CHALMERS
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Comparing rubber modified asphalt to conventional asphalt

Assessment of Trafikverket's road survey tool

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

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The way of rubber tyres to asphalt (HNA, 2012) (ecore Athletic, n.d.) (RuBind inc., n.d.)
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ABSTRACT

Asphalt is more than a black material that covers our roads. It is a complex material that contains various aggregates, fillers, bituminous binders and additives and can be produced with different modifications. One of the latest modifications is asphalt with rubber crumbs from recycled tyres. According to studies from the USA, rubber increases the road surface's resistance against wearing, plastic deformation and cracks, which provides a longer lifetime compared to conventional asphalt.

The aim was to analyse if rubber modified asphalt (RMA) also would have the same benefits on Swedish roads, considering the different climate zones and the use of studded tyres during the winter period. The quality of the road surfaces was determined by the condition of texture and rut depths. The results were based on annual surface measurements on roads within the same climate zone, similar paving date and traffic volumes. The suitability of the Swedish road administration's tool (PMSV3) for road surveys was also to be assessed. Comparing the measurements from PMSV3 to more accurate measurements determined the quality of the survey data.

The RMA was best suited in climate zone 1 with a longer lifetime on most of the analysed roads. In climate zone 2 the results were not clear enough for a certain conclusion and in climate zones 4 and 5 no clear results were obtained due to insufficient measurements. In climate zone 3 no roads were analysed. The texture on rubber modified asphalts was better on most of the analysed roads in the south of Sweden. The suitability of PMSV3 as a survey tool was analysed by comparing the measurements on the E4 in Uppsala and the principle road 47 in Falköping. The values differed by ±7% in Uppsala and ±18% in Falköping.

To conclude from the results PMSV3 is suitable as a survey tool regarding accuracy and cost, but needs further revision. The rubber modified asphalt contributes with better texture and increased rut resistance especially in climate zone 1. It has a good potential and needs further measurements for clearer results.

Key words: Rubber modified asphalt, RMA, GAP, polymer modified asphalt, PMSV3, Objektsmätning, rutting, texture, MPD, ABS

Jämförelse av gummimodifierad asfalt med konventionell asfalt

Bedömning av Trafikverkets analysverktyg för vägbeläggningar

Examensarbete inom master programmet Infrastructure and Environmental Engineering

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SAMMANFATTNING

Asfalt är mer än ett svart material som täcker våra vägar. Produktionsprocessen är väldig komplex då asfalt består olika aggregat, filler, bituminösa bindemedel och tillsatser som gör att många olika modifieringar kan tillämpas. En av de senaste modifieringar är asfalt med gummigranulat från återvunna däck. Enligt amerikanska studier ökar gummimodifierade asfaltbeläggningars motståndskraft mot slitage, plastiska deformationer och sprickor som resulterar i en ökad livslängd jämfört med vanlig asfalt.

Syftet var att analysera om gummimodifierad asfalt (RMA) har samma förmåner på de svenska vägarna med tanke på att klimatet skiljer sig och att dubbdäck används under vinterperioden. Vägbeläggningens tillstånd bedömdes utifrån textur och spårdjup som analyserades från mätningar på vägar i samma klimatzon, likartad beläggningsdatum och trafikflöden. I den andra delen av arbetet bedömdes hur lämpligt Trafikverkets analysverktyg (PMSV3) är för mätningar på asfaltytans tillstånd. Bedömningen byggdes på jämförelsen av PMSV3's mätvärden med värden från mer avancerade mätmetoder.

Enligt beräkningarna lämpar sig användningen av RMA bäst i klimatzon 1, där texturen var bättre och livslängden var längre än vanlig asfalt. I klimatzon 2 var resultaten inte entydiga för en slutgiltig slutsats och i klimatzon 4 och 5 var värdena otillräckliga föra att få tydliga resultat. I klimatzon 3 analyserades inte någon sträcka. För att bedöma lämpligheten för PMSV3 jämfördes mätvärdena för E4:an i Uppsala och riksväg 47 i Falköping, där mätvärdena skilde sig med ±7% respektive ±18%.

Slutsatserna är att PMSV3 väl lämpar sig för bedömningen av asfaltytans tillstånd ur noggrannhets- och kostnadssynpunkt. Gummiasfalt uppvisade potential för bättre textur och ökad slitagemotstånd främst i klimatzon 1 och behöver ytterligare mätningar för tydligare resultat.

Nyckelord: Gummimodifierad asfalt RMA, GAP, polymermodifierad asfalt, PMSV3, objektsmätning, spårdjup, textur, MPD, ABS

Contents

Preface

We are proud to have finished our education in Civil Engineering with a Master's in Infrastructural and Environmental Engineering with this thesis.

This thesis is an attempt to support the Swedish transport administration with its maintenance work on asphalt pavements. It had also the goal to be part of the rubber asphalt development that currently is going on in Sweden. Our role in this development was to analyze the current state of the performance of rubber asphalt test sections in Swedish climate conditions and provide a base for future analyses and working procedure. All conclusions made in this report are our own and were based on the results and experience we have gathered during our work.

We want to thank our supervisors Jan Englund at Skanska and Torsten Nordgren at the Swedish transport administration for making this thesis possible and for the support and material they have provided during our work. We would also like to thank our supervisor and examiner Gunnar Lannér at Chalmers University of Technology for his help and advice.

Finally we want to thank all the people that have answered our questions, contributed with ideas and showed interest for our work.

June 2015

Sandra Hellwig and Abdullah Karri

Notations

ABS	Asphalt concrete, high percentage of stones, standard type
ABT	Asphalt concrete, dense
B	Bituminous binder (bitumen)
GAP	Dense rubber modified asphalt
GMB	Rubber modified bitumen
HABT	Asphalt concrete, hard and dense
IRI	International roughness index
KF10	First lane from the right
KF20	Second lane from the right
KF30	Third lane from the right
KGOIII	Karl Gunnar Olsson asphalt mixing method
Med	Driving direction, south to north, west to east
Mot	Driving direction, north to south, east to west
MPD	Mean profile depth, describes the texture of the road surface measured in mm
MPD left	MPD on the left side of the lane
MPD middle	MPD on the middle part of the lane
MPD right	MPD on the right side of the lane
Objektsmätning	Special measurement for a road test section under regulated conditions
PMB	Polymer modified bitumen
PMSV3	Pavement Management System volume 3, Trafikverket's database for road data
RMA	Rubber modified asphalt
Rubber crumbs	Product from used car and truck tires used in RMA
Rutting, rut depth	Vertical compression or wearing of asphalt caused by tires, measured in mm
Rutting max 15	Rutting measured with maximum 15 lasers on the measuring car
RV	Riksväg, principal road
Trafikverket	Swedish Transport Administration
VTI	State road- and transport research institution
ÅDT	Total annual traffic divided on one day, vehicles per day

1 Introduction

1.1 Background

For a country the road network is as vital as the veins for the human body. All forms of transport, whether it is public transport, goods or car traffic rely on roads that provide safety, comfort and mobility. Since most of the roads are paved with asphalt, this material has a crucial effect on the driving quality and can be influenced in many different ways, ranging from the production process to material composition (Nordgren, 2015).

Asphalt has been used for a very long time as a sealer and construction material and could be tracked back to 3200 BC. The first modern use of this material occurred in 1829 in Lyon as a road surface for walkways. In Sweden asphalt was introduced in Stockholm for the very first time in 1876 at Stora Nygatan (Asfaltskolan, n.d.).

Even though asphalt is a very resistive material it can offer high performance under a limited time and tolerate loads to a certain degree. If lifetime or bearing capacity are exceeded, wearing appears in different forms and sizes. The most common deformations are rutting, decreased skid resistance and surface cracks. Typical causes include high axle loads (trucks), extreme temperature alterations or wrong material composition. In order to prevent these kinds of damages or to minimise the extent of their impact on the asphalt, several modifications have been developed in the material composition, material properties and in the production process. Today there are many different asphalt types optimized for different purposes and areas of use. More details and asphalt properties will be described further on in the project.

1.2 Problem

The Swedish transport administration (Trafikverket) is responsible for maintaining the public road network in order to provide safe, fast and comfortable every day driving. With annual surveys the road condition is controlled and investigated for any kind of damage. All data that is collected during these surveys is stored in a system called Pavement Management System (PMSV3), which is the Swedish transport administration's main tool for assessing the current road surface condition and is available as open source.

The VTI survey is a special ordered road survey using more advanced techniques and equipment. Roads are closed down for public traffic during these surveys in order to avoid any outer disturbance for the best possible results. Typical areas of use for VTI surveys are surface property analysis for new asphalt types, asphalt modifications and their comparison with standard asphalt. Another survey used is an object measurement (Objektsmätning), which uses the average value of three measurements for the same road section.

A new asphalt type that recently has been tested on Swedish roads is rubber modified asphalt. Many test tracks were constructed all around Sweden to determine if rubber modified asphalts are suitable for the country's roads and climate and if they result in longer lifetime, better surface properties and less wearing and deformation.

For this project the focus will be on the questions mentioned below.

1. Is PMSV3 convenient for road surveys?
2. Is rubber modified asphalt more resistant than conventional asphalt regarding rutting and change in texture over time?
3. Is rubber modified asphalt more profitable from a long term perspective?

1.3 Aim and objectives

The aim with this project consists of two parts. The first part is the comparison of rubber modified asphalt to conventional asphalt from a life time perspective. The second part is the suitability assessment of PMSV3 as an analytical tool

1.4 Limitations of the report

Trafikverket judges the road condition by four aspects, which are rutting, texture, IRI and deformation of the road edge. The comparison of the asphalt types and the analytical tools will be limited to two parameters, namely rutting and texture as well as to Swedish roads. Other deformations will be excluded in the results section. Moreover, the focus will be on rubber modified asphalt and standard asphalt despite other asphalt types appearing in the report.

1.5 Methods

Literature will be the base for the theoretical background of the project to gain understanding for the different asphalt types, production processes as well as deformations and how these are measured.

In order to establish the comparison of rubber modified asphalt to standard asphalt following steps will be used:

- Gather data from PMSV3
- Sort the data by date of placement, asphalt type and traffic volumes
- Calculate average rut depth and texture for each year and asphalt type
- Calculate the annual increase/ decrease for rut depths and texture for each type

After these steps the results will be presented in diagrams which enable a direct comparison. Furthermore, the results will be controlled if they fulfil Trafikverket's and VTI's requirements regarding rut depth and texture, as well as the remaining time before maintenance based on the latest measurement and average annual increase in rut depth.

PMSV3's suitability as an analysis tool will be assessed by comparing the rut depths measured by PMSV3 to Objektsmätning and VTI.

2 Literature review

In this chapter information about different asphalt types and production processes will be provided. The information has been retrieved from technical books, reports, studies and from the internet. Moreover, the testing methods and deformation types will be presented as a support to aid the understanding of the results in further chapters.

2.1 Asphalt types

Each asphalt type has a special purpose, area of use or specifications, which can be influenced in many ways during the production process. Most of the asphalt properties rely on the gradation, which is the aggregate size distribution, as well as the bitumen quality.

2.1.1 Conventional Asphalt

Asphalt is composed of the three main ingredients, aggregates, fillers and a binder (Bitumen). Air voids are also present in the mass depending on the grade of compaction. Other additives, such as cement occur also as ingredients. The mixture influences the quality and life time of the pavement (O'Flaherty, 2002).

Aggregates

Aggregates are crushed hard stones of different fractions. The main requirements for aggregates are the particle size distribution curve, the flakiness index and Ball-Mill value (Parhamifar, 2014). Aggregates are the most important part within an asphalt concrete surface to provide the essential resistance to the load and wearing. That is the reason why aggregates are present in a high amount in the asphalt concrete pavement.

Figure 1: Different sizes of aggregates (Werner Corporation, n.d.)

They can be classified in different ways either by their origin or type of preparation. Pit or bank aggregates are natural aggregates, which only need to be screened to the desired size and washed before using for asphalt production. Processed aggregates on the other hand are also natural stones, however they need to be blasted, crushed and screened to an accurate size, see Figure 1. The crushing process enables to shape the particles to an accurate size range. Another type of aggregates is synthetic, which are produced by changing the properties of the stone material (APAI, n.d.). This is either done to produce aggregates or can be a by-product.

Furthermore, aggregates can have different properties beside size and shape, such as roundness, surface texture, hardness and absorption.

Trafikverket has requirements concerning aggregates, which are closer described in Chapter 2.7.1.

Bitumen

The key ingredient of the asphalt mixture is bitumen (binding material). It is a bi-product from the oil production and is necessary to keep the aggregates attached to each other, see Figure 2. Additional functions of the bitumen are to prevent the aggregates from crushing, giving it strength to shape itself without failing, as well as giving the asphalt its bearing capacity (Parhamifar, 2014).

