehicle repair compensation in the Western Region is only 5% higher than in the Central Region, despite the fact that the distribution of vehicle repair compensations differ considerably between the regions and between different types of barriers (figures 5.32, 5.33, 5.34, 5.35, 5.36 and 5.37).

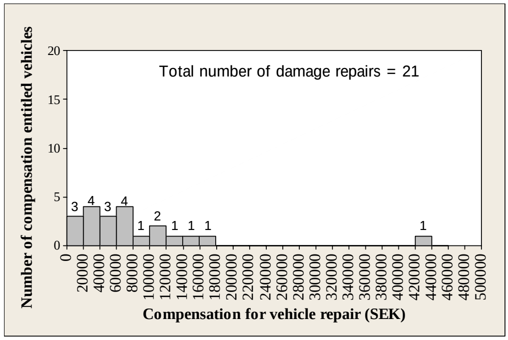

Figure 5.32 Distribution of the vehicle repair compensations in the Central Region regardless of barrier types, barrier positions, road types and speed limits

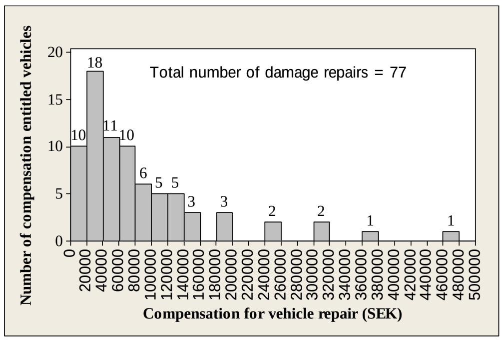

Figure 5.33 Distribution of the vehicle repair compensations in the Western Region regardless of barrier types, barrier positions, road types and speed limits.

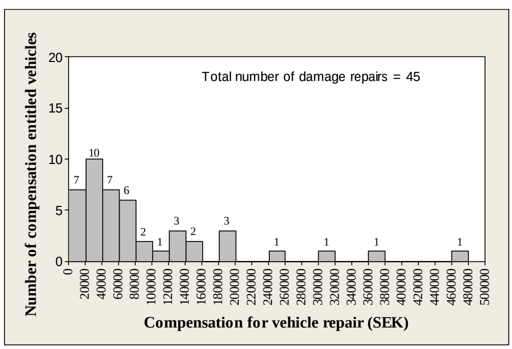

Figure 5.34 Distribution of the vehicle repair compensations due to impacts with the w-beam barriers in the Western Region regardless of barrier positions, road types and speed limits.

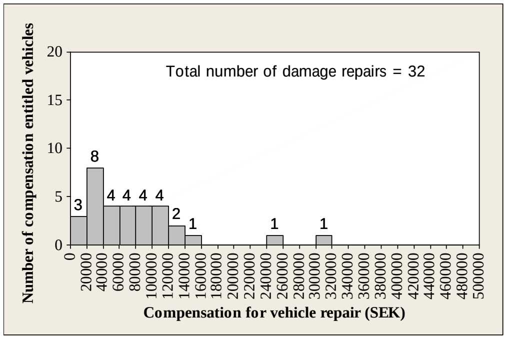

Figure 5.35 Distribution of the vehicle repair compensations due to impacts with the cable barriers in the Western Region regardless of barrier positions, road types and speed limits.

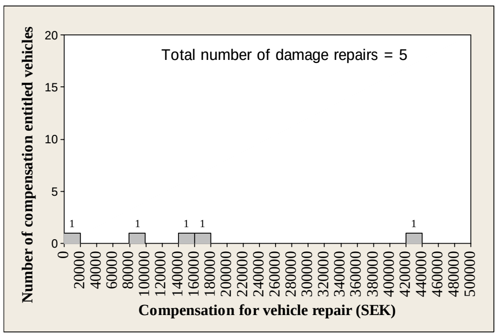

Figure 5.36 Distribution of the repair compensations due to impacts with the w-beam barriers in the Central Region regardless of barrier positions, road types and speed limits.

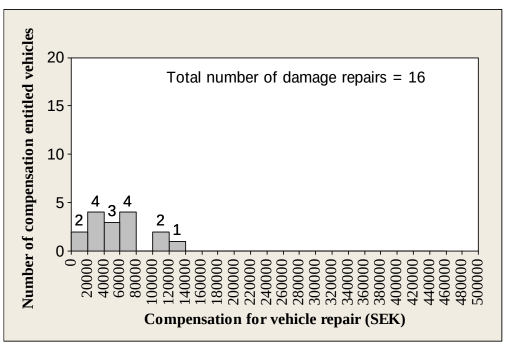

Figure 5.37 Distribution of the vehicle repair compensations due to impacts with the cable barriers in the Central Region regardless of barrier positions, road types and speed limits.

According to table 5.18, the average vehicle repair compensation due to collisions with w-beam barriers is three times higher than the average repair compensation due to collisions with cable barriers in the Central Region. The major factor contributing to a higher average vehicle repair compensation for w-beam barriers was a single buss repair which cost 431 000 SEK (figure 5.32). Also in the Western Region the average repair compensation is higher for collisions with w-beam barriers but the difference is only 13%.

Table 5.18 *Vehicle repair compensations regardless of road types, speed limits, barrier positions and barrier placements*

Central Region	**Cable barrier and W-beam barrier**	**Cable barrier**	**W-beam barrier**
Number of vehicle damages	21	16	5
Total compensation for vehicle damages (SEK)	1718169	874 109	844 060
Average compensation per vehicle damage (SEK)	81 818	54 632	168 812

Western Region	**Cable barrier and W-beam barrier**	**Cable barrier**	**W-beam barrier**
Number of compensated vehicle damages	77	32	45
Total compensation for vehicle damages (SEK)	6587983	2 535 443	4 052 540
Average compensation per vehicle damage (SEK)	85 558	79 233	90 056

It is important to mention that the results of this analysis must be interpreted very carefully as the data used was somewhat uncertain due to an occasional low number of accidents or some exceptional accidents that considerably influenced the results. Therefore, any definite conclusions based on these results will not be possible. Other factors underlying this uncertainty are:

- Damage repair compensations do not always correspond to the extent of vehicle damages. For example, when the repair costs for vehicle damages are estimated to be more than 80% of the market value of the vehicle, the insurance companies usually do not approve compensations for the real repair costs. In these cases the paid compensations are equal to the market value of the vehicles which usually are far lower than the repair costs, i.e. the compensation does not correspond to the real extent of the damage.

- Another uncertainty factor is that spare part prices are different for different vehicles. Expensive spare parts mean higher vehicle repair costs even if the extent of the damage is limited. Also in these cases the vehicle repair compensation does not correspond to the actual extent of the damage.
- Limited data relating to repair compensations probably affected the results as well. In many cases, the damaged vehicles or the insurance companies involved were unknown as this information was missing or incorrect. In many other cases, the damaged vehicles were not entitled to compensation depending on the type of insurance. In some other cases, the insurance companies refused to give any information about repair compensations due to secrecy restrictions. In these cases, it was not possible to get any information about vehicle damages. All these cases were excluded from the study.

5.9.4 Analyses of the seasonal effect on barrier repairs

According to table 5.19, 49% of the damage repairs in the Western Region are conducted during winter compared to 59% in the Central Region.

Table 5.19 Average cost per repair of road barriers depending on the seasons regardless of barrier types, barrier position, barrier placement, road types, and speed limits.

	Summer			Winter		
	Number of repairs	**Total annual repair cost (SEK)**	**Average cost per repair (SEK)**	**Number of repairs**	**Total annual repair cost (SEK)**	**Average cost per repair (SEK)**
Central Region	164	2 755 596	16 802	238	3 670 204	15 421
Western Region	347	4 015 306	11 571	336	3 714 546	11 055

In both regions the winter is defined as the period between 15 October and 15 April. No consideration has been taken to the fact that the winter is longer in the Central Region than in the Western Region

Table 5.19 also shows that the average cost per repair in the Central Region is 9% higher in the summer than in winter, compared to 4% in the Western Region. It also shows that the average cost per repair during winter in the Central Region is 40% higher than in the Western Region.

5.9.5 Analyses of the effects of barrier placements on the barrier damage repairs

Table 5.20 shows that repairs of barriers placed within the range of 0.5-2 metres from the traffic lane constitute 83% of all the damage repairs in the Central Region and 72% in the Western Region.

Table 5.20 Classification of road barrier placement regardless road types, barrier position, barrier types and speed limits

	Distance between the barriers and edge of traffic lane	
Central Region	**0.5-2 m**	**> 2 m**
Number of damage repairs	282	57
Damage repairs in procentage	83%	17%
Total annual repair cost (SEK)	4 493 031	929 326
Average cost per repair (SEK)	15 933	16 304
Western Region	**0.5-2 m**	**> 2 m**
Number of damage repairs	473	187
Damage repairs in procentage	72%	28%
Total annual repair cost (SEK)	5 132 635	2 197 308
Average cost per repair (SEK)	10 851	11 750

Table 5.20 also shows that the average cost per repair for the barriers installed farther than two metres from lane edges is higher than for barriers installed within the range of 0.5-2 metres from the lane edges. The difference is 2% in the Central Region and 8% in the Western Region.

5.9.6 Analyses of the effects of road alignment on barrier repairs

Table 5.21 shows that 71% of median barrier damages in the Central Region occurred on straight road sections compared to 61% in the Western Region. The result indicates that most of the damages occurred on the straight road sections in both regions.

Table 5.21 Distribution of barrier damage repairs between straight road sections and curves regardless of road types, barrier types, barrier positions, barrier placements and speed limits.

Central Region	**Straight road sections**	**Curves**
Number of damage repairs	237	98
Proportion	71%	29%
Western Region	**Straight road sections**	**Curve**
Number of damage repairs	383	245
Proportion	61%	39%

5.9.7 Analyses of the effects of road cross section type on barrier repair

Table 5.22 shows that the number of barrier repairs along the double-lane cross section directions is higher than along the single-lane cross section directions. It also shows that the proportion of damages repairs conducted on the lane shifts is 10% in the Central Region and 7% the Western Region.

Table 5.22 Proportion of the damage repairs of roadside and median barrier on different cross section types of the collision-free roads, regardless speed limits and barrier types

Central region	**Single-lane cross section**	**Double-lane cross section**	**From single to double**	**From double to single**
Number of repairs	102	147	11	17
Proportion	37%	53%	4%	6%
Western region	**Single-lane cross section**	**Double-lane cross section**	**From single to double**	**From double to single**
Number of repairs	19	23	1	2
Proportion	42%	51%	2%	5%

The available data about the precise position of the damages was limited to 277 damages in the Central Region and 45 damages in the Western Region for both roadside and median barriers. The limited number of barrier repairs in the Western Region is due to the fact that the studied collision-free roads is limited to 89 km compared to 527 km in the Central Region.

5.10 Discussion

This subsection discusses the results of the analyses in the same order as in which the results were presented in the previous subsection.

5.10.1 The effects of the speed limits on the barrier damage repairs

Before discussing the results of this analysis, it is worth noting that the comparison of repair costs per vkm between roads with speed limits of 70 km/hr and 110 km/hr was not possible in the same region as these speed limits did not exist along the same road type in the same region.

According to the results the repair costs per vkm for median barriers are generally lower along roads with a speed limit of 110 km/hr than along roads with 90 km/hr or 70 km/hr speed limits. This difference mainly occurs because the number of repairs per vkm is lower along roads with a 110 km/hr speed limit than along roads with 70 km/hr or 90 km/hr. A possible explanation for this phenomenon is that roads with a 110 km/hr speed limit have a better geometrical design standard than roads with speed limits of 90 or 70 km/hr such as smother alignment, good visibility and wider road median (Vägverket 2004c). These factors probably contribute to a lower risk for damage along roads with a speed limit of 110 km/hr. Another factor probably contributing to a higher risk for damages of median barriers on roads with speed limits of 70 or 90 km/hr is that these kinds of roads are usually located in urban regions with high traffic density, many connecting roads and consequently a higher accident risk.

5.10.1.1 Cable barriers

The results show that the average cost per repair of median cable barriers generally is lower at a speed limit of 110 km/hr than at 90 or 70 km/hr (table 5.10). This is due to the fact that costs for replaced parts of median cable barriers per vkm along the studied roads are higher at speed limits of 70 or 90 km/hr than at 110 km/hr (table 5.23). This indicates that the extent of damages on median cable barriers is less at a speed limit of 110 km/hr than at 70 or 90 km/hr, regardless of road type. A logical explanation for this phenomenon is hard to find.

In addition, the cost for material for temporary traffic arrangement per vkm for the studied repairs is lower at a speed limit of 110 km/hr than at 70 or 90 km/hr (table 5.23). This can be explained by the fact that most of the studied road sections with speed limits of 70 or 90 km/hr are located in urban regions. Damage repairs in those areas are costly as they usually are conducted at night with complicated temporary traffic arrangement measures to avoid traffic disturbance during the day.

Table 5.23 Cost items for repair of median cable barriers depending on the speed limits regardless of road types

Central Region	Speed limits	Number of damage repairs	Annaul trafic work (Mvkm)	Working-cost per vkm (SEK/Mvkm)	Cost for replaced parts per vkm (SEK/Mvkm)	Cost for material for temporary traffic arrangements per vkm (SEK/Mvkm)
	90	50	96	2 156	3 180	2 254
	110	279	776	1 795	2 012	1 132

Western Region	Speed limits	Number of damage reparis	Annaul trafic work (Mvkm)	Working-cost per vkm (SEK/Mvkm)	Cost for replaced parts per vkm (SEK/Mvkm)	Cost for material for temporary traffic arrangements per vkm (SEK/Mvkm)
	70	14	47.5	831	1 825	1 113
	90	46	151	802	1 566	886
	110	105	514	734	880	559

5.10.1.2 W-beam barriers

The results show that the repair cost per vkm for w-beam barriers along 4-lane roads in the Western Region is higher at speed limits of 70 km/hr than at 90 km/hr (table 5.12). This occurs mainly because the number of repairs per vkm for w-beam barriers along 4-lane roads is higher at a speed limit of 70 km/hr than at 90 km/hr. One factor which contributing to this difference was that many of the studied damage repairs along the 4-lane roads with a 70 km/hr speed limit were conducted in urban regions with high traffic density, many connecting roads and consequently a higher accident risk.

Another factor which resulting in higher repair costs per vkm for median w-beam barriers along 4-lane roads with a speed limit of 70 km/hr was that the extent of barrier damage along 4-lane roads was greater at speed limits of 70 km/hr than at 90 km/hr. This is obvious in the table 5.24 where the working-cost and cost for replaced parts for the w-beam barriers along the 4-lane roads is higher at speed limits of 70 km/hr than at 90 km/hr. Any explanation for this phenomenon is hard to find.

The costs for material for temporary traffic arrangements per vkm for the studied repairs are higher along 4-lane roads with a speed limit of 70 km/hr compared to those with a speed limit of 90 km/hr (table 5.24). An explanation for this is that repairs along the studied 4-lane roads with speed limits of 70 km/hr are conducted inside urban regions with costly repairs conducted at night with complicated temporary traffic arrangements.

Table 5.24 Cost items for repair of median w-beam barriers on the 4-lane roads depending on the speed limits

Western Region	Speed limits	Number of damage reparis	Annaul trafic work (Mvkm)	Working-cost per vkm (SEK/Mvkm)	Cost for replaced parts per vkm (SEK/Mvkm)	Cost for material for temporary traffic arrangements per vkm (SEK/Mvkm)
	70	26	336	352	120	199
	90	10	258	102	41	51

In contrast to the case mentioned above, the repair cost per vkm for median w-beam barriers along motorways are higher at speed limits of 110 km/hr than at 90 km/hr or 70 km/hr (table 5.11). Both the number of repairs per vkm and the average cost per repair are slightly higher at 110 km/hr speed limits than at 90 km/hr or 70 km/hr. Still the differences are rather small and they may be coincidental. Any explanation for a higher number of repairs per vkm on motorways with a speed limit of 110 km/hr is hard to find. Of course the speed limit itself could be an explanation for a higher accident rate but if so, why is that not the case for cable barriers?

Table 5.25 shows that the cost for materials for temporary traffic arrangements per vkm on motorways is higher at a speed limit of 110 than at speed limits of 70 or 90 km/hr, even though the motorways with 110 km/hr speed limits are mainly located outside urban regions with less complicated traffic situations. Any explanation for why the temporary traffic arrangement measures are higher on motorways with speed limits of 110 km/hr is hard to find.

Table 5.25 also shows that the cost for replaced parts for w-beam barriers per vkm along motorways is higher at a speed limit of 110 km/hr than at a speed limit of 90 km/hr. This indicates that the extent of damage to w-beam barriers along motorways with speed limits of 70 km/hr or 90 km/hr are less than along motorways with speed a limit of 110 km/hr.

