CHALMERS
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Analysis and Improvement Recommendations for Winter Maintenance on Bike Paths

From an Urban Environmental Perspective with focus on "Sopsaltning" in Stockholm

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

ENA CUPINA

Department of Civil and Environmental Engineering
Division of GeoEngineering
Road and Traffic Research Group
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015
Master's Thesis 2015:142

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Examensarbete 2015:142/ Institutionen för bygg- och miljöteknik,
Chalmers tekniska högskola 2015

Department of Civil and Environmental Engineering
Division of GeoEngineering

Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
Multihog with a combined plough and roller brush on the front and a spray bar at the back (Cupina, 20015).
Department of Civil and Environmental Engineering, Göteborg, Sweden, 2015

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ABSTRACT

This project has evaluated the possibility to replace or improve de-icing solutions containing Sodium Chloride, NaCl, which are used during the winter maintenance method "Sopsaltning", on the prioritized bike network in Stockholm. "Sopsaltning" uses street sweeping to remove snow followed by an application of brine. Further on, the location and recommendation of test segments were alternative solutions can be assessed and compared was conducted. Lastly, identification of limitations and recommendations on how "Sopsaltning" can be improved were performed.

The current de-icing agent and others, such as Molasses, Sulfonated lignin, Calcium Chloride and Sodium formate and combinations of these, have been compared in regards to efficiency, concentrations, costs, environment, disadvantages and benefits. The conclusion from an environmental, logistical and mechanical point is that it is possible to exchange de-icing agent. To ensure that the de-icing effects meet the results of the laboratory studies even in field, further testing is required.

Furthermore, to conduct a field study to find possible test segments the limitations of the maintenance machines, maintenance method, and organisation needed to be examined throughout the project. Machine and bike path designs, different surfacing, varying weather conditions, budget and environment are examples of a number of factors that affect the outcome of "Sopsaltning".

During the field study several potential test segments were found. The most beneficial test segments being bike paths located along both sides of Nynäsvägen between Sockenvägen and Gubbängen, in the southern parts of the city of Stockholm.

The recommended improvements of "Sopsaltning" include; extending the prioritized bike network, acquiring more equipment and personnel, route optimization and real-time monitoring applications, and using experiences and weather reports to conduct a daily planning process. In conclusion, higher financial resources are essential for improving "Sopsaltning" and achieving environmentally friendly winter maintenance.

Keywords: Winter maintenance, sopsaltning, de-icing agents, anti-icing, snow & ice control, snow removal, bike paths, cycleway, maintenance equipment.

Analys och förbättringsrekommendationer för vinterväghållning på cykelbanor
Ur ett urbant miljöperspektiv med fokus på sopsaltning i Stockholm

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

ENA CUPINA
Institutionen för bygg- och miljöteknik
Avdelningen för Geologi och geoteknik
Chalmers tekniska högskola

SAMMANFATTNING

Det här projektet har utvärderat möjligheten att ersätta halkbekämpningslösningar, innehållande natriumklorid, NaCl, med andra alternativ, för, vinterväghållningsmetoden Sopsaltning, på det prioriterade cykelnätverket i Stockholm. Vidare, utvärderades och rekommenderades teststräckor var alternativa lösningar kan testas och jämföras. Slutligen, identifierades begränsningarna med sopsaltningsmetoden samt förbättringsalternativ.

Den nuvarande halkbekämpningslösningen har jämförts med alternativa lösningar så som melass, lignosulfonat, kalciumklorid och natriumformiat och olika kombinationer av dessa. Jämförelsen har genomförts med hänsyn till effektivitet, koncentrationer, kostnad, miljöpåverkan, fördelar och nackdelar. Slutsatsen är att det är möjligt att ersätta NaCl-lösningarna med andra alternativ utifrån utgångspunkter som miljöpåverkan, logistik och teknisk design. Dock, för att säkerställa att halkbekämpningseffekterna når upp till laboratorieresultaten från även i fält, bör dessa testas ytterligare.

Begränsningarna med underhållsmaskinerna, sopsaltningsmetoden och organisationen som krävs undersöktes och utvärderades för att genomföra en fältstudie för att hitta möjliga teststräckor. Maskin- och cykelvägsutformning, olika typer av vägbeläggning, varierande väderförhållanden, budget och miljöpåverkan är exempel på faktorer som påverkar resultatet av sopsaltningsmetoden.

En fältstudie genomfördes för att utvärdera möjliga teststräckor som uppnår testkraven. Den mest fördelaktiga sträckan hittas på cykelbanorna längs båda sidor av Nynäsvägen mellan Sockenvägen och Gubbängen, söder om Stockholm.

Vidare, rekommenderas förbättringsförslag som att förlänga det prioriterade cykelnätet, införskaffandet av mer utrustning och personal, ruttoptimering och realtidsapplikationer, och med hjälp av erfarenheter och väderrapporter utvecklandet av en daglig planeringsprocess. Slutligen, mer ekonomiska resurser är avgörande för att förbättra sopsaltningsmetoden och uppnå ett miljövänligt vinterunderhåll.

Nyckelord: Vinterväghållning, sopsaltning, halkbekämpning, vinterunderhåll, snö och is, cykelvägar, cykelbana, vinterväghållningsutrustning

Contents

Preface

The project was carried out at the Department of Civil and Environmental Engineering, Division of GeoEngineering, Chalmers University of Technology in collaboration with SP Technical Research Institute of Sweden.

This Master's thesis would not have been possible without the support and encouragement of Viveca Wallqvist and the support of my colleagues at SP Technical Research Institute of Sweden. Furthermore, I would like to thank my supervisor at Chalmers University of Technology, Anders Markstedt for guidance throughout the project.

Additionally, I would like to thank Stockholm stad, Peab and Cycleurope for taking their time to participate in interviews.

Finally, I would like to thank everybody that has supported, given feedback, showed interest in my work, answered all of my questions and discussed different approaches. Without all of you this thesis would not have been possible to finalize.

Stockholm, September 2015

Ena Cupina

1 Introduction

The city of Stockholm, like many other cities, is experiencing an increased urbanisation and is one of Europe's five fastest growing urban regions (Stockholm stad, 2014). The need for transport increases daily, which strains the existing infrastructure system resulting in congestion. This is producing additional greenhouse gas emissions and poor air quality leading to an unsustainable situation (UN Habitat, 2012). Politicians, urban planners and traffic planners are tackling the emerging problems with policy documents and visions for a future resilient and sustainable city. The significance of these documents is to guide the urban development work towards resilience.

Several policy documents for the city of Stockholm, e.g. the comprehensive plan "The Walkable city" (2011), "Urban mobility plan" (2012) and the "Cykelplan 2012" (2012), all point to solving a part of the problem by improving the conditions for cyclists. The city has recognized the importance of easing and prioritizing cycling, since this is a sustainable form of transport that provides positive health effects and contributes to a more attractive city.

An increased amount of cyclists are commuting to and from work or school all year round (Stockholm stad, 2011). This leads to higher demands on the cycle network, the lanes are required to be well planned, safe and keep a good standard, even during wintertime (Stockholm stad, 2012). The importance of good winter maintenance on the bike network is crucial for this to be possible. The public costs for injured cyclists is high and the amount of accidents increases with the number of increased commuters; 75 % of all cycle related accidents are single accidents and 20 % of these accidents are due to surface conditions (Swedish Transport Agency; Region Skåne; Lund University, 2013), for instance slipperiness as a result of ice or grit. The numbers of cyclist that are injured every year means social cost in the form of reduced work labour, medical costs and injury benefits, materiel losses and insurance compensation. According to the Swedish Transport Administration the average cost per injured cyclist is set to 1 million SEK in short-term costs-benefit analyses, these cost calculations and values are based on socio-economic principles within the transport sector (Swedish Transport Administration, 2015a). These costs along with the actual injuries can be reduced by improving and optimizing the winter maintenance on bike paths.

There are several different methods for snow control and winter maintenance, often used at the same time, for example snowploughs, brine solutions, street sweepers and grit (Bergström, 2002). To improve the winter conditions on bike lanes the city of Stockholm has adapted a new form of winter maintenance on a chosen prioritized bike network, which will be more explained and presented on a map in Chapter 3 Current winter maintenance in Stockholm. The new method is called "Sopsaltning" and uses a street sweeper with a brine solution for clearing snow. "Sopsaltning" was evaluated during the winter 2013/2014 in the report "Sopsaltning av cykelvägar"

(2014) by the Swedish National Road and Transport Research Institute (VTI). The results show that this method provides a higher road standard during wintertime with overall better friction than traditional winter maintenance (Niska & Blomqvist, 2014). With new materials, new methods and new equipment emerging with an increased awareness to environmental effects it is important to evaluate, compare and investigate different approaches to "Sopsaltning". This paper will address these topics with help from SP Technical Research Institute of Sweden.

Furthermore, this project will review several types of potential and current de-icing agents such as sodium chloride, molasses, sulfonated lignin, calcium chloride and sodium formate and combinations of these. The agents will be compared in regards to efficiency and concentrations, costs, environment, benefits and disadvantages. Finally, concluding if it is possible to exchange the current de-icing agent from an environmental, logistical and mechanical point of view.

A pre-determined test segment would provide a simple and apparent location to test and evaluate new solutions. New de-icing agents can then reach the winter maintenance market faster by providing a new accelerated path, with comparative testing procedures located in Stockholm. Minimizing environmental effects, due to salt usage and increased urbanisation, by testing new developing solutions in Stockholm can then be applied in other cities with the same conditions.

1.1 Purpose and Aim

The focal purpose of this thesis is to identify the possibility to use several different types of salt compositions and brine solutions for "Sopsaltning", to evaluate and propose test segments on which the new solutions can be tested, and lastly, identify limitations and problems that occurred and suggested improvements on how the winter maintenance can be improved.

1.1.1 Objectives

The main purpose of this thesis is divided in to three main objectives:

- Identifying the possibility to use several different types of compositions and solutions to improve the effects of "Sopsaltning".
- Evaluating and proposing test segments on which the new solutions can be tested. These segments should meet the same requirements and be exposed to similar weather conditions.
- Identifying limitations and problems that occurred during the winter maintenance and suggest improvements on how this can be improved.

The first objective that regards general winter maintenance on bike lanes is accompanied by actions such as:

- Identifying the environmental issues associated with “Sopsaltning” and the different types of brine solutions.
- Recognizing which approaches and attitudes to winter maintenance exist.
- Comparing and evaluating different types of de-icing agents with regard to cost, environment, efficiency, benefits and disadvantages.
- Identifying different contractors, different machines types with different limitations and requirements.