Figure 2: Aggregates covered in bitumen (Petro Asian FZC, n.d)

The properties of bitumen depend on the crude oil properties which vary with the origin. One property is viscosity, which relies on temperature; at high temperature bitumen is liquid and becomes solid at a low temperature (Persson, 2014). The most common process is the refining of crude oil with atmospheric and vacuum distillation. Here lighter fractions, liquid petroleum gas, are separated first in atmospheric distillation and remaining fractions are removed within the vacuum distillation. The last step is done to prevent overheating. Further processes are available to achieve a variety of different properties (Persson, 2014).

To obtain the main properties of the bitumen different test are available, the softening point test, also called ring and ball method, and the needle penetration rate test, further described in Chapter 2.4.2.

In colder climate a softer binder shall be used due to its properties, and harder binder in warmer climate. In order to choose the correct binder type it is necessary to know the different climate zones in Sweden and in which one the asphalt will be used, see Chapter 4.

The price of bitumen is related to the price of HSFO, refining High Sulphur Fuel Oil; and additional costs of production, storage, packaging and additives.

2.1.2 Modified Asphalt

Changing demands on roads, pavements and additional climate changes have made it necessary to look deeper into the asphalt properties. The aim was to modify bitumen and asphalt so that the properties fulfil the higher demands and can meet these changes. One solution was additives, which are added to the bitumen or to the final asphalt mix. Below two different types of modification are described.

Polymer Modified Asphalt

Due to an increasing traffic load and a rapidly changing climate new kinds of asphalt need to be developed to resist these changes. One solution is to add polymers to either asphalt or bitumen (Persson, 2014).

These modifications were firstly patented during the mid-19th century with natural and synthetic polymers, mainly using neoprene latex and during subsequent-centuries the modification was further developed. Therefore in the 1970s PMA was commonly used in Europe due to lower maintenance cost, however further development of polymers made it more attractive to use in the US and other parts of the world (Yildirim, 2005).

The most common polymers that are styrene-butadiene rubber (SBR), styrene-butadiene – styrene (SBS), ethylene-vinyl-acetate (EVA), polyethylene and rubber (Yildirim, 2005).

This modification can increase the resistance of the pavement to withstand the increasing traffic load (Persson, 2014). Additionally, the main aim of PMA is to achieve greater elastic recovery of the binder, a higher softening point and viscosity as well as improving the cohesive strength and ductility when compared to conventional asphalt (Yildirim, 2005).

Rubber modified asphalt (RMA)

The modification of bitumen with rubber started in the early 1840's in the USA with the purpose to develop a road surface treatment with higher elasticity. The goal was to enhance the elastic properties of the binder through the addition of natural (latex) and synthetic rubber (crude oil based polymers). Since then, on-going development had continued until the early 1960s, when Charles McDonald, materials engineer for the City of Phoenix, succeeded in creating an asphalt mix with rubber crumbs.

Sweden also performed some tests in the 1950s with the goal of improving the road surface properties in addition to solving the environmental issue with scrapped tires (Asfaltskolan, n.d). They came up with a technique later on, the dry process, which is described later on in the report.

McDonald's success initiated entire projects to test the new surface treatment, whereupon many new asphalt products were developed such as Stress Absorbing Membranes (SAM) and Stress Absorbing Membrane Interlayers (SAMI) (Heitzman, 1992). As illustrated in Figure 3, the SAM layer is a chip- seal coat using asphalt-rubber instead of pure bitumen binders in the conventional method. When the SAM is overlaid with a coat of hot mix asphalt it is referred to as SAMI (FHWA, 2012).

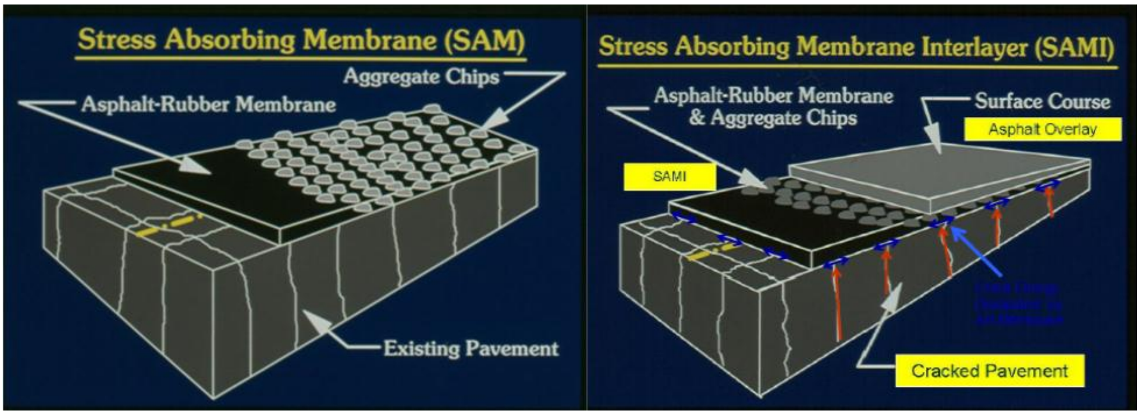


Figure 3: Schematic design SAM & SAMI (Way, George, 2012)

In the chip seal coating procedure the hot asphalt- rubber liquid is sprayed on the road surface, followed by aggregate material. The hot liquid is sprayed with a special distributor truck and the aggregates are spread out immediately and evened out with a roller as illustrated in Figure 4 (Carlson & Zhu, 1999). This technique however is mainly used in the US and not common in Europe, due to the bad working environment including fumes (Nordgren, 2015).

Figure 4: Chip seal coating. Spreading out aggregates on hot asphalt- rubber liquid (City of Mankano, n.d)

The main functions of the layers with rubber modified asphalt are:

- Absorption of stress caused by traffic and impact reduction on the remaining road construction
- Decrease reflective cracking
- Decrease noise
- Higher tolerance to thermal changes
- Decrease overall costs
- Better skid resistance

RMA's are produced in two different processes, the wet process and the dry process which give the asphalt different final performance- and working properties. These are described in the coming chapters of this report.

Advantages

Studies in northern and central Arizona on asphalt-rubber mixes showed that these modifications increase resistance against aging to a small degree. Moreover, increased resistance to hardening and improved fatigue life has been indicated as well as decreased sensitivity to temperature changes. The softening point for the asphalt-rubber increased by 11-14 °C, which is an important factor for rutting during warmer periods of the year (FHWA, 2012). Another benefit is the increased skid resistance and binder elasticity, which reduces the risk for rutting and cracking (Amirkhanian, 2013).

The greatest benefits of asphalt- rubber hot mix overlays were the reduced layer thicknesses and the associated reduction in the material usage and maintenance costs. Both chip seals and the hot mix overlays were found to have a great effect on reducing the reflection of alligator cracks, however the hot mix overlay provided a better riding surface and decreased traffic noise (FHWA, 2012). In general, RMA provides a longer overall pavement life and the possibility to use standard HMA paving and compaction equipment facilitates the work for contractors (Amirkhanian, 2013).

Disadvantages

Despite all benefits from RMA it also comes with some disadvantages. The use of RMA implies higher initial costs, which were twice the price of conventional asphalt. When the patents ended the price went down continuously and nowadays RMA costs 10-20 % more than conventional asphalt in the USA (Way, et al., 2011). Another drawback is the need for a blending unit and an agitated binder storage tank, if terminal blending is not used, which implies additional costs (Amirkhanian, 2013).

Not all contractors are familiar with the use of RMA, since the workability, binder storage stability and the emission of fumes is different than conventional asphalt. In addition to that it needs to be placed within a very short time, since the temperature must not sink too much (Lo Presti, et al., 2012).

Costs for rubber modified asphalt

Asphalt types come with various properties and can be made in different qualities. The choice of the asphalt type depends then on the cost. Rubber modified asphalt in Sweden is in general 20 to 30% more expensive than conventional asphalt (Nordgren, 2015). The additional costs emerge from the extra steps in the manufacturing process such as:

- Cost for rubber crumbs
- Complex manufacturing
- Higher amount of bitumen
- Lower production capacity for the mixing unit

For these reasons the modified asphalt layers need to provide longer lifetime in order to compensate for the additional costs. How much longer it needs to last depends on the designed lifetime and varies from road to road.

2.2 Production methods

The production process starts outside the factory. The requirements on the asphalt, such as amount of traffic, axle loads and climate zone determine the choice of type and amount of aggregates as well as binder. The next steps in the process occur in the factory where the mixing begins.

There are a variety of production processes, each with advantages and disadvantages. In the sections below the conventional process is presented in addition to a recently applied process with the name KGOIII.

2.2.1 Job Mix formula

The job mix formula is the first step in the production and can be compared to a recipe, where size and distribution of aggregates are determined in addition to the type and amount of binder. As previously explained each component comes with special properties, which are chosen according to the requirements for the new asphalt. Since achieving a perfect mix is very hard, upper and lower gradation limits are set as a range to keep the desired properties of an asphalt mix (Parhamifar, 2014).

Trafikverket has established guidelines and requirements on the material and asphalt to make sure the least allowed quality is maintained. More details about guidelines are available at Trafikverket's website with the search word *underhållsstandard.*

Gradation of asphalt concrete mixes

Asphalt mixes are divided into different gradations, each to fulfil certain properties of a road project or maintenance. The differences are shown in Figure 5.

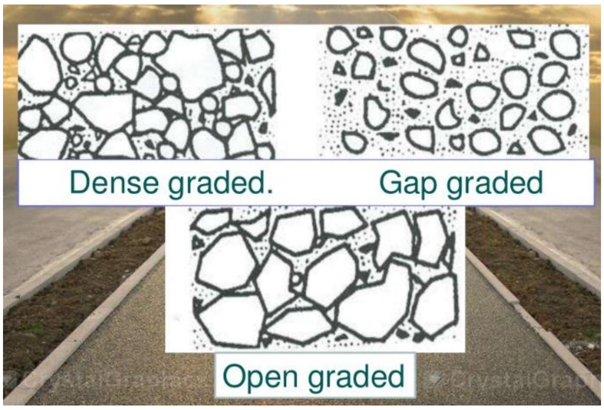


Figure 5: Aggregate structure in dense-, gap- and open graded asphalts (Tariq, 2013)

Dense-graded

Dense graded asphalt contains a well proportioned mixture of bituminous binder, aggregates, filler material, and/or some additives to change the final properties (Queensland Government, 2009). In dense graded rubber asphalts the rubber content varies between 5-10% by binder weight (Amirkhanian, 2013). It can be used in several layers of the road body as an almost impermeable layer to let water run off the road surface and improving the riding quality of the road, if used as a surface layer. The drawbacks though, are its sensitivity to hot climate and temperature variations, which could cause thermal cracking and a high risk of mirroring and less effective retroflection. In Figure 6 below, an example of a dense- graded asphalt concrete mix composition can be observed.

Figure 6: Dense graded asphalt mix (Way, George, 2012)

Open-graded

Open graded asphalt is composed of bituminous binder, aggregates and filler with or without additives (Queensland Government, 2009). It usually contains 12% to 20% rubber of the total binder mass if rubber asphalt is mixed (Amirkhanian, 2013). Only small amounts of fine material are used in order to achieve a high percentage of air voids. Figure 7 clarifies the proportions in an open gradation, especially the high content of larger aggregates. This type of asphalt is applied as a friction course with the purpose to decrease noise, increase skid resistance and increase surface drainage for higher safety.

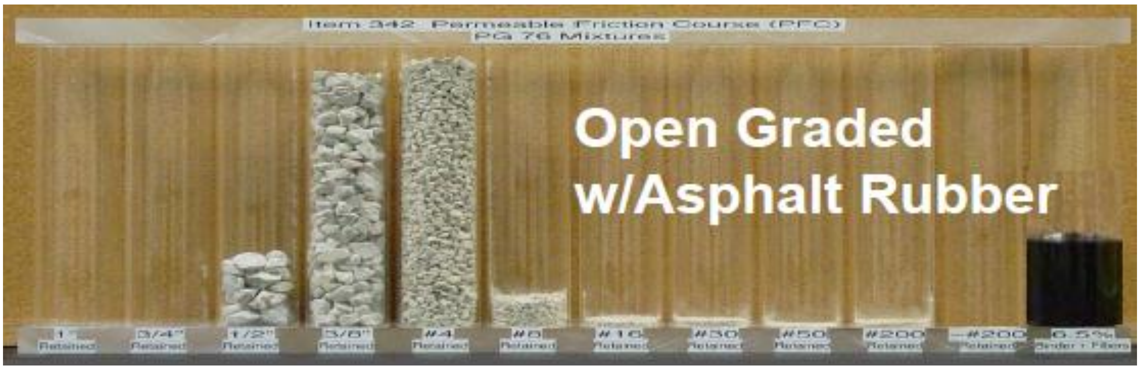


Figure 7: Aggregate content in open graded asphalt mix (Way, George, 2012)

Gap-graded

The structural differences of the gradations are shown in Figure 5. Gap- graded asphalt contains a large amount of coarse and fine aggregates, but a very small proportion of medium- sized aggregates. It has performance properties similar to the dense-graded asphalt mix; the difference though lies in the void distribution. The gap gradation creates a few large voids, whereas the dense gradation creates many small voids (Clemson University, 2002). In the rubber modified version the added amount of rubber should range from 18-20% (Amirkhanian, 2013). This type of gradation has good drainage for use in residential areas. Due to the porous structure more maintenance is necessary during the life time.

