CHALMERS

Implementation of road operation maintenance aspects in the planning and design phase

Investigation of cost savings and future recommendations

Master of Science Thesis in the Master's Programme Design and Construction Project Management

CHRISTINE BIANCHI

Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Research Group
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2013

Master's Thesis 2013:33

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ABSTRACT

The Swedish Transport Administration has the overall responsibility for the Swedish road network which also operates the road operation maintenance. The Swedish Transport Administration's goal is to ensure that the transport system is economically navigable and a sustainable transport system for all users. Due to the increasing traffic in Sweden, the need of maintenance has put great demand in the planning and implementation of road operation maintenance. The aesthetics has played a significant role in the planning and design phase of the Swedish road system, where the road operation maintenance aspects have been down-prioritized. Furthermore, the initial cost for a new build road can be kept at a low level; however, the maintenance costs can become extremely elevated. In addition, this can partially be due to the lack of knowledge, time and no feedback of experience between clients, contractors and consultants after ending a basic package of routine maintenance. The clients and the contractors shares a common view concerning the recurrent damages of road operation maintenance, meaning that these problems has been known for a period of time without any action to prevent it.

The aim of this master thesis is to implement road operation maintenance aspects in the planning and design phase by conducting a checklist with the intention for the clients, contractors and consultants using the checklist for future maintenance work. The checklist also contains improvement opportunities for future road operation maintenance and is based on the experiences from the interviewees. The checklist should in addition function as a support tool for effective maintenance planning for the consultants when designing a road towards reaching a reduced maintenance costs in the future. Even though the initial cost can be higher, however reduce the total costs of the road lifetime.

In excess of the presented results in the checklist, both good and bad examples from previous projects are stated in the report based on the interviewee's experiences and knowledge in this field. Due to the comprising maintenance area, the road operation maintenance focused in the report is road side areas with nine activities and one general activity occurring in the basic package of routine maintenance. The method chosen for the report is firstly literature studies both on internet and books and in order to obtain an impression from the construction industry, semi structured interviews were conducted which enables the interviewees to answer the questions without restraints. Towards understanding the difficulties in road maintenance and

reaching for improvements in the area, interviews were held with The Swedish Transport Administration, contractors and consultants.

The result has shown that the common vision shared between clients, contractors and consultants create an advantage and a successful use of the checklist, where the processes are easier to replace than changing the mindset of the personnel involved in the road operation maintenance. An important factor to enable the successfulness of the checklist for future maintenance is to modify the planning and design phase, meaning reducing the influence of the aesthetics where opportunity exists. The report specifies options to find a middle ground to meet the requirements, both from an aesthetic and from a road operation maintenance perspective. In addition, the checklist is based on the interviewee's experience, which facilitates the implementation and possibly implementation of the checklist. Short communication lines, progress meetings, and feedback will create a successful implementation of the checklist.

Key words: Road operation maintenance, planning and design phase, implementation, aesthetic, life cycle cost analysis, checklist

Implementering av drift- och underhållsaspekter i planeringsfasen
Utredning av kostnadsbesparingar och framtida rekommendationer

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SAMMANFATTNING

Trafikverket har det övergripande ansvaret för det svenska vägnätet och driver även drift- och underhållet av vägar. Trafikverkets mål är att säkerställa att transportsystemet är samhällsekonomiskt farbar samt ett hållbart transportsystem för alla användare. På grund av den ökande trafiken i Sverige, har behovet av underhåll satt stor efterfrågan i planering och genomförande av underhåll. Estetiken har varit av en betydande roll vid projektering av det svenska vägnätet, där drift- och underhålls aspekterna har blivit nedprioriterade. Detta föranleder till att initialkostnaden för en nybyggd väg hålls nere men där drift- och underhållskostnaderna skjuter i höjden. Detta beror delvis på brist på kunskap, tid och ingen erfarenhetsåterföring mellan beställare, entreprenörer och konsulter efter att ett driftkontrakt avslutats. Beställarna och entreprenörerna delar en gemensam uppfattning kring de återkommande drift- och underhållsskador, vilket betyder att dessa problem har funnits en längre tid utan någon möjlig handling att åtgärda detta.

Syftet med examensarbetet är att implementera drift- och underhållsaspekterna i planerings- och projekteringsfasen genom att upprätta en checklista med avsikt för beställare, entreprenörer och konsulter att nyttja checklistan för framtida drift- och underhåll av vägar. Checklistan består av förbättringsmöjligheter och alternativa metoder baserade från de intervjuade parterna. Checklistan ska även fungera som stödverktyg för projektörerna att designa en väg som i sin tur leder till att kostnaderna för drift- och underhåll under en vägs livstid framöver kan reduceras även om investeringen/budgeten blir högre i initieringsfasen.

Utöver resultatet presenterat i checklistan presenteras dessutom både bra och dåliga exempel från tidigare projekt baserade på de intervjuades erfarenheter och kunskaper inom området. Då drift- och underhållsområdet är väldigt omfattande och komplext, har fokus ställts på sidoområden med nio utvalda aktiviteter och en generell aktivitet som förekommer i driftpaketen. Den metod som valts för detta examensarbete är dels litteraturstudier på internet samt litteratur för att skapa en teoretisk plattform och kunskap för framtida intervjuer för rapporten. Dessutom, för att få en uppfattning om drift- och underhåll har semistrukturerade intervjuer utformats, vilket möjliggör för de intervjuade att besvara frågorna utan begränsningar. För att förstå svårigheterna i vägunderhåll och nå förbättringar inom området, utfördes intervjuer med Trafikverket, entreprenörer och konsulter.

Resultatet har påvisats att den gemensamma syn som delas mellan beställare, entreprenörer och konsulter skapar en fördel och en framgångsrik användning av

checklistan, där processer är lättare att ersätta jämfört med att förändra tankesättet hos personal som arbetar med drift och underhåll. En viktig faktor för att möjliggöra att checklistan blir ett framgångsrikt verktyg för framtida underhåll är att modifiera planerings- och projekteringsfasen, vilket innebär att minska inverkan av estetiken där möjlighet finns. I rapporten anges olika lösningar för att hitta en medelväg för att uppfylla kraven, både från ett estetiskt och ur ett drift- och underhållsperspektiv. Dessutom är checklistan baserad utifrån de intervjuades erfarenhet, vilket underlättar genomförandet och möjligtvis implementeringen av checklistan. Korta kommunikationsvägar, avstämningsmöten, och erfarenhetsåterföring kommer att leda till att implementeringen av checklistan kommer att bli framgångsrikt.

Nyckelord: Drift- och underhåll, planering, implementering, estetik, livscykelkostnadsanalys, checklista

Contents

Preface

The master thesis project was conducted for the master's degree in Design and Construction Project Management. The project was carried out in a department of road operational maintenance at Svevia, Sweden. The master thesis was done in collaboration with Svevia, Trafikverket, NCC, Skanska and Vectura which lasted from May 2012 until June 2013.

Primarily, I would like to thank my supervisor Karim Hawzheen at Svevia for the supporting and guidance during the project. I would also like to thank my supervisor Gunnar Lanner at Chalmers University of Technology for the support throughout the project.

Special thanks to all the interviewees that participated in the project. Without them I could not have conducted the research. I would also thank my opponents for providing feedback for my master thesis.

Finally, special thanks to my family who encouraged and supported me throughout the research.

Gothenburg June 2013

Christine Bianchi

Notations

Basic Package Of Routine maintenance	*The contract used for road operation maintenance between client and contractor.*
LCCA	*Life Cycle Cost Analysis is a process for evaluating the total economic worth of usable project segment by analyzing initial costs and discounted future cost, such as maintenance, user, reconstruction, rehabilitation, restoring and re-surfing costs, over the life of the project.*
Road side area	*From the road section and as far as the road owner has the recourse over the land.*
Road operation	*Road operation aims to keep the road navigable and maintain the function where the activities have duration of less than one year (for example winter maintenance, sanding, salting, emergency reparations of the surface etc.)*
Road maintenance	*Road maintenance maintains to ensure the function of the road over time, such as paving and drainage. Meaning that the duration of expected work is longer than one year but don't have the aim to add value to the road.*
Safety Zone	*The area outside the carriageway and free from obstacles.*
STA	*Swedish Transport Administration*
TMA	*Truck Mounted Attenuator. Energy absorbing protection that is placed back of the trucks.*

1 Introduction

Taking the road operation maintenance into consideration as early as in the planning and design phase has been challenging for clients, contractors and consultants. The aesthetics has been a significant part in the planning and design phase which has lead to down-prioritization of road operation maintenance aspects. In addition, the subject is very important due to the high maintenance costs carried out during the lifetime of the road, which can be reduced with accurate planning and execution methods. These difficulties often arise due to the lack of consideration to road operation maintenance aspects in the planning and design phase.

Generally, the main reason why road operation maintenance is not taken into consideration in the planning and design phase is the consultant's limitation of knowledge and no shared balancing in the projects. Due to the limited knowledge, it is almost impossible to plan the road operation maintenance in an early stage as needed. In addition, the absence of knowledge might be explained if there is insufficient feedback experience between clients, contractors and consultants.

Today, there is no efficient procedure or resource effective for all concerned parties to utilize on the subject of reducing the road operation maintenance costs (client, contractors and consultants). A checklist conducted for clients, contractors and consultants can therefore be an effective tool to cover the road maintenance challenges and minimize unnecessary costs in projects.

1.1 Background

The Swedish Transport Administration (STA) has the overall responsibility for the Swedish road system and operates the road operation maintenance. The STA has through the plan for transportation system established goals in order to fulfil dependable road transportation for its users through road operation maintenance. Due to the increasing traffic in Sweden, the need of maintenance has created high demand in the planning and the execution of maintenance (Trafikverket, 2011).

In the construction industry, reducing the road operation maintenance costs has been and is still challenging for the involved actors. Road operation maintenance refers to all activities needed to maintain the standard the road originally was designed for. Furthermore, the maintenance costs are a key element of the total expenditures of a project. Therefore, an immediate need exists to provide and highlight the importance of designing with maintenance in mind. Aesthetics, project budgets/investments, traffic safety and environmental affects have been the overall focus concerning the road design (Karim, 2011).

The client has a budget with an intention to maintain low construction costs which can't be breached and as a result, the road operation maintenance costs become down-prioritized. In addition, the client has a responsibility to the road users to construct safe and navigable roads to utilize and adapt to the surrounding landscape. The aesthetics has a distinct influence on the road design and is often prioritized more than the operation maintenance of a road. With a more appropriate road design some of these problems can be avoided.

The road operation maintenance costs in a Basic Package of Routine Maintenance always tend to exceed the planned costs for maintenance. Therefore, an interesting

aspect is to investigate the annual costs, and in addition the total costs of a product through its lifetime (LCCA). Life cycle cost analysis (LCCA) is a model which composes better investment decisions and reducing the upcoming maintenance costs (Huang, 2012).

By implementing the road operation maintenance aspects in the planning and design phase, a numeral of costs can be reduced with existing models and consequently recurrent damages can be avoided. The absence of knowledge and the lack of literature is in addition one reason why the implementation has not been successful in the construction industry. The existing knowledge is often in the operation areas and no feedback of experience is shared between clients, contractors and consultants.