Likewise, the second objective regarding the latest winter maintenance will be complemented by actions as follows:

- Estimating and identifying when “Sopsaltning” should be used and which problems can occur.
- Assessing how the logistics and prioritization of the snow clearing was handled.
- Proposing test segments that meet the same requirements and are exposed to similar weather conditions.

Lastly, the final objective considering the future and improvements is supplemented by:

- Recommend potential improvements to the current winter maintenance.
- Identify problems that may occur if alternative compounds and solutions are used and recommend necessary modifications for handling, storing and mixing the solutions.

1.2 Method

The different methods that were used throughout this thesis were a literature study, interviews and study visits to the different contractors. The literature study was applied to utilize the relevant background information, to identify and evaluate different aspects of potential de-icing agents.

This was then complemented by interviews with the client, e.g. the city of Stockholm to find out what was expected to be achieved by the winter maintenance and to which degree. Furthermore, interviews with the concerned contractors, such as Peab and Svevia, were conducted to learn their views and methods about winter maintenance, the interview questions can be found in Appendix I: Interview questions for Stockholm stad and Appendix II: Interview questions for Peab.

Further, a study visit to Cycleurope, a bike manufacturer and wholesaler, in Varberg, was completed. The intent with this visit was to learn how bikes are affected by winter maintenance and which limitations exist. Study visits to the contractors were performed to comprehend what type of limitations can occur due to different machines used for “Sopsaltning”, current storage facilities etc. Lastly, field studies were conducted, on proposed test segments to evaluate if the conditions and requirements were met even in reality.

1.3 Delimitations

This project will mainly centre around the city of Stockholm and the experiences of the city's winter maintenance on the prioritized bike network, leaving out walkways and pedestrian lanes. However, in Sweden these are often combined with bike lanes, therefore the results could be applicable to these as well. The results and conclusions reached in this thesis can be applicable to other cities and countries that which have similar metrological conditions and winter maintenance standards.

Even though several different methods of ice and snow control are available the main focus on improvement and recommendation will remain on "Sopsaltning". Due to reports stating that this is the current most efficient method (Niska & Blomqvist, 2014). In addition, this report will not cover other types of road and street maintenance and the impact that these might have on the winter maintenance.

During this project, invitations and contact were extended to both Svevia and Peab, which are the two main contractors; however, Svevia choose not to participate. Therefore, Peab was the only contractor interviewed and the experiences of "Sopsaltning" are based on their experiences.

Alternative de-icing agents that will be explored have already been tested in laboratory and the idea is to evaluate the possibilities to use these instead of current solutions. Mechanical limitations, human resistance and possible test segments can then be applied for testing these or other solutions in the future, hence this project is supposed to be seen as preparatory work.

When evaluating and proposing a test segment, this stretch of bike path will be located in the city of Stockholm and be part of the current prioritized bike network. As the intent of this project is to shorten the starting point to implement changes when these are required or desired. Thus, if the test segment is on an already existing route, the testing can be implemented more easily.

2 General information about winter maintenance

The climate in Sweden contributes to unsafe slippery surfaces, which can lead to accidents. Furthermore, in Stockholm the amount of frost days during a year vary, for example during year 2014 there were 53 days of frost (Swedish Meteorological and Hydrological Institute, 2015), while during the year 2013 there were 101 days of frost (Swedish Meteorological and Hydrological Institute, 2014)

Since road surface conditions contribute to 20 % of all single bike accidents in Sweden (Swedish Transport Agency; Region Skåne; Lund University, 2013). It is therefore important to apply ice and snow control, which is both preventative and on going. In Sweden several different types of winter maintenance methods are used often several at the same time (Bergström, 2002). The most common used methods are described shortly in the section below.

2.1 Different types of winter maintenance methods

There are several approaches to snow and ice control, such as chemical measures or mechanical measures. Winter maintenances that are chemical include for example salts or brine solutions (Möller, 2007). The salt compositions and brine solutions lower the freezing temperature of the water (Kostick, 2008).

The mechanical measures are instead distribution of grit, sand, ploughing or street sweeping (Möller, 2007). When distributing these substances the surface becomes less slippery due to higher friction while ploughing and street sweeping are used first after the snow cover has reached a couple of centimetres. A snowplough is used for ploughing the snow away from the bike lanes. Likewise, a street sweeper can be used for sweeping away the snow.

The single most common method for ice and snow control is a combination of ploughing followed by grit/sand distribution (Bergström, 2002). This method is mostly used due to its dual properties; the ploughing removes the current snow cover from the path while the grit/sand distribution remains its anti-skid properties even afterwards. However, this method presents several problems; such as grit/sand on the bike paths causes accidents during dry-land conditions, spring sweeping is then necessary to remove the grit/sand which then could be taken into consideration when comparing cost, and sand/grit consists of larger particles, thus the transport of the sand/grit is much greater that for other substances[1].

[1] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.

2.1.1 “Sopsaltning”

One combined chemical and mechanical winter maintenance method is “Sopsaltning”. This method uses a street sweeper with a brine solution for clearing snow (Bergström, 2002). In Stockholm, “Sopsaltning” was implemented and evaluated during the winter 2013/2014 by the Swedish National Road and Transport Research Institute (VTI) in the report “Sopsaltning av cykelvägar” (Niska & Blomqvist, 2014).

Several tests have been compiled and the results state that “Sopsaltning” is the most beneficial winter maintenance method (Niska & Blomqvist, 2014). According to the results, this method provides a higher road standard during wintertime with overall better friction than traditional winter maintenance.

Traffic safety, requirements and demands on environment as well as maintenance budget influence the choice for winter maintenance method. The underlying mechanism of how de-icing works needs to be further investigated and understood to optimize the applied amounts of de-icing agents (Klein-Paste & Wåhlin, 2013). The amount of used road salt is reduced with “Sopsaltning” compared to traditional methods, due to using diluted brine solutions. Additionally, when using this method there is no need for grit removal and spring sweeping[2]. The following chapter will address the use of ”Sopsaltning” in Stockholm in further detail.

[2] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.

3 Current winter maintenance in Stockholm

During the winter of 2013/2014 ”Sopsaltning” was tested on the streets of Stockholm (Niska & Blomqvist, 2014). Important bike lanes for work commuting were chosen as a part of a prioritized bike network, the method of “Sopsaltning” was then tested on these routes; a total of 60 km of bike lanes was used in this trial.

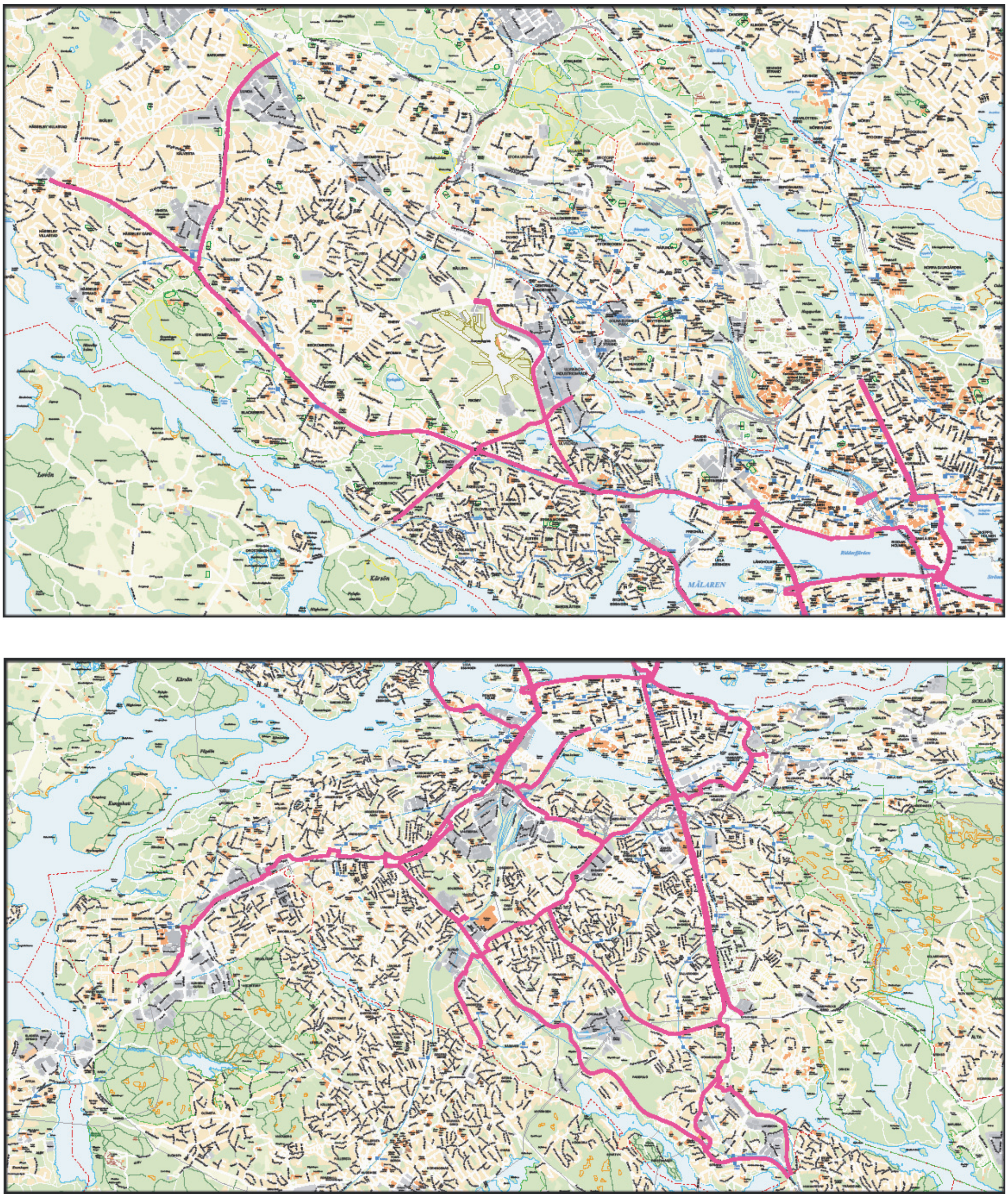

Figure 1 *Map of the prioritized bike network in Stockholm. The upper images display the western Stockholm and the lower image displays the southern Stockholm (Cykeljouren, 2014).*

Due to positive reactions from the users and increased bike usage during wintertime the procedure of “Sopsaltning” was extended to include 120km of bike paths the winter of 2014/2015[3].The map of the current prioritized network can be found in Figure 1. How the winter maintenance on these lanes was conducted can be found the following section.