2.2.2 Conventional process

The conventional hot asphalt mix production process consists of many steps in order to reach the highest quality for the final product. In this process coarse and fine aggregates are mixed together with mineral filler and finally bitumen as the binder. The optimal proportion is obtained in a so called Job Mix Formula, which has specifications for each aggregate size and binder content. Once the asphalt mix is processed the aggregates contribute to 92% of the total weight (EPA, 1995).

There are many different hot mix asphalt plants such as Batch Mix Plants, Parallel Flow Drum Mix Plants and Counter flow Drum Mix Plants that use different techniques for asphalt production. To stay within the scope of this project, only the batch mix plant will be described since it is the most common mixing plant in Europe (Nordgren, 2015).

In batch mix plants (Figure 8) the aggregates are placed in hoppers of the cold feed unit and transported to a dryer. In the next step the aggregates have to pass vibrating screens that separate the aggregates into different sizes. Afterwards the aggregates are stored, according to their size, in heated containers. While the aggregates are weighed and mixed according to the recipe, hot liquid bitumen is pumped into an asphalt bucket in the proper aggregate bitumen ratio. The aggregates are then dropped into the mixer and mixed for 6 to 10 seconds before the hot liquid bitumen is added and mixed with the aggregates for usually less than 60 seconds. Finally the hot mixture is either stored in a hot storage silo or dropped in a truck and transported to the job site (EPA, 1995).

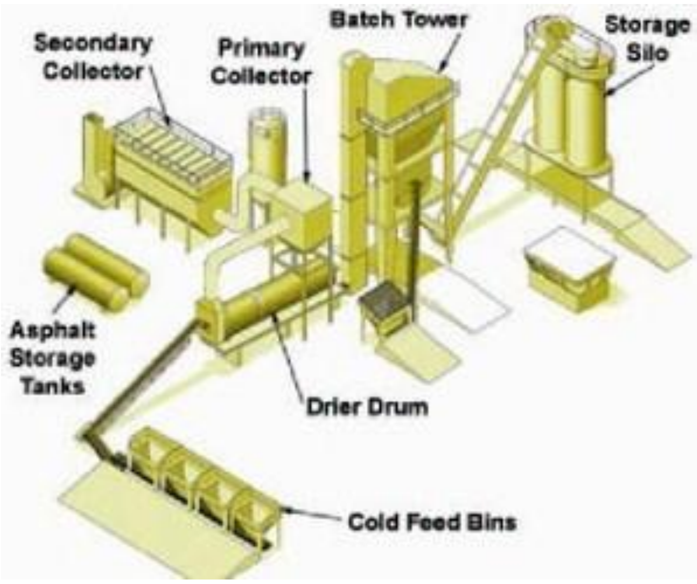


Figure 8: Batch Mix Plant (EPG, 2007)

2.2.3 Rubber modified process

For modified asphalt two mixing types exist; the wet and the dry process. Both are explained further in the Chapters below.

Wet process

In Sweden the most common method for rubber modified bitumen is the wet process. In the wet process, crumb rubber is used as a modifier for the bitumen. When the rubber is added to the asphalt and blended together a reaction starts, during which the rubber swells and softens. Continuous agitation (high viscosity process) is necessary in order to keep a homogenous mass and avoid a non-uniform distribution of the rubber crumbs in the mix (Lo Presti, et al., 2012). During the production of polymer modified bitumen the same process is used (Nordgren, 2015).

This process is influenced by the temperature and time and even the components of the materials used in the mix. The recommendations from the FHWA[1] are to keep the mixing temperature between 166˚C and 204˚C, and a reaction time between ten minutes up to two hours. The amount of crumb rubber, which is added to the bitumen can range from 18 to 25%.

According to the California Department of Transportation road overlays of a wet-process are less sensitive to distress, deflections and require less maintenance compared to conventional asphalt concrete (FHWA, 2012).

Another form of the wet- process is also known as the **terminal blend** or **field- blend**. In the refinery, the bitumen and rubber crumbs are mixed together at higher shear stress (up to 8000 revolutions per minute) at higher temperature (200 to 260˚C) until the rubber crumbs are completely digested in the binder, by depolymerisation. The difference between the two processes becomes clear in Figure 9. Terminal blend- binder can then be delivered as a conventional binder to the asphalt plant, which can use it without any modifications for the asphalt production (Lo Presti, et al., 2012).

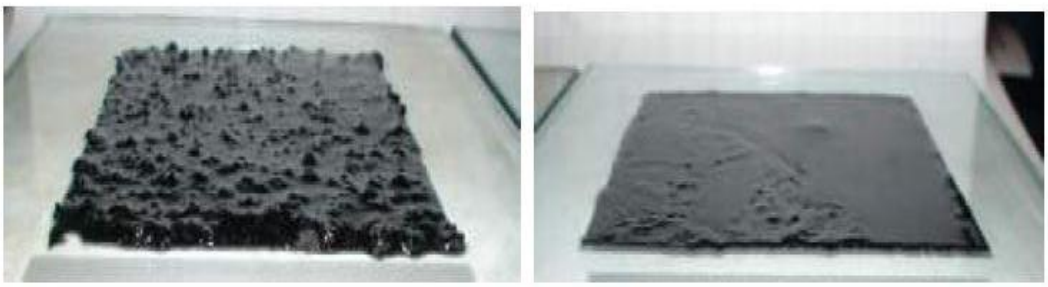


Figure 9: Rubber modified bitumen- high viscosity (left) and terminal blend (right) (Lo Presti, et al., 2012)

Dry process

In the late 1970s the dry process was developed and patented under the name PlusRide by EnviroTire. Here the granulated or crumbed rubber (1 to 3 weight percentage of the total mix) is added as part of the fine aggregates, not part of the binder as it is in the wet process. The size of the rubber particles varies from 2.0 mm to 4.2 mm. The difference from conventional asphalt methods is that this process produces denser asphalt with a void content of 2 to 4%, instead of 7.5 to 9%. Moreover, this process creates asphalt

[1] Federal Highway Administration, USA

with higher binder content, usually 10 to 20% higher than conventional asphalt (FHWA, 2012).

The addition of rubber requires both increased mixing time and temperature, which lies between 149˚C to 177˚C including preheating of the aggregates and rubber crumbs. The mixture is paved at 121˚C and needs continuous compacting until it decreases below 60˚C, otherwise the mixture would swell and be deformed (FHWA, 2012).

2.2.4 KGOIII

The KGOIII (named after its developer, Karl Gunnar Olsson) is a mixing process, developed to increase the level of homogenisation in the asphalt mixture. This process provides a thicker binder film (bitumen) and enables a complete coverage of the coarse stone material compared to conventional mixing methods (Andersson, 2008).

The process needs to follow a certain order to reach the best possible consistency and homogeneousness. First, the coarse ballast material (larger than 4mm) and the bitumen are added in the mixer followed by filler material, which is evenly spread in the mix. Finally the smaller ballast components (0 to 4 mm) are added, hence allowing the filler and the bitumen to distribute more evenly throughout the whole mass (Andersson, 2008).

Asphalt mixes for the KGOIII process have to follow strict guidelines in order to meet the standards for pavements. Compared to conventional processes the mixture in the KGOIII process should have higher content of material larger than 4mm. In addition to that the material passing through the 2 and 4 mm sieve must not exceed 8% and material passing through the 4 and 8 mm sieve should maximum be 18% (Andersson, 2008).

Heat and temperature are crucial in the mixing process. The temperature should be kept between 130°C and 140°C and temperatures over 150°C must be avoided in order to prevent the asphalt mix from damaging (Andersson, 2008).

Advantages with KGOIII

The advantage with this method is to achieve a better and more complete coverage of the stone material and a thicker bitumen film around them. This makes the asphalt more resistant to wearing. Moreover the process requires lower temperatures and lower binder content (0.5% less binder) without compromising compaction and pavement properties, which enables saving energy and decreasing environmental impacts.

Disadvantages with KGOIII

This method has some drawbacks, however not in the quality. The drawbacks lie in the production capacity of the asphalt plant and the workability of the mass. The longer mixing processes lower the capacity of some asphalt plants, causing losses or forcing them to extend the production facility in order to compromise the slowdown.

Another point is that the KGOIII asphalt is more sensitive to failures in the mixing process and therefore requires careful management, as well as it is tougher to work with than conventional asphalt. In the paving process also problems with joints, roller cracks and fat parts (when temperature is too high) were indicated.

2.3 Deformation types

A variety of deformations can appear due to external and internal influences, such as traffic load, climate and the E-Moduli of the subgrade. These are also reasons for a change in road surface properties and performance, which make it necessary to maintain the roads on a regularly base.

2.3.1 Rutting

Rutting appears in form of surface depression or compression in wheel tracks. This can be caused by deformations of any of the pavement layers or subgrade. This occurs either as a result of bad compaction during construction or plastic movement during warmer temperatures and high traffic loads, see Figure 10 (Huang, 2003). In Nordic countries the use of studded tires is common, which also cause rutting by wearing out material each time a vehicle passes over the surface (Nordgren, 2015).

This deformation is especially visible after heavy rains and known as hydroplaning, which can be a high risk for car drivers.

Figure 10: Extreme rutting in wheel paths (Auto Vina, 2012)

It can be measured as rut depth in mm with a dipstick every 15 meters or with help of a photographic distress survey (Huang, 2003). Nowadays, the rut depth is measured with either 15 or 17 lasers on a measurement car. The data for 17 lasers may be incorrect when measuring on smaller roads, due to driving on the road side marking and measuring from the wrong origin. There the measurement with 15 lasers is recommended considering that the lanes in Sweden are getting more narrow (Nordgren, 2015).

Requirements from Trafikverket concerning rut depth are shown in Chapter 2.7.2.

2.3.2 MPD - Mean Profile Depth

The road surface is described in different forms of texture. In year 2005, Trafikverket decided that the macro texture has to be measured by mean profile depth (MPD) as a standard requirement. MPD is used internationally as a standardized measurement. From 2010 the mega texture has to be measured as well in order to identify irregularities such as potholes or bridge edges. Macro texture is supposed to measure the road surface's homogeneity for the distribution of aggregates and binder.

The surface texture has great influence on many road properties and affects friction, intern- and extern noise emission, rolling resistance, tire wear, dewatering, drainage, light reflection as well as possibly the generation of particles. Macro texture is measured between 0.5 and 50 mm and affect properties as illustrated in Figure 11.

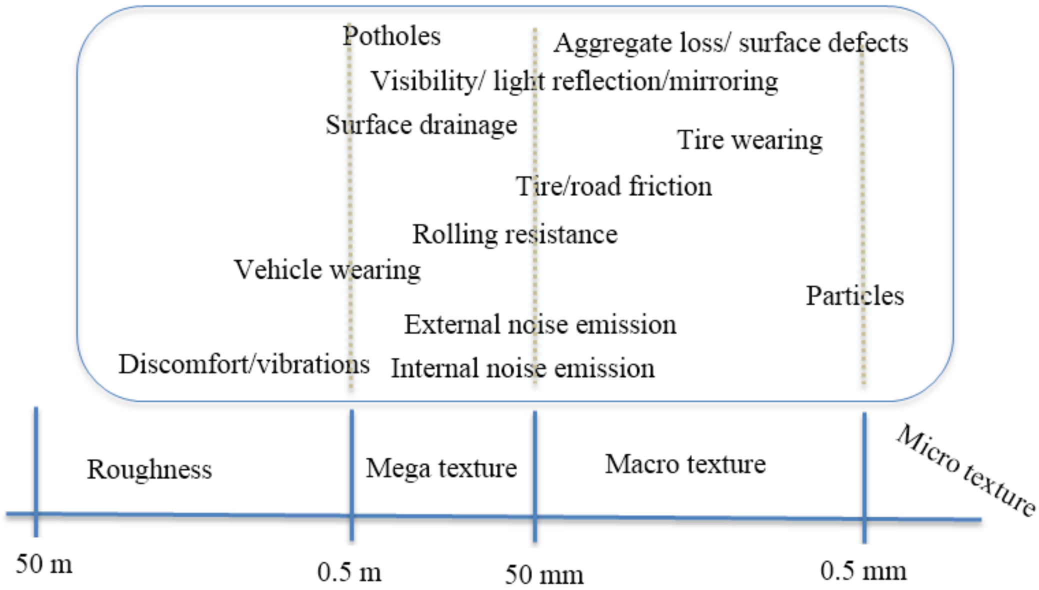


Figure 11: Micro-, macro-, and mega texture with respective wavelength interval as well as irregularities after (Lundberg, et al., 2011)

The quality of a road surface can be affected already during planning and choice of mixture. The production process can affect the final product as well as the transport to construction site, where temperature has to be kept at a certain level. The packing is also important and has to be done in a proper way.