Table 5.25 Cost items for repair of median w-beam barriers along motorways depending on the speed limits

Western Region	Speed limits	Number of damage reparis	Annaul trafic work (Mvkm)	Working-cost per vkm (SEK/Mvkm)	Cost for replaced parts per vkm (SEK/Mvkm)	Cost for material for temporary traffic arrangements per vkm (SEK/Mvkm)
	70	16	210	392	218	157
	90	42	637	351	183	117
	110	149	1 606	517	248	261

The analyses presented in this subsection indicates that the repair cost per vkm is generally lower for median w-beam barriers installed along roads with a speed limit of 110 than for median w-beam barriers installed along roads with speed limits of 90 km/hr or 70 km/hr. This indicated that the road geometry has an effect on barrier damages and the associated costs as the roads with a speed limit of 110 km/hr are distinguished by a high geometrical design standard such as smooth alignment, good visibility and a wide road median. Several previous studies in Sweden have also shown that the number of barrier repairs per vkm is lower along 14 meter wide collision-free roads than along 13 meter collision-free roads, especially in the southern regions (Carlsson and Brüde 2004, 2005).

5.10.2 The effects of road types on barrier repairs

The results show that the repair cost per vkm and the number of repairs per vkm for barriers along collision-free roads is higher than for barriers along motorways and 4-lane roads in both regions (table 5.13), even if the average cost per repair is almost the same for all barrier types. An explanation for these differences is that the road barriers along the collision-free roads are more exposed to damage as the distance between the barriers and the edge of the traffic lanes according to the Swedish specifications is within the range of 0.65 to 1.1 m. The distance between the road barriers and the edge of the traffic lanes is 1.75 m along normal standard motorways and 4-lane roads as these types of roads are designed with wider road medians compared to collision-free roads, see appendix 14. Another explanation for the difference in repair costs per vkm is that the geometrical standard for motorways is higher than for collision-free roads, e.g. motorways are usually designed with smoother alignment, good visibility and wider road median and road verge.

Another explanation for the high number of repairs per vehicle kilometre on collision-free roads is that this type of road is mainly equipped with cable barriers. As mentioned before, cable barriers have to be repaired even after minor damage because its construction is much weaker compared to w-beam barriers and Kohlswa-beam barriers. This fact is also an explanation for the higher number of repairs per vkm for barriers installed along 4-lane roads in the Central Region (table 5.13) where cable barriers are the only barriers used. In contrast, the use of cable barriers along 4-lane roads is limited in the Western Region.

5.10.3 The effect of the barrier type on barrier repairs and vehicle damages

The results show that the repair cost per vkm for cable barriers in the Western Region is three times higher than for w-beam barriers, even if the average cost per repair for both types are almost the same (table 5.15). As mentioned before, the weak construction of cable barriers could be a major factor contributing to a higher number of repairs per vkm for this type of barrier. Owing to their weaker construction, cable barriers lose all efficiency even after minor impacts and have to be repaired. However, w-beam barriers retain some degree of efficacy after minor impacts due to the rigidity of their elements (ASHTO 2006). Therefore, w-beam barriers are often not repaired after minor impacts.

The results also show a higher repair cost per vkm for Kohlswa-beam barriers compared to cable barriers and w-beam barriers (Table 5.15). The underlying factor for this difference is that the number of repairs per vkm for the Kohlswa-beam barriers is higher than for the w-beam barriers. This result is in contrast to the good reputation which the Kohlswa-beam barriers have as a strong barrier type which can withstand minor impacts without needs for repair.

It is worth noting that the use of Kohlswa-beam barriers in the Western Region during the studied year was limited to a barrier length of 12 km, installed along road sections with very high traffic volume and a high accident risk. In addition, the number of repairs of the Kohlswa-beam was only seven repairs during the studied year. These two factors probably contributed to a high number of repairs per vkm and low reliability in the results for the Kohlswa-beam barriers. A limited number of repairs may also indicate that many of the damages probably did not need to be repaired as Kohlswa-beam barriers retain some degree of efficiency after small impacts. Unfortunately, data about the number of non-repaired damages were not available as such damages usually are not reported to SRA. Having all those facts in mind, the results concerning the repair costs for Kohlswa-beam barriers have to be interpreted very carefully.

The comparison between cable barriers and w-beam barriers shows that the repair cost per vkm for cable barriers installed along motorways is more than two times higher than for w-beam barriers (table 5.16). The underlying factor for this difference is that the number of repairs per vkm for cable barriers is higher than for w-beam barriers. As mentioned before, the weak construction of cable barriers is the major factor which contributes to high number of repairs per vkm for this type of barrier. Due to this same fact, the SRA's part of the repair cost per vkm is to some extent higher for the repair of cable barriers than for the repair of w-beam barriers, despite the fact that the SRA receives compensation for the entire repair expense of cable barrier damages from the Swedish Motor Insurers or from the insurance companies (table 5.17).

It is noteworthy that no repairs of concrete barriers were conducted along the studied roads during 2006 in the Western Region, despite that 12 kilometres of the studied roads were equipped with median concrete barriers. These road sections were located in urban regions with an AADT within the range of 15000 to 20000 vehicles per day. The total amount of traffic work conducted along these road sections was approximately 90 million vkm. The limited data about concrete barrier repairs may be explained by the fact that normal collisions do not result in any damages to this kind of barrier owing to its stable construction. Collisions which do not cause any damage or that have not been repaired are usually not registered at all. The absence of repairs needed for concrete barriers might indicate that they can be the most profitable barrier type from a maintenance perspective.

The results also show that the average compensation per vehicle damage due to impacts with w-beam barriers is higher than the average repair compensation per vehicle damage due to impacts with cable barriers (table 5.18). This indicates that vehicle damage caused by w-beam barriers is greater than vehicle damage caused by cable barriers. This difference may occur because the w-beam barrier has a stronger construction and the impact surface is concentrated to a limited area. The combination of these two factors result in a strong redirecting force concentrated to a small area of the vehicle. This may lead to vital damage in the basic construction of the vehicle even if the surface damage is small. On the contrary, vehicle damages due to impact with cable barriers are mostly surface damages which are cheap to repair compared to damage in the basic construction. Unfortunately, the uncertain data which was used in the analysis of vehicle repair compensations made a reliable conclusion impossible.

Based on the results, and from a maintenance perspective, it is obvious that the use of w-beam barriers is more profitable than the use of cable barriers as the repair cost per vkm is lower for w-beam barriers than for cable barriers. This rests mainly on the fact that cable barriers have a rather weak construction and have to be repaired more often than w-beam barriers.

5.10.4 The seasonal effect on the barrier damage repairs

The number of repairs carried out during winter is higher than during summer in the Central Region (table 5.19). This result can be explained by poor road conditions and higher collision risks during the winter months. However the differences are very small and are less interesting as the number of the barrier repairs can not be correlated to seasonal traffic works. Measurements of the seasonal traffic work made in the early nineties in Sweden shows that 10.4 % of the annual traffic work in Sweden was carried out during July compared to 7% during January (appendix 15). However, the accumulated traffic work between May and September constituted 47.4% of the annual traffic work compared to 52.6% between October and April. This difference is very small and probably does not affect the difference in number of barrier damage between summer and winter.

Table 5.19 also shows that to some extent the average cost per repair is higher during summer than winter in both regions. This indicates that the extent of barrier damage is greater for collisions occurring during summer than during winter. This fact is also confirmed in table 5.26 which shows that the average number of replaced posts for cable barriers in winter is less than the average number of replaced posts in summer in both regions. An explanation may be that lower speeds during the winter, due to bad weather and road conditions, lead to lower impact forces at collisions with minor damage to the barriers. This explanation is in contrast to the results presented in subsection 5.9.1 which shows that the extent of damage to barriers along roads with speed limits of 110 km/hr is less than along roads with speed limits of 70 or 90 km/hr.

Table 5.26 shows that the number of replaced posts during winter is higher in the Central Region than in the Western Region and that the opposite situation exists during summer. An explanation for this is hard to find.

Table 5.26 The average number of replaced posts per damage repair of cable barriers installed as median and roadside barrier, regardless of road types, speed limits and traffic volumes

	Average repalced posts per repair during the studied year	Average replaced posts per damage during winter	Average replaced posts per damage during summer
Central Region	9.6	8.5	11.4
Western Region	9.5	5.9	15

This table is based on data from 341 damage repairs of cable barriers in the Central Region and 165 damage repairs in the Western Region, for both road side and median barriers.

The results also show that the average cost per repair during winter in the Central Region is higher than in the Western Region (table 5.19). This shows that colder winter climates contribute to higher repair costs, as the Central Region is characterized by its colder climate compared to the Western Region.

Table 5.27 shows that the average repair cost per replaced cable barrier post is higher during the winter in both regions despite the fact that more posts are replaced during summer than during winter. This difference is reasonable as post replacement usually takes more time during winters due to frozen posts and foundations.

Table 5.27 Average repair cost per replaced post for cable barriers installed as roadside and median barriers.

	Central Region	Western Region
Average repair cost per repalced post during summer (SEK/post)	1 421	1 031
Average repair cost per repalced post during winter (SEK/post)	1 662	1 356
Average repair cost per repalced post (SEK/post)	1 541	1 193

This table is based on data collected from 341 damage repair in the Central Region and 165 damage repairs in the Western Region regardless of road types, speed limits and traffic volumes. Similar analyses regarding the other types of road barriers are not possible because the data about replaced posts for the other barrier types is missing in the invoices.

Another factor contributing to a higher repair cost per replaced post during winter is that fewer posts are repaired during winter than summer (table 5.26). Figures 5.38 and 5.39 show that the average repair cost per replaced post is inversely proportional to the number of replaced posts. This relationship is probably due to the fact that some cost items are almost constant and not affected by the extent of barrier damage. For example, the cost for temporary traffic arrangements, usually constitute 20-24 % of the total repair costs, mainly depends on two factors:

- Road type: costs for the temporary traffic arrangements on motorways are higher than on the lower traffic volume roads.
- Night-time or day-time repair: night-time repairs means high working-cost compared to day-time repairs.

The result of this analysis has to be interpreted carefully as the underlying data was to some extent uncertain due to following factors:

- The repair costs per vkm and the number of repairs per vkm for the different seasons were not possible to calculate as the traffic works for the different seasons were not available. Therefore the effect of the traffic was not neutralised.
- In many cases damages took place during the winter but the repairs were conducted during the summer or vice versa.

- It was also hard to pinpoint the repair date as this was often not specified in the invoices. In those cases, it was assumed that the damages and repairs occurred during the same season. This assumption was based on the fact that barrier damages must be repaired within three weeks after the date of the reported damage.

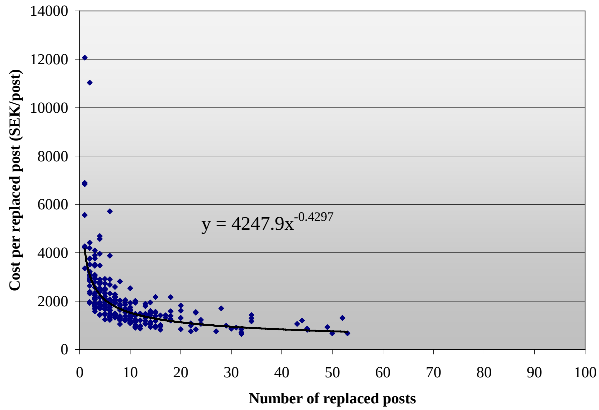

Figure 5.38 Relationship between the number of replaced posts and the repair cost per replaced post for cable barriers in the Central Region, regardless of road types, speed limits and traffic volumes.

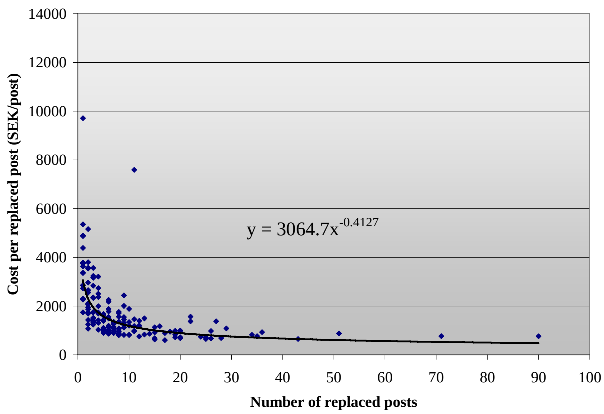

Figure 5.39 Relationship between the number of the replaced posts and the repair cost per replaced post of cable barrier in the Western Region, regardless of road types, speed limits and traffic volumes.

5.10.5 Effects of barrier placement on the barrier repairs

The results show that the number of repairs of barriers placed within 0.5 to 2 m from the traffic lane edges is higher than the number of repairs of barriers placed farther away than 2 m from the traffic lane edges (table 5.20). The common supposition within the SRA is that most of the barriers in both regions are installed within 0.5 to 2 metres from the edges of traffic lanes. This can be an explanation for the high proportion of damaged barriers placed 0.5-2 metres from the edges of traffic lanes. In addition, these types of barriers are more exposed to damages caused by snow removal equipment. However, it is remarkable that damages of this kind were not found among the 1084 studied damages. An explanation for this could be that damages caused by snow removal equipment are deliberately concealed by the maintenance contractors to avoid economical consequences.

The results also show that the average cost per repair for barriers installed farther away than two metres from the traffic lane edges is slightly higher than the average cost per repair for barriers installed within 0.5 to 2 metres from the traffic lane edges (table 5.20). These differences might be due to greater impact angles between the impacting vehicle and barriers located further away from the lane edges. However, the difference is marginal and does not approve greater damage to barriers installed more than two metres from the lane edges. Otherwise the common impression within the SRA is that damages should be less severe for barriers located further away from the lane edges.

The results of this analysis has to be interpreted very carefully as the number of repairs is not correlated to traffic works. Unfortunately, calculation of the traffic work is not possible as the lengths of the barriers with different placements are unknown in the studied regions. However, the analysis of the effect of road types discussed in subsection 5.10.2 indicates that the number of repairs per vkm and the repair costs per vkm for barriers along roads with wide medians are lower than for barriers along roads with narrow medians.

5.10.6 The effect of road alignment on barrier repairs

Table 5.21 indicates that most of the damages occurred on straight road sections in both regions. This is reasonable as straight road sections in both regions probably constitute a higher proportion of the road network compared to curved sections. Still, the results are less interesting as the number of barrier repairs is not correlated to the traffic work. Calculation of the traffic work was not possible as the exact lengths of the straight road sections and curves are unknown in the studied regions. However, the analyses of the effects of speed limits and road types (subsections 5.10.1, 5.10.2) indicate that roads with high geometrical design standards, i.e. roads with smooth alignment and good visibility contribute to fewer repairs per vkm and lower repair costs per vkm compared to roads with low geometrical design standards.

5.10.7 The effects of road cross section types on barrier repairs

The results show that the number of barrier repairs along double-lane cross section directions is higher than along single-lane cross section directions, despite wider roadways along double-lane cross sections (table 5.22). An explanation for this might be that overtake manoeuvres are only possible along double-lane cross section directions. In many cases drivers try to overtake as fast as possible to avoid lane shifts ahead. Under this pressure the risk for accidents and collisions with barriers increases. Drivers might feel that overtake manoeuvres on double-lane cross sections are difficult and the overtaken vehicles may be considered more dangerous than road barriers. Therefore, drivers often try to drive closer to the barrier than to the overtaken vehicles.

Contrary to common opinion, the results also show that the number of repairs conducted on lane shifts is much lower than the number of repairs conducted on double-lane or single-lane cross section directions (table 5.22). An explanation for this is that drivers are getting more and more accustomed to driving on collision-free roads and are more aware of accident risks while overtaking near lane shifts. Another explanation is that the length of the lane shift sections constitutes approximately 30% of the total length of collision-free roads.

The results must be interpreted carefully as they are based on a limited number of repairs in both regions. Information about the exact position of the damages was often missing. In addition, the results can not give a realistic picture about the effect of the road section on barrier damage repairs as the repairs are not correlated to the traffic work. The calculations of the traffic works are not possible as the exact lengths of the roads with different cross sections are unknown.

5.10.8 Comparison of the damage repair costs between the studied regions

Many of the results presented earlier in this chapter show that repair costs per vkm for barrier damages for almost all barriers types, regardless of road types or speed limits, are higher in the Central Region than in the Western Region (tables 5.7, 5.8, 5.9, 5.10, 5.13, 5.15, 5.16, 5.17). The major underlying factor contributing to this difference is that the number of repairs per vkm in the Central Region is higher than in the Western Region. This fact has also been confirmed in several previous studies(Carlsson and Brüde 2004, 2005). This means that the risks for barrier damage are higher in the Central Region than in the Western Region despite that traffic intensity is much higher in the Western Region than in the Central Region. The higher risk for barrier damage in the Central Region could, among other things, be attributed to the climate which is characterised by long, cold, and snowy winters with slippery road condition as a consequence.