3.1 Current organisation and logistic for “Sopsaltning”

In Sweden the Public Procurement Act regulates the establishment of public contracts (Ministry of Finance, 2007). This means that the contracting authority, i.e. Stockholm stad, is required to treat all suppliers/contractors equally, non-discriminatorily and in a transparent way. Additionally, Stockholm stad should take environmental and social considerations when choosing contractors.

Even though, this is the most equal way that prevents corruption, this act can be a problem when renewing a contract since it is not possible to consider previous experiences, good or bad. Though, Stockholm stad states that it is still possible to steer the procurement towards a certain contractor[4]. Nonetheless, it is not possible to state that a special type of equipment is to be used; however, techniques and results can to a very large extent be described in detail, which can favour a certain contractor.

The type of procurement used in this case, in Stockholm, is an operational procurement [5], which means that Stockholm stad states what level of maintenance is to be achieved. It is then up to the contractor to decide when this level is accomplished. The traffic office, part of Stockholm stad, sends out inspectors to see that the winter maintenance is fulfilled. Since “Sopsaltning” is a new method in Stockholm the procurement featured a development method, this meant that the traffic office takes responsibility and some of the costs to make sure that the winter maintenance works properly.

Additionally, the office is responsible for the collaboration with the contractor[6]. Stockholm stad provides the contractor with adequate education and information[7]. Additionally, the machine operators should keep a diary of the weather conditions, salt usage and results every day to ease the evaluation and improvement of “Sopsaltning”.

According to Stockholm stad and the current contract the winter maintenance should be carried out every day, and depending on the amount of snow it should be cleared before the morning rush and again before the afternoon rush[8]. The cycle paths should be trafficable at all time, however, it is up to the contractor to decide what trafficable is.

[3] Peter Ringkrans, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.
[4] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.
[5] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.
[6] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.
[7] Bengt Björkman Foreman at Peab Operation and Maintenance, interview on the 8th of June.
[8] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.

In the current situation, the contractor is Peab and eight drivers execute the winter maintenance[9], on the 120 km of prioritized bike lanes. The paths are cleared simultaneously with vehicles and the drivers are assigned an own area, if/when it is finished the drivers are called out to assist in the areas that have not been cleared yet. The amount of added sodium chloride, salt, and brine depends on the weather conditions; many days of precipitation and low temperatures demand higher salt amounts to achieve the same result[10]. The salt is stored uncovered in a large rock shelter and distributed to several deposits throughout the winter[11]. One such deposit is a large barn at Peab's storage facilities on Kvastgatan[12]. The salt is used to create brine solution that is used for "Sopsaltning". The brine is mixed in an Epoke EpoMix by adding the salt into a large water tank (Epoke, 2011), according to a dosage scheme that can be found in Appendix III: Dosing scheme for EpoMix 20.

A dosage tap regulates the salt concentration and a sensor controls the concentration. The mixing process operates at a mixing rate of approximately 5000l/h and stops automatically when the brine solution is complete and the 5000 litres storage tank is full (Epoke, 2011). The winter maintenance vehicles are then filled with this solution. According to the dosing scheme, this can be found in Appendix III: Dosing scheme for EpoMix 20, it is important to add the correct amount of salt otherwise the solution can convert to a supersaturated solution with precipitate of salt crystals. In turn, this can clog and seal the nozzles of the spreaders and hinder correct application and spreading of the brine. The dosage scheme points out that the added sodium chloride is supposed to contain 3 % water, to achieve the correct brine batch that provides a certain result.

According to the vehicle operators, this winter the salt did not have the desired effect on the ice and therefore larger amounts of salt were used[13]. The operators believe that they received a "bad batch" of salt, leading to higher concentrations of salt being applied on the cycle paths, as much as 9 g/m^2 when the temperatures were low[14]. However, this is not confirmed or tested.

On the other hand, confirmed amounts can be found in the report "Sopsaltning av cykelvägar" by VTI (2014) the volumes of applied salt and brine on the bike paths have been evaluated for the winter 2013/2014, and the results showed that the amounts of salt and brine was varied from 0-40 g/m^2, and the average amount was 3 respective 6 g/m^2; however, that winter was considered very mild and it only snowed a few days. The average temperatures during the winter of 2013/2014 were above freezing all winter months except January, which had an average temperature of -1,5 °C (Niska & Blomqvist, 2014).

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[9] Bengt Björkman Foreman at Peab Operation and Maintenance, interview on the 8th of June.
[10] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[11] Peter Ringkrans, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.
[12] Bengt Björkman Foreman at Peab Operation and Maintenance, interview on the 8th of June.
[13] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[14] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.

During the winter of 2014/2015 the responsible contractor for “Sopsaltning”, Peab, had access to eight vehicles with three different combinations of vehicles and equipment [15]. One of the combinations that was available was a multi-purpose machine, a Lundberg 6200 Lse, with a sweeper roller, a Holms SH, attached on the back, as can be seen in Figure 2. The machine’s design and dimensions may cause interruptions and difficulties during the winter maintenance. For example with a height of 2315 mm (Lundberg Hymas, 2009), this can eventually lead to problems going under viaducts that are lower than this[16]. The width of the machine is 1960 mm, which should not cause any problems when on bike paths and combined walkways; one-way pavements, on the other hand, are often narrower than this.

Currently “Sopsaltning” is used only on prioritized bike paths, however, taking into consideration that the sweep roller has a width of 2700 mm this might be a larger interference that expected when planning expansions (Holms Industri AB, 2015). Additionally, the design of the machine is ungainly due to its size, making the turning radius very wide, the length is 4923 mm without any attachments (Lundberg Hymas, 2009), though it is possible to lift the sweep roller almost vertical to ease with turns and avoid obstacles. According to the machine operators, this feature is highly appreciated and eases turns on narrow bike paths[17].

Figure 2 Lundberg 6200 Lse with a Holm SH sweeper attached on the back (Cupina, 2015).

A supplement to this combination is Combo plate spreader, Falköping C-1, on a semi-trailer. The plate spreader was attached to distribute the de-icing agent; in this case both brine solution and dry salt[18]. The plate spreader is a nozzle attached to a plate-like device on which the brine and/or salt is discharged, the plate is then spun and the solution and/or dry salt is hurled onto the bike lane, with a spreading width of 2-8 m depending on the number of rotations per minute (Friggåkers Verkstäder AB, 2013).

[15] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[16] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[17] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[18] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.

Figure 3, demonstrates the semi-trailer and a close-up on the plate spreader for better understanding.

Figure 3 To the left at Falköping's plate spreader on a semi-trailer and to the right a close-up of the plate (Cupina, 2015).

Peab had access to two combinations of this type; one additional set-up is being procured for next year[19]. According to the manufacturer the C-1 can be used to spread dry salt, sand, shingles or calcium chloride (Friggåkers Verkstäder AB, 2013), meaning that the nozzles and spreader can be used for other than these substances as long as the particles are in the same size. The combo plate spreader is equipped with two tanks for storage; which carry 1m3 of dry material and 660 l of solution[20]. The semi-trailer has a width of 1300 mm and a length of 2200mm (Friggåkers Verkstäder AB, 2013), which increases the turning radius even further.

Figure 4 Multi-purpose machine Wille 655c (Cupina, 2015).

[19] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[20] Friggåkers Verkstäder AB, e-mail at the 26th of June.

The second combination has the same type of set-up and design functions, however different manufacturers. This combination consists of a multi-purpose machine from Wille, as seen in Figure 4, with the same Holms SH sweeper roller attached on the back. The dimensions of this machine are in the same measurement as the Lundberg; with a height of 2330 mm, length of 5000mm and width of 1920 mm (Multimaskin, 2009). The attached plate spreader was a Schmidt Stratos B11L on a semi-trailer, seen in Figure 5.

Figure 5 To the left a Schmidt Stratos semi-trailer and to the left a close-op of the spreader (Cupina, 2015).

This plate spreader distributes the de-icing agent in the same way as in the other combination, with a spreading width of 2-6 m[21], the tank carries 1,1 m3 of dry material and 500 l of liquid (Aebi Schmidt Holding AG, 2015). Peab had access to two combinations of this type as well; however, one of the machines was unfortunately destroyed in an accident and was not in use during the winter of 2014/15[22].

Since the plate spreaders can distribute both brine solution and dry rock salt the amount of distributed salt can be varied from 0-40 g/m^2 (Niska & Blomqvist, 2014). Additionally, the simultaneous use of brine and salt provides a long-term de-icing effect on the bike paths. Therefore, the result left on the paths with the use of plate spreaders is not bare ground, except scattered grains of salt (Niska & Blomqvist, 2014). The visible salt grains are associated with corroding bikes and therefore can be perceived as problematic by the users.

The last combination in use was a Multihog with a combined plough and roller brush on the front and a spray bar, with nozzles for brine spreading at back of the vehicle. See Figure 6 and Figure 7 for illustrations. The Multihog can only distribute brine solution and the amount of salt san be varied from 5 to 25 g/m^2 (Niska & Blomqvist, 2014). However, the tank is larger than in the other combinations; a 1,2 m^3 tank equipped with three different sections of nozzles, with a combined spread radius of 10 m (Multihog Ltd, 2012). The dimensions of the Multihog are more compact than for

[21] Sebastian Strand Sales Supervisor at Aebi Schmidt Sweden AB, e-mail at the 25th of August.
[22] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.

the other combinations, since the brine tank is located on the actual machine and not on a semi-trailer. The dimensions of the vehicle without additional equipment are length 3400 mm, height 2400mm and width 1960mm (Multihog Ltd, 2012). Furthermore, the combined plough and roller brush have a width of 2400mm, which is narrower than Holms sweep roller. However, it is not possible to lift the plough and roller brush vertical above the rooftop of the vehicle; this is expressed as negative according to the machine operators[23].

Figure 6 Multihog with a combined plough and roller brush on the front and a spray bar at the back (Cupina, 2015).

Figure 7 On the left: the front of the Multihog with a combined plough and roller brush. No the right: a spray bar with nozzles on the back of the Multihog (Cupina, 2015).

[23] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.

According to the machine operators even though a Multihog has smaller dimensions it is less flexible. Three Multihogs were available for the winter maintenance[24]. The winter maintenance result achieved by the Multihog is bare ground; this is something that is very much appreciated by the users (Niska & Blomqvist, 2014).

It seems that the client, Stockholm stad and the contractors at Peab are in disagreement on which of the vehicles is providing the best result. The city values the impression of bare asphalt on the pike paths[25], while the contractor prefers the long-term effects that the brine in combination with dry salt provides[26]. When choosing a new de-icing agent the visual impressions appear at least as important as the de-icing effects; this due to the fact that the users have grown accustomed and come to expect at a certain snow clearance standard and traction.