1.2 Aim and objectives

The aim of the master thesis is to implement road operation maintenance aspects in the planning and design phase by conducting a checklist with the intention for the clients, contractors and consultants using the checklist for future maintenance work. The checklist is composed with suggestions of improving road operation maintenance aspects in the planning and design phase from the interviewers which is focused on road side areas affecting the road design. The checklist is attached as an appendix in this master thesis.

Furthermore, the report aims to carry out an investigation of recurrently common road operation maintenance in road side areas and examine the data in order to accomplish more effective maintenance. In addition, the report discusses good and bad examples on how the influence of aesthetics affects the costs of road operation maintenance.

In order to fulfil the aim the following objectives have been set:

1) Review the current literature on road operation maintenance and different actors
2) Evaluate road actors experiences (client, contractor and consultant)
3) Identify recurrent critical road side areas in road operation maintenance
4) Critically examine the recurrent road side areas in the Basic Package of Routine Maintenance through the interviews
5) Identify the problem areas in chosen road side areas
6) Conduct a checklist adapted for clients, contractors and consultants to utilize in the planning and design phase

1.3 Method

The method chosen for the master thesis is firstly literature studies both on internet and searching in books in order to create a theoretical platform for the future interviews in this report. Moreover, in order to obtain an impression from the construction industry, semi structured interviews were conducted which enables the interviewees to answer the questions without restraints. Towards understanding the difficulties in road maintenance and reaching for improvements in the area, interviews were held with The Swedish Transport Administration, contractors and consultants.

The literature study begins with a description of the Swedish Transport Administration which is the major owner of almost the entire road system in Sweden. Furthermore, definitions and terms are necessitating to be explained in this master thesis in order to comprehend the process of operation maintenance in Swedish road systems.

Finally, the result from the interviews are discussed and examined in order to conduct a checklist utilized for future road operation maintenance work. Moreover, both good and bad examples from previous projects are stated in the master thesis.

1.4 Delimitation

Due to the comprising maintenance area, the road operation maintenance focused in the report is road side areas with nine activities and one general activity which occur in the Basic Package of Routine Maintenance. The interview questions provide the interviewers the possibility to reply without restraints concerning their opinion of the generally upcoming problems on the subject of road side areas. In addition, the different activities discussed in the report are stated in *Figure 1*. Furthermore, due to the lack of literature focused in this field, this master thesis is mainly focused on the interview findings based on experiences from the clients, contractors and consultants.

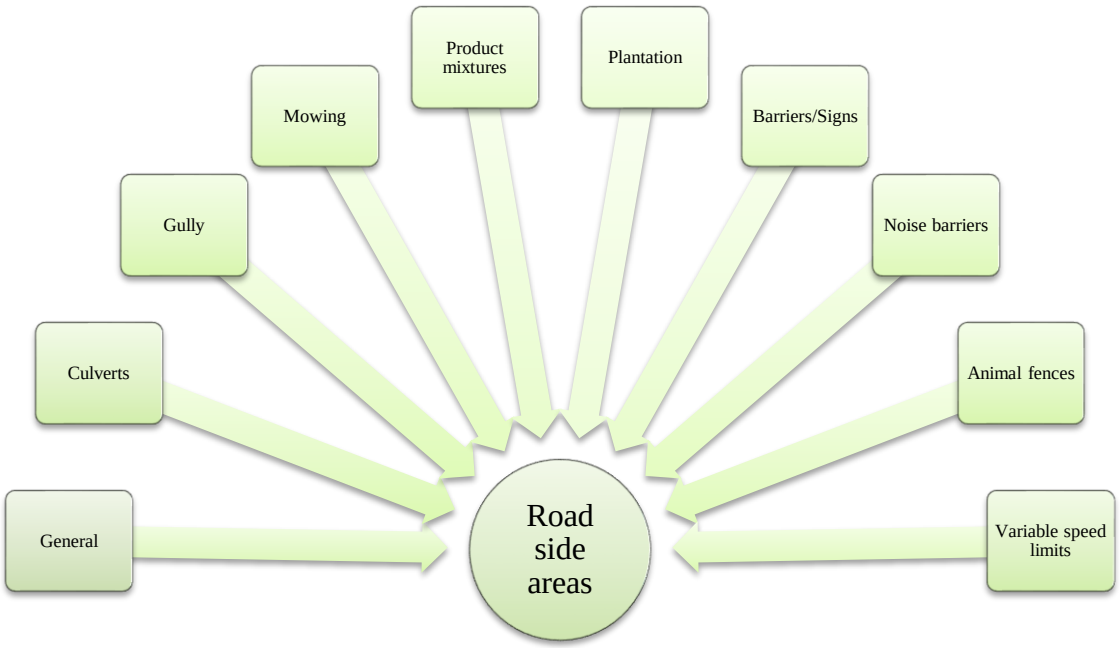


Figure 1 Illustration of the different activities attached to road side areas discussed in the report.

2 Definitions

2.1 The Swedish Transport Administration

The road operation maintenance in Sweden is operated by the Swedish Transport Administration (STA), the municipalities and private parties. The STA owns and maintain 98 500 km road system, the municipalities 41 600 km and private parties 74 500. The STA has the overall responsibility for the Swedish road transport system (Trafikverket, 2012). The STAs focusing perspective is to develop the public infrastructural of roads. In addition, the aim for the STA is to have long-term sustainable road systems with high quality, high safety for roads users and good function for transportation. The STA has a division for road operation maintenance that has its core in administration and development of the road system with the required quality. In the STAs annual report the performed measures for road operation maintenance are stated from 2009 to 2011, which are presented in *Table 1 and Table 2* (Trafikverket, 2011).

Table 1 STAs preformed measures, nominal value in millions of Swedish crowns for road operation.

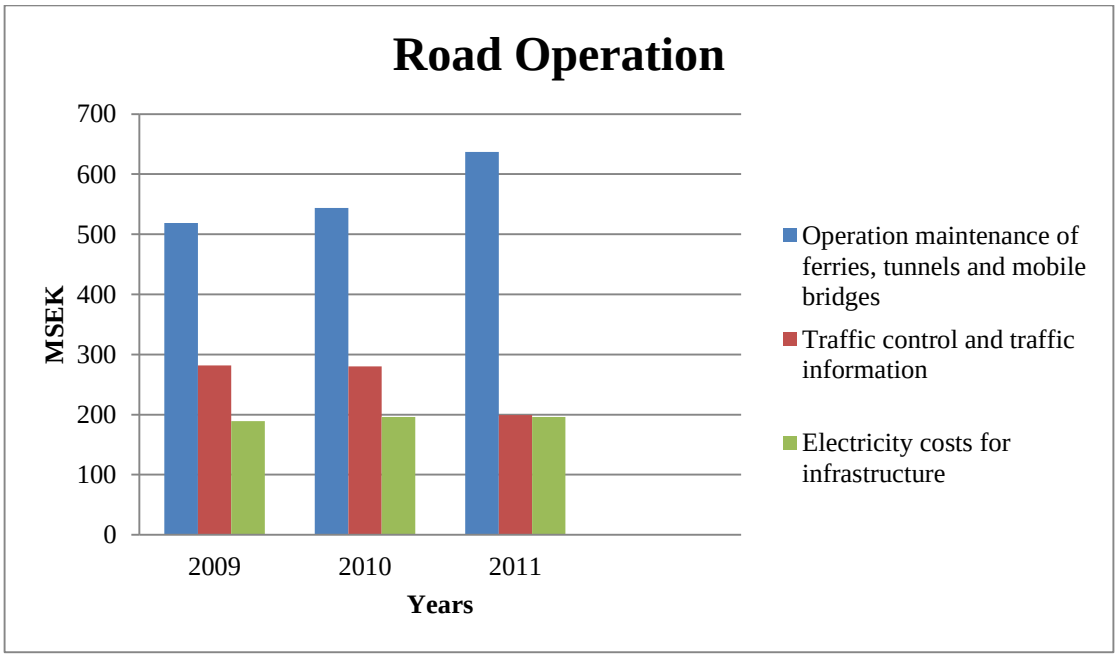
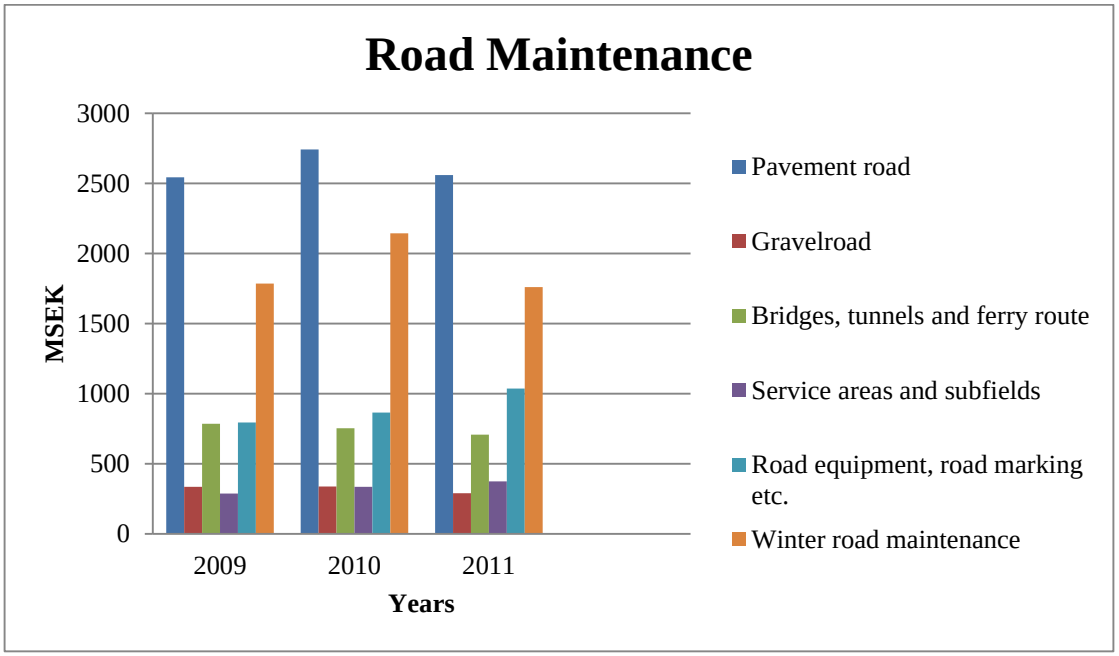


Table 2 STAs preformed measures, nominal value in millions of Swedish crowns for road maintenance.



Moreover, Sweden is divided into 120 road operation maintenance areas called *Basic Package of Routine Maintenance* containing 70-100 miles of road system in each area. Each area has its own maintenance contract lasting between three to six years, where the contractors are responsible for road operation maintenance (Trafikverket, 2012). *Figure 2* illustrates the different maintenance areas in Sweden and the different contractors executing the road operation maintenance. *Figure 3* illustrates the allocation of contractors that have the maintenance procurements 2012.