Differences in tendered prices for repairs between the two regions are another factor contributing to the difference in repair cost per vkm between the two regions. Figure 5.40 shows that prices for maintenance tenders are higher in the Central Region than in the Western Region. For example, the average price for a truck-mounted attenuator with its carrier in the Central Region is 42% higher than in the Western

Region. Higher tender prices in the Central Region indicate poor competition within the road maintenance market.

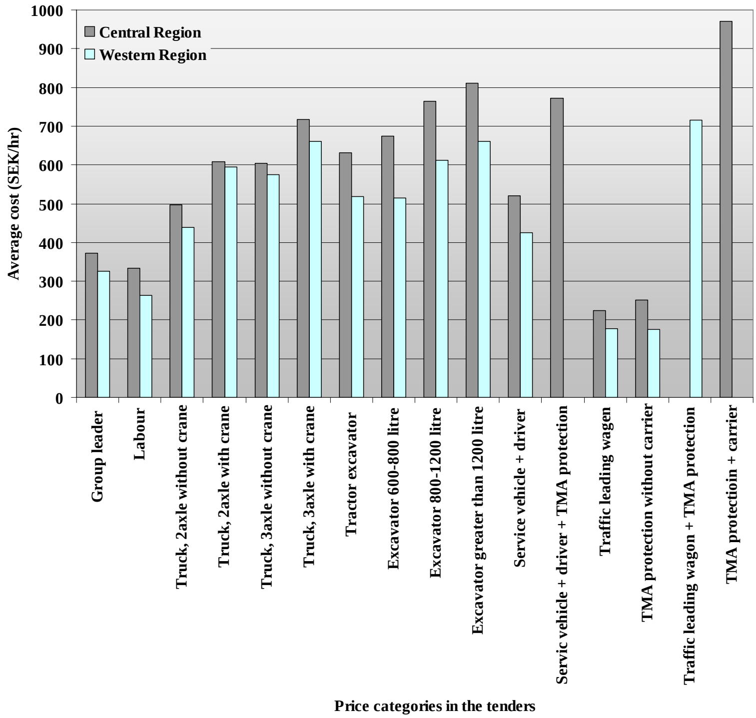

Figure 5.40 Average tender prices in both regions

The prices in this figure are taken from the tenders in the maintenance areas which are covered in this case study. Prices are index regulated to the price level of year 2006.

Another factor which contributes to higher repair cost per vkm in the Central Region is that the majority of the roads with barriers in this region are collision-free roads (table 5.1). As mentioned in subsection 5.9.2, the repair cost per vkm for barriers installed along collision-free roads are higher than for barriers installed along motorways and 4-lane roads (table 5.13). Median barriers installed along collision-free roads are more exposed to impacts and damages compared to the same type of barriers installed along motorways as road medians along collision-free roads are narrower than along motorways (appendix 14).

Another factor which contributes to higher repair costs per vkm in the Central Region compared to the Western Region is the frequent use of cable barriers as median barriers in the Central Region. As mentioned in subsection 5.9.3, the repair cost per vkm for cable barriers is approximately three times higher than for w-beam barriers. The frequent use of cable barriers in the Central Region is due to the fact that the most roads in the region are collision-free roads (table 5.1) which are usually equipped with cable barriers.

5.11 Conclusions

The number of barrier repairs per vkm and repair costs per vkm for median barriers along roads with speed limits of 110 km/hr is lower than along roads with speed limits of 70 or 90 km/hr. This shows that the risk for barrier damages is lower along roads with a speed limit of 110 km/hr compared to roads with speed limits of 70 or 90 km/hr.

The average cost per repair for median barriers is lower along roads with a 110 km/hr speed limit than along roads with 70 km/hr or 90 km/hr, i.e. damages to median barriers are less extensive along roads with a 110 km/hr speed limit than along roads with 70 km/hr. This differs from the common opinion that higher speeds lead to a greater extent of damage. An explanation for this difference is hard to find. However, this different indicate that higher geometrical design standard contribute to lower risk for barrier damages.

The number of barrier repairs per vkm and the repair costs per vkm for median barriers along collision-free roads are higher than along motorways or 4-lane roads, regardless of barrier type and speed limits. This is a sign of high risk for barrier damages along collision-free roads compared to motorways and 4-lane roads. This also indicates that higher geometrical design standards lead to lower risks for barrier damages, as the motorways and 4-lane roads are designed with higher geometrical standards compared to collision-free roads.

The number of repairs per vkm and the repair costs per vkm for cable barriers installed as median barriers along motorways are approximately two times higher than for w-beam barriers installed along the same type of roads, regardless of the speed limit. Based on this fact it is obvious that from a pure maintenance perspective the use of w-beam barriers along motorways is more profitable for both road authorities and the insurance companies. However, it is not clear what type of barrier causes greater damage to impacting vehicles.

The differences in the number of repairs and the average cost per repair between winter and summer are marginal. As the damage repairs and the associated costs can not be correlated to the seasonal traffic work, it is not clear how barrier repairs and their associated costs are influenced by seasonal effects. However, the number of replaced posts per repair is higher during summer than during winter, i.e. barrier damages are more extensive during summer than during winter. The average repair cost per replaced barrier post is higher during winter than during summer.

The analyses of the effect of barrier placement and road alignment did not clearly show how barrier repairs and the associated costs are influenced by these two factors. However, the analyses of the effects of road types and speed limits indicate that roads with higher geometrical design standard, i.e. roads with smooth alignment and wide medians and verges contribute to fewer repairs per vkm and lower repair costs per vkm compared to roads with lower geometrical design standard.

Along collision-free roads, the number of barrier repairs is higher along the double-lane directions than along the single-lane directions and lane shifts. However, it is not clear how the cross-section of collision-free roads affect repair costs as it is not possible to correlate the costs to the traffic works conducted along the different sections.

Barrier repair costs per vkm in the Central Region are much higher than barrier repair costs per vkm in the Western Region. The main factors which lie behind this difference are:

- High number of barrier repairs per vkm in the Central Region due to colder climate which are distinguished by long, cold, and snowy winters with slippery road condition as consequence.
- Frequent use of cable barriers in the Central Region.
- High maintenance tender prices.

It is remarkable that no repairs of concrete barriers were conducted in the Western Region, despite the fact that this barrier type exist along several road sections. This can imply that concrete barriers might be a profitable barrier type when it comes to maintenance costs as it probably can withstand minor impacts without damages.

6 Concluding summary

The most important findings from this research project are:

- Road authorities have made a lot of effort to increase maintenance efficiency, focusing mainly on improving operating practises and maintenance activities. However, the improvement potentials in the planning and design process have been neglected. Some efforts are purely cost savings, as the main focus has been on reduction of the frequency of maintenance activities rather than on streamlining these activities. As a result, some of their efforts have, to some extent, depreciated the maintenance standard.
- Sufficient consideration of maintenance aspects during the planning and design process requires development of efficient models for analyses of life-cycle costs, including maintenance costs. However, existing models have been created according to requirements for specific road projects and have seldom been developed and used after that. Several models have been developed for selection of the most favourable pavement types and the related maintenance strategies. No models for calculation of life-cycle costs for road barriers, traffic signs and road geometry have been found. The maintenance costs used in the models are often unrealistic and roughly calculated.
- Although insufficient consideration of maintenance aspects during the road planning and design process is a well-known issue, the underlying causes and consequences have, up to now, not been sufficiently studied and therefore improvements still remain to be made. The limited amount of literature pertaining to this subject confirms this fact.
- This research study has revealed a complex combination of problems which result in an insufficient consideration of maintenance aspects during the road planning and design process, se appendix 1. The identified problems

can be divided into six problem areas: insufficient consulting, insufficient knowledge, regulations without consideration of maintenance aspects, insufficient planning and design activities, inadequate organisation, and demands from other authorities. The problem areas are closely linked to each other. None of the problem areas can be completely eliminated separately from the other areas. On the other hand, the elimination of a problem in one problem area can also contribute to the elimination of problems in other areas.

- To eliminate the problem of insufficient consideration of maintenance aspects during the planning and design process, the following needs for change have been identified:
    - ➢ An urgent need for the establishment of well-defined long-term goals for maintenance and methods to evaluate the fulfilment of these goals.
    - ➢ Development of well-structured systems for experience exchange and consulting among actors involved in maintenance activities and in the planning and design process.
    - ➢ Increased knowledge regarding road maintenance among actors involved in the planning and design process.
    - ➢ Development of a systematic evaluation process with clear guidelines for the examination of completed road projects to ensure adequate consideration of maintenance as a part of a quality assurance system.
    - ➢ Incorporation of maintenance aspects in the planning and design related guidelines, regulations and other documents.
    - ➢ Creation of guidelines and requirements for future maintenance considerations, which should be incorporated into requests for quotations and other purchasing related documents.

    - Creation of incentives for consultants to consider maintenance aspects during the planning and design process to a sufficient extent.
- Barrier repair costs per vkm and number of barrier repairs per vkm along roads with speed limits of 110 km/hr are lower than along roads with speed limits of 70 km/hr or 90 km/hr.
- The number of barrier repairs per vkm and repair costs per vkm for cable barriers are higher than for w-beam barriers.
- The number of barrier repairs per vkm and barrier repair costs per vkm for barriers installed along collision-free roads is higher than for barriers installed along motorways or 4-lane roads.
- It is not clear how the number of barrier repairs and the associated costs are influenced by seasonal effects. However, the analyses show that barrier damages are more extensive during summer than during winter.
- The number of repairs per vkm and the repair costs per vkm for barriers installed along roads with wide medians are lower than for barriers installed along roads with narrow medians.
- Roads with high geometrical design standards, i.e. roads with smooth alignments and wider road median and verge, contributes to a lower number of repairs per vkm and lower repair costs per vkm compared to roads with low geometrical design standard.
- The number of barrier repairs per vkm and barrier repair costs per vkm are higher in the Central Region than in the Western Region due to:
    - High number of barrier repairs per vkm in the Central Region due to a colder climate distinguished by long, cold, and snowy winters with slippery road conditions as a consequence.
    - High maintenance tender prices in the Central Region.
    - Frequent use of cable barriers in the Central Region.

7 Recommendations and future studies

An efficient way for consideration of the maintenance aspects of road barriers during the road planning and design process might be the implementation of life-cycle costs analyses during the process. For this reason the road authorities are in a great need for a model which considers all the costs which are generated by road barriers, e.g. costs for design, acquisition, installation, maintenance, demolition and scrapping.

The most crucial factor for an accurate calculation of life-cycle costs is the use of accurate data. The accuracy of the data to be used depends on the amount and quality of the collected data. When it comes to road barriers collecting data relating to maintenance costs is the most difficult task. This difficulty is mainly due to the fact that maintenance costs are affected by a large number of factors such as speed limit, road type, seasonal effects, type of barrier and barrier placement. Consideration of the influence of all those factors in one model for calculation of life-cycle costs is a hard task as the access to the maintenance data regarding road equipment is very limited and poorly archived.

Based on the above mentioned facts some future studies have been planed within this research project. For example, a new case study is already underway in two regions in the SRA, the Northern Region and the South-eastern Region, in order to collect more data about maintenance costs for road barriers. The objective also is to collect the data that was not included in the first case study.

In the ongoing case study efforts have been made to study an interesting and relatively new barrier type called the Z-ellipse barrier. This type of barrier has been used as median barriers along four road sections in Sweden. Due to its stable construction, Z-ellipse barriers retain some degree of efficiency after minor impacts. Therefore a common opinion is that the Z-ellipse barrier is the future alternative for use along road sections with higher risks for barrier damage such as collision-free roads. However, the acquisition and installation costs for Z-ellipse barriers are three to four times higher than the acquisition costs for cable barriers.

Another important part of the future studies in this research project will be conducting statistical tests in order to guarantee the accuracy of the results. These tests will be conducted when the second case study is done. Later, a model for calculation of life-cycle costs for the different barrier types will be developed and evaluated. Also the influence of road barrier on the possibility to carry out other maintenance measures, as ploughing and mowing, and the associated costs should be considered in the model. Based on the results of these calculations, recommendations will be made concerning the selection of barrier types. The ambition is to create a model which later can be used by consulting firms during the design phases as a decision basis for the selection of a barrier type. For this reason there is a great need for the creation of databases which contain all the necessary data with the ability to update regularly. Any successful implementation of the life-cycle costs concept during the design phase is impossible with the current method of data archiving.

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Appendix 1

Analysis of problems

Activity: formulation of problems

Problem list

This list is based on the evaluation of the questionnaires given to different actors involved in road planning and design and road maintenance

P1: Road designs which cause unnecessary and costly maintenance measures. Often needs for unnecessary maintenance measures are due to problems which come up in certain locations on a road section. Some of those problems could probably have been avoided by choosing a more appropriate design at those locations if the designers had considered the maintenance aspects during the road planning and design phase.

P2: Insufficient consideration of maintenance aspects during the road planning and design process. Those types of designs require costly maintenance measures. For example, some road designs result in certain maintenance measures which only can be carried out manually without any possibility of using machines. One example is the need to mow stone-covered slopes. Another example is roads designed with no space for storage of snow after ploughing.

P3: Requests for quotations and other purchasing documents do not consider maintenance aspects. Usually, requests for quotations do not contain guidelines or requirements to bring the design in line with future maintenance needs. This is one of the factors contributing to the ignorance of maintenance aspects by designers during the design phases. There is a need for improving quotation requests by including maintenance aspects. For example, it is important to demand maintenance demonstration plans for the proposed designs from the consultants.

P4: Maintenance departments often carry out the reconstruction of improper designs without informing planning and design departments about the problems underlying the reconstruction. A reconstruction is necessary when a road design results in costly and unnecessary maintenance measures. This often happens within two to three years after the inauguration of the road. By that time the construction project has been completed and therefore the planning and design department is not responsible for any reconstruction expenses. Therefore, information about this type of reconstruction rarely reaches the project managers or the designers.

P5: For curiosity, aesthetic reason or ambition to stimulate technical development, project managers, consultants or architectures select new designs or products without any consideration of maintenance aspects. The stone-covered slope is an example of a design which generates maintenance measures which must be carried out manually. Sometimes, this curiosity also leads to installing several different kinds of roadside equipment along the same road section, e.g. the use of different types of road barriers along the same stretch of road. This variety generates unnecessary stock-keeping costs and delayed repairs.

P6: Road authorities do not demand maintenance plan descriptions from consultants for proposed road designs. This gives the designers a free hand to choose any road design without proper attention to maintenance needs. These kinds of designs often lead to costly maintenance measures.

P7: Maintenance aspects can easily be forgotten during the road planning and design process. There are many aspects which have to be considered during the process, e.g. traffic safety and environmental aspects. Road authorities normally give higher priority to traffic safety or environmental aspects than to maintenance aspects.

P8: Requests for quotations do not contain demands concerning consulting between consultants and actors involved in the maintenance process. This makes the designers believe that maintenance aspects are of less importance compared to other aspects, such as traffic safety. As a result, maintenance considerations will be absent in the requests for quotations. Since consulting firms do not receive compensation for this type of consultation, this aspect is not included.

P9: A limited investment budget prevents sufficient consideration of maintenance aspects during planning and design. The investment budget for each project is estimated on basis of a cost calculation which is done during the subprocess of feasibility study. Once this budget is approved in the national plan, the expenses for the project have to be kept within the budget frame. Sometimes there is a delay in the investment plans due to a reprioritisation of the project in order to prioritise a more urgent project at the expense of others. In those cases, the subprocess of construction starts several years later. During that period, the construction expenses will be increased due to increases in labour and material costs. In such cases, the project managers are forced to change the initial construction design to a cheaper design, such as design with lower geometrical standard, in order to cover the increased costs and to keep the project within the estimated budget frame. Designs which have a low investment cost often generate costly and unnecessary maintenance measures.

P10: Project managers are often forced to keep acquisition costs low during the calculation of project expenses. This happens when financial departments believe that the estimated investment cost, calculated by the project managers during the subprocess of feasibility study, is too high. In many cases, the project managers are forced to recalculate the costs in order to decrease the estimated investment cost. To keep the new estimated investment cost low, the project managers are forced to select designs which have lower investment costs without enough attention paid to the negative consequences regarding maintenance.

P11: Project managers at the road authorities rarely involve designers during the construction phases, mainly to avoid any additional costs covering the presence of the designers. However, the presence of designers is of crucial importance for knowledge improvement concerning the construction process and maintenance measures. Due to the absence of designers during the construction process, the consultants are missing valuable information and useful experience.

P12: The road authorities do not have any experience feedback process between actors involved in the maintenance process and the planning and design process. Often, inappropriate designs discovered after inaugurations of roads, are already well-known from previous road projects. Those designs are often reselected, because the designers are seldom informed about the negative aspects of the design.

P13: The road authorities do not have any database for collection of experiences from improper road designs which cause costly and unnecessary maintenance measures. Such a database would be a very valuable part of a systematic feedback process in order to increase understanding of the importance of maintenance aspects.

P14: The costs of maintenance measures which are generated by improper road design are not properly pursued. In the absence of a realistic picture of those costs, it is difficult to arouse enough attention within the organisation of the road authorities to deal with insufficient consideration of maintenance aspects.