3.2 Limitations for "Sopsaltning"

This winter maintenance method works less well on painted surfaces, were it appears that the surface is cleared when in fact an ice film is formed, leaving a surface with less friction and more slipperiness (Niska & Blomqvist, 2014). Likewise, intersections were several different types of winter maintenance overlap and different types of road users cross way are prone to less friction, since snow is dragged on to the bike lanes from the joining streets (Niska & Blomqvist, 2014). Furthermore, the evaluating friction measurements performed by VTI (2014) show that less friction could be found on manhole covers, painted symbols and irregularities in the asphalt when using "Sopsaltning" as a winter maintenance method.

Additionally, "Sopsaltning" encounters difficulties when the weather varies and as a result the snow clearing capabilities are less good. For example, high amounts of snow combined with varied temperatures produces a slush, which then freezes from the ground below[27]. This is a problem for "Sopsaltning" since the power brooms cannot sweep away the formed ice. To solve this some of the vehicles are equipped with a plough that can force the ice from the paths[28]. During the latest winter the weather was very changeable, therefore several of these problems were encountered[29].

One additional limitation for "Sopsaltning" is the implementation time. Not only is special equipment required, as well actual participation by machine operators is required to be realized correctly. Since, this is a quite new method the procedure is trial and error, this requires documentation about the weather conditions, salt amounts and actual result using the cyclist experiences[30].

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[24] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[25] Peter Ringkrans, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.
[26] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[27] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[28] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[29] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[30] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.

Obsolete negative views of cyclists need to be changed and cycling, as a dependable and everyday mean of transportation needs to be taken more seriously[31]. Comments and opinions about angry cyclist that never are satisfied, and that they should try to cycle in other parts of the city since they do not even know how good it is here, need to be addressed. During the interviews with Peab it was clear that this change is happening as the comment were mixed with compassion, understanding and loathing all in one. What is positive, however, is not seeing it as battle or competition between different types of transport, something that makes the climate of discussion much more calm and sober-minded.

Lastly, according to the manufacturers and previous experiences of the machine operators, there are no mechanical limitations to exchanging the current brine solutions with other de-icing solutions. The machines are already designed to handle other types of solutions and compounds, as long as the particles are in the of the same size scale as sand.

[31] Peter Ringkrans, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.

4 De-icing agents

Precipitation combined with low temperatures provides conditions for icy and slippery roads In sub-zero climates winter maintenance is essential for obtaining traffic safety, sodium chloride has been used since the early 1960's to de-ice road worldwide (Houska, 2007). De-icing agents are applied to the roads to lower the freezing point of water (Kostick, 2008). The main chemical used in Sweden for de-icing is sodium chloride, salt (Swedish Transport Administration, 2015b); this leads to significant amounts of salt being released into the environment. Using salts for this purpose comes with environmental risks (Kostick, 2008), to achieve a sustainable winter maintenance alternatives to sodium chloride needs to be explored. The section below will address these subjects further. It is desired to find solutions that reduce the salt-usage without compromising accessibility and traffic safety. The effect of the de-icing agents can be influenced by several parameters, e.g. weather conditions, air and ground temperature, surface texture, freezing time, de-icing agent concentration, traffic load, speed and axle loading (Klein-Paste & Wåhlin, 2013).

In on-going research at SP Technical Research Institute of Sweden, 22 currently used and known de-icing agents have been tested and compared in a project concerning vulnerable road users (Wallqvist, 2014). A temperature and humidity controlled method, to study frost formation and its dependence on temperature gradient and/or surface treatment of asphalt, was developed to test the efficiency of different de-icing agents. This method was designed to imitate field conditions, with ground frost overnight and then milder temperatures during the morning. The objective with the test has been to imitate a challenging field condition in the lab and then yield equivalent results, as a preparatory study before field trials.

Eight different combinations of de-icing agents from the original 22 agents were chosen for a closer testing. These agents are not necessarily the most effective de-icing agents; however, these are more environmentally friendly, in a reasonable price range and possess sufficient de-icing properties. In the sections below these eight chosen agents will be introduced, compared and to some extent evaluated.

4.1 Road Salt – Sodium Chloride – NaCl

A typical property of salts, such as sodium chloride, NaCl, is that these are highly soluble in water as well as having the ability to lower water's freezing temperature (Kostick, 2008). Road salt usually contains moisture, plaster, CaSO4, and even a hundredth of Sodium ferrocyanide, Na4Fe(CN)6; however, 97% of the road salt is pure NaCl (Swedish Transport Administration, 2015b). The obtained sodium chloride that was tested during the trials at SP Technical Research Institute of Sweden was not white as the salt observed at the storage facilities yet blue (Wallqvist, 2014). This could indicate that the received road salt is not always as pure as the manufacturer claims. This in addition with the open storage of the salt might explain the previous experience of less effective de-icing, since colour variations can be indicators of small contaminations.

Below −18 °C the use of salt or brine is ineffective; additionally the melting characteristics of salt becomes poorer and unreliable already below -6°C, hence, in Sweden the use is restricted below this point (Swedish Transport Administration, 2015b). The annual seasonal road salt usage on the national Swedish road network during year 2013 reached 244 000 tons (Swedish Environmental Protection Agency, 2013), it should be noted that most of this salt usage is used for de-icing roads used by motorized vehicles.

These vast amounts of salt leak out in to the surrounding environment and can cause environmental damages, such as contamination of ground water, disrupting plants and animals osmoregulation abilities and corroding vehicles, bikes, bridges, reinforcement etc. (Kostick, 2008). Precipitation can however reduce the environmental load of the salt due to dilution.

According to Cycleurope, a large bike manufacturer, most of their bikes are made in aluminium; therefore, the corrosion is not a main problem for bike users[32]. However, some parts of the bike are still made out of galvanized parts and when this coating is worn out then important parts can be damaged, such as spokes, nuts and bolts[33].

The use of sodium chloride as an anti-freezing and de-icing agent is vast (Kostick, 2008). This method is economically defendable and affordable, both diluted brine solutions and solid salt compounds are used; for both prevention and de-icing.

Additionally, “Sopsaltning” as a winter maintenance method is already an environmental improvement, since this method uses less amount of salt due to brine solution instead of rock salt. The foreman at Peab claims that no environmental damage is done to the surrounding green surfaces due to the low content of salt in the brine solutions[34], especially compared to the massive amounts of salt used to de-ice roads.

SP Technical Research Institute of Sweden evaluated NaCl as a de-icing agent on its own, as well as in a solution with Calcium Chloride and Molasses, in combination with merely Molasses and lastly, in combination with Lignosulfonate. This is to reduce the total amounts of released NaCl and determine the most effective de-icing agent.

The price of NaCl is approximately 600 SEK/ton[35] and this is, by far, the most inexpensive de-icing agent. Another advantage of using NaCl for winter maintenance is that there is no expiration date and therefore very large quantities can be obtained at a lower price. Further, NaCl is a known de-agent thus easy to obtain from current distributors and at the same time an efficient de-icing agent.

[32] Claes Alstermark Group Quality Director at Cycleurope, interview on the 2nd of June.
[33] Claes Alstermark Group Quality Director at Cycleurope, interview on the 2nd of June.
[34] Bengt Björkman Foreman at Peab Operation and Maintenance, interview on the 8th of June.
[35] Viveca Wallqvist Researcher at SP Technical Research Institute of Sweden, e-mail on the 4th of May.

4.2 Calcium Chloride – $CaCl_2$

Similarly as NaCl, calcium chloride, $CaCl_2$, is a type of salt with comparable ice melting properties. Furthermore, the dissolution of the agent is exothermic (Ihs & Möller, 2000), heating the surface and hence melting the ice and snow; providing a more effective de-icing agent. The lowest de-icing temperature is lower than for NaCl, calcium chloride can be effective at temperatures down to -51,6 °C (Ihs & Möller, 2000).

Additionally, $CaCl_2$ possesses hygroscopic properties and can retain water from the air, as a result a liquid layer can be kept on the surface of the roadway, which suppresses the dust and is used for this during the spring (Ihs & Möller, 2000). This characteristic can indicate that the amount of de-icing agents can be decreased since the solution will stay on the bike paths longer.

As for the environmental effects, calcium chloride is less harmful than NaCl; however, chloride can still affect plants ability to absorb nutrients (Blomqvist, et al., 2010). Furthermore, the corroding effects are the similar as for NaCl, as these effects are due to the chloride content. Additionally, $CaCl_2$can harm and damage concrete, due to these indications $CaCl_2$ is less used during winter maintenance (Ihs & Möller, 2000).

The price of $CaCl_2$is approximately 5000 SEK/ton[36], which is more than eight times as expensive as NaCl. During the trials at SP Technical Research Institute of Sweden, $CaCl_2$ was used in a solution combined with NaCl and Molasses. The benefits of these solutions are that the total amounts of NaCl can be reduced and replaced with two more environmentally friendly agents. Additionally, since $CaCl_2$ is effective down to lower temperatures, this combination of solutions will hopefully be able to be used below -6°C.

4.3 Sodium formate – HCOONa

The sodium salt of formic acid is known as Sodium formate, HCOONa (U.S Environmental Protection Agency, 2000). This chemical has hygroscopic properties and might therefore retain water from the air, which should be addressed when storing. This product has no known environmental effects and is highly bio-degradable (U.S Environmental Protection Agency, 2000).

The price of sodium formate is approximately 5500 SEK/ton[37], which is more than nine times as expensive as NaCl. This agent is mostly used at airports, since HCOONa is a de-icing agent that can de-ice large amounts of ice using lesser amounts of chemicals (U.S Environmental Protection Agency, 2000).

[36] Viveca Wallqvist Researcher at SP Technical Research Institute of Sweden, e-mail on the 4th of May.
[37] Viveca Wallqvist Researcher at SP Technical Research Institute of Sweden, e-mail on the 4th of May.

During the research at SP Technical Research Institute of Sweden, HCOONa was evaluated during the lab tests as a de-icing agent solely on its own and combined with two different solutions, one with molasses and the other one with lignosulfonate. The benefits of these solutions are that the NaCl will be replaced with two more environmentally friendly agents and that lower amounts of chemicals will be required.

4.4 Lignosulfonate – Sulfonated Lignin

Sulfonated lignin, known as lignosulfonate, is a by-product from the paper pulp industry (Backlund & Nordström, 2014). The characterizing properties of lignosulfonate are not established scientifically yet, due to the complexity of the material (Lebo, et al., 2008). Known is that this agent is a polymer and recognized as nontoxic (Kuusela, et al., 1989).