The main properties that should be controlled for macro texture are grip and amount of binder. Low MPD implies low grip and high MPD implies low amount of binder. For a new placed pavement the results can be bleeding (excessive amount of binder) and release of aggregates (insufficient amount of binder). On the longer run the damages could develop to potholes due to bad mixing of the product and bad placing during construction. Damages are also caused by the climate especially during winter and longer exposer to precipitation in form of increased wearing. This could lead to polishing the surface where a loss of aggregate would follow. Low temperatures cause ground frost, which in turn results in ground lifting. Uneven ground lifting can cause cracks in the pavement. Finally aging also affects the surface, since the binder oxidizes with time and releases the aggregates.

MPD can be measured independent of car velocity within the interval 30 to 70 km/h without any effects on the measurements.

Requirements from Trafikverket and VTI concerning MPD are shown in Chapter 2.7.2.

2.3.3 Bleeding

Bleeding on the pavement occurs when the bituminous part of the asphalt liquefies and appears on the surface, see Figure 12. This can be due to a high amount of binder or low amount of air voids in the asphalt mixture. It can decrease the skid resistance and make the surface appear shiny, reflecting and sticky (Huang, 2003).

Figure 12: Bleeding in the wheel paths (Pavement Interactive, 2010)

2.4 Testing methods

There are different tests available for aggregates, bitumen and finished asphalt, as well as tests can be used in the laboratory and field. Further on test methods from VTI are explained in this Chapter.

2.4.1 Laboratory tests for aggregates

For aggregate testing there are a variety of methods available, these are explained below.

Los Angeles abrasion test

The Los Angeles test is performed to attain a measure of degradation of the aggregates. Aggregates must resist heavy load and crushing if used for roads. Therefore steel balls are put together with aggregates in a drum and rotated. The material is then sieved with a 1.70 mm sieve and dried in an oven. The percent loss is received after taking the new and original weight (Haseeb, n.d.).

Nordic abrasion test

This test is used to determine the aggregates' resistance to wearing and is optimized to the Nordic countries due to the use of studded tires. It is a modified version of the internationally spread Micro Deval test. Water, aggregates and steel balls are added into the drum and rotated. The calculated loss rate gives the abrasion of the aggregates due to studded tyres (Test International, 2014).

Sieve analysis - Grain size distribution

To receive a good mixture between aggregates and voids the grain size distribution is composed according to requirements. One test therefore is the sieve analysis, here the aggregates are dried and weighted afterwards. Then the aggregates are sieved, see

Figure 13, and the remaining aggregates in each sieve are weighted and the cumulative weight is calculated as a percentage of the total weight (Civil Engineering Portal, n.d.). Afterwards all percentages are summed up and divided by 100 to receive a fineness modulus.

Flakiness index

The Flakiness index is the ratio between grain width and thickness. Therefore the weight of the stone material is measured, then added into a sieve and sieved for 10 minutes. Afterwards the remained material of each sieve is measured (Lund University , 2014). Thereafter, a calculation for each proportion should be done and plotted in a sieve curve using Equation 1, Equation 2 and Equation 3. The resulting index should be below 1.55.

Equation 1: Flakiness index 1

$$k = \frac{a - 50}{50 - b}$$

where,
a …proportion material passing over 50 %
b…proportion on material passing under 50 %

Equation 2: Flakiness index 2

$$x = \frac{3 * k + 1}{4 * (k + 1)}$$

Equation 3: Flakiness index 3

$$f = 2^X$$

Figure 13: Bar sieves for flakiness index (Controls Group, n.d.)

2.4.2 Laboratory tests for bitumen

Main tests for bitumen are the ring ball method and the needle penetration test as described below.

Ring and ball

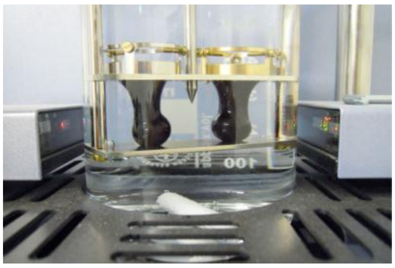


Figure 14: Ring and Ball method (Bieder & Jenzer , 2011)

With this method the temperature for the bitumen's softening point is determined, see Figure 14. Bitumen is filled into a ring, cooling down to room temperature and a steel ball is placed on it. Than the sample is placed in a beaker full with water and heated up until the ball falls through the binder. The achieved temperature gives the value of the softening point (Lund University , 2014).

Needle penetration

The needle penetration rate of the binder is achieved by placing a needle for 5 seconds on the sample of bitumen with a weight of 100g. The sample should have a temperature of 25°C. This will be repeated three times and a mean value can be calculated. It is measured in 1/10mm (Lund University , 2014). Typical penetration rates are 50/70 and 70/100 meaning that the needle penetrated the bitumen by 5 to 7 and 7 to 10 mm.

2.4.3 Laboratory tests for asphalt sample

Beside the aggregates and the binder also the finished asphalt can be tested of stability and for future performance.

CBR- California Bearing Ratio/ Marshall Compaction test and stability

For this test first an asphalt specimen needs to be produced, with the Marshall compaction. Then the hot mixed asphalt is paced in a plate cylinder and a hammer is dropped onto the asphalt 50 times from both sides. 50 Strikes reflect medium traffic load (Lund University , 2014). After cooling down, the height of the specimen is measured and put into 60°C hot water. Then the sample is put into the Marshall press with a pressure applied until failure in order to determine the specimen's strength, see Figure 15.

Figure 15: Marshall/ CBR Compression (Matest, n.d.)

Void content

Another parameter, which can be calculated, is the void content using Equation 7. Therefore the bulk density and the true density of the aggregates need to be calculated, with Equation 4, Equation 5 and Equation 6. The specimen and the aggregates need to be weighted within air then put into water and weighted again after draining (Lund University , 2014).

Equation 4: Bulk density

$$B = \frac{m1 * C}{m2 - m3}$$

Where,
B ... sample bulk density in g/cm^3
C… density of water
$m1$… dry weight in g
$m2$… water stored weight in air in g
$m3$… water stored weight in water in g

Equation 5: True density 1

$$A1 = \frac{m4 \; * \; C}{m4 - m5}$$

Where,
$A1$ … compacted density
$m4$ …sample weight in air
$m5$ …sample weight in water

Equation 6: True density 2

$$\mathrm{A} = \frac{1}{\left(\frac{\mathrm{Pb}}{\mathrm{Db}}\right) + \left(\frac{\mathrm{Ps}}{\mathrm{A1}}\right)}$$

Where,
A … compacted density
P_b …percent binder determined from table
D_b …density of binder determined from table
P_s … percent stone material (100-P_b)

Equation 7: Void content

$$H = 100 * \frac{A - B}{A}$$

Simulator for rutting

For this test a plate of asphalt is made and tested in a simulator, which can simulate different traffic loads. With this method, possible rutting can be recreated in order to determine the resistance of the asphalt mix, see Figure 16.

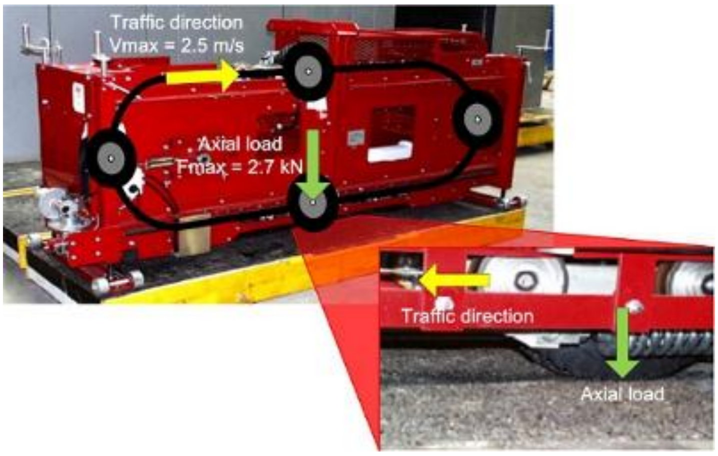


Figure 16: Tools for Accelerated Pavement Testing (EMPA, n.d.)

Prall test

The Prall test is used to measure the abrasion caused by studded tyres during the winter season. The specimen is tested for 15 minutes with 40 steel spheres see Figure 17. The abrasion value is measured in mm (Lind, 2012).

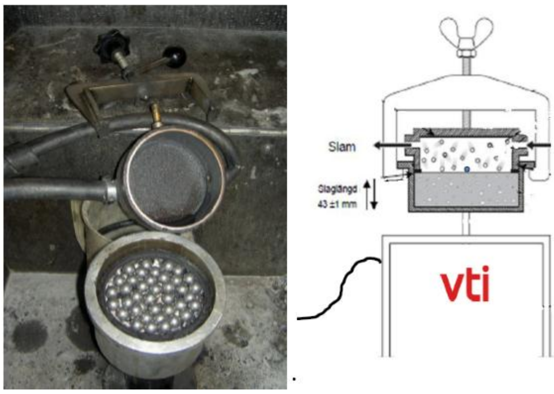


Figure 17: Test equipment and sketch (Lind, 2012)

ITSR test

The indirect tensile strength ratio (ITSR) is an indicator of the pavement's sensitivity to water. This test can predict future damage due to water (Vanseenkiste, et al., 2008). Therefore a specimen is tested under a constant deformation rate of 50.8 mm/minute to measure the ultimate failure load (Ministry of Transportation, Ontario, 2001). A dry and a wet specimen shall be tested and the maximum load is noted. To calculate the ratio Equation 8 and Equation 9 shall be used.

Equation 8: ITS for dry and wet specimen

$$ITS = \frac{2000 * P}{\pi * h_{ave} * d}$$

Where,
ITS …Indirect Tensile Strength in kPa
P…maximum applied load in N

h_{ave} … average height of the specimen in mm to one decimal place
d …diameter of the specimen in mm to one decimal place

Equation 9: Indirect tensile strength ratio

$$TSR = \left(\frac{ITS_{wet}}{ITS_{dry}}\right) * 100\%$$

Where,
$ITSwet$ … average ITS of all wet specimens in the set
$ITSdry$ … average ITS of all dry specimens in the set

2.4.4 Field tests

Field tests are available for different sub-layers of the road. Three are mentioned below.

Static plate bearing test

This test is for the bearing capacity of the aggregates in field. A hydraulic strength is added to the plates and the settlements are measured depending on added load, see Figure 18. After that a graph settlements against bearing pressure gives the bearing capacity (Subadra Consulting Ltd, n.d.).

Figure 18: Hydraulic Jack for plate bearing capactity measurement (Iowa State University, 2015)

Falling weight deflectometer

This test can be used for the road infrastructure and each layer. It is measured to identify the structural capacity and performance, load capacity of the road as well as it can be used for maintenance purposes (Roadway Inventory & Testing Section (RITS), 2005)

A weight is dropped onto a load surface and the deflection of the drops is measured with sensors in a series. A principal sketch is shown in Figure 19.

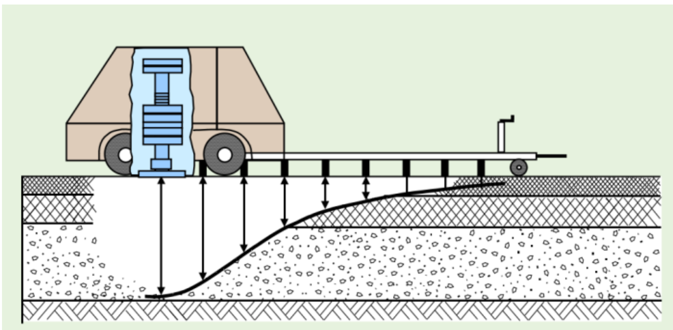


Figure 19: Sketch of FWD principal (Bast, 2010)

Rutting/ Rut depth

The manual method for measuring rut depth of the road is the straightedge method, shown in Figure 20. The maximum depth between the straightedge and the bottom of the pavement at gauge are measured. The straightedge shall have a minimum length of 1.73 m and should be laid at the two highest points on the sides of the rut, called contact areas, where the gauge is laid perpendicular to the straightedge and the distance can be measures. The measurement shall be done at various places to receive the greatest distance.