P15: It is difficult to calculate the costs for road maintenance measures before work plans are established. Details about selected road designs are decided during the subprocess of creating a work plan. Any estimation of the maintenance costs before that phase will be difficult and inaccurate. For example, roadsides can be designed in many different ways with big differences in maintenance costs as a result. Still, the maintenance costs are roughly estimated during the initial phases of planning and design based on prior experiences of maintenance. For example, estimations of maintenance costs at the SRA are based on specific tables in SRA's document "New construction and improvement - influence correlations"(Vägverket 2001). Those tables are to some extent inaccurate and based on old maintenance data.

P16: Road authorities do not make life-cycle cost analyses for the proposed road designs during the road planning and design process. Life-cycle costs consist of all costs generated by a product over its service life, from production to scrapping. These consist of acquisition costs, maintenance costs and scrapping costs. Traditionally, the "Pay off" approach is more common for the estimation of costs for infrastructure investments in which the main focus is on investment costs. Maintenance costs considered in this approach are only for few years. As a result, investment costs have a decisive role during the selection of road designs, without any optimisation of the life-cycle cost.

P17: The investment department does not receive information from the maintenance department concerning costs and difficulties related to maintenance measures. This is due to lack of an appropriate experience feedback process between the departments.

P18: Actors involved in the planning and design process do not have any incentives which encourage consideration of maintenance aspects during the

process. Therefore, consideration of maintenance aspects does not interest them as far as the evaluations of completed road projects do not contain any evaluations of maintenance consequences.

P19: Until roads have been in operation for a few years, it is hard to predict difficulties concerning maintenance measures. Sometimes the designs are selected according to the guidelines and regulations, but still generate unnecessary and costly maintenance measures.

P20: Road authorities often exclude maintenance aspects in the final evaluation of road construction projects. Evaluations carried out during the final project meeting, are limited to the budget frame, time frame and difficulties which have been faced during the construction phase. Projects which are completed within the estimated budget and time frame are considered successful projects.

P21: The land expropriation process is a time-consuming process which road authorities often try to avoid by selecting designs which require less land. This often happens in the case of urgent needs for improvement of an existing road. In those cases, negative consequences for maintenance are not considered. To avoid problems of this type, there is a need for guidelines ensuring consideration of maintenance aspects during the planning and design process.

P22: Delay in the planning process. Sometimes, the road survey is established several years after the creation of the feasibility study. During that period of time, the acquisition costs exceed the estimated costs because of increased material and labour costs. Compensations covering any additional costs are limited to 10% of the estimated budget. When the additional costs are higher than the compensations, the project managers are forced to make some cost-saving efforts in order to keep the acquisition costs within the budget frame. For example, selection of designs with low acquisition costs often results in negative maintenance consequences. The SRA has made efforts to reduce the time delay in the planning process to avoid this type of problem.

P23: Project managers are sometimes forced to choose designs which are not optimal for maintenance, even if they are aware of the negative consequences for future maintenance. The reason for choosing these designs is a combination of limited investment budget, a complicated land expropriation process and delay in the planning process. Another reason is that road authorities give higher priority to designs for efficient traffic safety without enough regard to the consequences for future maintenance. For instance, collision free roads, which are well known for high traffic safety efficiency, do have higher maintenance costs. The maintenance costs for these road types are estimated to be twice as much as the maintenance costs for traditional road designs. To avoid this type of problem, there is a need for guidelines ensuring consideration of maintenance aspects during the process of road planning and design.

P24: Road authorities rarely require that consultants and project managers to have knowledge of maintenance related guidelines and regulations. Therefore, designers and project managers often have a very limited knowledge about how the maintenance measures are carried out in reality. Limited maintenance knowledge is another underlying factor for insufficient consideration of these aspects during the road planning and design process.

P25: When recruiting of designers and project managers, maintenance experience is not considered as a qualification. This is one of the facts that underlie the improper knowledge which designers and project mangers suffer from concerning maintenance aspects.

P26: Career of the designers often starts directly after graduation, with no experience of road construction or maintenance. Compared to maintenance contractors and construction firms, consulting firms often offer a higher salary for newly graduated engineers. This makes consulting firms more attractive. This is another factor underlying poor road maintenance experience.

P27: Educational programmes for actors involved in planning and design do not consider road maintenance aspects. These programs focus mainly on other aspects such as construction, management, traffic safety and environment. This is also an underlying cause of insufficient knowledge regarding maintenance aspects.

P28: Road designers assume that maintenance aspects have already been considered during the establishment of design related guidelines and regulations. If they follow these guidelines, they believe that the maintenance aspects will be sufficiently considered. However, most of these regulations and guidelines, e.g. Road Design Manual (Vägverket 2004c), cover maintenance aspects to a very limited extent.

P29: Road authorities do not require consultants to use maintenance experts to deal with maintenance related questions. This gives the consultants an indication that maintenance aspects have a low priority and leads to ignorance of maintenance aspects during the planning and design process.

P30: Road authority management has no appropriate established methods for following up the process performance. For instance, for each subprocess there are guidelines for experience feedback. However, such feedback activities are seldom carried out. Road authorities are in need of effective systems to follow up performance of the different subprocesses. Such systems contribute to the reduction of discrepancies between the intended and the actual performance of the subprocesses.

P31: Consultants have insufficient financial resources to perform maintenance related consulting on their own initiative. The cost for consultation has to be covered by the consultants in so far as the consultation is not required by road authorities. This increases the expenses for the consultant.

P32: Reduced consulting among actors involved in maintenance activities and in the road planning and design process due to limited acquisition budgets. Limited investment budgets force project managers to reduce expenses during the planning and design process. This is often done by reducing activities such as consultation concerning maintenance aspects. However, consultation expenses are mostly ignorable compared to reconstruction expenses which must be conducted because of belated observance of inappropriate designs.

P33: Consultants and road authorities underestimate maintenance problems which are due to inappropriate road designs. This underestimation is due to insufficient experience of the negative consequences regarding future maintenance.

P34: Absence of maintenance experts during the creation of design and planning related regulations and guidelines. Limited resources and limited time prevent maintenance experts from reviewing regulations and guidelines. Sometimes, regulations and the guidelines are not referred for consideration, due to time pressure and the enormous work which is required for the establishment of regulations and guidelines.

P35: According to the public purchasing directive, road authorities are not allowed to stipulate specific materials or products in the requests for quotations,

even if experience shows that those products contribute to reduced maintenance costs. An obvious example is the variation of road barrier types along the same road section. Because of the public purchasing law, road authorities can only specify the functional requirements for road barriers without specifying any brand. In these cases, construction contractors prefer the cheapest brand which fulfils the functional requirements, regardless of other existing brands along the same road section. This variation leads to increased stock keeping expenses for maintenance contractors.

P36: Due to inadequate general rules for consulting works in architectural and engineering activities (ABK96) (Byggandets Kontraktskommitte 1996) road authorities have a limited ability to claim compensation from consultants for reconstruction expenses relating to improper road design. According ABK96, the fines are limited to 100 price base amount. Expenses for reconstruction work is often much higher than that.

P37: The status of actors involved in planning and design is sometimes considered higher than the status of maintenance actors. There are many factors contributing to the status differences, e.g. higher salaries for project managers and consultants, compared to salaries for maintenance managers. In addition, the construction of new roads has traditionally been more attractive than the maintenance of the existing roads.

P38: Information is spread insufficiently between different departments within the road authorities. This issue results in poor knowledge dissemination within the organisation.

P39: Development of different processes within the road authorities is carried out in isolation from each other. The organisation as a whole is not optimised. For example, development of new road equipment, such as road barriers, speed reduction measures, is carried out without consulting the maintenance department as to the maintenance consequences.

P40: Time, knowledge and sometimes interest from the management is not sufficient for establishing consultation guidelines between different departments and processes. This factor also underlies the limited interest for creation of such guidelines at other levels in the organisation.

P41: Road authorities have no guidelines for the coordination of different processes. Without such coordination there will be a shortage in experience and knowledge interchange among the processes. The creation of coordination guidelines can make any possible feedback process more efficient.

P42: Road authorities have no long-term goals concerning maintenance. During the initial phases of the road planning and design process, specific project goals are established based on the operational sub-goals and long-term goals. None of those specific goals are related to maintenance aspects. This is another factor which contributes to a lack of interest in maintenance aspects. A problem is defined as a situation which is experienced as unsatisfactory by the involved actors. Experiences from the situation deviate from the expected results or specific goals valid for the situation (Goldkuhl and Röstlinger 1998). So long as road authorities do not have clearly defined goals relating to road maintenance, the negative consequences of inappropriate road designs on road maintenance are not considered as problems.

P43: Road authorities have an insufficient organisational structure to deal with coordination of different processes. Each department is concerned about its own financial resources. For example, the construction department always tries to reduce the acquisition costs as much as possible in order not to overtake the budget. The construction department is not concerned about how the reduction of acquisition costs will affect the future maintenance.

P44: Maintenance departments do not have enough time or resources to review work plans and other construction related documents during the road planning and design process. As a result of this issue, maintenance departments are seldom represented in meetings when selected designs are discussed during the planning and design process.

P45: Designers have no model for calculation of maintenance costs for the suggested road designs. Without such a model it will be impossible to identify the design which can generate an optimal life-cycle cost. A model for calculation of life-cycle costs is of a great importance for decision makers during the planning and design process.

P46: Municipalities and county administrations present arguments which are perceived to be more important than maintenance aspects. This is one of the reasons why maintenance aspects are often overlooked during the planning and design phases.

Appendix 2

Analysis of problems

Activity: classification of problems

Problem areas

The main problems are:

P1: Road designs which causes unnecessary and costly maintenance measures

P2: Insufficient consideration of maintenance aspects during the road planning and design process

Problem areas are:

Insufficient Consulting: consists of problems 3, 8, 9, 10, 11, 30, 31, 32, 33, 40, 41, 42, 43 and 44.

Insufficient knowledge: consists of problems 4, 12, 14, 13, 17, 24, 25, 26, 27, 28, 29 and 42.

Regulations without consideration of maintenance aspects: consists of problems 12, 13, 14, 34, 35 and 42.

Insufficient planning and design activities: consists of problems 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 36, 42 and 45.

Inadequate organisation: consists of problems 12, 30, 37, 38, 39, 40, 41, 42 and 43.

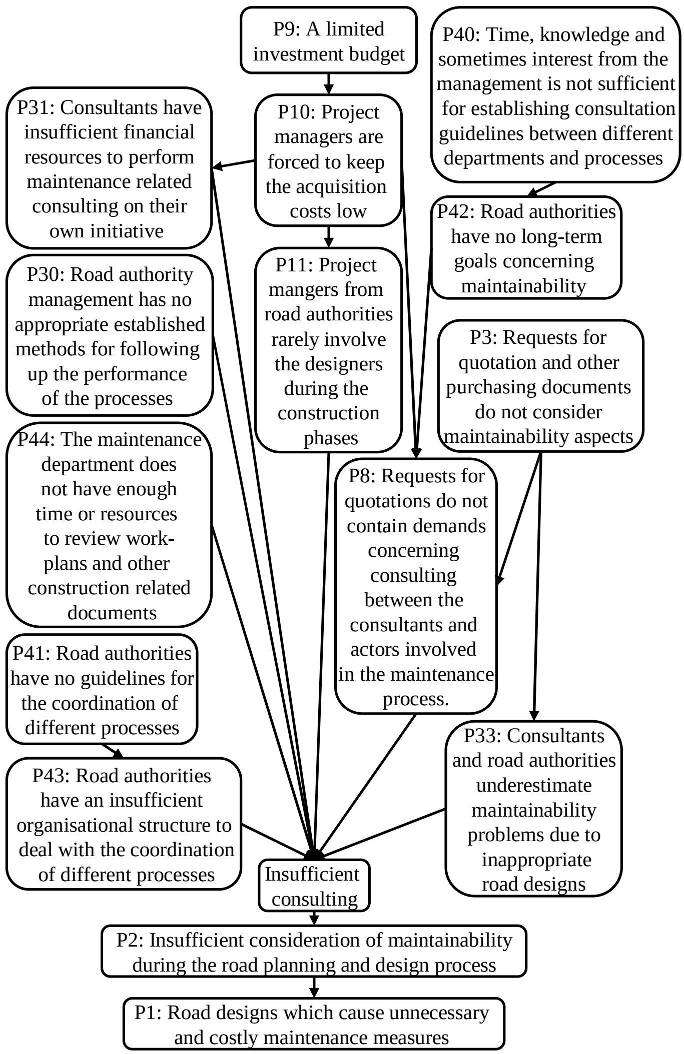
Demands from other authorities: consist of problem 46.

Appendix 3-a

Analysis of problems

Activity: Analyses of relations between problems

Problem graph document. Problem area insufficient consulting

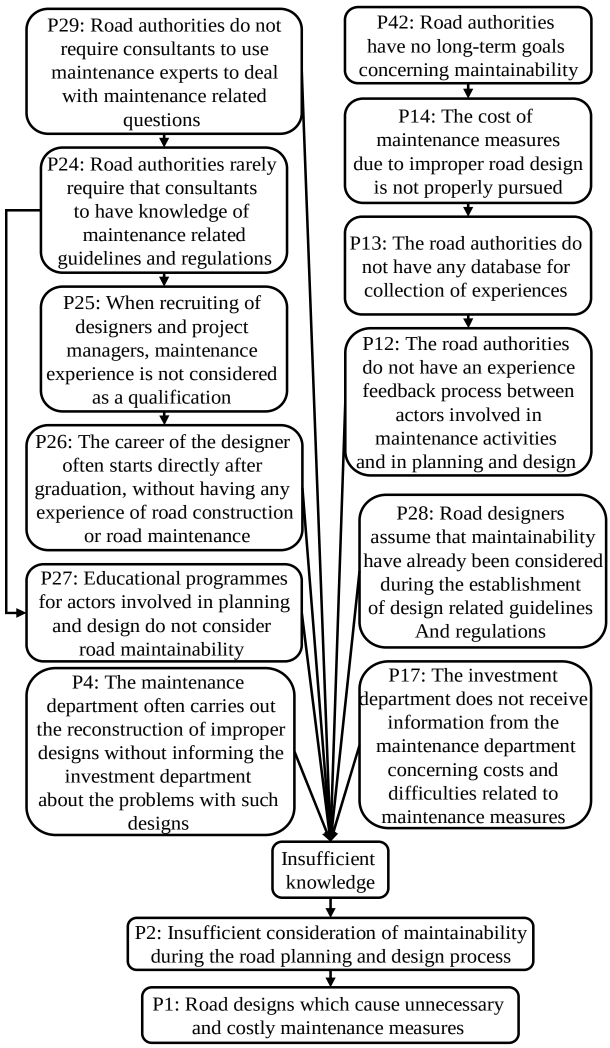


Appendix 3-b

Analysis of problem

Activity: Analyses of relations between problems

Problem graph document. Problem area insufficient knowledge

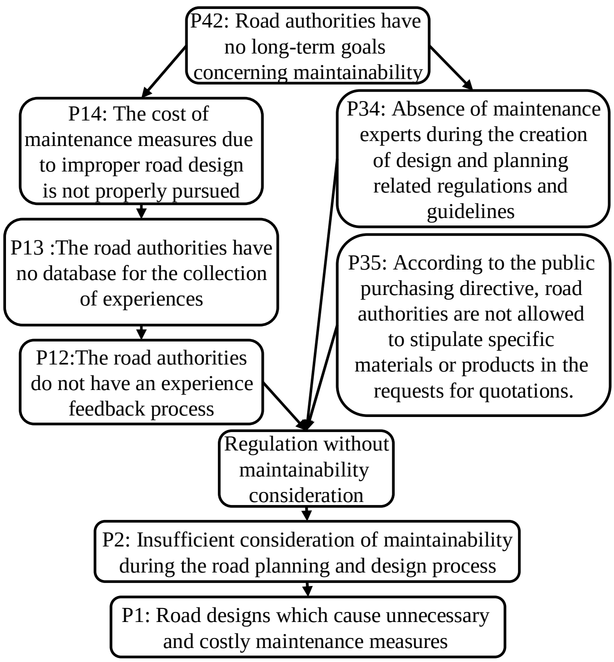


Appendix 3-c

Analysis of problem

Activity: Analyses of relations between problems

Problem graph document. Problem area regulation without consideration of maintenance aspects