Examples of activities including in the road operation maintenance contracts (Trafikverket, 2012):

- Winter maintenance
- Managing gravel roads and pavement roads
- Maintenance of service areas
- Repairing of smaller damages in the road pavement and potholes
- Clearance of mowing and road embankment
- Changing of damage road marks
- Occasional pavement work

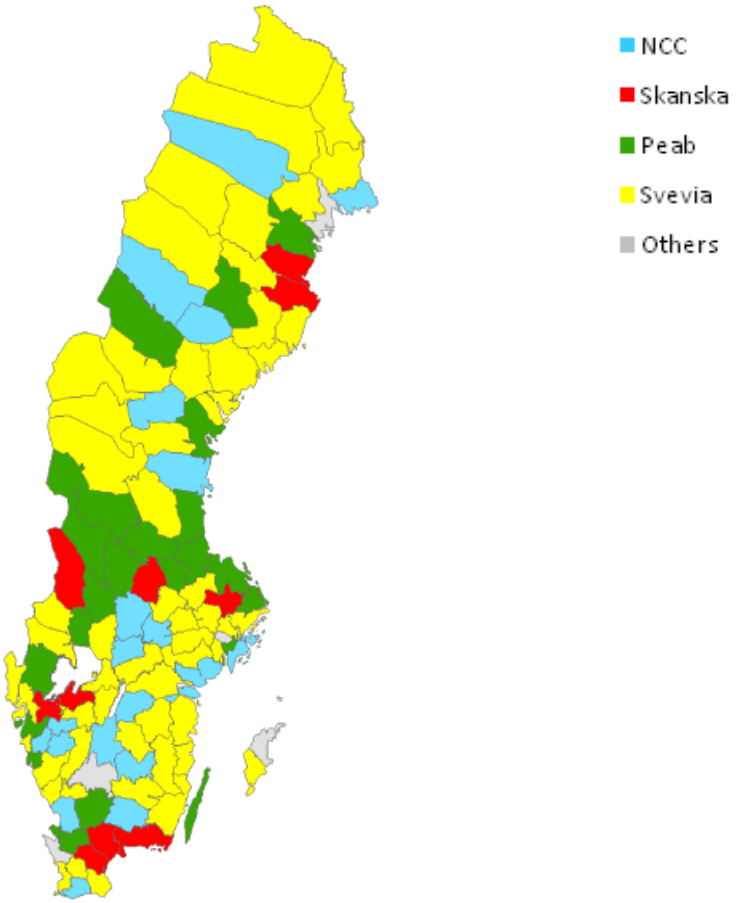


Figure 2 Illustration of road operation maintenance areas in Sweden and the different contractors operating in the maintenance packages (Trafikverket, 2012).

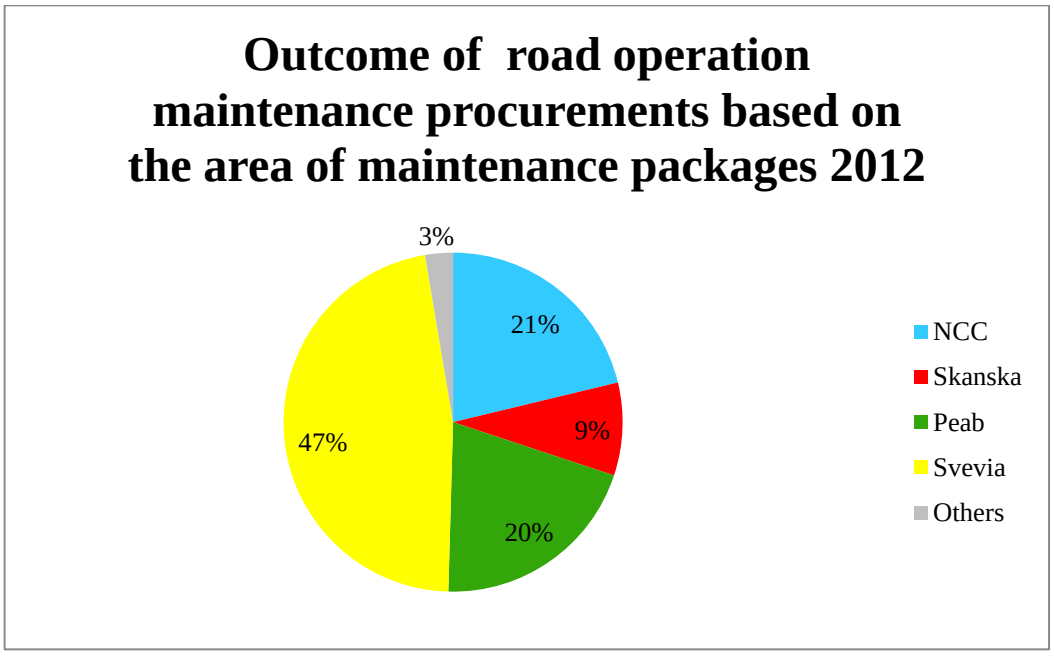


Figure 3 Outcome of road operation maintenance procurements based on the area of the maintenance packages 2012.

2.2 Road maintenance

Road operation maintenance is needed after a road has been constructed and can be described as all activities taking place on and close to a road. Moreover, road operation maintenance is divided into two categories *road operation* and *road maintenance* depending on the maintenance required (World Bank, 1997).

STAs definition of *road operation* is (Trafikverket, 2012):

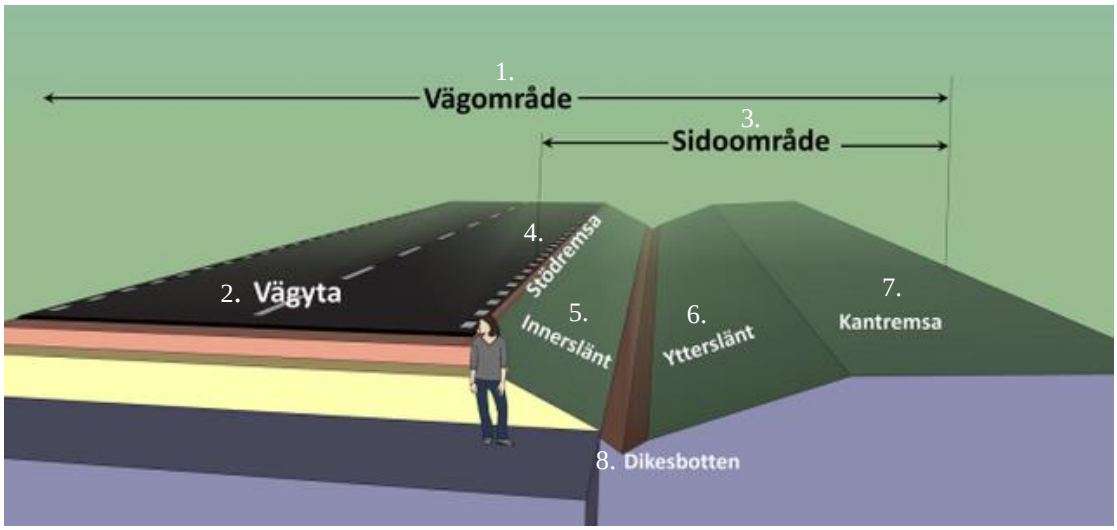
Road operation aims to keep the road navigable and maintain the function where the activities have duration of less than one year (for example winter maintenance, sanding, salting, emergency reparations of the surface etc.)

STA definition of road maintenance is (Trafikverket, 2012):

Road maintenance maintains to ensure the function of the road over time, such as paving and drainage. Meaning that the duration of expected work is longer than one year but don't have the aim to add value to the road.

2.3 Road side areas

Developing the road design, the road side areas have a great influence of the character of the road room. Normally there are spaces for road side areas, *see Figure 4*, in road construction, but when planning the road design in cities the space for road side areas reduces and the need of separation of different road users groups increases. In addition, the safety zone minimizes the more densely build-up there is. A safety zone can be explained as the area outside the carriageway and free from obstacles. Furthermore, an indication of a city location can be a separation with kerbstones between the road and pedestrian and bicycle path (Vägverket, 2004).



1. Road area
2. Road section

3. Road side area
4. Support strip
5. Inner slope
6. Outer slope
7. Edge strip
8. Ditch bottom

Figure 4 The road section and side areas (Blomqvist, 2012).

2.4 Procurements of road operation maintenance

The first step in selecting a contractor is through a letter of enquiry containing a tender document, which is transmitted to different contractors and are established by The Swedish Transport Administration. Furthermore, the contractor with the lowest bid is always selected to execute the demanded work in the contract (Nordstrand, 2008). The STA always applies design and build contract varied with functional requirements and cost-plus pricing when procuring a *Basic Package of Routine Maintenance*[1].

Applying design and build contract, the client has one contractor responsible for both the planning and the road operation maintenance of the area. Furthermore, the client can demand that the contractor has functional requirements, meaning that the contractor is obligated to fulfil the client demands regarding the road area. In addition, the client employs cost-plus pricing meaning that the contractor transmits an invoice after an activity has been completed, which are in general performed by monthly payments. The contractor must declare the production costs for preformed quantity in the maintenance area in order to acquire the payments. *Figure 5* illustrates the structural organisation when applying design and build contract (Nordstrand, 2008).

[1] Pettersson Arne, meeting 2012-05-28

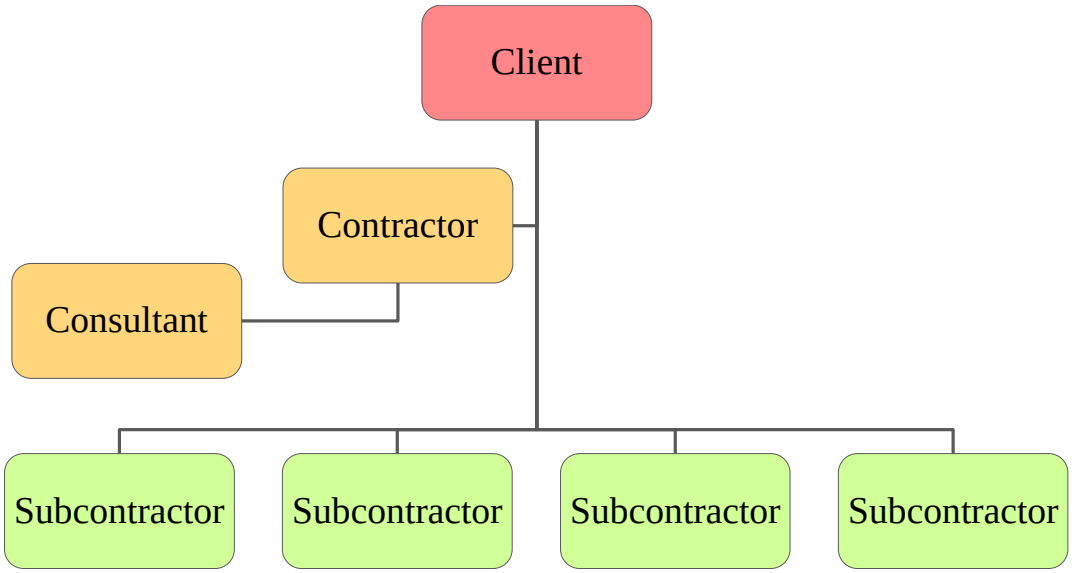


Figure 5 Structural organisation of design and build contract in the procurement phase and throughout the basic package of routine maintenance.

2.5 Life cycle cost analysis LCCA

Life Cycle Cost Analysis can be defined as:

A process for evaluating the total economic worth of usable project segment by analyzing initial costs and discounted future cost, such as maintenance, user, reconstruction, rehabilitation, restoring and re-surfing costs, over the life of the project.

Moreover, the analysis gives both clients and consultants the required supplementary information and the opportunity to gain more information and compose better investment decisions. In addition, LCCA primary purpose is to encompass the possibility to measure long-term as well as the short-term implications of activities. LCCA has been applied to evaluate road systems for several years in order to get the best return on the funds (Huang, 2012).