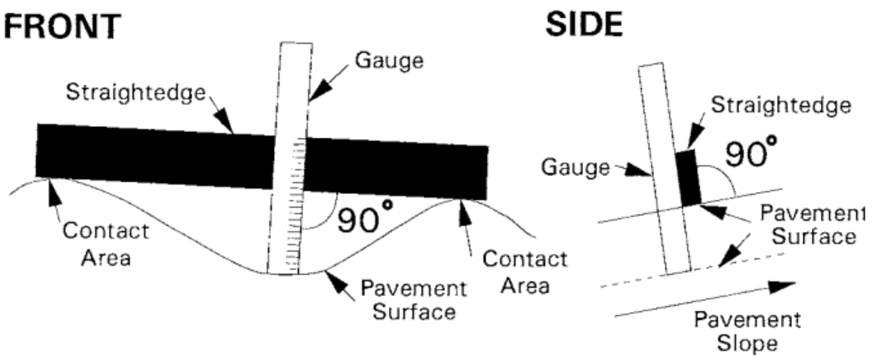


Figure 20: Rut measurement (ASTM International, 2011)

Another option is the automatic method where laser or ultrasonic transducers, also called profilometer, are used to measure the rut depth in mm of the transverse road profile.

There are various technologies available including ultrasonic lasers, point lasers, scanning lasers and optical systems. The amount of lasers can vary, for Trafikverket 15 or 17 lasers are used for the measurement. Figure 21 shows such a transducer with lasers, however due to the amount of lasers the positions are changing. The measuring steps vary depending on the speed of the measuring car (Mellela & Wang, 2006).

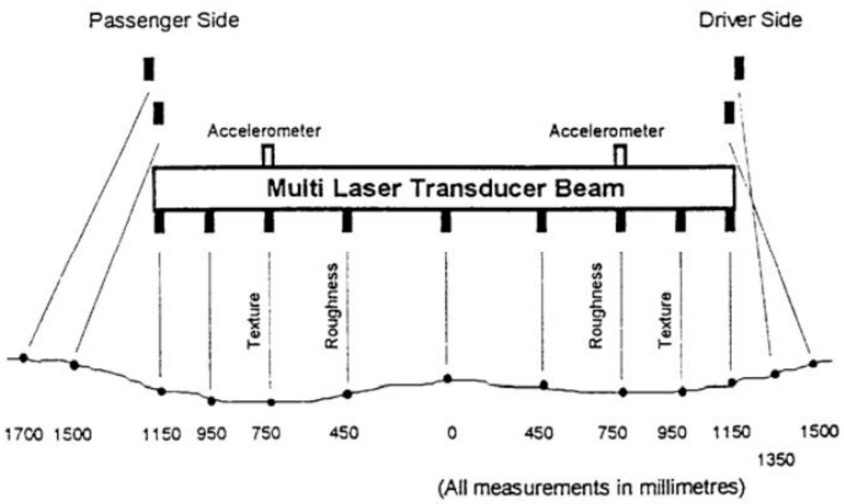


Figure 21: Multilaser/ Profilometer laser positioning (Mellela & Wang, 2006)

MPD- Mean Profile Depth

The mean profile depth can also be measured manually or with different technologies. The manual method is the Sand patch test, in which 25 cm³ of sand are filled into the apertures and spread (Kim, et al., 2013), shown in Figure 22. Further on the mean texture depth (MTD) can be calculated with Equation 10. Nowadays, glass is used instead of sand for the patch method due to it being less sensitive to moisture (Nordgren, 2015).

Figure 22: Sand Patch Test (Kim, et al., 2013)

Equation 10: Mean Texture Depth (Kim, et al., 2013)

$$MTD = \frac{4\,V}{\pi\,D^2};V = \frac{\pi\,d^2\,h}{4}$$

where,
d … Sand diameter
h … Sand Cylinder height

Another option to measure the MPD is the portable laser profile. For this test the time is measured, which the emitted laser needs to reflect from the pavement surface and back to the car (Kim, et al., 2013).

2.5 Trafikverket system

Trafikverket has an internal system, which is used for starting new projects, for their follow up and for the evaluation of projects related to maintenance. This system is composed of VU+, VUH and PMSV3 which are smaller individual, yet connected systems, see Figure 23 (Darabian, 2015).

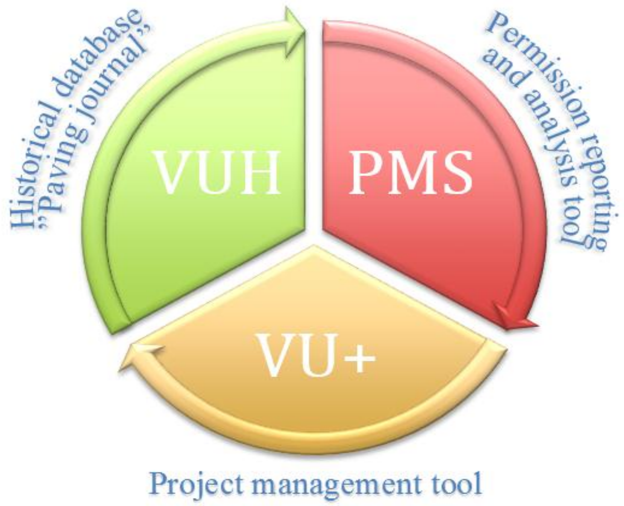


Figure 23: Systems in Trafikverket's working routines after (Darabian, 2015)

<u>VU+</u>

VU+ stands for road maintenance planning management maintenance system. It has recently been developed and renamed to PLS *paving*, which means *Project Management System for paving.* PLS is the tool for planning, cost estimation and project planning as well as project follow-ups, where the stored data provides a base for future decision making and result handling. It was developed according to Trafikverket’s requirements in order to provide an effective tool for project leaders to work in a uniform method (Darabian, 2015).

<u>VUH</u>

VUH (*vägunderhållsdata*) is an abbreviation for road maintenance data and forms the database where all paving data is stored and used as input for other systems (Darabian, 2015).

<u>PMSV3</u>

PMSV3 (Pavement Management System) is the third part of the system and provides information about the state road-network surface conditions. The data stored in VUH and other databases forms the input for several querying functions, such as IRI, rut depth, texture and other forms of deformation. Data can be retrieved for many stretches and illustrated in form of tables, graphs, maps and pictures. This enables the assessment of necessary maintenance measures at the right place and right time. Moreover it is Trafikverket’s tool for following up previous projects and evaluating maintenance methods as well as it is open to the public (Trafikverket, 2014).

2.6 Road surveys

The road surveys are necessary to determine the current state of the road. The roads are investigated for different deformations and damages such as cracks, texture, rut depths, IRI and many other parameters. In the chapter below the most relevant survey methods for this project are presented, as well as their differences.

2.6.1 PMSV3 Road network measurement

The data in the PMSV3 are recorded from a single measurement, using a specially equipped car with 17 lasers. However, measurements from 15 lasers exclude possible measurements from the verges and other irregularities. Moreover, the lane widths are shrinking which makes measurements with 15 lasers more suitable (Nordgren, 2015). The measurements are done during normal traffic conditions. The lasers record one value for rutting (rut max15) and MPD right, middle and left (mean profile depth) each 20 meters (Nordgren, 2015).

2.6.2 Object measurement (Objektsmätning)

For the Objektsmätning a car with similar equipment is used as for the survey for PMSV3. The difference is that each section is measured 3 times, which provides a higher degree of certainty for the measurements. From these three measurements an average value is determined. The measuring car is driven at traffic speed, without closing down the road in usual traffic condition. The cost for this survey type lies between 20,000 to 30,000 SEK for 5 to 10 km of measured track (Nordgren, 2015).

2.6.3 VTI

VTI uses more advanced measurements. The roads are closed in order to avoid any disturbances from traffic. For measuring the surface wearing (especially from studded tires) a laser profile meter is used that measures the profiles in estimated 1240 points per cross section (415 points per meter) see Figure 24. Moreover an area of $1m^2$ is marked and divided into 11 lines, which is measured each year. The goal with these procedures is to help identifying how much aggregates are torn out each year and how resilient the wearing course is.

Figure 24: Laser profile meters (Karlsson, 2015)

Profiles are measured with Primal (Figure 25), a method where sampling points are marked with colour and a steel nail to be sure the same spot is measured each time. A robot rolls from the middle line between the lanes and moves towards the verge, taking measurements each 4th millimetre. The cost for this survey is much higher than for the Objektsmätning and can be for 5 to 10 km up to 100’000 SEK on a high traffic road (Nordgren, 2015).

Figure 25: Profile cross section measurement with Primal (Karlsson, 2015)

2.7 Requirements from Trafikverket and VTI

Trafikverket’s standards and regulations for the entire production process of asphalt products are based on the European standards. These regulations define material properties and proportions in asphalt mixtures. Testing methods and the paving procedures have to be performed in a regulated and secure way. Moreover, once the road is constructed it should fulfil required qualities and last for the planned time frame.

The work is controlled frequently with sampling, laboratory tests and onsite tests to assure the correct quality of the material, material composition and implementation of working routines.

2.7.1 Aggregates

The mixing process is very crucial in the asphalt production regarding the product. In the mixing process time and temperature are very important regarding the binding properties and have to be monitored with great care. Binding ability for asphalt, independent of type, deteriorates the longer it is stored and it should therefore be transported to the working site as soon as possible (Nordgren, 2014).

Conventional hot mix- asphalt has the requirement to be produced in a batch- or drum mix plant with a temperature exceeding 120˚C (Trafikverket, 2005).

Table 1 below shows the required standards for stone aggregates in the asphalt mix.

Table 1: Testing standards for stone aggregates (Trafikverket, 2005)

Testing method	Standard SS-EN	Tested stone material Test fraction
Nordic abrasion test	1097-9	11,2 - 16 mm
Micro Deval value	1097-1	10 – 14 mm
Los Angeles value	1097-2	10 – 14 mm
Flakiness index	933-3	≥ 4 mm
Proportion of grains with broken and crushed surface	933-5	≥ 4 mm

2.7.2 Deformations

Mean profile depth (MPD) and rutting

Trafikverket and VTI have assembled requirements for the mean profile depth and rut depth to make a classification of MPD and rutting values possible.

In the tables below the quality of the road and the effects are presented related to MPD intervals.

Table 2: VTI classification of MPD with speed limits, considering texture (Lundberg, et al., 2011)

MPD- area in mm	Velocity 90-100 km/h	Velocity 70 km/h	Velocity 30-50 km/h
0-0.30 mm			Bad
0,31–0,50 mm		Bad	Good
0,51–0,70 mm	Bad	Excellent	Excellent
0,71–1,00 mm	Excellent	Acceptable	Acceptable
1,01–1,50 mm	Excellent	Bad	Bad
1,51–2,00 mm	Acceptable	Bad	
2,01–mm	Bad		

There are many more measurements that can be used for classification; however we chose to limit our choice to these in order to stay within the scope of the study.

Table 2 above is retrieved from VTI and modified so they fit this study. Modified means data that is not relevant for MPD or rutting was removed (Lundberg, et al., 2011).

Trafikverket has requirements and standards for MPD and rutting as well, which are presented in the Table 3 and Table 4 below (Trafikverket Underhållsstandard, 2012).

Table 3: Trafikverket requirements for MPD based on traffic volumes and speed limits (Trafikverket Underhållsstandard, 2012)

Traffic (vehicles/day)	Lowest MPD [mm] according to speed limit (km/h)							
	120	110	100	90	80	70	60	50
0-250		≥ 0.20	≥ 0.20	≥ 0.20	≥ 0.20	≥ 0.20	≥ 0.20	≥ 0.20
250- 500		≥ 0.25	≥ 0.25	≥ 0.25	≥ 0.25	≥ 0.20	≥ 0.20	≥ 0.20
500- 1000		≥ 0.30	≥ 0.30	≥ 0.30	≥ 0.25	≥ 0.25	≥ 0.25	≥ 0.25
1000- 2000		≥ 0.33	≥ 0.33	≥ 0.33	≥ 0.28	≥ 0.28	≥ 0.28	≥ 0.28
2000- 4000	≥ 0.35	≥ 0.35	≥ 0.35	≥ 0.35	≥ 0.30	≥ 0.30	≥ 0.30	≥ 0.30
4000- 8000	≥ 0.35	≥ 0.35	≥ 0.35	≥ 0.35	≥ 0.30	≥ 0.30	≥ 0.30	≥ 0.30
>8000	≥ 0.40	≥ 0.40	≥ 0.40	≥ 0.40	≥ 0.35	≥ 0.35	≥ 0.35	≥ 0.35

Table 4: Trafikverket requirements for rutting based on traffic volumes and speed limits (Trafikverket Underhållsstandard, 2012)

Traffic (vehicles/day)	Maximum rutting [mm] according to speed limit (km/h)							
	120	110	100	90	80	70	60	50
0-250		≤ 18.0	≤ 18.0	≤ 24.0	≤ 24.0	≤ 30.0	≤ 30.0	≤ 30.0
250- 500		≤ 18.0	≤ 18.0	≤ 22.0	≤ 22.0	≤ 22.0	≤ 22.0	≤ 22.0
500- 1000		≤ 18.0	≤ 18.0	≤ 20.0	≤ 20.0	≤ 24.0	≤ 24.0	≤ 24.0
1000- 2000		≤ 15.0	≤ 16.0	≤ 17.0	≤ 18.0	≤ 20.0	≤ 21.0	≤ 21.0
2000- 4000	≤ 13.0	≤ 13.0	≤ 14.0	≤ 14.0	≤ 16.0	≤ 16.0	≤ 18.0	≤ 18.0
4000- 8000	≤ 13.0	≤ 13.0	≤ 14.0	≤ 14.0	≤ 16.0	≤ 16.0	≤ 18.0	≤ 18.0
>8000	≤ 13.0	≤ 13.0	≤ 14.0	≤ 14.0	≤ 16.0	≤ 16.0	≤ 18.0	≤ 18.0

3 Method

The project was mainly built up on collecting literature from Trafikverket, VTI and international road administrations. With this data a literature review was formed with necessary information to understand the results.