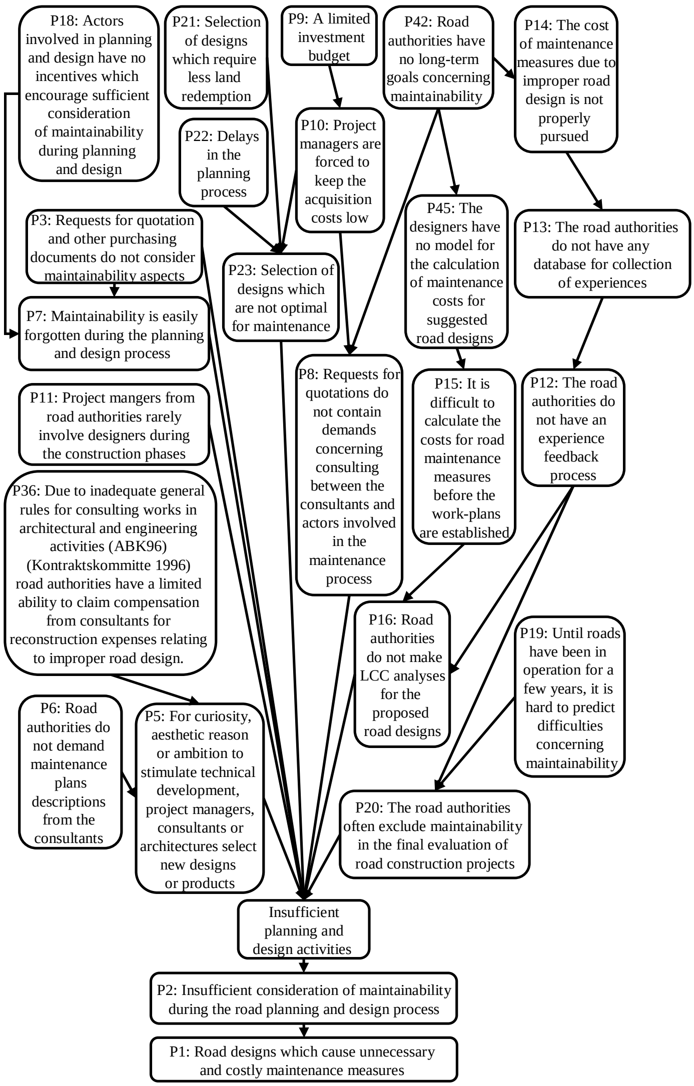


Appendix 3-d

Analysis of problem

Activity: Analyses of relations between problems

Problem graph document. Problem area insufficient planning and design activities

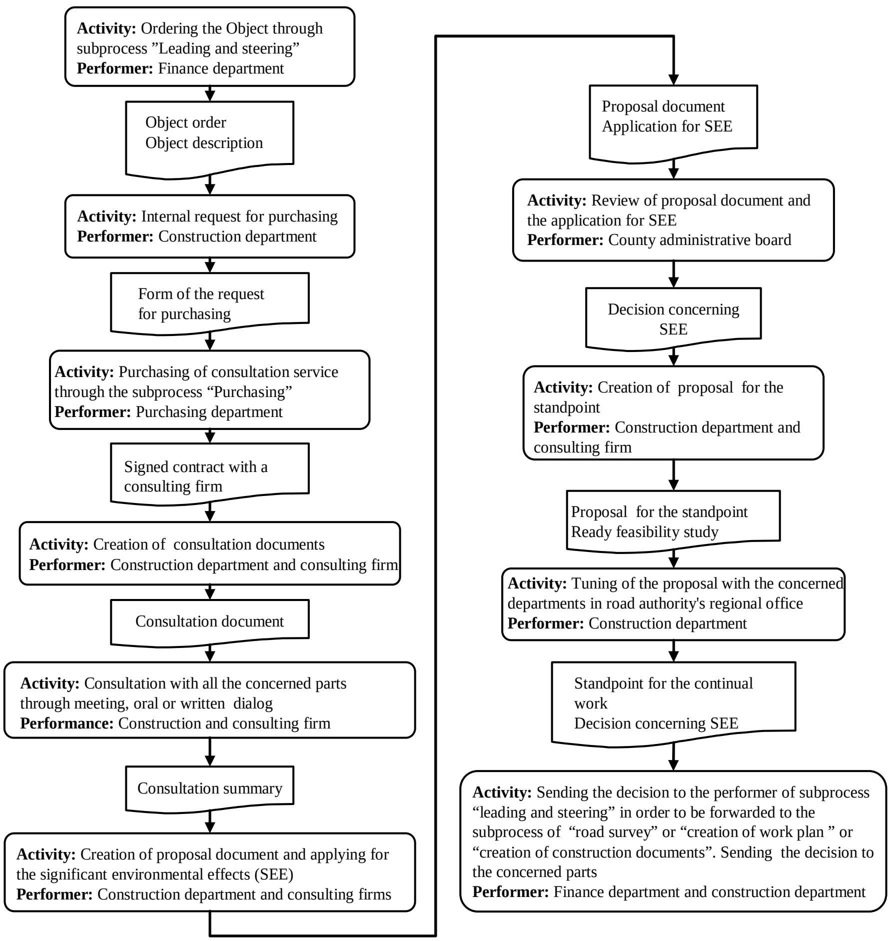


Appendix 4-a

Analysis of activity

Action graph document

Subprocess: Feasibility study

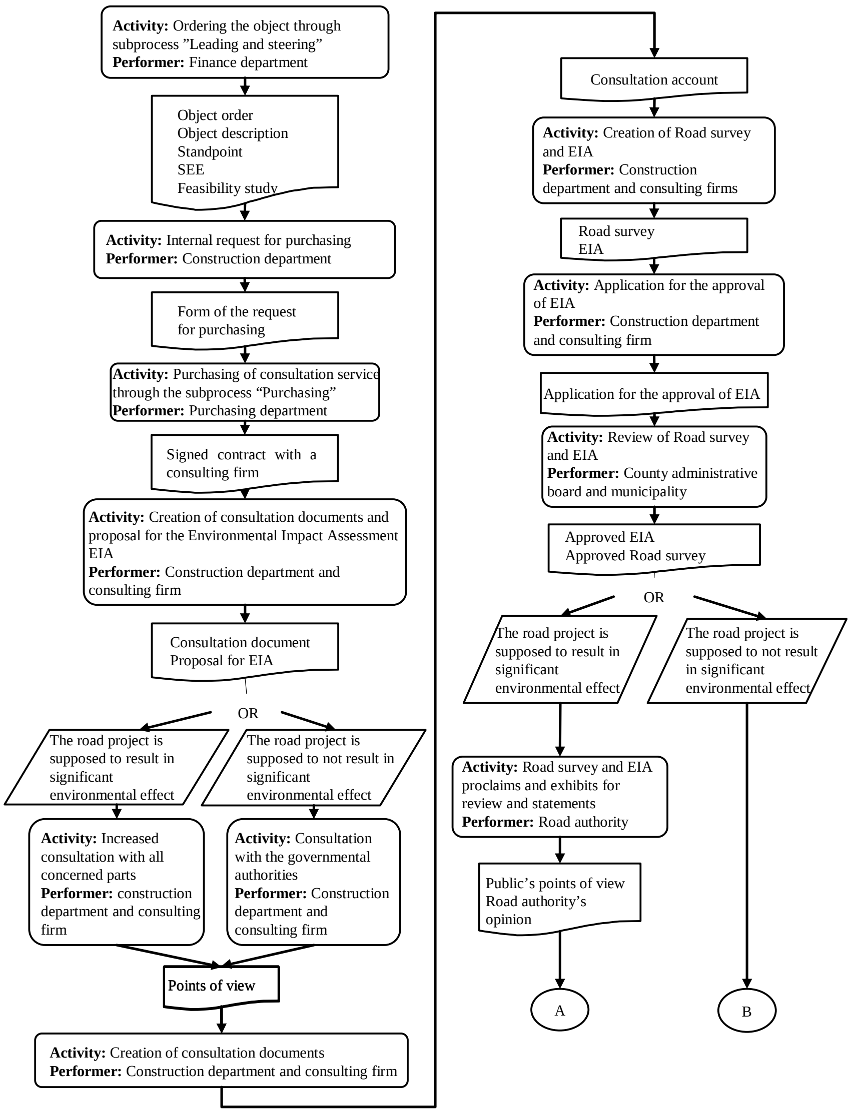


Appendix 4-b

Analysis of activity

Action graph document

Subprocess: Road survey

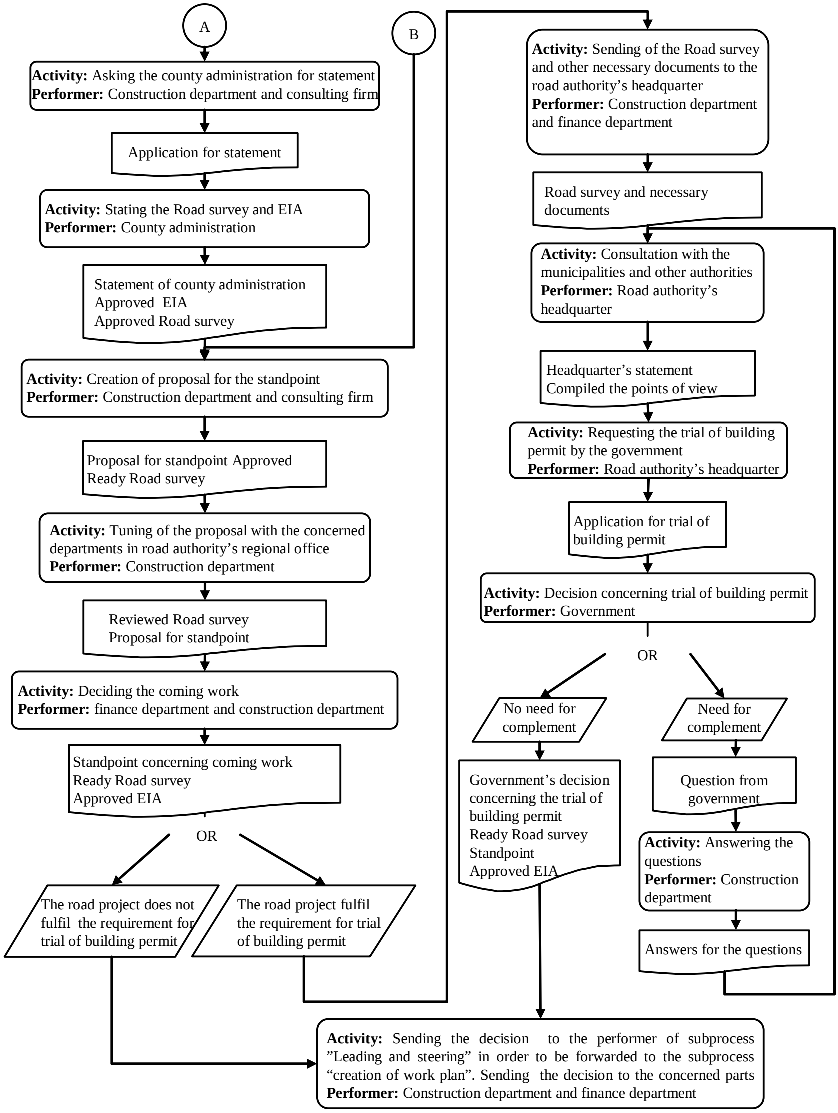


Appendix 4-b

Analysis of activity

Action graph document

Subprocess: Road survey

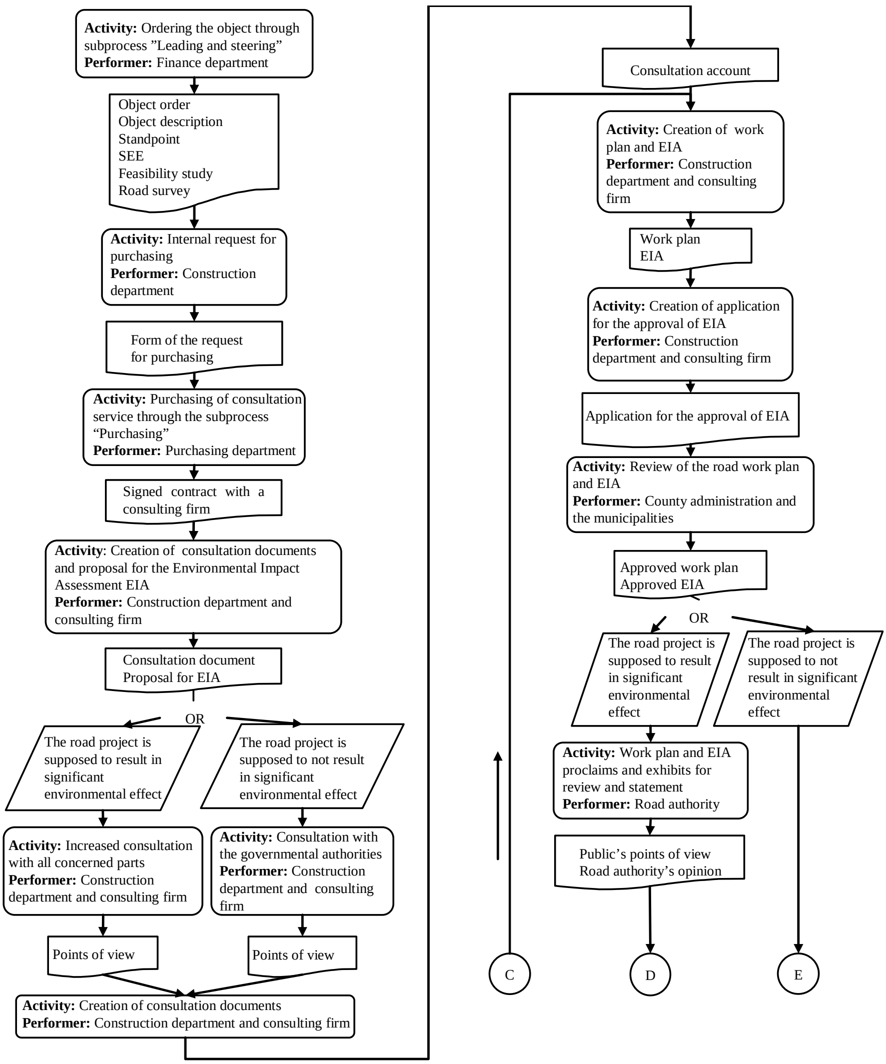


Appendix 4-c

Analysis of activity

Action graph document

Subprocess: Creation of work plan

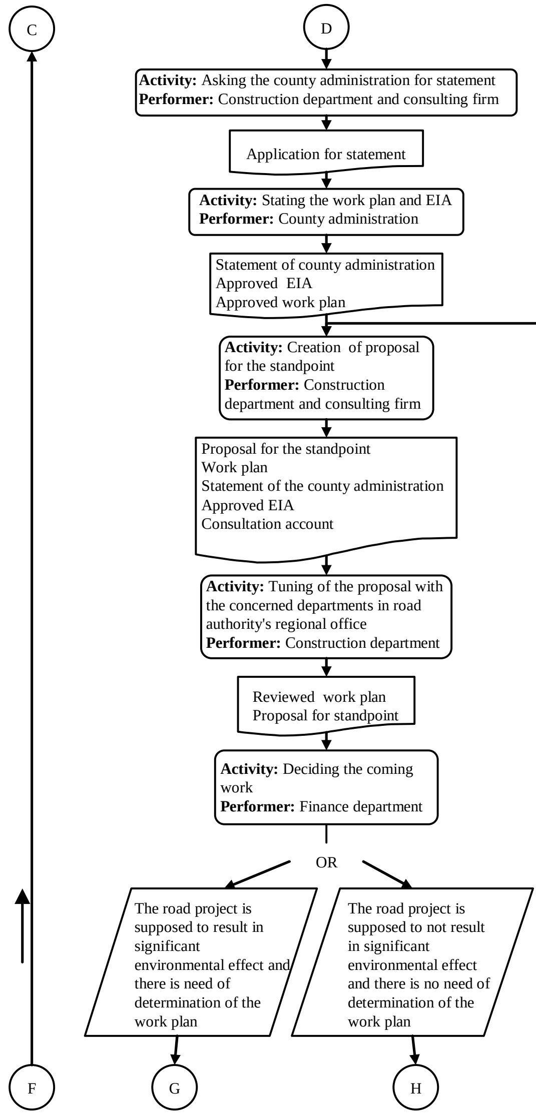


Appendix 4-c

Analysis of activity

Action graph document

Subprocess: Creation of work plan

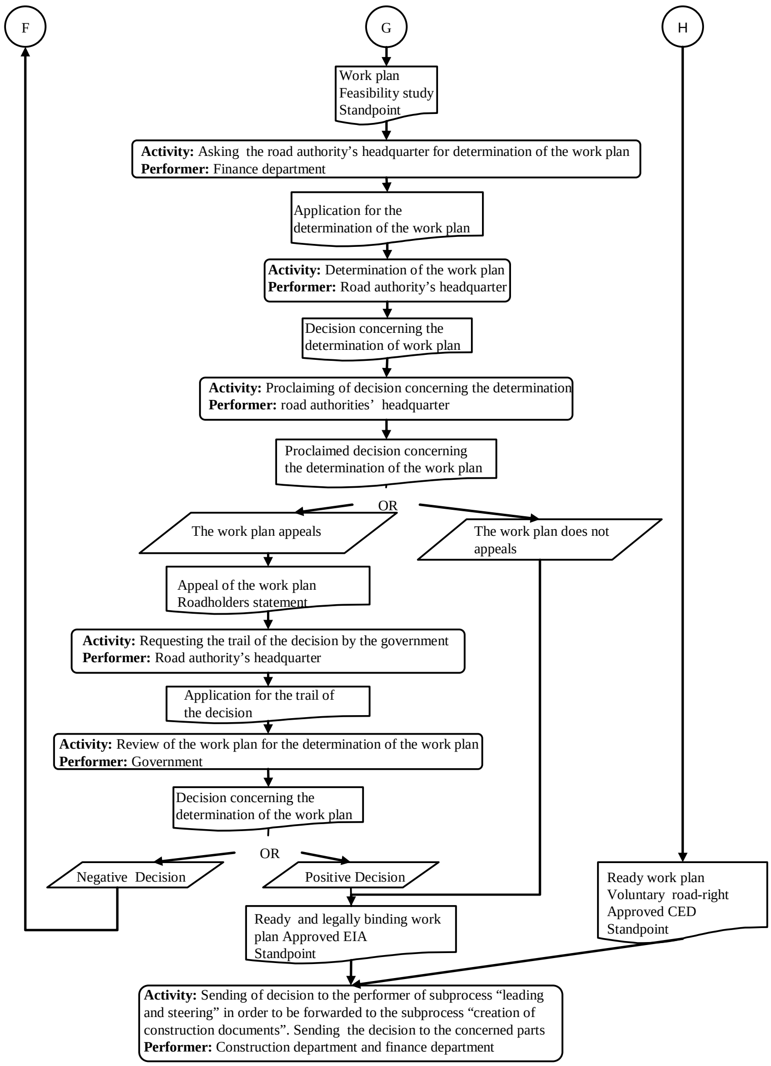


Appendix 4-c

Analysis of activity

Action graph document

Subprocess: Creation of work plan

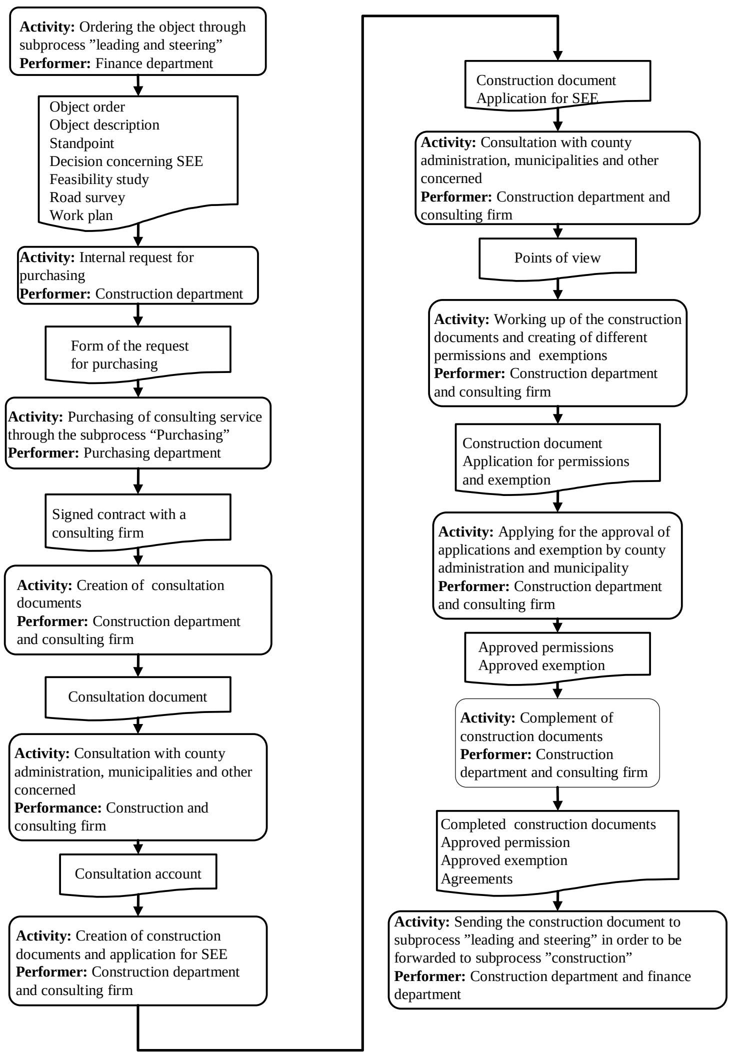


Appendix 4-d

Analysis of activity

Action graph document

Subprocess: Creation of the construction documents

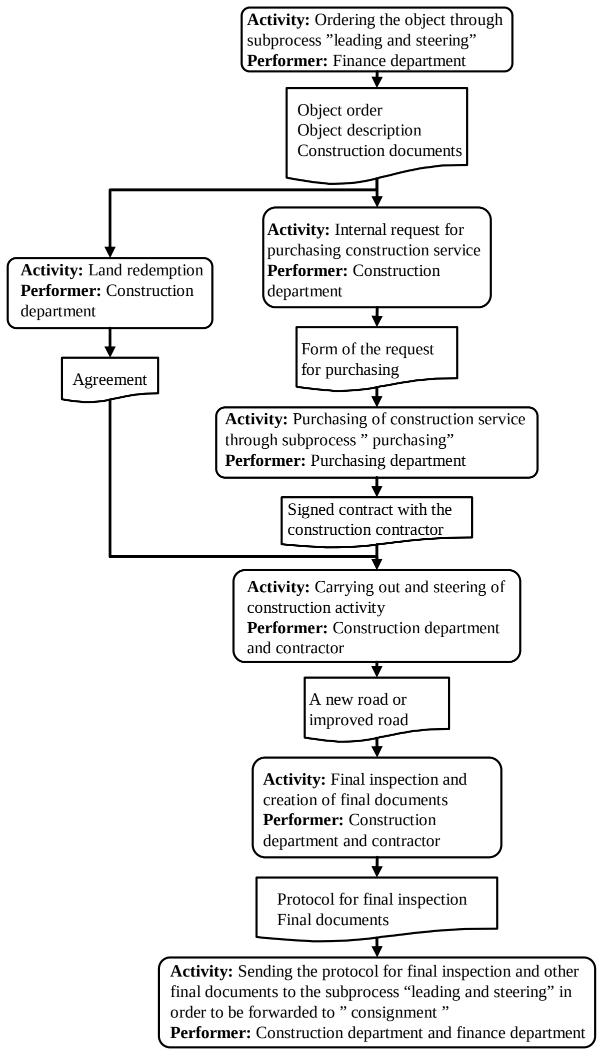


Appendix 4-e

Analysis of activity

Action graph document

Subprocess: Construction

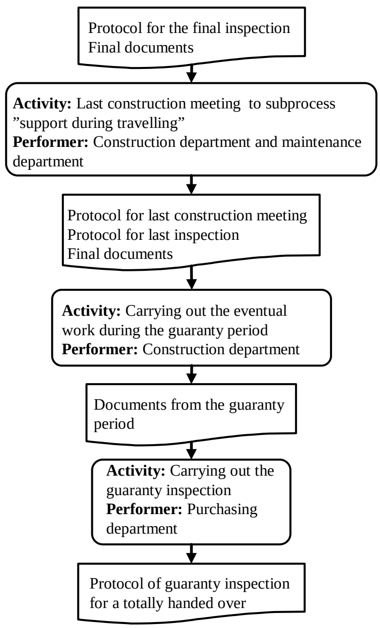


Appendix 4-f

Analysis of activity

Action graph document

Subprocess: Consignment

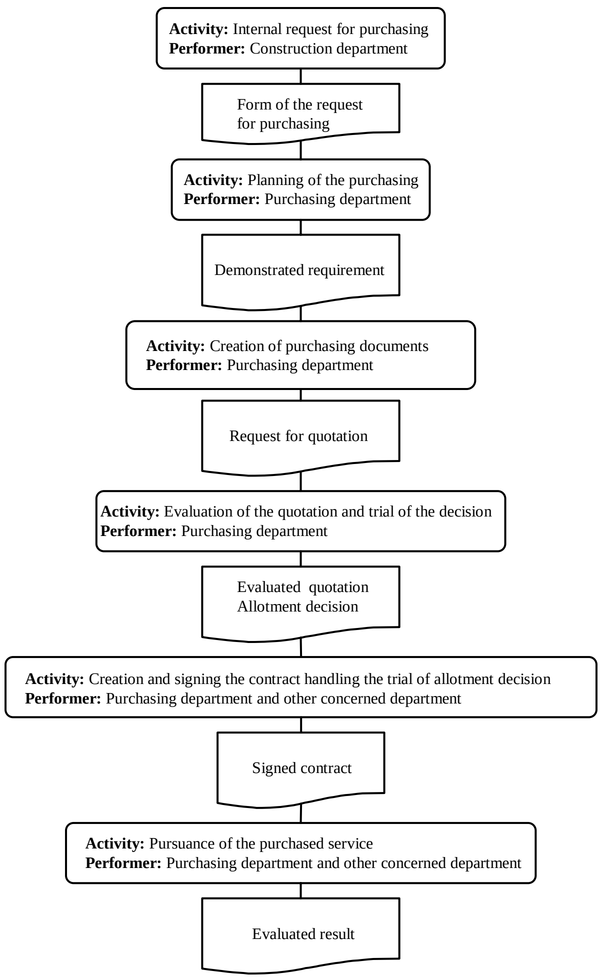


Appendix 4-g

Analysis of activity

Action graph document

Subprocess: Purchasing



Appendix 5

Analysis of goals which govern the road planning and design process

List of goals

SG: transport-related policy sub-goal

LSG: long-term stage goal

The overall transport-related policy goal

A socio-economically efficient and long-term sustainable transport system for individuals and business community throughout the country.

SG1: An accessible transport system: The transport system is to be designed so as to meet the basic needs of individuals and the business community.

SG2: A high transport quality: The design and the function of the transport system is to permit a high level of transport quality for individuals and the business community.

LSG1: The quality of the road transport system has to be gradually improved.

SG3: A safe traffic: the long-term goal for road traffic safety is for no body to be killed or seriously injured as a result of traffic accidents. The design and operation of the transport system should be brought into line with the requirements that this goal entails.

LSG2: The SRA, through its activities, has to contribute to a reduction in the number of fatalities and serious injuries due to traffic accidents. The number of fatalities and severe injuries due to traffic accidents in the road transport sector must be reduced to less than 270 persons by 2007.

SG4: A good environment: The design and performance of the transport system should be adapted to the requirements for a good and healthy life environment for every one, where natural and cultural environments are protected against damage. Good management of land, water, energy and other natural resources is to be promoted.

LSG3: Noise

Inhabitants should not be exposed to road noise exceeding 65 dB equivalent levels outdoors. In those cases where the outdoor levels can not be reduced, the equivalent level indoors must not exceed 30 dB.

LSG4: The localisation of road infrastructure

The road transport infrastructure has to be located in such a way that it functions in harmony with the surroundings. A road transport infrastructure must be designed with natural resources and cultural treasures taken into consideration.

LSG5: Environmental harmful material

The use of environmentally harmful materials must be avoided in road infrastructures and the use of non-renewable materials must be minimized. The used materials must be recyclable.