Additionally, lignosulfonate is hydrophobic (Backlund & Nordström, 2014); therefore, used as an environmental sustainable dust suppressant (Oscarsson, 2007). The impact of lignosulfonate on nearby vegetation is minor and the agent decomposes in an environmentally friendly way (Alzubaidi, 1999). In addition, this de-icing agent is less corrosive than water, which is a benefit since the agent is used for road maintenance as a dust suppressant.

The price of lignosulfonate is approximately 4000 SEK/ton[38]. Lignosulfonate used to be produced as an effluent from all pulp industry; however, new pulping processes have evolved and today merely a third of the world's total pulp effluent comprises of lignosulfonate (Lora, 2008). Sweden has a large pulp industry and the potential to use domestic lignosulfonate are vast (Backlund & Nordström, 2014). The two main uses for lignosulfonate today are dispersants for concrete production and animal feed binders (Lora, 2008).

Throughout the trials at SP Technical Research Institute of Sweden, lignosulfonate was assessed as a de-icing agent in two different solutions. The first one was combined with NaCl, with the benefit of reducing the total amounts of NaCl released during winter maintenance. In the second solution, lignosulfonate was paired with HCOONa, thus replacing the NaCl with a more environmentally friendly compound. Using lignosulfonate as a de-icing agent would provide advantages such as handling by-products while at the same time minimizing the transports distances compared to using imported NaCl.

4.5 Molasses – Sugar beet juice

Sugars and residues from organic industries can be used as de-icing agents. One such residue is molasses, which is extracted from sugar beets; this is the remaining effluent after sugar crystallization (Salomonsson, 2010). Molasses is mainly used as a feeding

[38] Viveca Wallqvist Researcher at SP Technical Research Institute of Sweden, e-mail on the 4th of May.

additive for cattle since it has a 50% of sugar content; this might lead to an increase of wildlife on the bike paths.

The price of molasses is approximately 1800 SEK/ton[39], which is the second most inexpensive de-icing agent, with a cost that is the triple amount compared with NaCl.

As with the NaCl, molasses was evaluated in four of the eight de-icing tests conducted by SP Technical Research Institute of Sweden. In the first test pure molasses was evaluated, followed by a solution with NaCl, then NaCl and $CaCl_2$, and finally, combined with HCOONa.

Several tests in the United States have revealed that if mixing molasses with NaCl, the new compound will adhere better to the applied surface (Kostick, 2008). Followed by, fewer de-icing applications, which contributed to cost savings in both labour hours and de-icing agent usage. This is one of the benefits that is desired to be achieved. Additionally, molasses is biodegradable and environmentally friendly. Though, the disadvantages with using molasses as a de-icing agent are that wildlife can be attracted to the area were molasses is applied as well as the fact that the solution has an expiration date and the solution decomposes, which can cause odours (Kostick, 2008).

4.6 Compiled de-icing agent's results

Presented in Table 1, are the compiled results of the de-icing agents, tested at SP Technical Research Institute of Sweden. The benefits, disadvantages, environment impacts and costs are presented in one table for a clear overview.

The first column, of Table 1, presents the combinations of used de-icing agents; the second column displays the different distributions and weight concentrations (Wt) between the used de-icing agents. Further on, the third column shows the results of at what temperature the ice was completely melted (Wallqvist, 2014). Followed by the fourth column, which shows the price per ton for the different tested combinations. Lastly, in the fifth and sixth columns environmental effects, disadvantages and benefits of the de-icing agents can be found.

[39] Viveca Wallqvist Researcher at SP Technical Research Institute of Sweden, e-mail on the 4th of May.

Table 1 Compiled de-icing agent's results.

De-icing agent	Wt % (% agent)	Melting Temp.[**] °C	Economy SEK/ton	Environment and disadvantages	Benefits
Sodium chloride NaCl	16 (100)	-1,5	**600**	Contaminates groundwater, corrosive to metals, disrupts the plants' and the animals' osmoregulation systems	Already in use, easy to store, no expiration date, known efficiency. The most inexpensive de-icing agent option.
	20 (100)	-2			
Sodium formate	16 (100)	-7,5	**5500**	This product has no known environmental effects. The most expensive option.	Highly bio-degradable and no use of NaCl
Molasses	8 (100)	-1,8	**1800**	Environmentally friendly. Organic material has an expiration date, potential odour and wildlife can be attracted	By-product and organic material that decomposes naturally, domestic production, less transportation, the second least expensive option, not corrosive, fewer applications. No use of NaCl.
	50 (100)	-4,2			
Sodium Chloride + Calcium Chloride + Molasses	8 (48,5)+ 0,5 (3)+8 (48,5)	-9	600*0,485 +5000*0,030+1800* 0,485 =**1314**	Can contaminate groundwater, can affect plants ability to absorb nutrients, corrosive to metals, possible effects on concrete and wildlife can be attracted. Partly an organic material that has an expiration date and potential odour.	Partly bio-degradable and partly domestic production, effective down to low temperatures, decreases the NaCl amount and fewer applications
	16 (76) +1 (5) +4 (19)	-12	600*0,76+ 5000*0,05 +1800*0,19 =**1048**		

Sodium Chloride + Molasses	12 (60) + 8 (40)	-2,3	600 *0,6 + 1800 *0,4 =**1080**	Can contaminate groundwater, can affect plants ability to absorb nutrients, corrosive to metals, possible effects on concrete and wildlife can be attracted. Partly an organic material that has an expiration date and potential odour.	Partly bio-degradable, decreases the NaCl amount and fewer applications, partly domestic production.
	16 (80) +4 (20)	-10	600 *0,8 + 1800 *0,2 =**840**		
Sodium Chloride + Sulfonated lignin	12 (60) +8 (40)	-2,3	600 *0,6 + 4000*0,4 =**1960**	Can contaminate groundwater, can affect plants ability to absorb nutrients, corrosive to metals, possible effects on concrete. Partly an organic material that has an expiration date and potential odour.	Partly bio-degradable, decreases the NaCl amount and fewer applications, partly domestic production
	16 (80) +4 (20)	-9	600 *0,8 + 4000*0,2 =**1280**		
Sodium formate + Sulfonated lignin	12 (60) +8 (40)	-7,7	5500 *0,6 + 4000 *0,4 =**4900**	Environmentally friendly. Organic material has an expiration date, potential odour.	By-product and organic material that decomposes naturally, domestic production, less transportation, no NaCl.
	16 (80) +4 (20)	-8,3	5500 *0,8 + 4000 *0,2 =**5200**		
Sodium formate + Molasses	12 (60) +8 (40)	-2,4	5500 *0,6+1800 *0,4 =**4020**	Environmentally friendly. Organic material has an expiration date, potential odour, wildlife can be attracted	By-product and organic material that decomposes naturally, domestic production, less transportation, not corrosive, fewer applications, no use of NaCl.
	16 (80) +4 (20)	-10,4	5500 *0,8+1800 *0,2 =**4760**		

**The presented temperatures are results from experiments carried out at SP Technical Research Institute of Sweden lead by Researcher Viveca Wallqvist. The temperatures show at which temperature the ice was completely melted from the test specimens. This does not necessarily imply that the solutions cannot be effective below these temperatures. Research conducted by Klein-Paste and Wåhlin (2013) suggests that the de-icing agents weaken the ice to an extent that allows a vehicle tire, a bike tire or even a pedestrian's foot, to break the ice and reach the surface below and achieve better friction. This would indicate that even low amounts of de-icing agents can have the desired anti-icing properties at much lower temperatures that previously believed (Klein-Paste & Wåhlin, 2013).

4.7 Comparison and analysis of the de-icing results

When it comes to comparing the cost of the different solutions, the results, found in Table 1, only reflect the cost of the agent itself. According to the table, NaCl is the most inexpensive agent, thus, the most economical option. However, the numbers do not take into consideration the winter maintenance quality produced per segment, such as the amount of agent required per square meter or the efficiency of the agent. To achieve a more correct and representative price tag the costs need to be broken down in chemical costs, labour hours, vehicle and machine costs, fuel costs and so forth.

Furthermore, some of the solutions will lead to economic gains due to fewer applications of the agent, reduced spring sweeping, reduced application of dust suppressant and environmental gains by not using NaCl. Several combinations containing NaCl only reduce the NaCl concentration from 20% to 16%, this small decrease might neither lead to enough environmental gains nor justify the higher de-icing costs. Additionally, the use of less corrosive agents would lead to gains in form of not damaging reinforcement and other metal infrastructure, and no corrosion on bikes and other vehicles. Gains that are difficult to calculate beforehand, therefore, the costs are much more complex than the visible and countable numbers.

Moreover, even if it is more expensive to use other solutions that NaCl, the cost benefit analysis in the report "Transport transitions in Copenhagen" (Gössling & Choi, 2015) shows that the cost of driving a car instead of biking is six times as costly for society as a whole. Providing opportunity, correctly designed infrastructure and winter maintenance on bike paths can encourage car users to switch mode of transport, hence justifying the higher costs of switching de-icing agents and improving public health. Additionally, during the interviews both Stockholm stad and Peab[40] were open to replacing the NaCl with a more environmentally friendly de-icing agent, if it is proven that the de-icing results are similar. Stockholm stad has confirmed that there is room in the winter maintenance budget for a costlier change[41].

In the current budget, the cost of the winter maintenance is the design value. If instead the environment was viewed as the design value and regarded the environmental effects, the four most favourable de-icing combinations would be molasses, sodium formate, molasses and sodium formate, as well as sodium formate and lignosulfonate,

[40] Bengt Björkman Foreman at Peab Operation and Maintenance, interview on the 8th of June.
[41] Peter Ringkrans, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.

as these do not contain any NaCl. Hence, these options are nontoxic and have little or no environmental impact. On the other hand, the disadvantages of the organic materials are that they have an expiration date, potential odour when applied, and can attract wildlife. These potential disadvantages need to be evaluated during the testing to see if this will have an impact on the final recommendation.

In addition, when consideration is taken to the effectiveness of the de-icing agents, regarding the temperature at which the de-icing agent is efficient, then the combination containing calcium chloride is by far the most beneficial.

5 Test segment evaluation – Field study

The intention of this field study is to establish a national test segment area within an urban environment to ease the testing of new de-icing agents. Evaluating and choosing test segments that already are in use, with established routines and dedicated personnel, may lead to faster testing and evaluation and hence faster implementation of new de-icing agents.

5.1 Limitations and obstacles for test segment

As presented earlier, in section 3.2 Limitations for “Sopsaltning”, according to VTI’s friction study (2014) and consultations with the machine operators[42] this winter maintenance method works less well on surfacing such as painted surfaces, manhole covers and irregularities in the surfacing, therefore, in this field study recommendation stretches were this occurs will to the possible extent be avoided.