Afterwards tracks with RMA were searched with help of the analysis tool in PMSV3, which can filter out tracks according to properties such as wearing course type. For the analysis on the parameters texture (MPD) and rut depth were used, since these two parameters are the most important ones for Trafikverket to determine the quality and condition of the wearing course. These properties are also used for the comparison of different asphalt types.

An analysis template in excel was programed to analyse and sort the data according to asphalt type, years and traffic volumes. Sorting the data by these variables enabled filtering out the sections, which were placed on the same date and had similar, if not equal traffic volumes. When this was achieved the two asphalt types could be compared for rut depth and texture with equal conditions. Since most of the sections included thousands of values, the average values for each section were calculated in addition to the average annual increase/ decrease, standard deviation, maximum and minimum value as well as the variance.

Afterwards the results were controlled if they fulfilled Trafikverket's and VTI's requirements for maximum allowed rut depth and minimum allowed MPD and when the next maintenance would be necessary. The years until next maintenance were calculated according to Equation 11 below and helped determine, which asphalt type lasts longer.

Equation 11: Years until next maintenance based on rut depth

$$\frac{last\ measured\ rut\ depth\ [mm] - maximum\ allowed\ rut\ depth[mm]}{average\ value\ for\ annual\ change\ since\ latest\ maintenance\ [mm/year]}$$

The classification of the texture was based on the last measured left and right MPD, which were in the contact areas of the tires on the asphalt. MPD middle could be used as an indicator for the climate impact on the surface, since this area is not exposed to the same contact frequency with tyres as the left and right side.

The next step was the assessment of PMSV3 as an analysis tool, where the measured results were compared to those from Objektsmätning on the E4 in Uppsala and from the analysis on the RV47 in Falköping from VTI. The results were expressed as a deviation in form of percent. Depending on the outcome PMSV3 was judged for its suitability for further analysis.

4 Analysis and verification of results for asphalt

All data that has been analysed will be gathered in this chapter and explained. The results will mainly be presented in form of diagrams and tables, with focus on rut depth and MPD. The rubber modified asphalt and the standard asphalt will be compared according to their resistance against wearing caused by traffic. Moreover the sections will be checked for Trafikverket's (Table 3 & Table 4) and VTI's (Table 2) classification and requirements in addition to the remaining time before the next maintenance. The majority of the investigated tracks were covered with standard asphalt and rubber modified asphalt, since they were the focus of study for this thesis. Other types were nevertheless also included, such as polymer modified asphalt, partly due to their presence in the analysed sections and partly due to curiosity.

The data for most of the tracks was retrieved from PMSV3 in this project. Additionally for the quality verification of PMSV3, measurements from Objektsmätning were used. The comparison to Objektsmätning will be mentioned; otherwise the results are based on PMSV3. More details about the measurement procedure and equipment are explained in Chapter 2.6

In Table 5 below the investigated tracks are presented with their number, asphalt type, location, length and direction. They are also sorted according to their climate zones (Figure 26), since the stiffness of the binder needs to be adjusted to the local climate for best road properties.

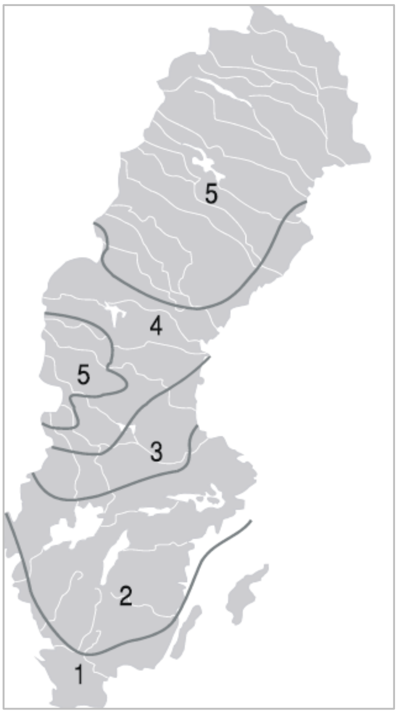


Figure 26: Climate zones 1 to 5 in Sweden (Vägverket, 2004)

In Appendix XIII a list of all analysed tracks for this study is attached. These tracks were not included in the results due to the lack of relevant or sufficient data.

Table 5: List of tracks used for the investigation according to climate zone

Road no.	Climate zone	Location	Direction	Start-and Stoppoint	Asphalt type	Lanes	Speed limit [km/h]
E4	1	Kropp-Hyllinge	Med	15870-20415	ABS 70/100 B GAP 70/100 B	10, 20	110
E6	1	Fredriksberg-Lockarp	Mot	108091-112673	ABS 70/100 B GAP 70/100 B	10, 20	110
E6	1	Kronetorp-Salerup	Mot	98965-105524	ABS 70/100 B GAP 70/100 B	10, 20	110
E6	1	Petersborg-Vellinge South	Mot	115947-125955	ABS 70/100 B GAP 70/100 B	10, 20	110
E6	1	Sunnanå-Kronetorp	Med	36016-41005	ABS 70/100 B GAP 70/100 B	10, 20	110
E6	2	Ullevi-Kallebäck	Med	176896-179689	ABS 70/100 PMB GAP 70/100 B	10, 20	70
RV47	2	Falköping	Med	21220-23720	ABT 70/100 B PMB, 6 types	10	80
E4	2	Uppsala-Knivsta	Med	84720-101445	GAP16 0.6% Wetfix GAP16 0.6% Wetfix Pt2 GAP 16% 0.3% Wetfix 1% Cement GAP 16% Increased Temp ABS 70/100 ABS 50/70 GAP 16 Increased Temp Pt2	10, 20	110
E4	2	Viby-Sollentuna, Stockholm	Mot	27317-30873	ABS 70/100 B GAP 70/100 B	30	110
E4	4	Broänge-Hökmark	Med	156720-164260	GAP16 100/150 ABS 16 100/150	10	90
E12	4	Lycksele	Med	151932-158798	ABTS 11 ABTS 11 GMB	10	50-90
E12	4	Lycksele	Mot	307155-309235	ABTS 11 ABTS 11 GMB	10	50-90
E12	4	Storuman-Stensele	Med	245181-252932	GAP 16 ABT 16 GMB ABT 16 B 160/220	10	50-90
E4	5	Gäddvik-Nickbyn	Med	72795-89450	GAP 16 ABS 16 100/150	10	110
E4	5	Gäddvik-Nickbyn	Mot	112038-130608	ABS 16 GMB ABS 16 100/150	10	110

4.1 Climate Zone 1

Climate zone 1 is the southernmost zone in Sweden with the warmest temperatures during the year. In this zone cities such as Malmö, Helsingborg and Kristianstad are located.

4.1.1 E4 Kropp- Hyllinge med

This road section is located north east of Helsingborg with a length of 13.4 kilometres (Figure 27). The speed limit is 110 km/h and the traffic volume varies between 4500, 13383 and 11734 vehicles per day, (Trafikverket, 2015). A standard asphalt ABS 70/100 B and a rubber- modified asphalt GAP 70/100 B were placed in June 2010. In the figures below the results are sorted according to traffic to enable a direct comparison.

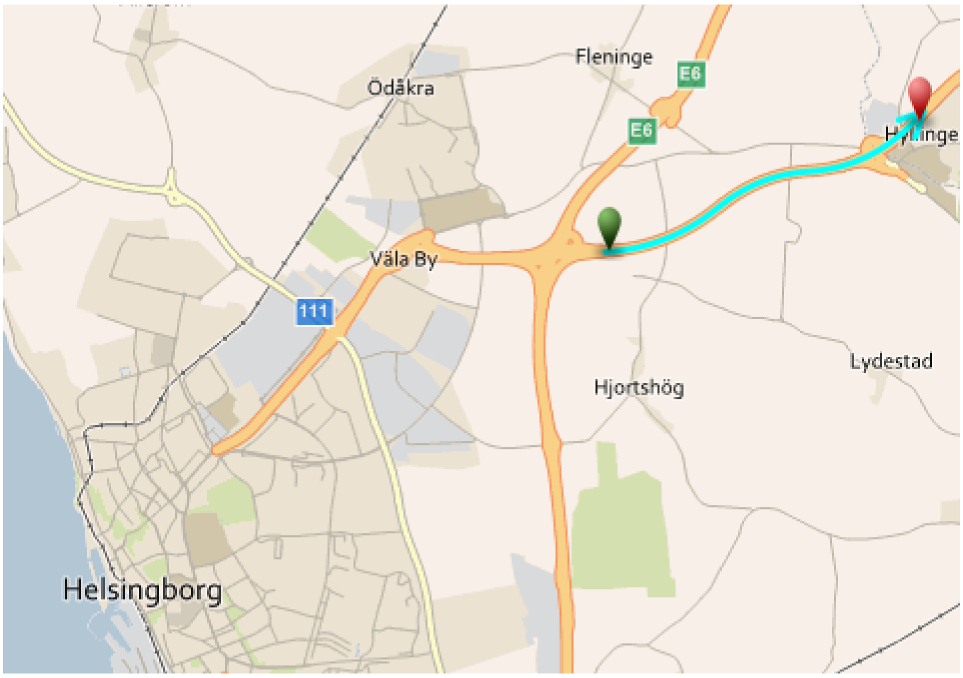


Figure 27: E4 Kropp- Hyllinge, 15870- 20415 (Trafikverket PMSV3, 2015)

KF 10

Figure 82 and Figure 83 in Appendix I: E4 Kropp-Hyllinge provide an overall picture of the average rutting and MPD values along the road. In general the road is covered with GAP and the part with ABS is relatively small, which can influence the average values. The rut depths are greater for GAP, while the MPD is higher for ABS. The peaks in the graph could not be related to potholes or major deformations on the road surface since PMSV3 did not show such.

The values in Figure 28 and Figure 29 deviate between 18- 40% from the average values, which indicates an uneven rut pattern.