LSG6: Discharge

By 2010 carbon dioxide emissions should be at 1990’s highest level. The amount of the following emissions has to be reduced by 2005:

- Sulphur: by min. 15% counted from year 1995
- Nitrogen oxides: by min. 40% counted from year 1995
- Volatile Organic Compounds by min. 60% counted from 1995

The amounts of carbon oxide, nitrogen dioxide, sulphur dioxide, soot and particle emission for urban regions has to be below the limits and the established environmental quality norms. Carcinogenic substances must be halved compared to the 1998 level.

SG5: Positive regional development: The transport system should promote a positive regional development, both by evening out differences in the potential of various parts of the country to develop, and by counteracting the disadvantages of long transport distances.

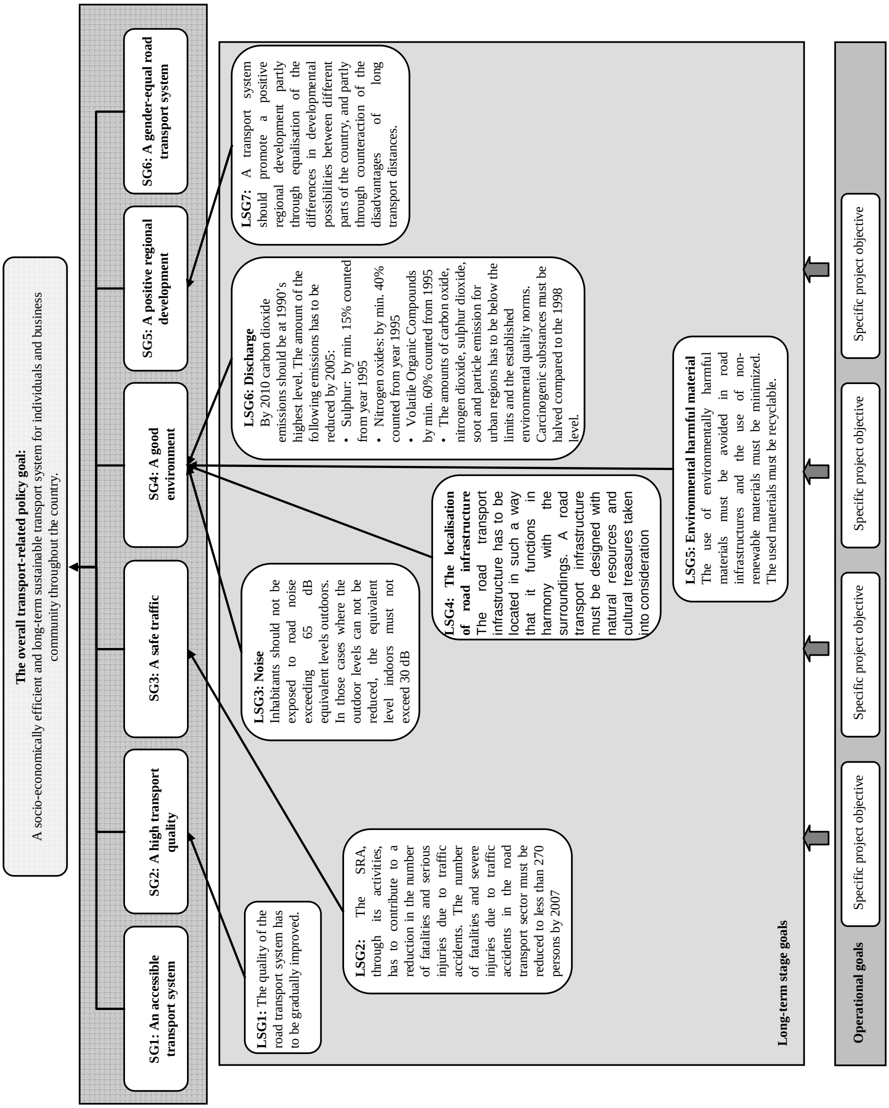
LSG7: A transport system should promote a positive regional development partly through equalisation of the differences in developmental possibilities between different parts of the country, and partly through counteraction of the disadvantages of long transport distances.

SG6: A gender-equal road transport system: The road transport system is to be designed to fulfil the transport needs of both women and men. Women and men are to be offered an equal opportunity to influence the creation of the transport system, its design and management, and their values to be equally important.

Appendix 6

Analysis of goals governing the process of road planning and design

Analyses of relations between goals. Goal graph document



Appendix 7

Analysis of needs for change

Problem evaluation

Problem status document

Criteria for classification of the identified problems were:

- NPS: No solution for the problem
- SP: Solved problem
- NC: Needs for change

For the last category of problems, priority was set according to the following criteria presented without priority:

- A problem which was the cause of several other problems
- A problem which was connected to high costs or which could result in serious consequences
- A problem which was crucial to the solution of another problem
- A problem which was emphasised during the interviews
- A problem which was relatively simple to eliminate, thus generating a large positive effect for little effort.

P1: Road designs which cause unnecessary and costly maintenance measures.
P2: Insufficient consideration of maintenance aspects during the road planning and design process.

The objective of this study was to identify the needs for change which would result in elimination of these two main problems.

Evaluation: NC Priority: high

P3: Requests for quotations and other purchasing documents do not consider maintenance aspects.

This problem is one of the basic causes of the main problem and elimination of this problem has to be highly prioritised during the formulation of needs for change.

Evaluation: NC Priority: high

P4: Maintenance departments often carry out reconstruction of improper designs without informing the planning and design department about the problems with such designs.

This problem can to some extent be solved indirectly if the construction department and the maintenance department have a common budget. However, this solution is not possible with the current organisational structure of the SRA. The problem can also be solved through consultation between the planning and design department and maintenance department. However, the possibility of such a consultation is limited because reconstructions usually are carried out several years after the road installation.

Evaluation: NPS

P5: For curiosity, aesthetic reason or ambition to stimulate technical development, project managers, consultants or architectures select new designs or products without any consideration of maintenance aspects.