The shortcomings of applying a life-cycle cost analysis in road maintenance are the existing models cannot be used as a standard model, due to the models limitation of only being developed for specific projects. Furthermore, collecting data for the life-cycle cost analyses can be a dilemma, because there are no procedures effective enough for collecting measures concerning planning, design, construction and maintenance. One reason for not using the life-cycle cost analysis is that the costs can in some cases be higher than the investments costs leading the client to reject possible actions of effective road operation maintenance (Karim, 2011).

3 Interview findings

3.1 General

Generally, the consultants do not receive any documentation at all regarding road operation maintenance during the design phase; however they usually work with the regulations without local connection to the project. Consultants believe that there are no basic requirements for maintaining an area for road operation maintenance. Furthermore, a road project is designed and construct, and afterwards allocate the contractors that has the responsibility of execution of the maintenance area to find methods / equipment enabling the road operation maintenance at a best possible extent. Examples of problems occurring with this method are that large cities have difficulties in maintaining the surface / area when there is no place to store the snow, which results in too narrow passages. Conflicts also arise when the land is expensive and should generate money.

The information / documents obtained during the planning and design phase are highly vital to enable the implementation of road operation maintenance. If the STAs maintenance organization was present in the planning process, this would be a clear improvement. In addition, the STA would have the opportunity to provide information on local preferences and customizations such as in terms of snow removal, green open space, drainage, etc. An LCCA-analysis is a method that takes the entire cost picture (investment cost + road operation maintenance costs+ socioeconomic costs) into accounts of alternative solutions before the road is built. The method could be a good option to reduce redundant costs that could be reduced.

Probably, there have been no previously direct routines regarding implementation of road operation maintenance aspects. There is no direct difference compared to earlier years but today discussions arise on how to implement road operation maintenance in the design phase. The consulting firm has seen a clear and increasing demand of their views, however it is relatively seldom that road operation maintenance is taken into consideration in the planning and design phase. In many cases, the reason the road operation maintenance is not taken into account has been the increasing focus on aesthetics. For example, pump stations are expensive to maintain and built, which are normally being integrated instead of finding better appropriate maintenance solutions.

The consultants are in a disagreement whether they believe that the budget can be a cause to the maintenance aspects not being taken into consideration. The views are separated, believing the funds is not deciding, meaning that it is often cheaper to build with road operation maintenance into consideration. In a contrary, the funds have an impact due to the non-common budget.

The main reason why the maintenance has been down-prioritized in the planning and design phase has been the shortage between specialists. Moreover, there are too many actors that can influence the planning of a project. The maintenance group at STA tries to influence a project in the initial phase of a road design, and additionally influencing more during ongoing projects. The clients also states that the aesthetics

has been challenging, however has become more improved during the years from a maintenance perspective.

Time is also a factor affecting the maintenance aspects. There are projects such as highway and barrier road project designed and build for 7 billion and no maintenance personnel was included in the planning and design phase. The maintenance therefore got down-prioritized even though the maintenance has a significant part in a road project. The recommendation is to have specialists in road operation maintenance working full time with only the documents associated to road projects. However, there is no requirement from the client of designing with road operation maintenance in mind.

From the client's point of view, the general perspective regarding recurring road operation maintenance is the winter maintenance, which is the main activity in a contract. This of course depends on if the winter comes early and if the snow causes problems with availability. In addition, during the summer half-year the main activity of maintenance is mowing. However, the geographical placement has a major influence on the recurring maintenance activities in the Basic Package of Routine Maintenance. Frequently recurring barrier damages during the winter does not occur because of difficulties in reaching all the spaces, however, the slipperiness existing is the main cause of collision damages. The "*first"* slipperiness on the road results in approximately 100 barrier damages. Furthermore, there are no shortages in road design according to the clients because all the obstacles such as barriers, speeding bumps etc. exist due to a specific function needed on the roads.

The most common recurring maintenance for the contractors diverges, due to the different contract contractors have with the client and the maintenance area. The contractors have a responsibility to perform for most part one activity if the municipality is the client, such as winter maintenance, traffic signals etc. In a contrary, if the STA is the client, the contractor has the total area of maintenance, which facilitates the execution of maintenance for the contractor. In addition, the contractor acquires a holistic perspective over the maintenance area which is seen as an advantage. As a contrast, having one activity contract with the municipality, where there are other contractors maintaining the same area with different activities can be seen as a disadvantage, due to the possible upcoming difficulties in collaboration between the different contractors.

Comparing the inner city of Gothenburg, Borås and a small town upcountry, the most common operation maintenance diverges. Contractors maintaining the inner city maintenance area believe the winter maintenance and pavement maintenance is the activity that reoccurs the most, where the winter maintenance is approximately 60 % of the client's budget and problems arises when there is no area for placing snow, *see Picture 1*. Narrow passages are as well a problem affecting winter maintenance. However, by having edged refuges in circulations, contributes to difficulties for snow ploughs to reach all the necessary surfaces which also can cause collisions. In addition, these problems are raising unnecessary costs for the society. By pursuing the same slope on both road and verge leads to increased accessibility for the snow

plough and facilitates the plowing when the execution can be completed simultaneously.In a contrary, the most recurring maintenance upcountry is activities as mowing, clearance and cleaning of ditches. One possible reason to the differences stated, could be that in the inner cities have more habitation and roads compared to country roads and more bare grounds.

Picture 1 Illustration of problem areas with barriers and snow maintenance (Karim, 2012).

Mowing is the most expensive part per metre road. Mowing and clearing of ditches shall be completed around September every year, depending on the content in the contract. The frequency depends on how adjustable the activity is in the Basic Package of Routine Maintenance. Moreover, the client makes a call-of agreement on the frequency of cleaning ditches. Pavement maintenance is the activity that cost the most for the contractors in larger cities, due to the higher amount of traffic and population. More pavement damages on smaller roads come into existence, since the client undertakes the damages on the larger roads.

The shortages in road design are normally due to the aesthetics, investments and road safety. The contractors agree with each other that the aesthetics has an overall focus of road design, which in a contrary, according to the contractors; the road design should be practical, accessible and more standardised. According to the clients, there are no shortages in road design since all the obstacles existing such as barriers, speed bumps, etc. exists due to the function the special feature has on the roads. Questions arising are usually how to improve road safety. Road users should always feel safe but when problems take place caused by aesthetic influences the working environment becomes insufficient for professional workers. Obstacles on the side ways are causing difficulties regarding availability needed for road operation maintenance. However,

clients do believe that aesthetics has been challenging but has improved over the years from a road operation maintenance perspective.

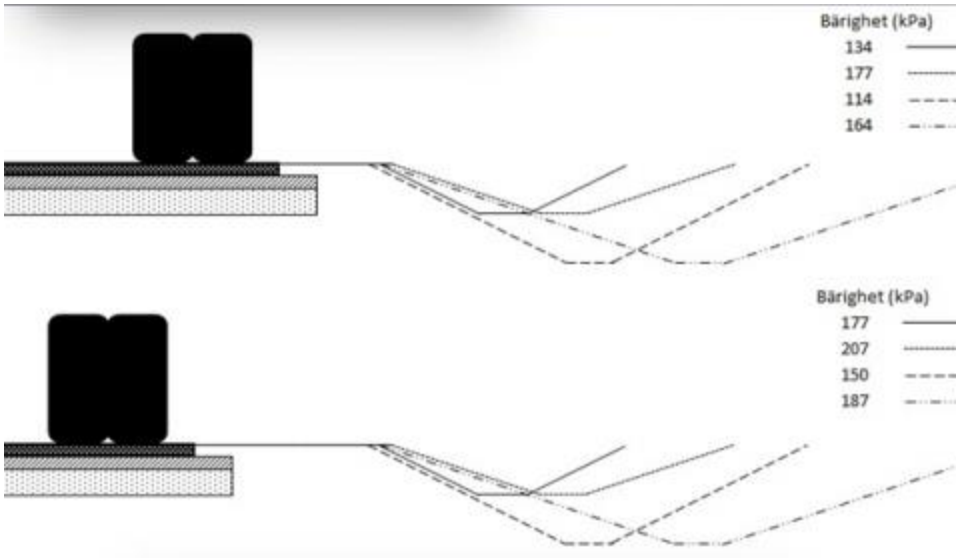
3.2 Road side areas

Mowing is an activity where the price is fixed; meaning that the contractors have the possibility to choose which procedure is most suitable. Normally, the client has a contractual demand of maximum 15 centimetres in the cities. The maintenance can increase if there is a numerous of obstacles leading to additional mowing by hand, however, the client has seen a change in minimizing the unnecessary obstacles. In addition, the obstacles can't be eliminated entirely, due to the function the obstacles provide in a society.

The process of mowing is normally done with a machine or by hand, where *Picture 2* shows how the mowing machine operates. Mowing on highways is usually executed night-time, because there are less vehicles, resulting in less interruption of the traffic. Obstacles such as barrier, signs etc. cause difficulties when maintaining the areas. Mowing and clearing is usually included in the contract with the client and is not a call-off agreement. On the other hand, there are machines that can manage to execute mowing by hand; however the action creates a cost increase. The contractors state that it is almost impossible to mow next to cable barriers; instead a solution is having concrete, asphalt or stones replacing the vegetation. Furthermore, if the area in the median is too narrow problems arise with the reaching of the mowing aggregate; leading to increased need of hand mowing. The optimal space for the mowing aggregate is two meters in order to reduce or even eliminate the need of mowing by hand.

Picture 2 Illustration of the machinery work when mowing alongside a road (Karim, 2012).

Moreover, mowing and cleansing of ditches are also problem areas in road operation maintenance. The problems occurring short after mowing and cleansing of ditches, is often rutting, cracking and roughness/warpiness occurring in the bituminous pavement. These problems occur when a machine drives on the road edges. This problem is very common and also very expensive from a maintenance perspective. Information from a conference shows approximately 10 % of the budget for maintenance of paved roads is spent on repairing edge deformations[2]. *Picture 3* illustrates the increasing bearing capacity in kPa when having wider shoulder compared to small shoulder. The placement of the wheel truck in picture below and the weight is constant on both small and wide shoulder.



Picture 3 Illustration of increasing bearings comparing wider and small shoulder (Granlund, 2012).

Moreover, another difficulty is when the gradient of the slope is rapid and the machines cannot drive on the slope during execution of maintenance. An advantage in facilitating the maintenance for the contractors is if the gradient of the slope is flatter, the easier the machine can mow without affecting the traffic. In addition, the working environment becomes safer for the professional workers, whereas the costs will also reduce, due to the reduction of TMA- protection (Truck Mounted Attenuator). Furthermore, with a wider shoulder the maintenance costs of mowing can be reduced with these suggestions. Furthermore, a suggestion is also to have a service area in order for service personnel to perform the necessary preparatory work without being directly on the road.

Destruction and sabotage of plantations is very common i Sweden, leading to high maintenance costs due to the necessity of new plantation. The general ambition of having plantation is to accomplish the aesthetics. The decisions of choosing plantation at an area that is less suitable for maintenance or hardly manageable plantation lead to an increase of costs. Moreover, the parties involved in the Basic Package of Routine

[2] Granlund Johan, meeting 2012-10-05

Maintenance have a common view that the plantation contribute to higher costs and contribute to needing additional maintenance. When working in circulations the workers are exposed for danger and the need of working protection such as TMA etc. increases.