Likewise, limitations affected by machine design will be taken into consideration, as mentioned in section 3.2 Limitations for “Sopsaltning”. The design limits state that no path should be narrower that 2700mm, due to sweep roller width; no passing or tunnel should be lower than 2400m, due to vehicle height; and sharp, narrow turns should be avoided if possible, due to vehicle length.

Additionally, stretches that are confirmed to have less friction are avoided in the recommendations, to not taint the results later, such as stretches with intersections, kerbstone and cobblestone material, bridges, viaducts and road bumps (Niska & Blomqvist, 2014). Furthermore, limitations and obstacles as road dividers in the shape of pillars and concrete blocks, and posts or signs placed close to the bike path, reducing the width of the passage[43].

Moreover, since “Sopsaltning” accomplishes different results when the weather conditions vary, hence, similar weather conditions on the test segments are important. Choosing segments that are prone to the same weather conditions such as precipitation, wind and temperature are important for comparing the results. Lastly, street design can affect the out coming results, for example to have a similar run-off this is depended on street angel and the amount of storm water wells. Thus, steep hills cannot be recommended since testing friction there will provide a different result than on a flat stretch.

[42] Hans-Erik Jansson Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[43] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.

5.2 Method for selecting test segments

The prioritized bike network is currently 120 km long[44], therefore, compiling a visual inspection directly on these will be time consuming and inefficient. Thus, this field study started by studying the map of the network, were several cohesive stretches without intersections were sought. However, Stockholm is a dense populated urban area; consequently, intersections were found virtually everywhere.

Additionally, the few stretches that are long, cohesive and uninterrupted were found at the edges of the network, further out from the city centre in the suburbs. Lower flows of commuters can be expected at the edges of the prioritized bike network, this in turn might influence the dispersal of the solutions, which could affect the de-icing results (Klein-Paste & Wåhlin, 2013). As a result, a few stretches closer to the city centre will be investigated even though these will not be uninterrupted.

Since the prioritized network expands along the west side of Stockholm trough the centre of the city and ranging down to the suburbs in the south, test segments will be assessed in areas in the west of the network, in or near the centre and lastly in the south as well. Thus different solutions can be compared with each other on similar sites that additionally are exposed to the same type of weather conditions.

After that, the potential stretches marked on the studied map were visited by bike for a visual inspection. This is to confirm that no other obstacles are found on the stretch.

5.3 Recommendation and evaluation of test segments

Intersections disturb the results of "Sopsaltning" as a winter maintenance method. Thus, the recommendation is to recommend a minimum length of test segment, which is at least 500m long, to be certain that middle of the segment will be undisturbed and untainted by other winter maintenance methods and other traffic flows.

According to the machine operators[45], when testing other de-icing agents previously, only a small amount of solution was tested. It might not always be possible to test a full tank of de-icing solution; due to uncertainties in results or only a small quantity of agent is available. Therefore, recommending stretches near the parking garages and storage facilities will facilitate for the operators and save time on transport. A desire, expressed by the machine operators[46], is to test the new solution over one whole area, using the same vehicle the whole time. This since it is time consuming to change solutions and clean the tanks, measure the exact amount of solution required for only one test segment, especially if the solution is viscous while the weather conditions require constant winter maintenance[47]. As a result, the recommendation is to select

[44] Pye Seaton, Project Manager Traffic Office at Stockholm stad, interview on the 25th of May.
[45] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[46] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.
[47] Jimmy Skipsna Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.

stretches near the parking garages and storage facilities; these are located on Kvastgatan south of Stockholm.

Several segments meet the above mentioned criteria in the south of Stockholm, such as alongside the network between Globen-Larsboda, Stureby-Gubbängen, Älvsjö-Farsta, Stureby-Gullmarsplan, Gullmarsplan-Årstaberg, Fåfängan-Slussen, Fruängen-Midsommarkransen and Slussen-Högalid.

Figure 8 A selection of bike paths from the prioritized network that fulfil the requirements (Cupina, 2015)

The bike paths in Figure 8 are located between Stureby-Gubbängen, Älvsjö-Farsta, Fruängen-Midsommarkransen, Stureby-Gullmarsplan and Gullmarsplan-Årstaberg. The paths fulfil all or several of the previously mentioned requirements.

Additionally, if not taking into account the proximity to Kvastgatan, segments that fulfil the rest of the criteria can be found in west of the city, between Traneberg-Hässelby villagård, Johannelund-Hjulsta, and Ulvsunda- Mariehäll.

Figure 9 Examples on obstacles encountered on the bike paths along the prioritized network; cracked road surface; mixing of different types of surfacing and paint; height maximum of 2,65 m; intersection with different types of surfacing and paint; kerbstone and cracked road surface; bus stop dividing and narrowing the bike path (Cupina, 2015).

The field trip was conducted on bike and the above mentioned stretches were inspected and documented to ensure no obstacle or other inconveniences were present, a selection of the encountered obstacles can be seen in Figure 9. The measured width of the inspected bike paths ranged between 3m and 4,7m, however at some points the width narrowed to make room for bus tops and signposts, as can be seen in Figure 9.

The most favourable outcome for choosing the segment is to recommend stretches that run on both sides along the same road. In that case two different de-icing agents can be compared during the same time while at the same time being exposed to the same weather conditions. One such segment can be found along Nynäsvägen, between Globen and Sofielundsplan. The prioritized bike path runs along both sides of the road. Figure 10 illustrates the bike path in four images, two at each side of Nynäsvägen. As can be seen, the east bike path is completely undisturbed, no markings, manhole covers or other types of obstacles. The bike path on the west side of Nynäsvägen, on the other hand, is marked with painted surface markings, as well as some different types of surfacing. Additionally, one part of the west path is covered from above by an event arena, that exact part of the bike path will not be exposed to any precipitation.

Figure 10 *Nynäsvägen - between Globen and Sofielundsplan. Images 1-2 show the bike path on the east side of the road. Images 3-4 illustrate the bike path on the west side (Cupina, 2015).*

This needs to be taken into consideration when using the west side of the bike path as a test site. Thus, it is important to avoid testing on the covered part of the path, the painted markings and the different surfacing to not obtain false results.

Furthermore, additional test segments that fulfil the requirements and run long both sides of the road can be found along Nynäsvägen between Sockenvägen and Gubbängen. On both sides of the road the bike path mostly runs through groves of trees, as can be seen in Figure 11.

Figure 11 Bike paths along Nynäsvägen, between Sockenvägen and Gubbängen (Cupina, 2015).

As can be seen in the images in Figure 11, these bike lanes are completely bare, no marking or paint can be found on the surface. Presenting a uniform surface on which the de-icing agents can be tested. In addition, theses bike paths are located the closest to Kvastgatan, were the parking garages and storage facilities are found. Selecting these paths a test segment would be time efficient, as it would be close to drive to and from the garages were the de-icing agents are found. Therefore, the final recommendation is to use these paths, along Nynäsvägen between Sockenvägen and Gubbängen, as test segments.

Additionally, not only is it important to decide and evaluate a test segment for testing, it is important to execute the de-icing tests during different types of weather condition. Experience shows that the weather conditions have great impact on the result.

To conclude, even though the bike path runs along the same road, it should be noted that the result still can differ due to wind direction, shielding in the form of noise protection walls, buildings etc. The images of the potential test segment are taken during summer; hence, the leaves have still not been shredded. Thus, it appears that the segments are considerably shielded from the weather elements; this will not be the case during the winter months.

6 Improvement recommendations

One recommendation for improvement is to require more vehicles and more personnel who can manoeuvre the machines in shifts. Thus, the vehicles can always be in motion without risking overtired personnel or potential sick leave. Furthermore, having equipment that is not in use just since there are not enough operators is inefficient With more vehicles in motion it will be easier to repeat the de-icing maintenance faster during extreme weather conditions. Though, this of course will be a financial issue.

Moreover, knowing that “Sopsaltning” is more effective than other winter maintenance methods, an improvement of the current scenario is to extend the current network even further and to include pavements as well. This will require procuring smaller vehicles that can provide winter maintenance on narrower paths and pavements. These smaller machines can be used as supplement to the larger ones. During the visit at Peab there was a mention about a new smaller multipurpose machine that had reached the maintenance market[48]. This indicates that the size of the current machines has been a problem for executing the winter maintenance method to the desired extent.

The procurement contract for the winter maintenance method states what level of maintenance is supposed to be achieved and it is then up to the contractors to decide what trafficable is. When it is up to the individual to decide what is good enough, there will be different levels of maintenance; hence, the description is open to interpretation. One improvement would be to introduce quantifiable objectives and by means of these, obtain a more uniform result. Measurable targets are easier to relate to and act thereafter.

Since the weather conditions contribute to challenging situations for the winter maintenance, one improvement would be to add staff members or to involve the machine operators in the planning process. If studying weather reports and the previous winter’s diaries this can then be used to plan how the winter maintenance will be conducted the following day. To plan ahead can lead to more effective and directed winter maintenance, with the possibility to alter the route and prioritize exposed bike paths.

An improvement, which would benefit the users, is a real time application in which it is possible to see what paths have been cleared, where the winter maintenance vehicles currently are and when the maintenance vehicles will return again. Moreover, this technology can be used to see and coordinate the winter maintenance in real time, by seeing which parts have been cleared route optimizations can be applied.

[48] Göran Henecke Machine Operator at Peab Operation and Maintenance, interview on the 8th of June.

7 Discussion and concluding remarks

As mentioned before, policy documents, in Stockholm, present cycling as the solution to urbanization and congestion, due to space-efficient transportation and health benefits. “Sopsaltning” is a promising method that can encourage cycling even during wintertime. The use of the method has up to now been limited to NaCl. Ways to implement and test alternative substances in field have been missing. Thus, the purpose of this thesis has been to identify the possibility to use other de-icing solutions for “Sopsaltning”, and locate test segments on which the alternative solutions can be tested, and finally, identify limitations and suggest recommendations for how winter maintenance can be improved.

During this project several limitations have been pointed out and the implications of these have been discussed. The limitations of “Sopsaltning” as a method are that less friction is found on different types of surfacing compared to the results achieved on the actual bike path. This is a problem for the users; hence, the surface appears to be free of ice, when in fact it is not. Research needs to be conducted on these parts as well and not just the bare bike paths, to avoid serious injuries and unnecessary public costs. When evaluating and comparing the results, all types of surfaces should be taken in to consideration. Some of the de-icing agents might provide higher fiction on these surfaces than others.