The interviewees put a great emphasises on this issue because of its serious economic consequences. Therefore this issue has to be highly prioritised.

Evaluation: NC Priority: high

P6: Road authorities do not demand maintenance plan descriptions from consultants for the proposed road designs.

This problem generates serious economical consequences which designers or project leaders have no idea about, because they are not obligated to consider maintenance aspects as a basis for design selection. It is also obvious from the analysis of problems that this problem constitutes a basis for other problems related to regulations and the planning and design process. In addition, this problem is of crucial importance for elimination of problem five. The problem is relatively easy to solve by establishing maintenance impact statements during the planning and design process. Therefore this problem has to be highly prioritised.
Evaluation: NC Priority: high

P7: Maintenance aspects can easily be forgotten during the road planning and design process.

The effect of this problem can be reduced indirectly by solving problems 6, 8, 18, 20 and 42. That’s why this issue can have a low priority.
Evaluation: NC Priority: low

P8: Requests for quotations do not contain demands concerning consulting between consultants and actors involved in the maintenance process.

There is a great need to improve quotation requests through the establishment of clear demands for maintenance related consulting and guidelines for this kind of consulting. This issue can be eliminated indirectly by solving problem 42 and by solving knowledge related issues. Therefore this issue can have a lower priority.
Evaluation: NC Priority: low

P9: A limited investment budget prevents sufficient consideration of maintenance aspects during planning and design.

There is a great need for change in the road authorities' limited flexibility and rigid restrictions concerning the investment budget. According to the problem graphs in appendix 3, this problem underlies many other problems, such as problems 10 and 11, and has serious economic consequences. Therefore this problem has to be highly prioritised.
Evaluation: NC Priority: high

P10: Project managers are forced to keep acquisition costs low during the calculation of project expenses.

This problem underlies problems 8, 11, 31 and 32. Therefore, it is reasonable to give a high priority to this problem to the extent that it generates unnecessary maintenance measures with serious economic consequences as a result.
Evaluation: NC Priority: high

P11: Project managers at the road authorities rarely involve designers during the construction phases, mainly to avoid any additional costs covering the presence of the designers.

This problem can be indirectly eliminated through elimination of problems 9, 10 and 32. Therefore the problem can have a low priority.
Evaluation: NC Priority: low

P12: The road authorities do not have any experience feedback process between actors involved in the maintenance process and the planning and design process.

According to the problem graphs in appendix 3, this problem underlies a number of problems. Also, the elimination of this problem is of crucial importance to the elimination of the insufficient knowledge with reference to maintenance aspects. Therefore, this problem has to be highly prioritised.

Evaluation: NC Priority: high

P13: The road authorities do not have any database for collection of experiences from improper road designs which cause costly and unnecessary maintenance measures.

This is a well-known problem and underlies problem 12 which is also a source for a number of problems. The elimination of this problem is of crucial importance for establishing an experience feedback process. Therefore, it is reasonable to give this problem a high priority during the formulation of needs for change.

Evaluation: NC Priority: high

P14: The cost of maintenance measures due to improper road design is not properly pursued.

This problem generates serious economic consequences as it constitutes an obstacle for road authorities having a greatly needed database. Therefore it is reasonable to give this problem a high priority.

Evaluation: NC Priority: high

P15: It is difficult to calculate the costs for road maintenance measures before the work plans are established.

The elimination of this problem is a difficult task. For example, roadsides can be designed in many different ways with big differences in maintenance costs as a

result. The design details are decided during the subprocess of creation of the work plan.
Evaluation: NPS

P16: Road authorities do not make life-cycle cost analyses for proposed road designs during planning and design.

This problem is well-known by road authorities and consulting firms and is one of the bases for the main problem. This problem is relatively easy to eliminate and will probably give a big positive affect for a little effort. Therefore it is reasonable to give this problem a high priority.
Evaluation: NC Priority: high

P17: The investment department does not receive information from the maintenance department concerning costs and difficulties related to maintenance measures.

This problem can be indirectly solved through elimination of problem 12. Therefore it is reasonable to give this problem a low priority.
Evaluation: NC Priority: high

P18: Actors involved in the planning and design process do not have incentives which encourage sufficient consideration of maintenance aspects during planning and design.

It is not easy to find a solution for this problem. However, it can be solved partly by solving problem 20. Therefore, it is reasonable to give this problem a low priority.
Evaluation: NC Priority: low

P19: Until roads have been in operation for a few years, it is hard to predict difficulties concerning future maintenance.

Elimination of this problem is not an easy task. Creation of a database of collected maintenance experiences can reduce the effect of this problem. Therefore it is reasonable to give this problem a low priority.
Evaluation: NC Priority: low

P20: Road authorities often exclude maintenance aspects in the final evaluation of road construction projects.

It is difficult to blame inappropriate road designs as having a negative effect on road maintenance until the road has been in use for at least a few years. This makes the elimination of this problem a difficult task. Therefore it is reasonable to give this problem a low priority during the formulation of the needs for change. The creation of a database for collection of experiences of maintenance can reduce the effect of this problem.
Evaluation: NC Priority: low

P21: The land expropriation process is a time-consuming process which road authorities try to avoid by selecting designs requiring less land expropriation.

This problem can generate high costs and can results in seriously negative consequences on future maintenance. The elimination of this problem does not require extensive efforts, thus it gives a big positive effect for a little effort. Therefore, it is reasonable to high prioritize the problem.
Evaluation: NC Priority: high

P22: Delay in the planning process.

The SRA has made efforts to reduce this time delay between the subprocess of feasibility study and road survey in order to avoid this type of problem.
Evaluation: SP

P23: Project managers are sometimes forced to choose designs which are not optimal optimised for maintenance, even if they are aware of the negative consequences for future maintenance

This problem can be eliminated by solving the combination of problems forming the base for it, i.e. problems 9, 10, and 22. Therefore, it is reasonable to give this problem a low priority during the formulation of needs for change, despite the generated high costs and seriously negative consequences because of the increased need for maintenance measures.
Evaluation: NC Priority: low

P24: Road authorities rarely require consultants and project managers to have knowledge of maintenance related guidelines and regulations.

This problem has to be highly prioritised because it can generate high costs and can result in seriously negative consequences. In addition, the problem contributes to insufficient knowledge of maintenance aspects within consulting firms.
Evaluation: NC Priority: high

P25: When recruiting of designers and project managers, maintenance experience is not considered as a qualification.

It is fairly simple to consider maintenance experience as a merit for recruitment. However, it is not clear if this can be the main solution because good maintenance experience requires long periods of practical work. This is a reason why the problem has a low priority during the formulation of needs for change.

Evaluation: NC Priority: low

P26: Career of designers often starts directly after graduation, with no experience of road construction or road maintenance.

This problem can be reduced through implementation of trainee programs for newly graduated designers and project leaders. It would also be desirable to introduce courses in road maintenance in the education programs offered by universities and institutes. The first solution is relatively simple but to obtain acceptable results the participants must have qualified assignments. The second solution requires a fairly long period of time before results will be attained. This problem can be indirectly solved by considering maintenance aspects in planning and design related guidelines and regulations. Therefore, it is reasonable to give a low priority to this problem.

Evaluation: NC Priority: low

P27: Educational programmes for actors involved in planning and design do not consider road maintenance.

This problem is one of the bases for insufficient knowledge of, and low interest in maintenance aspects. This problem is relatively easy to eliminate by taking advantage of knowledge which maintenance departments and maintenance contractors have. Therefore, it has a high priority.

Evaluation: NC Priority: high

P28: Road designers assume that maintenance aspects have already been considered during the establishment of design related guidelines and regulations.

This problem can be eliminated through improved knowledge of maintenance and the associated regulations and guidelines. In addition, the effect of this problem can be limited if regulations and guidelines are established with more focus on maintenance. Therefore, it is reasonable to give this problem a low priority during the formulation of needs for change.

Evaluation: NC Priority: low

P29: Road authorities do not require consultants to use maintenance experts to deal with maintenance related questions.

This problem underlies a number of other problems which contribute to insufficient knowledge and insufficient consulting concerning maintenance aspects. Therefore it is reasonable to give this problem a high priority. Another reason for this high priority is that by utilizating specialist competence the problem of insufficient knowledge, which consultants suffer from, can be considerably eliminated.

Evaluation: NC Priority: high

P30: Road authority management has no appropriately established methods to follow up process performance.

The elimination of this problem may result in more frequent consultantion. However, it will be of lesser importance than improvements in consulting. Therefore a low priority can be given to this problem.

Evaluation: NC Priority: low

P31: Consultants have insufficient financial resources to perform maintenance related consulting on their own initiative.

This problem generates higher costs and results in seriously negative consequences. In addition, removal of this problem is of vital importance for eliminating the problem of insufficient consulting. Despite this, the problem can have a low priority because the best solution is through removing problems 9 and 10 which are basic causes for this problem.
Evaluation: NC Priority: low

P32: Reduced consulting among actors involved in maintenance activities and in the road planning and design process due to limited investment budgets.

This problem has to be high prioritised because it is a basic cause for many other problems. In addition, this problem is of a crucial importance for the elimination of insufficient consulting.
Evaluation: NC Priority: high

P33: Consultants and road authorities underestimate maintenance aspects problems which often are due to inappropriate road designs.

This problem can be low prioritised because it can be solved indirectly through improvements of maintenance knowledge.
Evaluation: NC Priority: low

P34: Absence of maintenance experts during the creation of design and planning related regulations and guidelines.

During the formulation of needs for change, this problem should be high prioritized because it constitutes one of the basic causes for insufficient consideration of maintenance aspects during the planning and design process. Therefore, the problem

results in seriously negative consequences on maintenance. The problem is relatively easy to solve and the elimination gives a big positive effect for a little effort.
Evaluation: NC Priority: High

P35: According to the public purchasing directive, road authorities are not allowed to stipulate specific materials or products in the requests for quotations, even if experience shows that those products contribute to reduced maintenance.

Several efforts have been made by the road authorities in order to reduce the effect of this problem. For example, the SRA tries to make central purchases, i.e. purchase products such as roadside equipment from the producer instead of letting the construction contractor purchase the instruments.
Evaluation: SP

P36: Due to inadequate general rules for consulting works in architectural and engineering activities (ABK96) (Byggandets Kontraktskommitte 1996) road authorities have a limited ability to claim compensation from consultants for reconstruction expenses relating to improper road design.

Any changes in ABK96 require enormous efforts and coordination between the SRA and the other concerned actors.
Evaluation: NPS

P37: The status of actors involved in planning and design is sometimes considered higher than the status of maintenance actors which contributes to the absence of consulting between the actors.

This problem is mainly related to an inadequate organisation which is not included in this investigation. However the SRA has made efforts to eliminate this status difference between the different departments within the organisation.
Evaluation: SP

P38: Information is spread insufficiently between different departments within the road authorities
This problem can indirectly be eliminated by creating an efficient system for feed-back. In addition, the problem is partly caused by an inadequate organisational structure which is not included in this investigation. Therefore, the problem has a low priority.
Evaluation: NC Priority: Low

P39: Development of different processes within the road authorities is carried out in isolation from each other.
This problem is related to inadequate organisational structure within the road authorities. Due to the delimitations of this investigation the elimination of this problem will not be included.
Evaluation: NPS

P40: Time, knowledge and sometimes interest from the management is not sufficient for establishing consultation guidelines between different departments and processes.

The elimination of this issue, which is related to the organisational structure, is not included due to the delimitation of this investigation.
Evaluation: NPS

P41: Road authorities have no guidelines for the coordination of different processes.

While coordination between different departments is very important for the experience-feedback process, it is still not clear to what extent the creation of guidelines can eliminate the absence of coordination. Therefore, this problem has a low priority.

Evaluation: NC Priority: low

P42: Road authorities have no long-term goals concerning maintenance aspects.

This problem generates high maintenance costs and results in seriously negative consequences. Therefore, it has to be highly prioritised.

Evaluation: NC Priority: high

P43: Road authorities have an inadequate organisational structure to deal with coordinating different processes.

The elimination of this issue, which is related to the organisational structure, is not included in this investigation because of delimitation.

Evaluation: NPS

P44: The maintenance department does not have enough time or resources to review work plans and other construction related documents during the road planning and design process.

This problem results in seriously negative consequences for future maintenance. It is one of the underlying causes of insufficient consulting. Therefore, the problem has a high priority.

Evaluation: NC Priority: high

P45: The designers have no model for the calculation of maintenance costs for suggested road designs.

This problem is one of the basic causes of the absence of life-cycle-cost calculations. The problem is relatively simple to eliminate, thus having a large positive affect with little effort. Therefore, it has a high priority.

Evaluation: NC Priority: high

P46: Municipalities and county administrations present arguments which are perceived as more important than maintenance aspects.

The elimination of this issue is not included in this investigation due to its delimitation.

Evaluation: NPS

Appendix 8

Analysis of needs for change

Formulation of needs for change

List of needs for change

Needs for change	**Concerned problems**
Need to establish well-defined and long-term goals concerning maintenance aspects	P5, P6, P7, P8, P16, P21, P33 and P42
Need for well-structured systems for consultation and exchange of information between actors involved in maintenance activities and in the road planning and design process.	P5, P7, P8, P9, P11, P12, P13, P14, P17, P19,P20, P21, P23, P24, P25, P26, P27, P28, P29, P31, P32, P33, P38, P41 and P44
Need for increased knowledge concerning road design within the organisations of road authorities, contractors and consultant firms to support future maintenance.	P5, P7, P8, P9, P11, P12, P13, P14, P16, P17, P18, P19, P20, P23, P24, P25, P26, P27, P28, P29, P31, P32, P33, P34, P38, P41 and P45
Need for change in the evaluation process carried out for each completed road construction project. The evaluation process must contain clear guidelines concerning maintenance aspects as a part of the quality assurance system.	P5, P7, P8, P17, P20, P30, P33 and P38
There is a great need to complete guidelines, legislation and other documents which govern planning and design to include maintenance aspects.	P3, P5, P6, P7, P9, P10, P11, P12, P13, P14, P16, P17, P18, P19, P20, P21, P23, P24, P25, P27, P28, P29, P30, P31, P32, P33, P38, P41 and P44
Need for change in requests for quotations and other purchasing related documents. These documents should contain requirements for the consideration of maintenance aspects.	P6, P5, P6, P8, P18, P20, P29, P33, P38, P41, P44 and P45
Need for increased incentives for consulting firms to encourage adequate consideration of maintenance aspects during the planning and design process.	P5, P7, P8, P18, 29, 24 and P33

Appendix 9

Questionnaire for identification of difficulties and problems which prevent sufficient consideration of the maintenance aspects during the road planning and design process in Sweden

Name of the respondent:……………….

Sex……….

Age…….

Company/Authority……………

Position in the company/authority………………..

Experience:

Road maintenance…………..

Road planning and design…………..

Other…………..

General questions

Organisation

- How is the organisation of your company/authority structured?
- How the process of road planning and design carried out in your company/authority?
- What are the goals which steer the activities in your company/authority?

Communication

- How do you experience the internal communication and coordination between different departments in your company/ authority?
- How do you experience the consulting between the maintenance department and the construction/investment department?
- How can the consulting concerning maintenance aspects be improved?

- In which phase of the road planning and design process is the consulting efficient?
- Do the project managers get any feedbacks from the maintenance department/experts?

Goals concerning road maintenance

- How often are maintenance aspects considered during the road planning and design process? For which road components? During which phase of the road planning and design process?
- Do the road authorities have any clear goals concerning maintenance? Is it easy to fulfil the goals? Is it easy to follow up the goal fulfilment?
- Is it possible to affect the fulfilment of the goals during the selection of road designs?
- If there are no goals concerning reduction of maintenance costs, what are those goals which can be appropriate for reduction of maintenance costs?
- What are the requirements which the road authorities should demand from the road designer to reduce the total life-cycle costs of roads?
- How should the road authorities follow up those requirements?
- Are there any new contracts or funding forms which can encourage sufficient consideration of maintenance aspects during the road planning and design process?

Regulation and Guidelines

- Compared to aspects such as environment and traffic safety, how do you experience the consideration of maintenance aspects in the planning and design related regulation and guidelines?
- For better consideration of maintenance aspects during the road planning and design, what are the improvements and changes which have to be conducted in regulation and guidelines?

- Do the road authorities involve maintenance experts during the establishment of planning and design related regulation and guidelines?
- How often do the road authorities use life-cycle cost analyses during the planning and design process?

Knowledge concerning road maintenance

- Which are the experiences that the road authorities require from the consulting firms? Is the maintenance experiences considered?
- Which are the aspects that have to be considered in the knowledge improvement programs for the project managers and road designers? Is the maintenance aspect considered in the programs?
- How often do the road designers establish maintenance plan descriptions or maintenance impact statements for the selected road designs and road components?
- How are the different experiences spread in your authority/company?
- Do the road authorities properly peruse those road designs which result in costly and difficult maintenance measures?
- What makes the road designer to select road designs which result in costly and unnecessary maintenance measures? Is it

  Insufficient knowledge of maintenance?