Suggestions of places where plantations should be reduced or be eliminated:

i. In circulations
ii. Areas where maintenance need expensive TMA- protection
iii. Side areas
iv. Areas where there are difficulties in reaching all spaces
v. Areas where there is many obstacles
vi. Small passages

Normally, having plantations in circulations indicates the STA doesn't have the responsibility of the maintenance; instead it is the municipality that has the task of maintaining the area. In a contrary, the STA has the maintenance in circulations if there is grass, asphalt or other materials, not plantations or trees. Today, there is no alternative method or materials that can substitute plantations according to the clients. Moreover, the STA has tried with synthetic grass without any success for the reason if a vehicle runs over the synthetic grass almost the entire area curls together and gets damaged.

There are different factors affecting the opportunity for contractors to perform the maintenance as they hope. Furthermore, different opinions and decision-making affects the overall maintenance. As mentioned before, the most common inadequacy is plantation at spaces that are hard to reach such as circulations and street refuges. Contractors have similar experiences from earlier maintenance that is better to use one sort of plantation rather than several different. In addition to above experiences, having plantations that are sensitive to salt result in needing to change all the plantations, due to the salt required during winter.

The cost for the activity increases due to the laws for safety working environment for professional workers, requiring TMA- protection. Maintaining plantations in circulations also affect the road users by necessitate of shutting down the road path or guide the drivers to alternative directions. There are difficulties in having a clear sight for drivers if there are trees in circulations, see *Picture 4.* From a road safety perspective, it is better not to use trees or other high plants because of the reduction of the sight for road users.

Picture 4 New plantations in a circulation. The picture is taken at Skattegårdsrondellen in Gothenburg (Bianchi, 2012).

Road 190 in Hjällbo is an example where there is no possibility to have plantations in a circulation. This resulted in all plantations was removed and replaced by synthetic grass. However, the importance of easy manageable and easy reachable areas reduces the cost for maintenance and reduces the expose of danger for professional workers. E45 between Gothenburg and Trollhättan is an example where the municipality wants a great amount of plantations and where the STA speak in response that the municipality need to maintain the area. If the municipality has difficulties in maintaining areas with plantation, the STA can decide to remove it all, at the cost of municipality.

Aesthetics has always been a significant part of designing a road. Nowadays, creating a design that is a joy for the eyes has not been easy for the contractors to maintain a specific area. By mixing different products may lead to greater aesthetics for the population, but in the long run, create non attractive areas, due to the difficulties in maintenance. Research has proved that radar controlled speed signs has just as much speed reduction as speed bumps. Radar controlled speed signs is a good alternative to speed bumps and creates the road operation maintenance easier to execute. In addition, the method also reduces the possible maintenance costs that occur when speed bumps are used.

Mixing materials such as natural stone tiles, cobblestones, etc. creates difficulties when executing the placement of the stones evenly, and as a result, contractors who maintain the field must sweep /salt away the snow to prevent damage during ploughing. When designing of urban environments it often occurs that the space needed for snow stocking areas is forgotten and usually the maintenance contractor may find it difficult to clear the snow after refuges, pedestrian crossings, speed bumps, and plantations. Moreover, bus shelter and weather protection are designed without considering being "easily cleared" when snowfall. This leads to problems when the architect's task is to create a pleasing "aesthetic" product and not a functional product from a total cost perspective. The opportunity of feedback often

comes too late, and usually at final inspection, where the designer rarely is called and present.

Mixing different products, contributes diverse damages on the products, such as driving damages, settlings, damages on splits etc. *see Picture 5*. Furthermore, the heavy traffic and the increasing of vehicles contribute and accelerate the damages towards appearing in an earlier phase than before. Nevertheless, products that are attractive to use, such as cobblestones, disks don't assemble the requirements for the traffic loads. *Picture 6 and 7* illustrates the possible outcome of maintenance difficulties in product mixtures. Kerbstones of concrete or granite that doesn't have a support made of concrete will result in damages due to vehicle collisions. The surrounding area of different product mixtures may therefore be unattractive due to the difficulties in maintenance and the increasing of heavy traffic and the amount of vehicles. In addition, the most expensive maintenance problem is if the surface has damages such as settlements, abrasion etc. whereas the damages are too severe a new surface of bituminous pavement needs to be executed. In a contrary, the STAs goal to have different materials is to make the road users more observant of the surrounding areas such as the road, pedestrian crossing, sidewalk, bicycle path etc.

Picture 5 Settlings caused by heavy loads. The picture is taken in the city centre of Gothenburg (Bianchi, 2012).

Picture 6 Problem areas with tares. The picture is taken at Kaserntorget in Gothenburg (Bianchi, 2012).

Picture 7 illustrates the difficulties in maintaining the areas (Trafikverket, 2011).

Clients and contractors share the same vision with the purpose of using more clean/similar material, which facilitates the maintenance. In a contrary, the client and contractors vision diverges in the execution phase when discussing patterned concrete as an alternative to mixing materials. The disadvantage with the mentioned method is the expensive maintenance costs arising if the material underneath the applying patterned concrete breaks. Alternative areas were the method can be considerate is inside circulations or in sidewalks. An alternative of using patterned concrete could be at areas as in *Picture 8* shows, were no heavy traffic loads can cause damages on the material. Furthermore, if there emerges damages on pipes etc. underneath the patterned concrete on a road or sidewalk, the costs for resetting the material gets too expensive due to the need of redoing the entire area of material. In a contrary, the execution of having cobblestones instead of the patterned concrete facilitates the maintenance because the stones are separated from one another and can be handled detached. By using this method you reduce the upcoming tares that easily arise between cobblestones, due to one material (concrete). However, the carriageway shall only be of one material, due to the upcoming settlings from vehicle loads. Moreover, velocity reducing techniques such as speeding bumps, often made of cobblestones are not to be recommended due to future maintenance. However, alternatives such as chicanes may be an alternative for future planning of road design. Meanwhile, mixing products such as steal armature concrete at bus-stops is an excellent method due to the tension and fatigues caused by heavy loads from motorbuses. In addition, the method is relatively expensive from a maintenance perspective but in a long-term economic and environmental sustainable due to less need of maintenance compared to bituminous pavement.

Difficulties arise when contractors want to apply alternative materials that are three times more expensive than standard materials, even though these materials reduce the maintenance in the long-term. The intuition from the STA is to reduce the maintenance costs even though the investments cost is more expensive, however the economy still has the overall control over a project.

Picture 8 patterned concrete (Roos, 2006).

There are three rows with larger cobblestones and asphalt in Älvängen, which has resulted in settlements at different levels. In addition, problems occurring in this situation are when the plough vehicle shall plough and there are different ground levels, which contribute to damages on the cobblestones. Product mixtures also results in difficulties in drainages. 1996 In Åsa, small cobblestones were used instead of larger stones, which resulted in accumulation of water. Mixing different products in sidewalks are to be preferred than in roads, due to the limited amount of heavy loads. Furthermore, bus stops made as an hourglass with different products such as cobblestones with concrete material need to be stabilized with a layer of asphalt in order to stabilize the cobblestones in order to reduce settlements etc.

3.3 Drainage

In northern Sweden, the re-occurring difficulties are often ground frost that affects the culverts placement. Nowadays, there are cellular plastic under the culvert that function as a protection from frozen ground. The cellular plastic also needs to be placed over the culvert and not only underneath it in order for the cellular plastic to protect the entire culvert. In addition, having two pipes in different size putted into each other and fill with joint foam is an excellent procedure and method to fulfil a safe frozen ground protection. This is an already existing procedure in Sweden.

Furthermore, transition alongside the roads longitudinal direction needs to be done in order to reduce the road operation maintenance of the culverts. Moreover, the consequences of not doing the mentioned procedure, creates vibrations and strong asymmetrical bumps which also can create accidents, *see Picture 9*. An aid during road operation maintenance period is to use a GPS-equipped excavator when ditching to avoid accumulation of water in the ditches.

Picture 9 The possible damages occurring when there is frozen ground and without having any preventive solutions (Granlund, 2012).

Rust damages are the mainly common damages on culverts and are often very expensive. Nowadays, plastic is often used instead of the metal culverts and small metal culverts with a diameter of 200-400 millimetres are now changed into plastic. Normally, the culverts need to be changed after 30 years regardless of material, due to damages that can't be avoided. Major costs follow the maintenance in changing the culverts and can cost up to 30 000- 50 000 SEK. The material costs approximately 7 000 SEK and the rest are for the necessary work such as shutting down the road and for the work of changing the culvert. In addition, under dimensioned culverts is a common flaw in road design, which needs a comprehensive investigation in stream calculations in the planning and design phase where the criteria depends on many factors. Estimating the required dimension of a culvert is often difficult in the planning and design phase because the criteria's changes and is depending on many factors. The dimension of culverts is depending on both the placement and which road that need a culvert. Moreover, a stream calculation is required at every water course.

Plastic, metal and concrete culverts are the material normally used in Sweden. Plastic is a relatively new material compared to metal and concrete, where the advantages is the installation due to the lightly weight compared to concrete. In addition, the material is not as expensive as the others materials. Splits can be reduced by using plastic instead of other materials, which reduces the damages a culvert can obtain. Moreover, plastic culverts are a good alternative because of the even area inside and perforated externally. Contractors and clients have to wait 30-40 years to observe the advantages and disadvantages with plastic as an alternative to metal and concrete culverts.

Damages arising using stone culverts are normally settlings and fatigues often caused by traffic and rinsing of clogged culverts. Separations and fractures are more common on concrete culverts than other materials. Culverts underneath the road are often more expensive and can be challenging to repair due to the placement and size. *Picture 10* demonstrates how a well- functioning culvert should be working.

The placement of the culverts has an impact on which material to use. For example, concrete is often used underneath highways but larger culverts (>4 meters in diameter) are often metal. Metal is also used when oval culverts is needed. In

contrary, the plastic culverts are more suited than other materials because the culverts need to be smaller underneath the roads.

An alternative method that reduces the costs when replacing the culverts is called relining. Relining means that the pipe initially gets cleaned from soil and damages and adjusting without needing to excavate. The new pipe can then be placed inside the old pipe. The mentioned method is well suited method in order to reduce the future maintenance costs. The method can only be performed if the culvert is not too damaged.

Picture 10 A good functioning culvert (ViaCon, 2010).

Nowadays, the placements and location of gullies in Sweden can be improved in order to minimize damages on gullies. The heavy traffic loads from vehicles and trucks speed up the process of fatigues and other stated damages. Alternative execution methods that other countries such as The United States practices that can be implemented in Sweden, is by placing the gullies underneath the sidewalk. Re-thinking of the placement is from a sustainability perspective that needs to be considerate and probably be launched in Sweden also.

Gullies main purpose in a road system is to make sure that the water don't become standing on the road surface and damage the pavement. Normally, when a gully is clogged the main reason are leaves, gravel and waste preventing the water stream to the gullies. *Picture 11* illustrates the upcoming problems when a gully is blocked.

Picture 11 A plugged gully (Västerbottens- Kuriren, 2011).