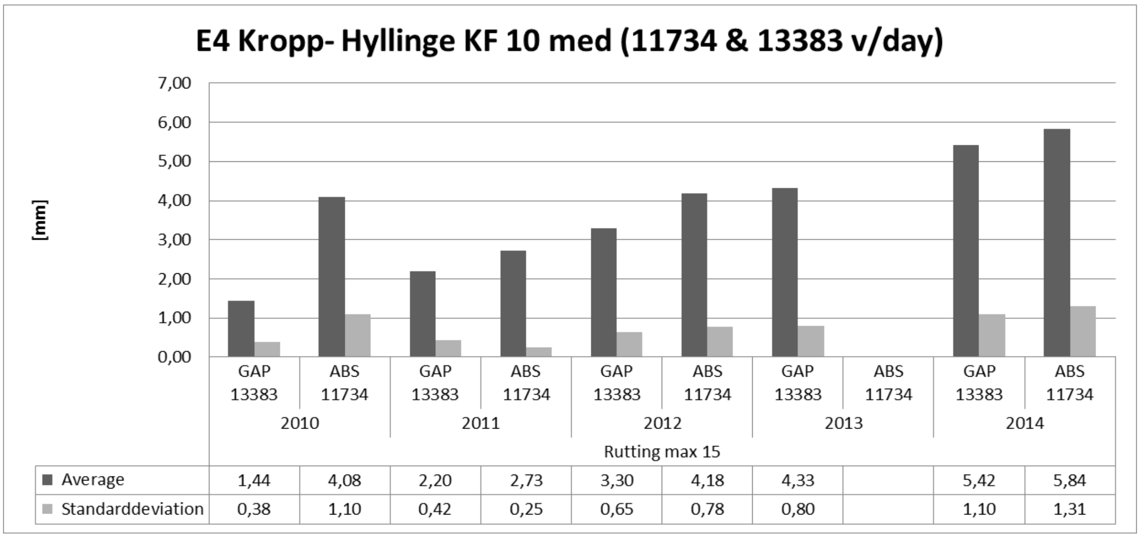


Figure 28: Average values and Standard deviation of rutting on GAP and ABS, high traffic volumes

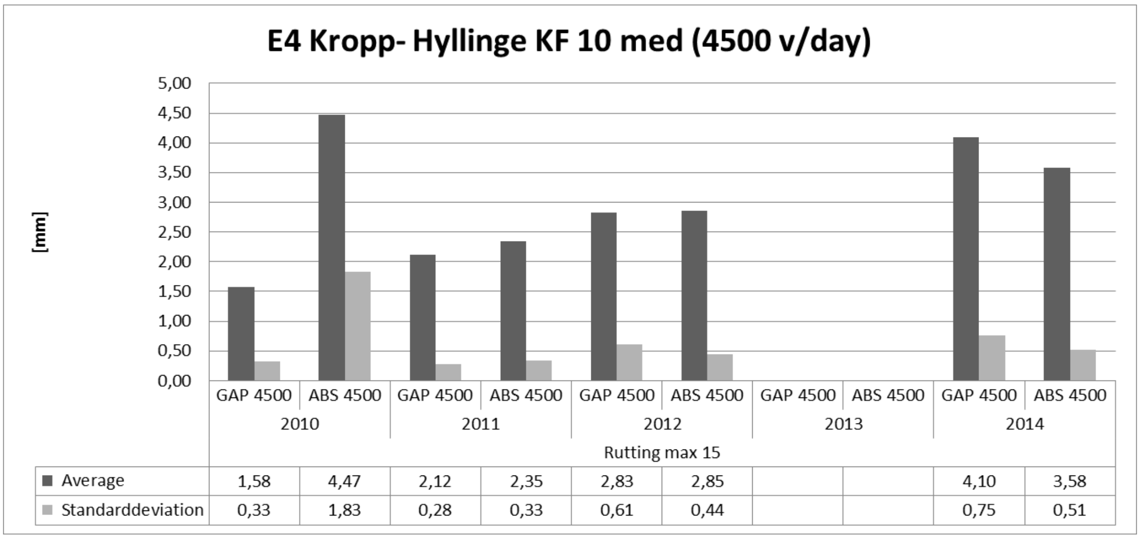
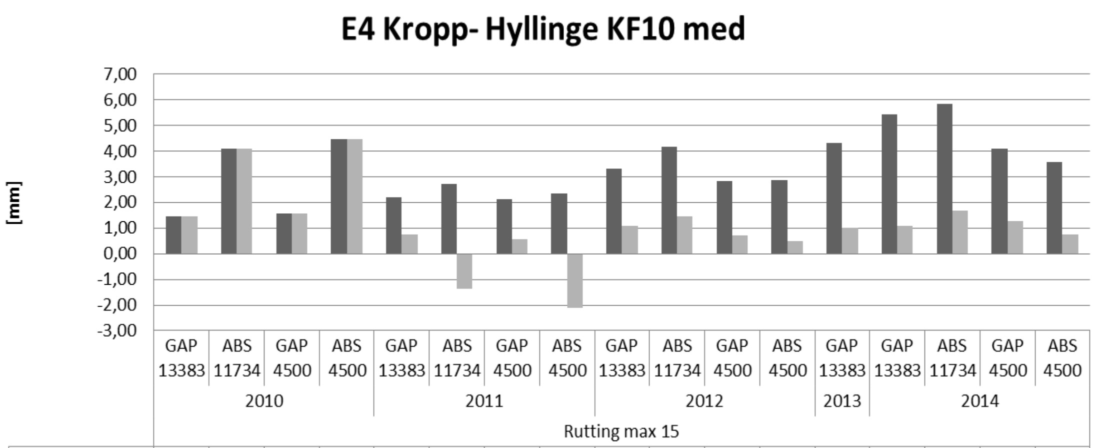


Figure 29: Average values and standard deviation of rutting on GAP and ABS, low traffic volume

In Figure 30 below the sections for standard ABS and the rubber- modified asphalt were sorted by the traffic volume and compared. The ABS was placed in 2010 after the road measurement, which explains the high values in 2010. Thereafter the increase in rut depth can be followed for each year.



	GAP 13383 (2010)	ABS 11734 (2010)	GAP 4500 (2010)	ABS 4500 (2010)	GAP 13383 (2011)	ABS 11734 (2011)	GAP 4500 (2011)	ABS 4500 (2011)	GAP 13383 (2012)	ABS 11734 (2012)	GAP 4500 (2012)	ABS 4500 (2012)	GAP 13383 (2013)	GAP 13383 (2014)	ABS 11734 (2014)	GAP 4500 (2014)	ABS 4500 (2014)
Average	1,44	4,08	1,58	4,47	2,20	2,73	2,12	2,35	3,30	4,18	2,83	2,85	4,33	5,42	5,84	4,10	3,58
Rate of change	1,44	4,08	1,58	4,47	0,76	-1,35	0,55	-2,12	1,10	1,44	0,71	0,50	1,02	1,10	1,66	1,27	0,73

Figure 30: Average values and annual change for rutting on standard ABS and GAP

According to the figure above the rut depth on the GAP increased more slowly than the ABS in 2011 and 2012. It increased on an average of 1 mm per year. In 2014 the rut depths on the GAP became higher than on the ABS on the section with 4500 vehicles per day, however on the other sections the rutting on the ABS remained higher although the traffic there is lower.

In Appendix I: E4 Kropp-Hyllinge Figure 84, Figure 85 and Figure 86 the mean profile depth was measured for the left, middle and right part of the lane. In all three figures the MPD values are higher for the ABS than for the GAP, independent of traffic.

Table 6 below shows the current state for the investigated road and if VTI's and Trafikverket's recommendations are fulfilled. The average value from all years for the rate of change on rutting will be used to estimate when the next maintenance is necessary, starting from the last measured year.

Table 6: Current state and classification for E4 Kropp- Hyllinge KF10 according to VTI and Trafikverket

Section	**Trafikverket**		**VTI (0.71-2.00 mm)**	**Years to next maintenance**
	Rutting (≤13mm)	**MPD (≥0.40mm/ ≥0.35mm)**		
GAP 13383	Yes	Yes	Bad	7
ABS 11734	Yes	Yes	Excellent	7
GAP 4500	Yes	Yes	Bad/Excellent	14.5
ABS 4500	Yes	Yes	Excellent	23

Comparing the remaining years to maintenance, the GAP and ABS have equal lifetime although the traffic is higher on the section with GAP. On the section with 4500 vehicles per day the lifetime for the ABS is longer by 8.5 years.

KF 20

The same description applies to this lane as for the first lane regarding location, traffic and materials.

According to Figure 87 and Figure 88 in Appendix I: E4 Kropp-Hyllinge the rutting is more extreme for the ABS than for the GAP. However, the difference is related to the age of the ABS, which was placed in 1994 compared to the GAP in 2010 according to PMSV3. To approve this statement these dates have to be verified since the measured values resemble those of newer asphalt compared to the other sections.

The measurements on this lane differ from those on the first lane. The ABS has much higher rutting and a much higher standard deviation than the GAP (Figure 31).

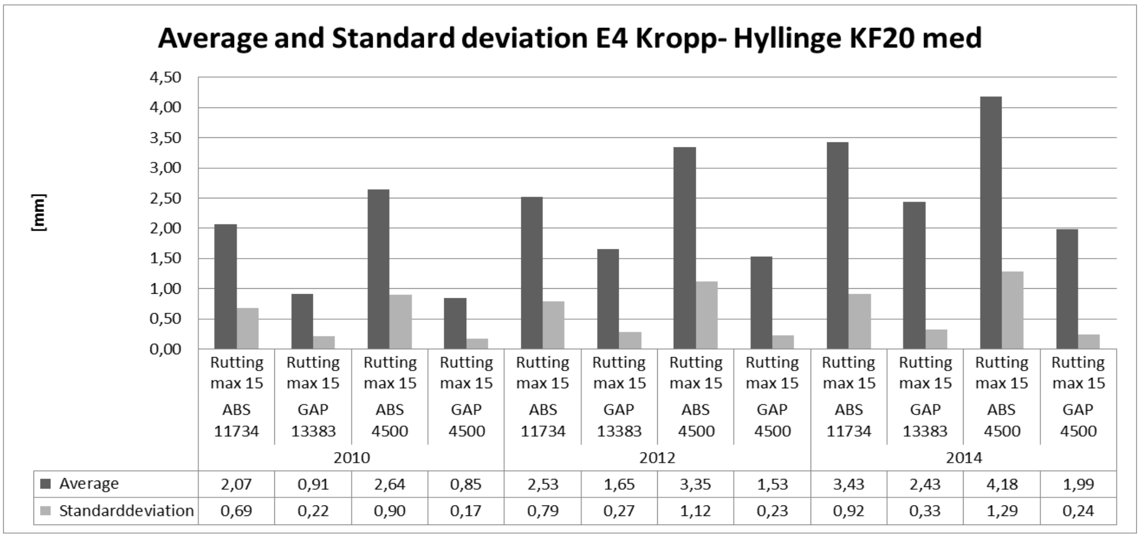


Figure 31: Average values and standard deviations for rutting, MPD left, middle and right on ABS and GAP

Knowing that there was a difference in time when the asphalts were laid, the average values are not comparable. On the other hand the rate of change in Figure 32 provides information on how fast the two surface layers deteriorate. According to the rate of change in 2012 the rut depth increases by 0.73 mm for the GAP and 0.56 mm for the ABS in two years. In 2014 the rut depth increased by 0.74 mm for the GAP and 0.87 mm for the ABS in two years.

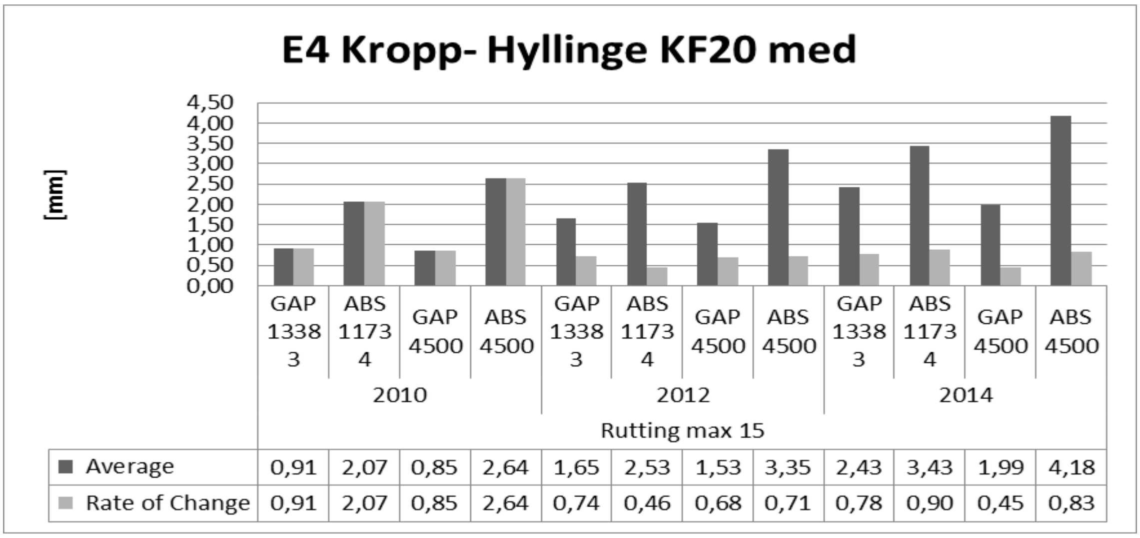


Figure 32: Average values and rate of change for rutting on GAP and ABS

In Appendix I: E4 Kropp-Hyllinge Figure 89, Figure 90 and Figure 91 the MPD's were measured. In general ABS has higher values than the GAP except for the right MPD; however for both there was no significant change visible through the years.

Table 7: Current state and classification for E4 Kropp- Hyllinge KF20 med, according to VTI and Trafikverket

Section	Trafikverket		VTI (0.71-2.00 mm)	Years to next maintenance
	Rutting (≤13mm)	MPD (≥0.40mm)		
GAP 13383	Yes	Yes	Excellent	27.8
ABS 11734	Yes	Yes	Excellent	28.1
GAP 4500	Yes	Yes	Excellent	33.4
ABS 4500	Yes	Yes	Excellent	22.9

According to Table 7 the GAP 13383 lasts two years less than the ABS 11734. At 4500 vehicles per day the GAP has 10.5 years longer lifetime than ABS. According to last years' measurements the texture is very similar for both types and in excellent condition.