One of the biggest problems with “Sopsaltning” is the result during weather changes. Swift changes leave no room for planning ahead which leaves the bike paths insufficiently cleared. In addition, the method is not recommended to be used during temperatures below -6 °C due to the efficiency of the current brine solution. Replacing the NaCl solution with an efficient and environmentally sustainable de-icing agent could improve the winter maintenance conditions and decrease the amounts of accidents along with environmental gains.

The current documentation about the weather conditions, salt amounts and actual result using the cyclist experiences are used to evaluate the winter maintenance method. Instead the documentation could be used to plan the following day’s maintenance. Monitoring the weather conditions in different parts of the city and then tailoring the snow clearance after the present situation. Changing the selection and prioritization of which paths to clear first would lead to a more efficient maintenance.

As mentioned before, the mentality towards the cyclist community needs to be improved. The perception that cyclists should be satisfied with what is offered, instead of obtaining the best possible solutions and results, are out-dated and potentially dangerous. Cyclists are overrepresented in traffic accidents and a large amount of these are due to inadequate maintenance. Investing in improving the maintenance levels on bike paths will actually profit the society; besides an improved sense of security on bike paths leads to a higher proportion of cyclists. A recommendation is to adopt a no tolerance policy towards accidents caused by maintenance issues, and let several different actors work towards the same goal.

The existing machine designs, used for “Sopsaltning” in Stockholm, are over dimensioned to fit on all bike paths. Procuring a smaller and narrower machine as a complement to the existing ones can help to expand the network to contain more paths.

The visual impressions seem as significant as the de-icing effects when deciding on a new de-icing agent. The users have become accustomed to a certain level of winter maintenance and the results provided with this method. Selecting a solution, which will provide less traction or leave an ice-slush would be negative for Stockholm stad, consequently the vehicle and solution which can provide the cleanest outcome is of great interest for the city. The contractor on the other hand, favours the vehicle that can provide long-term effects, such as those were a combination of both salt and brine is used. The possibility to use the same machines and attachments for “Sopsaltning” with other de-icing agents is beneficial from an economic perspective. The brine solutions can be exchanged whereas the equipment stays the same.

As mentioned earlier, there are both mechanical and chemical approaches for snow and ice control. The present chemical approach used in Stockholm is composed of NaCl in solid or dissolved form; this affects the environment and infrastructure containing metals. Discovering other solutions that reduce salt-usage without compromising accessibility and traffic safety is a possibility. During this thesis eight different combinations of solutions have been compared in regards to costs, efficiency and concentrations, environment, disadvantages and benefits.

The main issue with the de-icing solutions and combinations are the costs. NaCl is the most inexpensive de-icing agent in this evaluation and comparison, while, the most expensive solution, sodium formate, is more than nine times as costly as NaCl. Huge differences in price are a big problem; hence, the winter maintenance is restricted by a budget. However, the combinations where some of the NaCl is replaced with other agents proved to be much more effective at lower temperatures that if only using NaCl. This could indicate the possibility to use “Sopsaltning” during lower temperatures than what is routine today. The price of the most effective combination, which is NaCl/ $CaCl_2$/molasses, is approximately the double cost of NaCl. Several of the discussed agents act as dust suppressants, are less corrosive towards metals, remain on the paths longer and provide environmental gains; thus, higher de-icing costs do not necessarily imply more expensive overall maintenance.

Furthermore, the higher de-icing expenses could be justified by the fact that the cost of driving a car instead of a bike is six times more costly for the society. Thus, this could be realized by providing the possibility for car users to switch mode of transport by replacing the NaCl with more efficient and at the same time environmentally friendly de-icing agents. In addition, the desire and the budget to switch to more environmentally friendly solutions exist amongst both the client and the contractor.

Viewing the environment as the design value for the winter maintenance, then the actual cost of the de-icing agents will not be that relevant, compared to providing options that are nontoxic and have little or no environmental impact. The price differences would even out a bit, if only comparing the four most environmentally friendly de-icing combinations (molasses, sodium formate, molasses and sodium formate, sodium formate and lignosulfonate).

Evaluating the potential disadvantages of the environmentally friendly solutions is important for the selection of de-icing agent. Problems such as potential odour, short expiration date and wildlife attraction should be assessed during testing. The results of the effectiveness of the agents can come to be affected by other unexpected indicators and then the effectiveness at which temperature the de-icing agents are applied can alter.

During the field study the revealed potential challenges and limitations regarding "Sopsaltning" were compiled and the quest for stretches that fulfilled the requirements began. As expected, it was difficult to find stretches that meet all requirements; hence, Stockholm is an urban area that is densely populated. Interruptions and obstacles in the form of intersections, manhole covers and viaducts were found ever so often. The decision was made that a potential test segment should be 500 m long to ensure that the middle of the segment would be uninterrupted. It is possible that this length could be decreased while still obtaining a valid result and in that case the potential segments that would be used for testing could be several more that the ones mentioned in the field study. However, the recommendation for test segments revolved around presenting segments close to Peab's facilities on Kvastgatan and this intention was achieved even with the requirement of 500 m. The importance of presenting test segment near the storage facilities was to carry out the expressed desires from the machine operators, which found testing small amounts of solutions time consuming and inefficient.

Achieving comparable de-icing results of new agents requires using the same test method on comparable paths. In addition, experiences have shown that the de-icing results have been greatly affected by the weather conditions. Thus, testing two or more solutions simultaneously requires testing on paths close to each other. Consequently, the most favourable test segments run along the same road. Nevertheless, note that the outcome of the de-icing effects may fluctuate depending on variables such as wind direction, shielding in the form of noise protection walls, buildings, etc. In the presented recommendations, bike paths that achieve this have been preferred over paths that run along one side.

The organisation and realizations of the current winter maintenance in Stockholm can be improved. Several improvement recommendations have been presented in this thesis. The recommendations have emerged after interviews with the machine operators and Stockholm stad, and during analysis of the current machines, organisation and field study.

Currently the winter maintenance contract states that maintenance should be conducted up to twice a day, depending on weather conditions. This is sometimes not enough and during poor conditions the first snow-clearing round takes more time not managing to clear all paths before the morning rush. This problem can be solved by introducing more machines and more personnel that can execute the maintenance in shifts. Moreover, using the existing experiences about weather conditions and results of “Sopsaltning” a daily planning process can be developed and implemented. This would result in more successful winter maintenance with the possibility to target actions.

Furthermore, an additional improvement would be to expand the prioritized bike network to incorporate all bike paths and even pavements. This will demand obtaining smaller machines that can fit on narrower paths and pavements. These smaller machines can be used as a supplement to the larger ones. The disadvantage is of course that acquiring more machines and hiring more personnel is a major expense; which could be compensated by lower public costs achieved by more efficient winter maintenance and fewer accidents.

The contract for winter maintenance indicates what level of maintenance is to be obtained; the contractors then decide what trafficable is. As the description is open to interpretation, it is up to every contractor to determine what level is sufficient enough. Measurable objectives are easier to relate to and act accordingly. Consequently, introducing measurable goals will result in more constant outcomes of the winter maintenance.

The winter maintenance can be improved by using a real-time application to obtain route optimizations, an improvement that will benefit both the users and the operators. The user will gain a real time overview of which paths have been cleared so far and what part is next in line to be cleared, while the operators can use the same system to view and coordinate the winter maintenance.

8 Summarized conclusions

This project has investigated the possibility to exchange the current de-icing agents used for "Sopsaltning", and located test segments on which alternative solutions can be evaluated and compared, and lastly, limitations and recommendations for how winter maintenance can be improved have been identified.

Moreover, several limitations with "Sopsaltning" have been observed within this project. The effects and potential solutions of these have been deliberated. The conclusion from a logistical and mechanical point of view is that it is possible to change the current de-icing agents, which contain NaCl, to other alternative agents. Nonetheless, these new agents need to be tested to see if the de-icing effects meet the results of the laboratory studies even in field.

Consequently, the conducted field study took into consideration the discussed limitations and presented several potential test segments that meet the requirements. Bike paths located on both sides of Nynäsvägen between Sockenvägen and Gubbängen are presented as the most beneficial test segments. As a result of the location being closest to the contractor's storage facilities and the design of paths does not contain any limiting obstacles. Furthermore, the paths run along the same road thus being exposed to similar weather condition and then two de-icing agents can be tested and compared at the same time.

The current winter maintenance could be improved by extending the prioritized bike network, procuring more machines, personnel and several different contractors, introducing measurable goals for the result of the maintenance, route-optimization and real-time applications to see which paths have been cleared, and daily planning process that uses the existing experiences and weather reports to accomplish a more successful winter maintenance with the option to target actions.

In conclusion, to improve the winter maintenance method in Stockholm and to achieve sustainability from an environmental point of view higher financial resources are required. These resources should be seen as investments since an improved winter condition on bike paths could lead to higher amounts of cyclists, which in turn could lead to health benefits; provide public gains in form of reduced emissions and fewer accidents, as well as possible environmental and material gains if decreasing the amounts of salt.

9 Future research and follow-up

Based on this report, one of the most natural follow-ups is to test and evaluate new de-icing solutions on the recommended and proposed stretches of the prioritized bike network. The focus should be on evaluating the effects of the solutions de-icing properties, assessing if these have the same impact on ice and snow in the field as in the lab. Followed by, using these results to recommend a change to an alternative solution. In addition, further research involving the de-icing agent can be conducted on different types of coloured asphalt and paint coatings. Then it will possible to examine and determine which type of coloured asphalt and paint coatings provide most friction with which de-icing agent.

Moreover, a cost benefit analysis, CBA, where all of the de-icing agents are compared and evaluated based on costs, environment and efficiency based on field results could be conducted. This CBA would then act as a foundation for the decision making process when recommending new de-icing agents, this would enlighten the hidden costs and gains of de-icing agents.

As a complement to the information received by Cycleurope more information is required about the potential negative effects of salt on bike tires, on bike frames constructed in for example carbon fibre and the effects on electric bikes and their batteries. The cycle market is expanding; new materials and new types of bikes are emerging. Another potential research field is the effects of different de-icing agents on bikes and bike components. This is to minimize and avoid the use of solutions that will damage and cause unnecessary wear on bikes.

Furthermore, the research can continue by developing and providing a real time application, in which it is possible to see if a certain path has been cleared of snow. This is something that could benefit the road users and encourage more people to take the bike during wintertime and thereby improve public health.

Lastly, research has begun on developing and testing new types of surfacing specially designed for bike paths. This surfacing can be further tested and evaluated with regards to winter conditions. One approach is to test the winter maintenance on these new materials as well, to test which of the de-icing agents will leave the best result.