The most frequently recurrent damages distinguish when asking clients or contractors. The clients agree that more damages occur in the inner city caused by the increasing amount of vehicles when the placement is in the tire-tracks or if gullies are placed in the inner side of a lane in a circulation. Changing damaged manhole cover is the most common maintenance procedure due to the traffic loads. The heaviest part of maintenance costs occurs when there is a need of changing gullies in inner cities. Due to the exposes of traffic loads, the pavement is exposed for fatigues, which will lead to damages and maintenance will be required in a greater extent. Furthermore, to reduce the possible damages, changing or replacing a gully is more expensive to do afterwards. Cleansing is also recurring road operation maintenance that is performed 1-2 times per year. The replacement can be done by moving the entire gully and use a connection pipe.

Old non-adjustable gullies results in higher maintenance costs because when new asphalt need to be executed, the gullies need to be adjusted to the new height. The procedure is to excavate the gully, rearrange, and redo the pavement with new asphalt. There is a need in changing the old gullies into adjustable in order to prevent the procedures with old gullies. The STA does not have a preventive perspective, however, when damages occur, the STA consider alternative methods. The problem should be analyzed on how cost effectiveness the change can be.

The shortages in road design are when gullies are placed in the tire-tracks or at start and stop positions. In addition, the pavement around the gully is extra sensitive and gets exposed for fatigues and maintenance occurs. In a contrary, when gullies are placed at a poorly placed position it is often because of obstacles such as other pipes standing in the way. Furthermore, STA always take gullies into consideration when broadening a road. All the contractors agree that replacing is needed if the future costs shall reduce. Changing the manhole cover on the gully can cost approximately 1 500 SEK each only for the material. Moreover, cleansing can cost 150 SEK including the needed work, TMA, only if there are several scheduled gullies to execute.

An alternative are kerbstones with openings instead of gullies in bicycle paths which result in reducing maintenance of settlements, rinsing etc. The gullies can also be made of plastic in order to reduce the maintenance costs however the STA does not know how well adaptable the material is compared to standard materials. Information of how adaptable plastic is can only be shown in a couple of years.

E45 Bohus- Nödinge is an example where there is no other place for pipes than just underneath the road construction. By having houses alongside E45, there cannot be any other places for the pipes. This is an explanation of why the road has a specific design and the road operation maintenance can't be taken more into consideration.

3.4 Road equipment

There are many examples that can be stated regarding selection of wrong materials without any consideration to maintenance, which contributes to higher maintenance costs where there are flaws in road design. An issue is explained with 2 +1 roads where the decision has been that both side of the road should have barriers of cable, *see Picture 12*. If there is a damage occurring on the guardrail, where there is only one lane consideration must be taken to the median barrier, due to the need of detaching and lead the traffic to the opposite road lane, in order to repair the damage. The guardrails are being placed without securing the back support against the slope.

Picture 12 Illustrates a 2+1 road with cable barriers (Karim, 2012).

Road design has its deficits in barrier maintenance which is being shared from both clients and contractors. Normally, the selection of barriers is too many and can become extremely expensive for the contractors. Today, the amount of selection is

approximately 15-20 different barriers and 3-4 different cable barriers in a maintenance contract. Having this range of barriers is a disadvantage for both clients and contractors, due to the increasing costs it is requiring. Furthermore the STA cannot tell in the procurement what kind of barrier they wish for due to the competitive purpose. Furthermore, the contractors have difficulties when barriers are special designed and constructed in a different country due to the delivery times and the impossibility to have a stock of the needed barriers at a warehouse.

Special designed high capacity pipe-beam barrier produced by Fracasso made in Italy are barriers which are more aesthetical attractive than W-beam barrier, which is illustrated in *Picture 13*. The W-beam barrier is usually practiced as guard barriers which has the purpose of not being stiff, instead be able to stretch approximately 1, 5 metre when a collision occur (Trafikverket, 2011). Difficulties with expensive TMA exists when the need is required for changing barrier and signs alongside a road when the shoulder is too small, which affect the road users. Moreover, the procedure in ordering high capacity pipe-beam barrier produced by Fracasso is complicated because the order need to be at least 1 000 metre and the cost for each metre is 5 000 SEK. Secondly, the delivery time is another factor that affects the maintenance costs. Thirdly, a collision at one point results in 100 metre damages of detaching due to the collision. However, the complexity of problems is the option of choosing approved barriers according to the standards. The Italian brand has barriers that are more stable and approved, however, W-beam barrier are much better from a maintenance perspective due to the long-term sustainability and works better than other barriers. Concrete barriers are extra recommended from a safety perspective compared to cable barriers.

Picture 13 W-beam barrier (Karim, 2012)

The most common damages on barrier and signs are made by vehicles. A damaged framework caused by a collision can cost up to 50 000- 100 000 SEK to change.

However, to reduce the cost occurring on the portal is to encompass a barrier in front of the portal beam. The solution of changing a barrier beam is less expensive than changing a portal. A portal can cost approximately 250 000 SEK instead of a barrier that costs about 10 000 SEK. In addition, energy absorbing groundwork is an additional solution in order to reduce the maintenance costs.

There are down turned end terminal barriers which are dangerous for road drivers when a collision occurs. This kind of barrier design leads to uncontrolled occurrence after a collision and is not recommended at a speed above 70 km/h. The problems with the barriers are often the placement of start and end of the barrier. *Picture 14* illustrates a down turned end terminal barrier (Wenäll, 2006). However, there is other better suited material used instead of down turned end terminal barrier such as energy absorbing end terminals.

Picture 14 Consequences of a collision when using a down turned end terminal barrier (Wenäll, 2006).

Utilize noise barriers made of wood is a common suggestion from the contractors in order to reduce the maintenance costs. The total costs of maintenance are normally higher when using glass material. Wood materials normally undergo decay or decomposition when the wood hasn't been impregnated, but is still less expensive than glass. From an aesthetic point of view, wood can be seen as less aesthetic than glass but can generate problems in the future.

Common damages on noise barriers depend on the geographically placed area; however the most common damage is vandalism, where noise barriers made of glass

are the most expensive and exposed of them all. The most common damages upcountry are done by storms, which can cost approximately 300 000 -400 000 SEK each year which depends on the geographical area. Each noise barriers made by glass can cost between 30 000 -35 000 SEK to change, where the glass stands for approximately 10 000 SEK and the remaining costs is installation. Moreover, the activity that is most expensive in changing is not the glass itself; instead the customized measures are often the activity that increases the expenses.

Normally the lifetime for noise barriers made by wood is 10-20 years where glass has to a large extent longer lifetime than wood, however, the wood is better protected by utilize wood impregnation which prolong the lifetime. The shortages in the road design are usually the choice of wrong material, which is the main reason due to the focus of aesthetics.

The design of existing road system can cause difficulties in accessibility for the professional workers due to the lack of working area; however this can be a recommendation for future planning of new roads. Furthermore, according to the contractors, an advantage is that vandalism is reduced if the chosen material is wood comparing with materials such as glass. Broken glass is a common damage when choosing glass as noise barriers, and is often caused by vandalism *see picture 15*. The dilemma occurring when glass is damaged is that the entire piece needs to be replaced. In a contrary, the advantage with wood is that replacing damaged material is much easier with wood than glass, when individual damaged pieces of wood can be replaced. Cleaning noise barriers made of glass is also a road operation maintenance cost needed to be taken into consideration when choosing materials.

Picture 15 Illustration of noise barriers made of glass (Karim, 2012).

E45 is a good example of the consequences of using glass noise barriers. The costs for changing the broken glasses were approximately 500 000 SEK. However, the clients agree that wood is a better choice from a maintenance and an economic perspective, however, in some cases, having houses alongside a road that need noise barriers, glass is to be recommended due to the fulfilling aesthetics glass creates for the population living in the area. In this case, the aesthetics has an influence that's need to be considerate.

Kallebäck had noise barriers made of green glass, *Picture 16 and 17,* and when the sun shined through the glass, the consequence was that the residents nearby got their furniture's bleached by the sun. in this scenario, Kallebäck is an example where the design has its flaws and in order to solve the dilemma, a film or a cloth on the existing glass was placed over the green glass in order to the light to refract different. In this case, the color of the glass was the item causing the problems, not the glass itself.

*Picture 16 Illustration of green glass noise barriers at Kallebäck (*Karim, 2012)

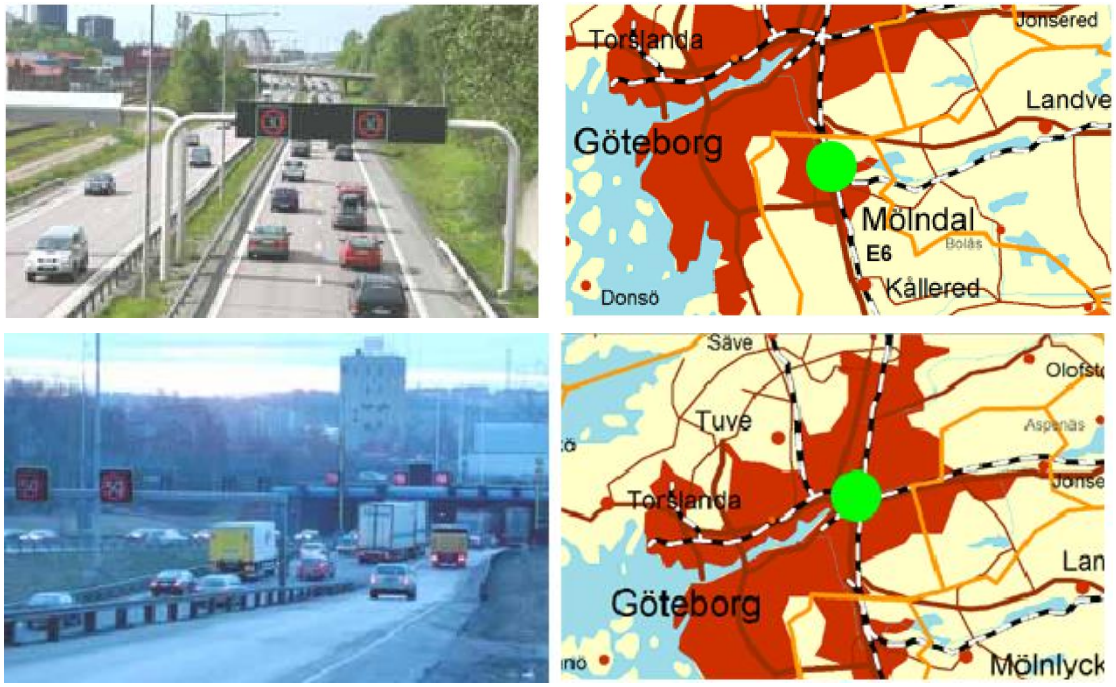
*Picture 17 Illustration of broken green glass noise barriers at Kallebäck (*Karim, 2012)

In Sweden, animal fences exist in the countryside's or outside the cities alongside the road system. Depending on the area the damages separates and the most common damages occurring are accidents created by cars or damages caused by animals. Furthermore, comparing the activities mentioned in this master thesis, the damages on animal fences is a minor part of the road operation maintenance cost perspective. In the Basic Package of Routine Maintenance the frequent maintenance are executed every second year. In addition, the maintenance occurring at animal fences are in general mowing 1 metre at each side of the fence and at times changing damaged fences.