  Socio-economic aspects?

  Insufficient road funding?

  Aesthetics aspect?

  Other?

Road emplacement and alignment

- What are the problems and difficulties which are faced during conduction of road maintenance measures due to insufficient road alignment or emplacement?

- Are the road designers and project managers aware of the problems and difficulties?
- How are the problems solved? What are the economic consequences?
- Is it possible to avoid the problems through selection of other road designs? How?

Road barriers

- What are the maintenance related problems and difficulties which are caused by insufficient design of road barriers?
- Are the road designers and project managers aware of those problems and difficulties?
- How are the problems solved? What are the economic consequences?
- Is it possible to avoid the problems through selection of other road designs? How?

Roadside design

- What are the maintenance related problems and difficulties which are caused by insufficient design of roadsides?
- Are the road designers and project managers aware of those problems and difficulties?
- How are the problems solved? What are the economic consequences?
- Is it possible to avoid the problems through selection of other road designs?

Circulations and roundabout

- What are the maintenance related problems and difficulties which are caused by insufficient design of roundabouts?
- Are the road designers and project managers aware of those problems and difficulties?
- How the problems are solved? What are the economic consequences?

- Is it possible to avoid the problems through selection of other road designs?

Speed reduction measures

- What are the maintenance related problems and difficulties which are caused by insufficient design of speed reduction measures?
- Are the road designers and project managers aware of those problems and difficulties?
- How are the problems solved? What are the economic consequences?
- Is it possible to avoid the problems through selection of other designs?

Bus stops

- What are the maintenance related problems and difficulties which are caused by insufficient design of bus stops?
- Are the road designers and project managers aware of those problems and difficulties?
- How are the problems solved? What are the economic consequences?
- Is it possible to avoid the problems through selection of other designs?

Appendix 10

A questionnaire for identification of problems and difficulties which prevent sufficient consideration of maintenance aspect during the planning and design phases in the Nordic countries.

Name of the respondent:…………… Age:… Profession:………………

Name of the Company/authority………... Position in the company/authority:……

1. How is the organisation of your company/authority structured?
2. How is the process of planning and design conducted in your company/authority?
3. What are the goals which control the activities of your company/authority?
4. How is the knowledge spread in your company/ authority?
5. How do your company/authority manage the internal consulting or coordination?
6. What are the maintenance difficulties and problems which are faced by your company/authority due to ignorance of maintenance aspects during road planning and design process?
7. Is it true that the consultants and road authorities underestimate maintenance aspect problems which are caused by inappropriate road designs?
8. Do the road authorities have goals concerning maintenance aspects and reduction of maintenance costs?
9. Do you agree with those who believe that the insufficient consideration of maintenance aspects partly depends on the low interest from the management to give maintenance aspects a high priority? Could you give an example?
10. Is it true that the development of the different processes within the road authorities is carried out in isolation from each other and that the organisation as a whole is not optimised?
11. Do the road authorities have any guidelines for the coordination between different processes such as investment and maintenance?

12. Do the actors involved in the planning and design process have any incentives which encourage consideration of maintenance aspects during the planning and design process?
13. Is the consideration of maintenance aspects during the planning and design process neglected due to an insufficient investment budget? Can you give an example?
14. Do the road authorities make any life-cycle cost analyses for the proposed road designs during the planning and design process? Is there any model for the calculation of maintenance costs for the suggested road designs?
15. Do you agree with those who believe that curiosity, aesthetic reasons or ambitions to stimulate technical development make project managers, consultants or architectures select new designs or products without consideration of maintenance aspects?
16. Do the road authorities demand maintenance plan descriptions or maintenance impact statements from consultants for the proposed road designs?
17. Are maintenance experts involved during the creation of road planning and design related regulations and guidelines?
18. Is it true that the career of the designer often starts directly after graduation, with no experience of road construction or road maintenance? If yes, why? What is the solution?
19. Do the road authorities require that the consultants must have knowledge of maintenance related guidelines and regulations?
20. Is the road maintenance aspects considered in knowledge development programmes for actors involved in the road planning and design process?
21. Do the road authorities require consultants involved in road planning and design to use maintenance experts to deal with maintenance related questions?

22. Is it true that the status of actors involved in planning and design is sometimes considered higher than the status of maintenance actors which contributes to the absence of consulting between the actors? If yes, explain why. What is the solution?
23. Are the maintenance aspects considered in the requests for quotations and other purchasing documents? Do the requests for quotations contain any demands concerning coordination between the consultants and actors involved in the maintenance process?
24. Does the maintenance department or any other maintenance expert review work plans/design documents and other construction related documents before the start of construction?
25. Are the designers involved during the construction phases?
26. Does any experience feedback processes exist between actors involved in maintenance activities and actors involved in planning and design to inform about costs and difficulties related to maintenance measures?
27. Is the cost of maintenance measures due to improper road design properly pursued?
28. Do the road authorities have any database for the collection of experiences of inappropriate road designs?
29. How often do the road authorities precede evaluation of the road projects when the construction works are completed? Which aspects are included in such evaluations? Are the maintenance aspects included in such evaluations?
30. Do the road authorities have ability to claim compensation from consultants for the reconstruction expenses due to improper road design?
31. In addition to the previous mentioned facts, what make the road authorities select designs without sufficient consideration of maintenance aspects?

Appendix 11

The structure of the database established for road barrier repairs

Maintenace area	Repair number in the database	Repair number in SRA's archive	Observation date	Repair location	Barrier type
Bollnäs	17	88603535/18	2006-01-13	E4 NG pos. 113,6	Cable barrier
Bollnäs	18	88603536/18	2006-01-13	E4 Norradalen, 500m south o	Cable barrier
Bollnäs	19	88603540/18	2006-01-13	E4 Styvje pos 100,5	Cable barrier
Bollnäs	30	88606065/18	2006-02-10	E4 pos 113,1, norr Alebosjön	Cable barrier

Straight road or curve	Median or roadside barrier	Distance between barrier and edge of traffic lane, Class A or B	Design speed (km/h)	Road type	Single or double lanes
Straight	Median	A	110	MW	double
Straight	Median	B	110	MW	double
Straight	Median	B	110	MW	double
Straight	Median	B	110	MW	double

Registration number of the vehicle/vehicles	Insurence company	Sum of repair cost (SEK)	Cost of Staff (SEK)	Cost of staff %	Cost of temporary traffic managment material (SEK)	Cost of temporary traffic managment material %
Unknown	Unknown	7517	4490	60%	1104	15%
Unknown	Unknown	16984	6860	40%	1361	8%
Unknown	Unknown	11140	6336	57%	1361	12%
EOU 162	Trygg Hansa	10851	6854	63%	1554	14%

Cost of spare parts (SEK)	Cost of spare parts %	Other costs (SEK)	Other costs %	Repair posts	Cost/post (SEK/post)	Season	Vehicle repair cost (SEK)
1520	20%	207	3%	2	3759	vinter	Unknown
8360	49%	403	2%	11	1544	vinter	Unknown
3040	27%	200	2%	4	2785	vinter	Unknown
2040	19%	270	2%	4	2713	vinter	Unknown

Appendix 12

The structure of the database established for traffic works

Road number	Start point	End point	Link length (m)	Road type	Design speed (km/hr)
E4	1473A 17.11	1571A 27.14 (583)	5770	MW	110
E4	1571A 27.11 (583)	1571A 28.09 (583.04)	13390	MW	110
E4	1571A 28.11 (583.04)	1571A 35.09 (673)	10450	MW	110
E4	1772A 7.10 (611/613)	1772A 3.17 (615)	1044	MW	110
E4	1772A 3.22 (615)	1774A215.01	3466	MW	110
E4	1774A 90.04 (622)	1774A159.07	4300	MW	110

	AADT			
Type of median barrier	Reference year	Year of repair	Time difference in years	Traffic calculation factor
Cable barrier	2002	2006	4	1,08243216
Cable barrier	2002	2006	4	1,08243216
Cable barrier	2002	2006	4	1,08243216
Cable barrier	2002	2006	4	1,08243216

AADTº during the reference year			AADT during the the year of barrier repair		
Vehicles	Trucks	Axle par	Vehicles	Trucks	Axle par
6530	1030	8120	7068,282005	1114,905125	8789,349139
6250	1100	7960	6765,201	1190,675376	8616,159994
6470	1110	8190	7003,336075	1201,499698	8865,11939
23830	2070	25650	25794,35837	2240,634571	27764,3849

Traffic work during the reference year			Traffic work during the year of barrier repair		
Vehicle (Veh.m/day)	Trucks (Trucks.m/day)	Axel par (Axp.m/day)	Vehicle Million veh.km/year	Trucks Million trucks.km/year	Axle par Million axp.km/year
40783987,17	6433002,57	50714544,53	14,88615532	2,348045938	18,51080875
90586041,39	15943143,28	115370382,3	33,06390511	5,819247299	42,11018954
73184861,99	12555671,84	92640497,63	26,71247462	4,582820222	33,81378163
26929310,14	2339222,492	28986017,84	9,829198202	0,85381621	10,57989651

Appendix 13

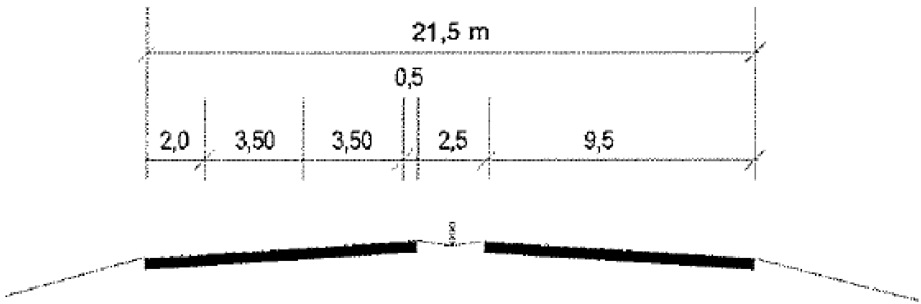
Table for road barrier repair costs

Type of median barrier	Region	Road type	Speed limit	Number of repair per vkm (Rep/Mvkm)	Average cost per repair (SEK)	Repair cost per vkm (kSEK/Mvkm)
Cable barriers	Central Region	Motorway	70	No repair		
			90	0.41	19 217	7.952
			110	0.27	16	4.270
		Collision-free arterial roads	70	None existing		
			90	0.75	17 127	12.845
			110	0.62	12 876	7.982
		Collsion-free country roads	70	None existing		
			90	0.76	14 327	10.888
			110	0.24	16 410	4.006
		4-lane roads	70	No repairs		
			90	0.39	8 797	6.892
			110	None existing		
	Western Region	Motorway	70	None existing		
			90	None existing		
			110	0.20	10 639	2.173
		Collision-free arterial roads	70	0.46	12 103	5.537
			90	0.41	11 335	4.703
			110	None existing		
		Collsion-free country roads	70	0.22	13 470	2.910
			90	0.25	10 229	2.552
			110	None existing		
		4-lane roads	None existing			
W-beam bariers	Central Region	None existing				
	Western Region	Motorway	70	0.08	10 146	0.773
			90	0.07	10 049	0.662
			110	0.09	11 178	1.037
		Collision-free arterial roads	None existing			
		Collsion-free country roads	None existing			
		4-lane roads	70	0.08	8 797	0.682
			90	0.04	5 303	0.205
			110	None existing		
Kohlswa-beam barriers	Central Region	None existing				
	Western Region	Motorway	70	0.23	6 659	1.510
			90	None existing		
			110	None existing		
		Collision-free arterial roads	None existing			
		Collsion-free country roads	None existing			
		4-lane roads	70	0.08	8 797	0.682
			90	None existing		
			110	None existing		
Pipe barrier	Central Region	None existing				
	Western Region	None existing				

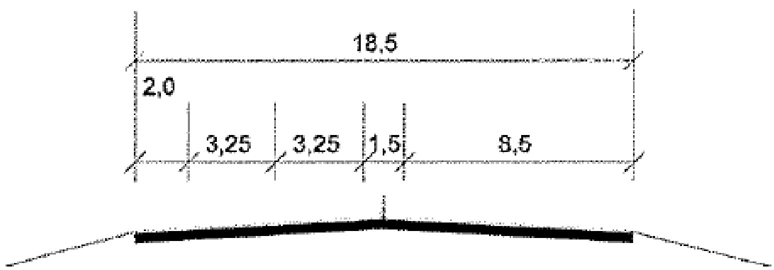
Appendix 14

Typical cross-sections for different road types (source: Road Design Manual)

Typical cross-section for motorways

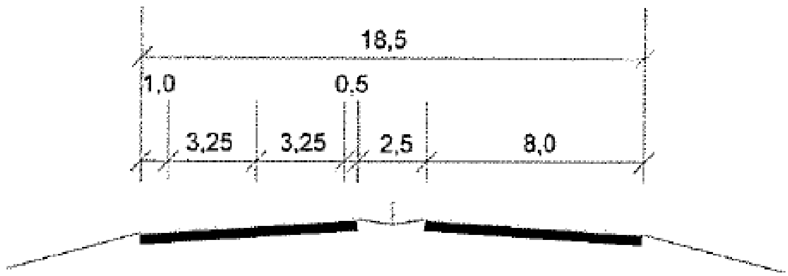


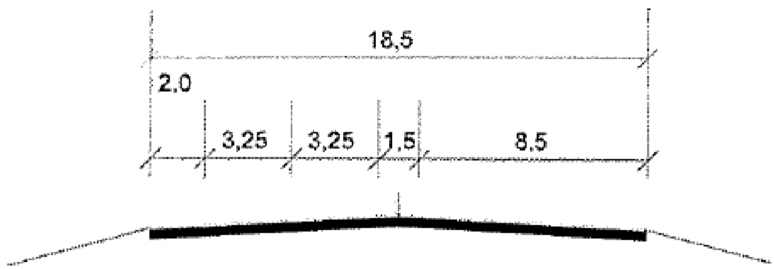
Typical cross-section for motorways with regular standard

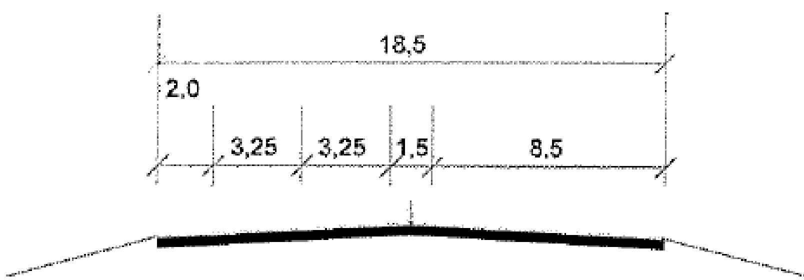


Typical cross-section for motorways with low standard

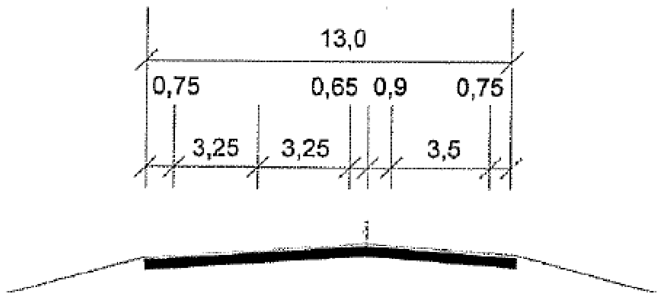
Typical cross-section for 4-lane roads



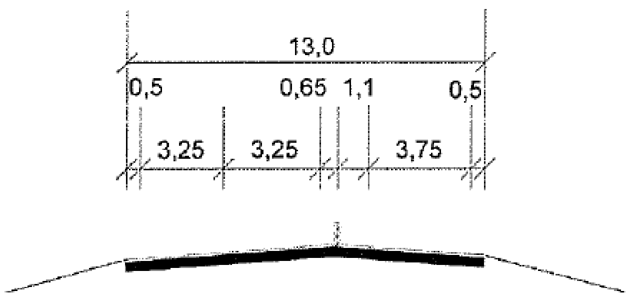




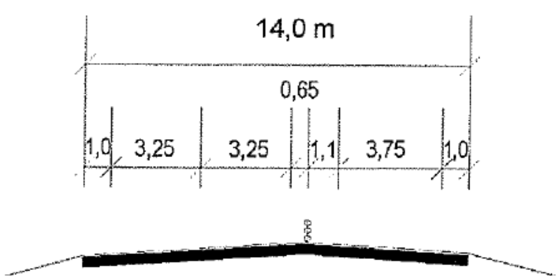
Typical cross-section for collision-free roads



Typical cross-section for collision-free country roads with bicycle- and pedestrian paths, converted from a regular 13 m wide roads



Typical cross-section for collision-free arterial roads and collision-free country roads without bicycle- and pedestrian paths, converted from a regular 13 m wide roads



Typical cross-section for newly constructed collision-free arterial roads

Appendix 15

Distribution of traffic work over the year along the Swedish road network measured 1990 (Source: SRA Consulting).