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Appendix I: Interview questions for Stockholm stad

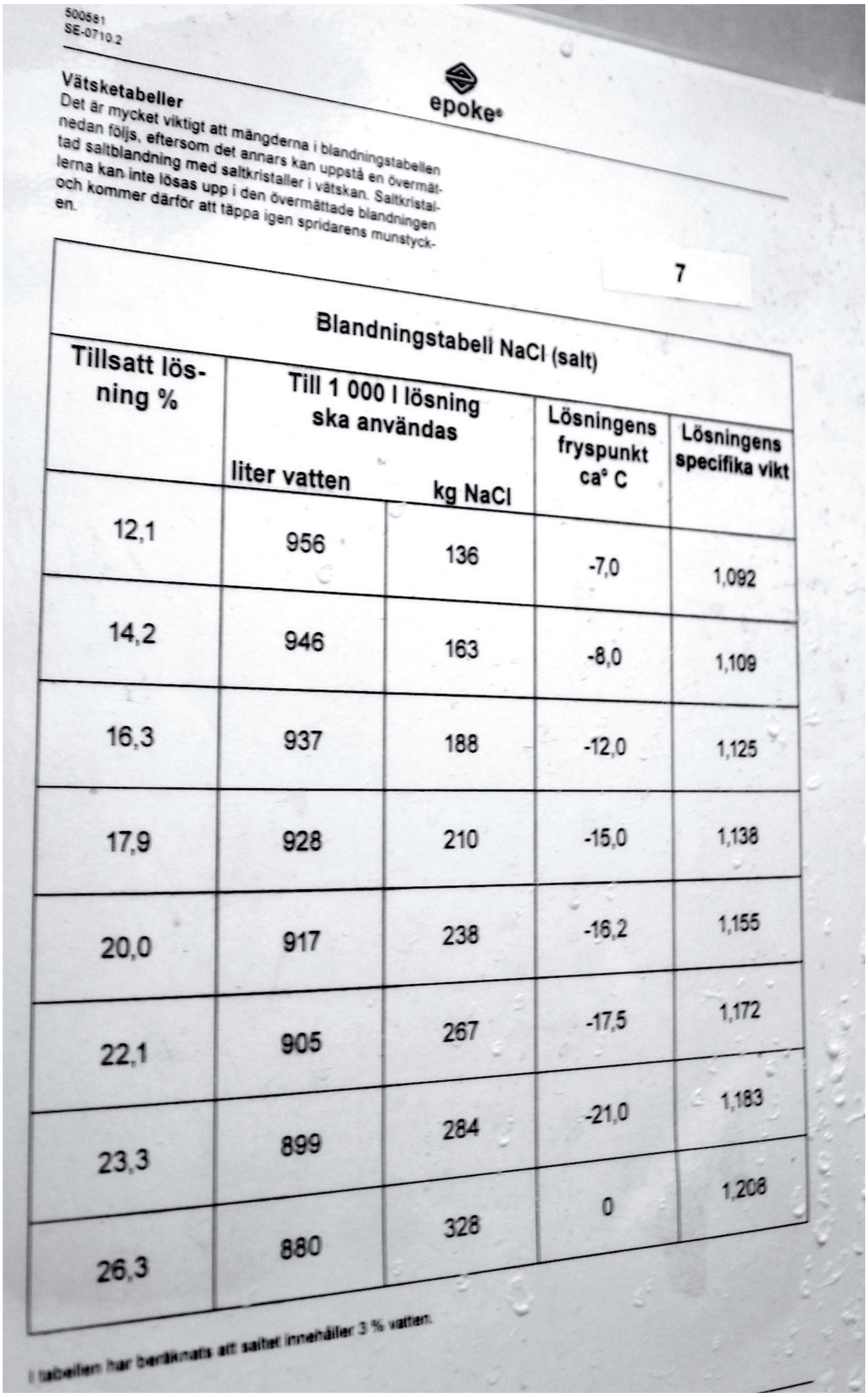
1. Namn och titel
2. Beskriv snöröjningen.
3. Vad förväntas av entreprenörerna?
4. Hur lång tid löper det nuvarande vinterväghållningskontraktet?
5. Hur gör ni om ni inte är nöjda med deras insatser? LOU – kan ni väga in bra/dåliga erfarenheter?
6. Hur lång tid har det tagit att byta?
7. Hur prioriterats det? Är det skillnad på prioriterat cykelstråk och vanlig GC-bana?
8. Hur mycket salt gick åt totalt? Finns det en ekonomisk översikt?
9. Finns det utrymme för dyrare lösningar, om dessa är mer miljövänliga?
10. Hur förvaras saltet? Hur länge?
11. Hur ofta ska det röjas? Under pågående nederbörd? Barmark? Minusgrader? Finns det någon övervakning av kommande väderförhållanden så att man manuellt kan skicka ut bilar när man vet att det ska börja snöa, okulärbesiktning?
12. Hur funkar överlappningen mellan olika entreprenörer/olika vinterväghållningstekniker?
13. Hur ser beredskapen ut? Körs det dygnet runt, sju dar i veckan?
14. Vilka situationer/förutsättningar är svårast för snöröjningen? När gick det sämre att sopsalta? Varför? Hinder, temperature, gropar, hål, korsningar, nederbörd, vägutformning?
15. Vad gör ni när det är för dåliga förutsättningar? Uppmuntrar till att blanda metoder eller låter snön vara? Hur påverkar detta den fortsatta snöröjningen?
16. När det uppstår modd, vallar och salthögar, åtgärdas detta på något sätt efteråt? Ingår extra insatser i avtalet eller är det en extra kostnad och i så fall uppmuntras det till att använda dessa?
17. Upplevdes det att vissa delar av cykelbanan var mer hala? I så fall kan du ge exempel på typ av underlag?
18. Några skillnader på tillvägagångssättet jämfört med föregående år? Utökning, utrustning osv?
19. Finns det möjlighet att testa en annan lösning på utvalda sträckor nästa vinter? Var skulle en sådan stäcka kunna vara? Vill ni helst då köra med hela taken full eller mindre?

20. Vad ska vi undvika när vi väljer teststräcka?
21. Vad tycker du kan förbättras för att få till en bättre snöröjning?
22. På hemsidan står det att ni testar och utvärderar nya metoder löpande, spännande! Kan du berätta lite om vad ni har testa förr och vad ni testar nu, kan man ta del av utvärderingarna på internet? Var ni med och testade CMA? Vad kom man fram till då?
23. Miljöbarometerna gör resvaneundersöningar samt undersökningar kring hur mkt Antal kilometer cykelväg, cykelbana och cykelfält i Stockholms stad, 2011års värde var 762 km, nyare siffror?
24. Övriga planer för framtiden, resvaneundersökningar för att se antalet som cyklar?
25. Kommunvelometern är ett ganska bra verktyg för att se hur staden ligger i förhållande till andra kommuner. 2015 års undersökning har kommit och Stockholm ligger på en 12:e plats, av totalt 37 kommuner. Det som staden faller på, enligt undersökningen, är drift och underhåll samt även befintlig infrastruktur. I Stockholm läggs 197 kr/invånare på infrastruktur och underhåll medans medelvärdet ligger på 286 kr/invånare. Dessutom går endast 4 % av denna budget till drift och underhåll ca 7,3k kr/invånare medans medelvärdet ligger på 34 % det vill säga 93,5 kr/invånare. Varför tror du att det blev så? Planeras det förbättringar? Vilka? Hur? Och När?

Appendix II: Interview questions for Peab

1. Beskriv snöröjningen.
2. Vilka delar av Stockholm kör ni?
3. Hur prioriterats det? Skillnad på prioriterat cykelstråk och vanlig GC-bana?
4. Hur mkt salt gick åt totalt? Finns det en ekonomisk översikt?
5. Finns det utrymme för dyrare lösningar, om dessa är mer miljövänliga?
6. Hur förvaras saltet? Hur länge?
7. Skulle det vara ett problem att förvara det kortare tid? Varför?
8. Hur ofta kör ni? Under pågående nederbörd? Barmark? Minusgrader?
9. Hur ser er beredskap ut? Kör ni dygnet runt, sju dar i veckan?
10. Vilka situationer/förutsättningar är svårast för snöröjningen? När gick det sämre att sopsalta? Varför? Hinder, temperature, gropar, hål, korsningar, nederbörd, vägutformning?
11. Vad gör ni när det är för dåliga förutsättningar? Blandar metoder eller låter snön vara? Hur påverkar detta den fortsatta snöröjningen?
12. Vilka fordon har ni att tillgå? Hur många totalt? Hur många förare finns det, en per bil?
13. Vilket av dessa är bäst? Varför?
14. Hur stor tank har de? Hur blandar ni lösningen innan eller i fordonet? Finns det några andra begränsningar?
15. Vilka inställningar kördes fordonen med? Hur mkt salt per m2?
16. Är spridningen konstant på fordonen eller varierar det med tillexempel hastighet?
17. När uppstår modd, vallar och salthögar? Åtgärdas detta på något sätt efteråt?
18. Upplevde du att vissa delar av cykelbanan var mer hala? I så fall kan du ge exempel på typ av underlag?
19. Några skillnader på tillvägagångssättet jämfört med föregående år? Utökning, utrustning osv?
20. Var ni med och testade andra lösningar?
21. Finns det möjlighet att testa en annan lösning på utvalda sträckor nästa vinter? Var skulle en sådan stäcka kunna vara? Vill ni helst då köra med hela taken full eller mindre?
22. Vad ska vi undvika när vi väljer teststräcka?
23. Vad tycker du kan förbättras för att få till en bättre snöröjning?

Appendix III: Dosing scheme for EpoMix 20



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Vätsketabeller
Det är mycket viktigt att mängderna i blandningstabellen nedan följs, eftersom det annars kan uppstå en övermättad saltblandning med saltkristaller i vätskan. Saltkristallerna kan inte lösas upp i den övermättade blandningen och kommer därför att täppa igen spridarens munstycken.

7

Blandningstabell NaCl (salt)

Tillsatt lösning %	Till 1 000 l lösning ska användas: liter vatten	Till 1 000 l lösning ska användas: kg NaCl	Lösningens fryspunkt ca° C	Lösningens specifika vikt
12,1	956	136	-7,0	1,092
14,2	946	163	-8,0	1,109
16,3	937	188	-12,0	1,125
17,9	928	210	-15,0	1,138
20,0	917	238	-16,2	1,155
22,1	905	267	-17,5	1,172
23,3	899	284	-21,0	1,183
26,3	880	328	0	1,208

I tabellen har beräknats att saltet innehåller 3 % vatten.