From a maintenance perspective, the distance should be close between the road and the fences but in a contrary, the distance may affect in some part the maintenance due to the availability for the professional workers and the impact of occlusion during service. Normally, gates are placed with continuity in order to facilitate the maintenance because an animal fence can be several kilometres long and can cause difficulties in reaching the areas needing maintenance. To facilitate the maintenance, a larger area is needed in order for a four-wheeler to pass at each side of the fence. Secondly, areas of gates with sufficiency intervals are as well a request from the contractors to facilitate the maintenance. In addition, a suggestion when planning new areas for animal fences is to contact the local residents in order to locate the animal paths in order to distinguish the most suited placement for the fences.

The material used today is normally galvanized net but wood constructions can in various areas occur. Plastic can also occur, however is far too expensive to use as a fence. From an economic standpoint, the interviewees do not know which material is better suited to use in this maintenance activity.

Variable speed limits is a relatively new method, the first test site in this field trial was set up in October 2003. Furthermore, the aim with implementing variable speed limits is to easily adjust the speed to traffic conditions. In Gothenburg, E6 has several areas were variable speed limits have been used, *see picture 18*. Earlier, traditional marking with metal signs were used. In addition, the variable speed signs have reduced the accidents and the pace has been slower in traffic.



Picture 18 Variable speed limits at E6 in Tingstadstunneln and Mölndal Gothenburg (Vägverket, 2008).

Normally, there are four different traffic situations that are suitable to use variable speed limits (Trafikverket, 2010).

i. Crossing traffic
ii. Poor road conditions
iii. Heavy traffic and frequent congestion
iv. Unprotected road users

The most recurring issue occurring when using variable speed limits is normally communication problems in the facility, which is the part (error diagnosis) that cost the most. Due to the relatively new method, there are no abundances of experiences concerning variable speed limits; however, the questions arising when discussing the shortages in road design tend to be:

i. Lack of space in the section. There is not enough space for the marking material.
ii. Short distance in longitudinal section. Difficult to fit with the required marking between the slip road and entrance, for example a lane control systems.

Taking the road operation maintenance into consideration in the planning and design phase can be difficult in this field, when for example the placement of the traffic places that is controlled by the need of society interchange. As for the design of a section, it is mostly a question of cost; a wider section provides higher costs. There are other materials that can be used in the communication part, such as radio relay link. However, implementing the material would probably result in lower investment costs, but probably increases the costs for operation and maintenance than using existing material as fibre.

Moreover, the placement does affect the road operational maintenance costs. Variable speed limits may require barrier protection, which can increase the costs for road operational maintenance. Furthermore, if there are no hard standings for service vehicles in connection with the barriers, it generally requires TMA- protection, which results in increased costs for maintenance. Consideration should be done if it is reasonable to invest for accessibility or for road operation maintenance.

Earlier experiences in variable speed limits that affect the intention of reducing road operation maintenance are:

i. Long distance ⇨ problematic in maintaining stable communication
ii. No logic transparent control systems ⇨ difficulties in error diagnosis
iii. Easy/clear management of input/ computer data ⇨ strong system

A transparent technique is important in order to reduce road operation maintenance. Transparent technique refers to that STA haven't built or administer the logic. The risk is high that the knowledge of the system/ function disappears with time from the person who has the responsibility of the facility. The system needs to be accessible, perspicuous and understandable for the person who has the responsibility of the facility.

Furthermore, the communication needs to be safe meaning that this type of system is composed by communicating trough protocols between one fully or partially centralized logic. In connection with error function, the decentralized units should be able to communicate "upwards" with the intention to solicit attention. If there is no stable or secure communication, the difficulties arises in understanding where the problem picture exists at an error function.

4 Discussion

4.1 Introduction

Road operation maintenance is a component of a road lifetime affecting consultants, clients, contractors and road users. In recent years, there have been attempts on focusing more on road operation maintenance than before. An explanation is the resembling recurring damages in Sweden causing higher operation and maintenance costs than required. The lack of literature and the absence of exchanging experiences has been a contribution to the reduced focus on maintenance. The major element that has affected the road planning and design phase has been the aesthetics. An explanation of the high focus of aesthetics can be explained as when driving through a community, the first that visitors and the citizen comprehend is the aesthetics and not the high demanded maintenance it requires, which can be understood why the main focus has been on the aesthetics.

4.2 Consultant, client and contractor

4.2.1 Documentation

The absence of literature creates higher demand on the experience and today there is no information or guidance on how to execute road operation maintenance effectively. When comparing the results from the interviewees, interesting results were observed, which were the common thoughts shared between consultants, clients and contractors. There is no question that all the involved actors want to create more effectiveness in road operation maintenance, however the lack of documentation and reconciliation creates difficulties in maintaining and fulfilling the requirements road operation maintenance is needed. One observation made from the interviews where the nonexistence of reconciliation of frequent damages at the end of a Basic Package of Routine Maintenance contract. The client knows by the payment plan exactly how much each activity cost, and from the client perspective, reconciliation is in the clients favour to reduce the upcoming unnecessary costs this creates. However, by having a reconciliation of the most expensive and recurring damages, the client can take the experience and compose the next procurement more cost and execution effective. In addition, a reconciliation meeting containing exchanging knowledge and experience between the client and the contractor may be a learning possibility for all parties involved. Thereafter, the documented reconciliation needs to be shared with the consultants in order to involve the entire chain from road design to road operation maintenance. In a contrary, without any feedback of experience, the consultant unreflecting chooses solutions that can be difficult to maintain.

The lack of knowledge and literature creates difficulties in maintaining adequate standard in operation maintenance. The main problem is the knowledge only existing in the fields among the personnel working with maintenance, which is often not documented and shared with new generations of persons just graduated from school, which lack the knowledge of working experiences in the fields. It is crucial that the experience is shared with the new generation which are going to work with road operation maintenance including both client and contractors, but also the consultants. In order to reduce the distance of knowledge between the new and the existing

generation, it is crucial to document and obtain a balance between knowledge and experiences.

When planning larger infrastructure projects, it is crucial that a numerous of operation maintenance managers are included in the planning and design phase in order to bring inputs on the maintenance aspects. There have been projects where this has not been implemented and the reason has often been the limitation of time which will create maintenance issues in the future. In order to achieve good implementation of road operation maintenance, good planning is required and a new way of reasoning in order to make the procedure an integral part of the future work. In addition, an important aspect needed to be considerate is to have 1-2 persons from the operation maintenance division working only with the documents in the planning and design phase. This is where the problems emerges and where is more pleasurable to inaugurate a new aesthetical build road, rather than discuss the maintenance problems occurring after a few years from the opening ceremony where the aesthetics has controlled the project design.

4.2.2 Action of improvements

The checklist is based on the experiences and knowledge from the interviewees and is structured in examples where the road operation maintenance activities can either be eliminated or reduced. The checklist is entirely based on experience from clients, consultants and contractors. Solutions are stated in order to facilitate the maintenance for all actors involved and is easy manageable. In some cases, the initial cost can be higher than planned but at the end of a Basic Package of Routine Maintenance contract, the maintenance costs are reduced and the total cost of a road throughout its lifetime, is reduced. The LCCA is an excellent tool in calculating the lifetime of a road including all costs. In addition, taking the LCCA into account that include both investment costs and operating and maintenance costs, facilitates the future material selection and foremost cost effectiveness by reducing unnecessary costs for road operation maintenance.

Moreover, the constant focus has been on the aesthetics, which has led to road operation maintenance has become down prioritized. According to the interviewees, there is difficult to balance the aesthetics and road operation maintenance. A reason is the influence from other actors than clients and contractors, which need to be examined in order to find a balance between, facilitate the execution of road operation maintenance and also reduce the unnecessary costs. The main focus has always been to create a safety environment for road users, high quality and nevertheless, a pleasant environment for all road users. There are solutions mentioned in the report which can be executed in order to encompass a sufficient balance between the aesthetics and the maintenance.

The clients argues that mixing different materials such as cobblestones, asphalt, bricks etc. creates awareness for the road users that there are different road sections as bicycle path, walkway, the actual road course etc. In these cases there is an understanding awareness from the client, why they execute mixing materials.

Moreover, there are activities where the aesthetics can be compromised with road operation maintenance and still fulfil a pleasant view for the population. In some cases, aesthetics can affect the safety for road users and for the professional workers executing the maintenance. In these cases, the safety plays a more important role than the aesthetics. Plantations in circulations and different barriers are some activities that need to be revised.

The aesthetics has also a negative perspective, where the design has become the major part of a road design. Noise barriers made of green glass are an activity that has influenced the resident's nearby negatively. Kallebäck is an example discussed in report that needed to be re-designed due to the impact the material had on the residents. Noise barriers made of green glass is an illustration where the aesthetics had too much influence in the design phase, and even caused problems for the residents living in the area.

Furthermore, mixing materials in road sections is not to be recommended. By choosing the execution with different products, becomes difficult for contractors to fulfil the standard, due to the expensive maintenance costs it creates. It is important to know that in some cases, there are materials and other executions methods, which facilitate the road operation maintenance that is comparable with materials that are difficult to maintain and should be taken in consideration. Patterned concrete is a product that fulfils the aim of aesthetics and as well creates less effort of maintenance. Discussion elevates when there is a need of road operation maintenance underneath the patterned concrete, which can be seen as a disadvantage for the chosen sectors of application.

Furthermore, the road operation maintenance is particularly important in city centre where the space for professional workers is minimal. When there is not enough space the execution of maintenance affects the road user's extremely. An example is winter maintenance, when there is no storing area for the ploughed snow. According to the interviewers, this activity is the most expensive part in a Basic Package of Routine Maintenance contract. Due to the recurring problems snow is creating in Sweden, the activity should be revised in order to reduce the costs the snow creates. However, the activity can be implemented in an early stage as the design phase with the intention to create larger areas for snow storing. Due to Sweden's geographical placement the risk of snowing is of a substantial role, which needs to be revised in order to reduce recurring future problems.

Furthermore, a challenge for the contractors has been the safety for the professional workers. As mentioned in the report, having plantations in circulations carries costs and affect the working environment, which can be solved without difficulty. Substitutes such as synthetic grass are a much better preferred material for all involved parties; however, opinions diverge between contractors and clients. One reason is the possible outcome of a collision with a vehicle, where it is likely that there is a need of resetting work. However, the costs of resetting the material are much lower than the maintenance needed if there were plantations. In addition, other materials such as asphalt, stones etc. may also be considerate as substitutes, due to the

efficiency in road operation maintenance. The interviews between the consultants and the contractors resulted in mutual response regarding asphalt and stones, where they concurred with each other.

From the contractor point of view, the working environment is greater due to the elimination of grass cutting and the exposure of danger from passing vehicles. From the client point of view, the costs from TMA, occlusion during the working period and reducing the influence on the travellers are much enhanced with the mentioned method. Nevertheless, having plantations in circulations also affect the traveller's sight, which can cause collisions.

A common factor resulted from the interviews were the amount of barriers. A common line throughout the report is the aesthetics when planning the road design. All contractors agreed on the challenges when there are special customized barriers that have long delivery time and are extremely expensive. In addition, a contract can contain up to 20 different barriers and the contractors don't have the possibility to have different barriers in store. Clients cannot tell in the procurement stage what kind of barrier they wish to use, due to the competition purpose. The customized barriers are often more aesthetical correct comparing to other barriers however both fulfil the requirements. However, the main purpose of barriers is simply to maintain the safety level for road users.

The previously used barriers can still be used today, but there will be a compromise with aesthetics. The question of barriers is a part of the aesthetics that can be adapted to the road operation maintenance, as it does not directly affect residents' opinions as much as noise barriers. It is understandable that lengthways of houses next to a road becomes affected by the aesthetics of noise barriers choice of material, and in this case, it is important to oblige the residents' opinions. Even if wood is to be preferred when having noise barriers, in some cases, glass is much better suited than other existing materials.

Information stated in the report regarding different materials and the safety connected to barriers are important to discuss and to provide better solutions then what existing today. A report was written regarding crash tests using different barriers solutions, where some barriers that fulfil the requirements but should not considerate in some cases. Having down turned end terminal can result in overturn after a collision with the use of this kind of barrier and it is crucial to overview other alternatives to down turned end terminal. The studied report presented facts that only these barriers can be used at a velocity of 70 km/h or less. The main focus in order to make a decision is not only the velocity on the road, but it is also the surrounding area that has an influence on the decision making of placement.

5 Conclusions

It is evident that earlier discussion regarding implementation of road operation maintenance has its challenges. The construction industry has shown necessity for change in order to create efficiency in future maintenance planning. However, there are an amount of challenges needed to be solved and sorted out in order to construct the implementation at a successful phase. Previous initiatives have been done, although it requires other solutions, even though the vision is shared between clients, consultants and contractors. The cohesiveness in vision creates an advantage to create a successful utilization of the checklist. Processes are easy to change compared to changing the mind-set of the personnel working with maintenance, and if they are open and aware of the need for changes, the implementation can therefore be successful.

A negative aspect resulted during the interviews, were the lack of reconciliation during and after ending a Basic Package of Routine Maintenance, even though there are problems recurring and known before for clients, consultants and contractors. To reduce the recurring damages costs, the key is feedback to consultants and contractors, in order to include the whole chain affecting future and current maintenance. The knowledge exists, however only out in the fields, which aggravates the learning possibilities for new examined students and also existing personnel. Scheduled meetings in the planning and design phase facilitates the overall lifetime of a road, including how to become more effective in implementing the road operation maintenance. A key perspective important to considerate is when a facility has unjustifiably high operational maintenance costs, which requires elevated maintenance work in order to meet the requirements stated in the maintenance contract, can be referred to the road is not designed accurately.

An important factor to make the checklist a successful tool for future maintenance is to modify the planning and design phase, meaning to reduce the influence from the aesthetics. The report states different solutions in finding a middle course to fulfil the requirements both from aesthetics and maintenance perspectives. Furthermore, the checklist is based on the interviewee's experience, which facilitates the implementation. Moreover, there are some materials used to highlight the aesthetics, however creates problems in accessibility and safety for both road users and the professional workers executing the road operation maintenance in Sweden. In these cases, it is crucial that the aesthetics does not take ascendancy over the planning and design phase. The checklist is easy manageable and divided into each activity discussed in this master thesis including comments on alternative methods or the effects on road operation maintenance, which contributes to simplicity of applying the checklist as effective as possible. Furthermore, when the checklist is based on the interviewees, the checklist creates a greater understanding of how to interpret the stated suggestions. Time and reflection should be asked concerning why new constructed roads often obtain damages with very large settlings, frost damage and other deformations compared to older constructed roads. An additional point should also be taken into consideration regarding why costs are constantly increasing, where an investigation should be carried out. Should the documents be revised, have the knowledge paused? Short communication lines, progress meetings, and feedback will create a successful implementation of the checklist.

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Appendix: Checklist for future maintenance work

	Type A: Winter maintenance		
	Method	**Example**	**Comments**
A1	Construction	i. The road height should be at the right height to minimize the large amounts of snow settles on the roadway	Better accessibility.
		ii. Replace barriers into flat slopes	
		iii. Use the painted refuges instead of curbs equipped refuges	
		iv. Avoid obstacles and narrow passages if possible	Should be adapted to winter maintenance execution.
		v. Review the placement of road signs, lights for better accessibility for winter vehicles	
		vi. When using kerbstones attempt to smoothen the alignment and avoid angular corners which facilitates the sand harvesting for plough vehicles	

		vii. At lateral sites, add weather protection with another angle to the road so the plough trucks will not place the snow in weather protection, which require handwork	
		viii. Avoid elevated location of shelters that has kerbstones	Often requires an extra vehicles and extra sand harvesting costs.
		ix. Avoid kerbstones at service areas	Instead, use painting and soft lines.
		x. Open up areas where there is forest and rocks in order for the sun and light to affiliate the areas in order to minimize slipping areas	
		xi. Aiming to have the same slope on road and shoulders (Valid at paved shoulders)	Simplification and reduction of winter maintenance.
	Type B: Culverts		
	Method	**Example**	**Comments**
B1	Selection of material	i. Use plastic culverts where it is possible	Easy manageable during maintenance.
		ii. Plastic is easier to manage during installation and maintenance compared to other materials	

B2	Consider alternative culverts designs	i. Check the stream in order to obtain the correct diameter	The geography has an impact in choosing the diameter.
		ii. Make carefully stream calculations	Reduces the risks for overflows.
		iii. Isolated culverts in specific geographical areas	Reduces soil frost thawing.
		iv. Make sure that transition is executed 24 meters before and after the culvert	
		v. Reduce at a minimum of plantations nearby culverts	
B3	Other	i. Carefully check other private pipes to make sure that the culverts maintain the same stream	
		ii. Relining rather than changing the entire culvert	Reduces the costs by eliminate the excavation of the culvert.
		iii. Mark-ups for placement of culverts	Reduces the work time of maintenance.
		iv. Place a gully upstream a road culvert	Reduces clogging.
		x. Review the placement of a culvert	Affects the selection of material.

	Type C: Gullies		
	Method	**Example**	**Comments**
C1	Relocation of gullies	i. Avoid gullies in tyre-tracks and in circulations	Risks for damaged manhole cover, reduces damages.
		ii. When broadening the road, make sure that the gullies accompany the road	Make sure that there are no pipes blocking for relocation.
		iii. Consider alternative placement of gullies	
		iv. Connection pipe as short as possible	
C2	Structure	i. Use gratings in gullies	Reduces clogging.
		ii. Change old non-adjustable gullies to adjustable	Reduces future costs in eg. pavement maintenance.
		iii. Review gullies	Suggestion: Gullies underneath the sidewalk horizontally.
		iv. Use collecting bags in gullies	Better quality and reducing the maintenance costs.
		x. Mark-ups for gullies	
		xi. Larger sand collector	Reduces clogging.

C3	Consider alternative to gullies	i. Use cupols in ditches where is possible	
	Type D: Drainage		
	Method	**Example**	**Comments**
D1	Preparatory work	i. Check for cables before ditching	
		ii. Investigate the materials of other landowners	
D2	Structure-design for durability/ maintainability	i. Marking of drainages	Reduces the maintenance work.
		ii. Kerbstones with openings	Reduces upcoming rinsing and settlements.
		iii. Avoid green area's median barrier	Suggestion: asphalt or base course.
D3	Design/ Alternative materials	i. Plastic gullies	New in the market, no experience on how the material is.
		ii. Develop existing under dimensioned roads	

	Type E: Mowing		
	Method	**Example**	**Comments**
E1	Relocation of features	i. Avoid locating a phone, plantations, signs or other obstacles	Reduces the maintenance work.
		ii. Reduce the use of hand held tools	
E2	Design	i. Increase verge to facilitate the machinery of mowing	Reduces the interference of traffic.
		ii. Higher gradient on slope	Creates area for mowing with machine.
		iii. 2 metre free area at each obstacle	Enable space for the mowing aggregate and reduce the mowing by hand.
		iv. Access to a service area	Enables space for service vehicle, reduces TMA.
		v. Avoid plantations or grass in median barrier	Alternatives such as asphalt, concrete, stones etc.
	Type F: Product mixtures		
	Method	**Example**	**Comments**
F1	Design	i. Avoid mixing materials in a road section	Reduces settlements, fatigues etc.

		ii. Avoid speed bumps	Suggestion: chicaner, variable speed limits.
		iii. Avoid kerbstones and cobblestones in a road section	Suggestion: Patterned concrete.
		iv. Reduce the amount of seams	Reduces damages on the asphalt and sensitivity.
		v. Steel armature concrete at bus-stops	Enables to manage the heavy traffic, reduces upcoming damages.
		vi. Execute asphalt areas with "soften" lines and minimize stone areas.	
		vii. Concrete space at speed bumps	Longer sustainability and better accessibility.
		viii. Avoid kerbstones under median barrier	Creates extra costs for mowing, cleaning.
	Type G: Plantations		
	Method	**Example**	**Comments**
G1	Reduce the amount of maintenance	i. Move signs away from trees and plantations	Reduces mowing by hand.
		ii. Avoid plantation near signs and fences	Reduces mowing by hand.
		iii. Avoid different plantations in the same	

		area	
		iv. Avoid plantations as possible	Suggestion: Synthetic grass.
		v. Avoid plantations or grass in median barrier	Alternatives such as asphalt, concrete, stones etc.
		vi. Use low growth plantations	
G2	Design	i. Avoid plantations in circulations	Reduces the upcoming risks of damages for professional workers, TMA and the impact on the traffic.
		ii. Avoid plantations near culverts in order to reduce damages caused by roots	
	Type H: Barriers/signs		
	Method	**Example**	**Comments**
H1	Replacement of barriers/signs	i. Move signs away from trees and plantations	
		ii. Avoid placement of plantations near signs or other obstacles	
		iii. Down turned end terminals is more suitable in some cases	Only at velocity less than 70 km/h.

H2	Alternative models	i. Reduce the amount of barrier models	Difficulties for the contractor to maintain and store.
		ii. Spring fundament is to recommend	
		iii. Consider concrete barriers as median barrier at high traffic roads	Better suited from a security perspective.
		iv. Barrier in front of a portal	The exchange of a barrier is less expensive than a portal.
		v. Avoid special customized barriers	W-beam barrier is recommended. Fulfil the requirements.
		vi. Choose W-beam barrier as possible	Less expensive.
	Type I: Noise barriers		
	Method	**Example**	**Comments**
I1	Material	i. Avoid noise barriers made of glass due to increased vandalism	In some areas it is necessary to use noise barriers made of glass.
		ii. Consider wood or plastic constructions	Make sure that the material is impregnated.
		iii. Avoid special customized measures of noise barriers	High maintenance costs when needing to order new material.

I2	Design	i. Make sure that the noise barriers are easy accessible	
		ii. Avoid obstacles near noise barriers	
		iii. Place the noise barriers in order that required area for snow stocking	
		vi. Access to passage way at noise barriers	Facilitates future road operation maintenance.
	Type J: Animal fences		
	Method	**Example**	**Comments**
J1	Design	i. Larger road area between the road and the animal fence	Fewer collisions.
		ii. Enable passage for a four-wheeler to pass	Mowing is normally done 1 metre at each side of the fence.
		iii. Enable free sight from the road	Avoid plantations.

	Type K: Variable speed limits		
	Method	**Example**	**Comments**
K1	Technical	i. Easy and clear computer data	
		ii. Simplify error diagnosis	The system shall be build with transparent technique.
		iii. Secure computer communication	
K2	Construction	i. Make sure the marking material have the required space	
		ii. Make sure that the is service areas for service vehicles	In connection to signs etc.
		iii. Not too far of a distance	Difficult to maintain communication.