4.1.2 E6 Fredriksberg- Lockarp KF10 & 20 mot

This section of the E6 is located in the south of Malmö and has a speed limit of 110 km/h (Figure 33). The road is covered with a standard ABS 70/100 B and rubber-modified asphalt GAP 70/100 B. The road was separated in sections with traffic volumes of 7157, 17064 and 19089 vehicles per day (Trafikverket, 2015). The ABS was placed in 2010 and the GAP in 2009.

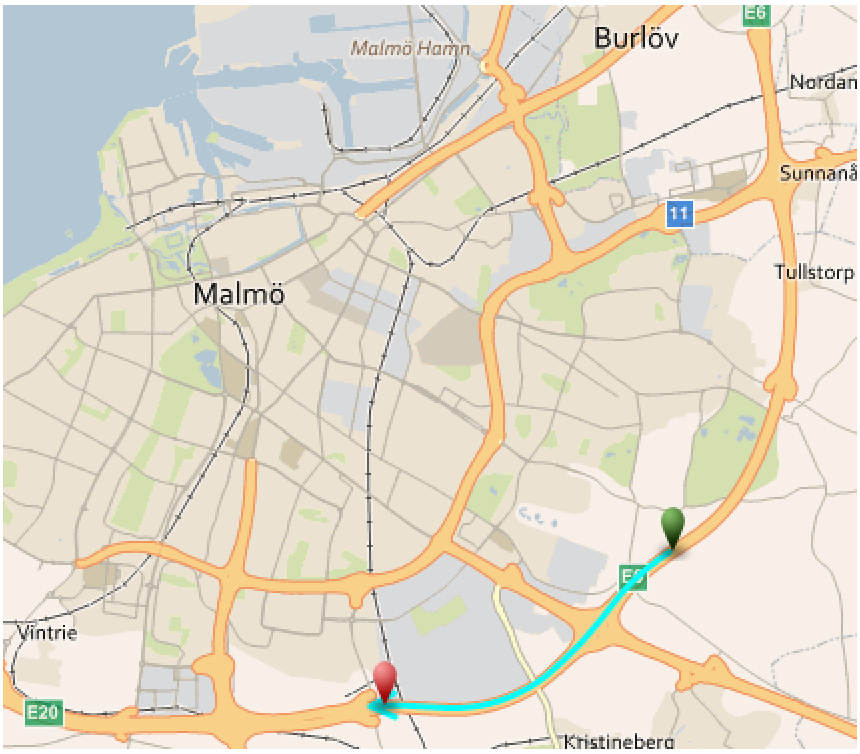
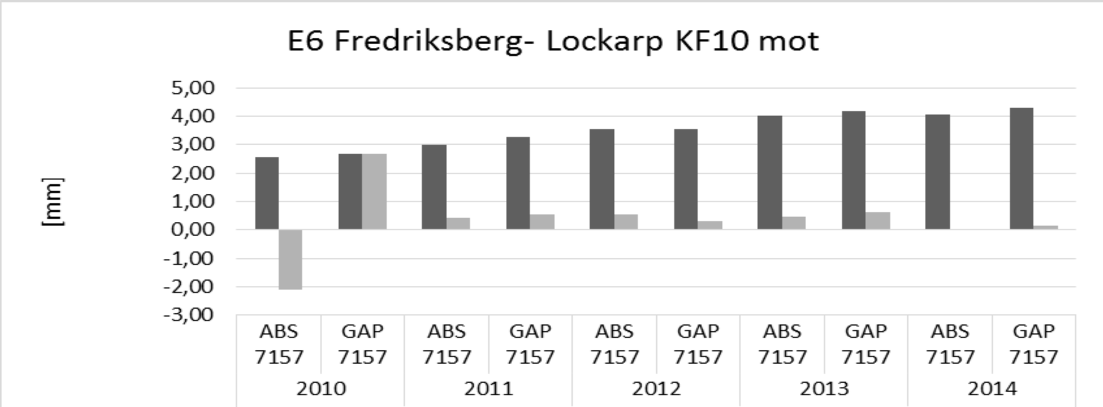


Figure 33: E6 Fredriksberg- Lockarp, 108091- 112673 (Trafikverket PMSV3, 2015)

KF 10

Figure 92 and Figure 93 in Appendix II: E6 Fredriksberg-Lockarp Appendix II: E6 Fredriksberg-Lockarp demonstrate the road condition regarding rutting and MPD and were separated according to similar traffic in order to evaluate each asphalt type's resistance to wearing. The reason for the high peak in the end of each measurement for the GAP is unknown.

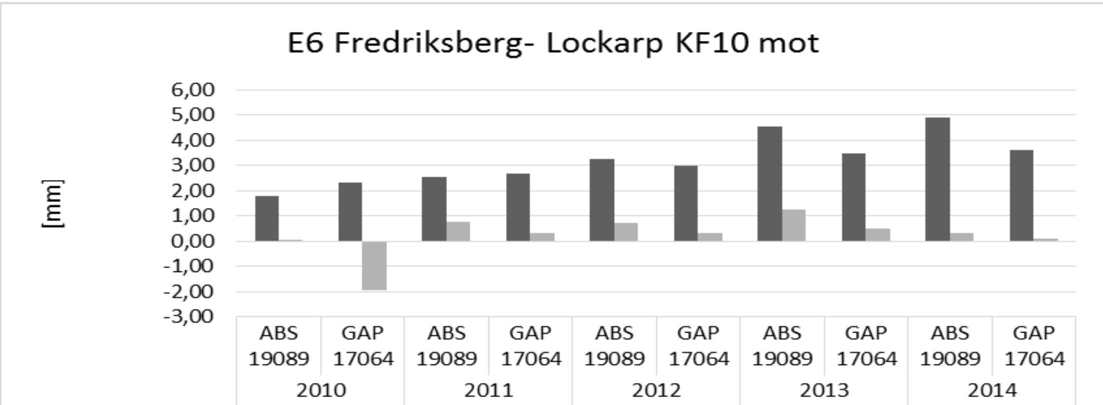


	ABS 7157	GAP 7157	ABS 7157	GAP 7157	ABS 7157	GAP 7157	ABS 7157	GAP 7157	ABS 7157	GAP 7157
	2010		2011		2012		2013		2014	
Average	2,57	2,69	2,99	3,26	3,53	3,56	4,01	4,16	4,05	4,30
Rate of Change	-2,09	2,69	0,43	0,56	0,54	0,30	0,48	0,61	0,03	0,14

Figure 34: Average values and rate of change for rutting on GAP and ABS with traffic volume of 7157 vehicles per day

The difference between GAP and ABS becomes clear in Figure 34. The initial rutting for the GAP is higher than the initial rutting for the ABS (2010). Apart from that the GAP deteriorates faster than the ABS as the average rate of change proves.

In the sections with higher traffic the picture changes. As illustrated in Figure 35 the rutting is larger for ABS than for GAP, however this can be related to the higher traffic on the ABS section.



	ABS 19089	GAP 17064	ABS 19089	GAP 17064	ABS 19089	GAP 17064	ABS 19089	GAP 17064	ABS 19089	GAP 17064
	2010		2011		2012		2013		2014	
Average	1,77	2,34	2,54	2,69	3,27	2,99	4,54	3,50	4,88	3,61
Rate of Change	0,03	-1,96	0,77	0,34	0,73	0,31	1,27	0,51	0,34	0,11

Figure 35: Average values and rate of change for rutting on GAP and ABS with traffic volume of 17064 and 19089 vehicles per day

Figure 94, Figure 95 and Figure 96 in Appendix II: E6 Fredriksberg-Lockarp represent the average MPD values on the left, middle and right part of the lane. The values on the section with 19089 vehicles per day are lower for the ABS, which can be related to the high traffic intensity compared to the other sections. The remaining sections have a more or less constant average value and a low changing rate. Another observation is higher rutting on the GAP at lower traffic volumes.

Table 8: Current state and classification for E6 Fredriksberg- Lockarp KF10 mot, according to VTI and Trafikverket

Section	Trafikverket		VTI (0.71-2.00 mm)	Years to next maintenance
	Rutting (≤13mm)	MPD (≥0.40mm)		
GAP 17064	Yes	Yes	Excellent	29,6
ABS 19089	Yes	Yes	Bad	13
GAP 7157	Yes	Yes	Excellent	24.2
ABS 7157	Yes	Yes	Excellent	21.6

In Table 8 the sections are put into classes according to the VTI classification system. All sections are rated with excellent except for the ABS on with 19089 vehicles per day on the left and right MPD. On that section the road quality was severely degraded after 2010.

At the sections with higher traffic the GAP lasts over 16 years longer than the ABS. On the section with lower traffic the GAP provides a longer lifetime as well, by 2.6 years.

KF 20

The measurements for the second lane are made each second year. In Figure 36 below the rut depths from 2010 to 2014 can be compared for the different sections. On the sections with higher traffic, the rut depths on the rubber modified asphalt are smaller than on the standard asphalt. The rate of change is larger for the ABS, which is an indicator for faster deterioration. On the other sections the rut depth are very similar.

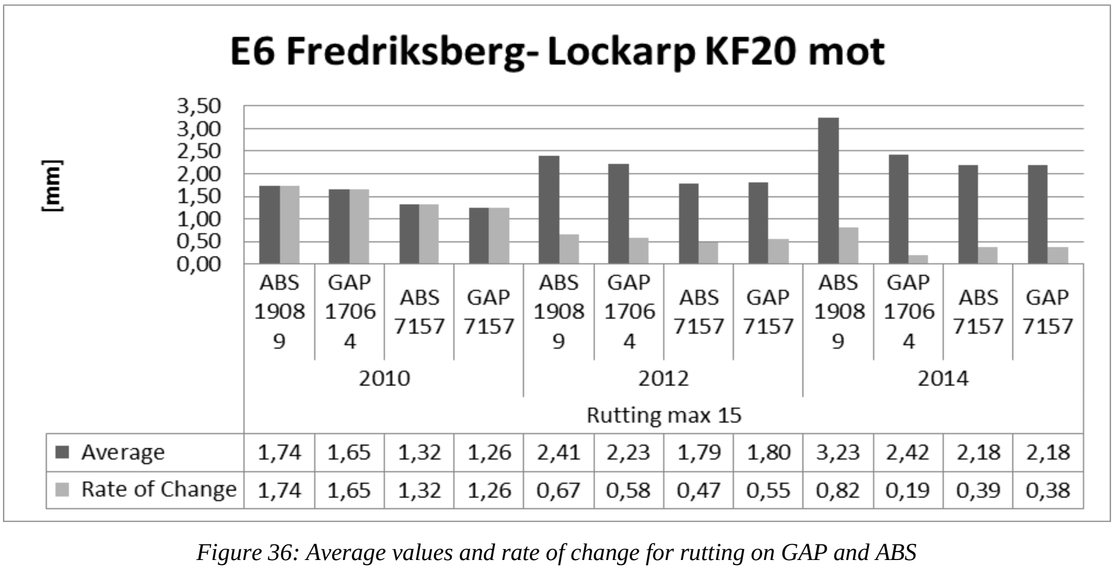


Figure 36: Average values and rate of change for rutting on GAP and ABS

Figure 97 and Figure 98 in Appendix II: E6 Fredriksberg-Lockarp show the MPD values for the left and middle track. On the right MPD the ABS at 19089 vehicles per day is significantly low compared to the others in Figure 99 (Appendix II: E6 Fredriksberg-Lockarp), but still within the interval for excellent quality. The ABS at 19089 vehicles per day has the lowest values for texture.

In Table 9 below the quality and the lifetime were assessed for both asphalt types. At 7157 vehicles per day the ABS lasts about four years longer. At the sections with higher traffic the GAP lasts almost 29 years longer than the ABS according to calculations.

Table 9: Current state and classification for E6 Fredriksberg- Lockarp KF20 mot, according to VTI and Trafikverket

Section	Trafikverket		VTI (0.71-2.00 mm)	Years to next maintenance
	Rutting (≤13mm)	MPD (≥0.40mm)		
GAP 17064	Yes	Yes	Excellent	55
ABS 19089	Yes	Yes	Excellent	26.2
GAP 7157	Yes	Yes	Excellent	46.5
ABS 7157	Yes	Yes	Excellent	50.3

4.1.3 E6 Kronetorp- Salerup mot

This section of the E6 is part of the outer ring road in the east of Malmö going in the south direction (Figure 37). The speed limit is 110 km/h (Trafikverket, 2015) with two lanes, each composed of standard asphalt ABS 70/100 B and a rubber- modified. The ABS was placed in 2007 and the GAP in 2009. On this road the traffic varies between 6000 and 20890 vehicles per day. The comparison however will be related to 10000 and 18061 vehicles per day, since both asphalt types are within these traffic volumes enabling a direct comparison.

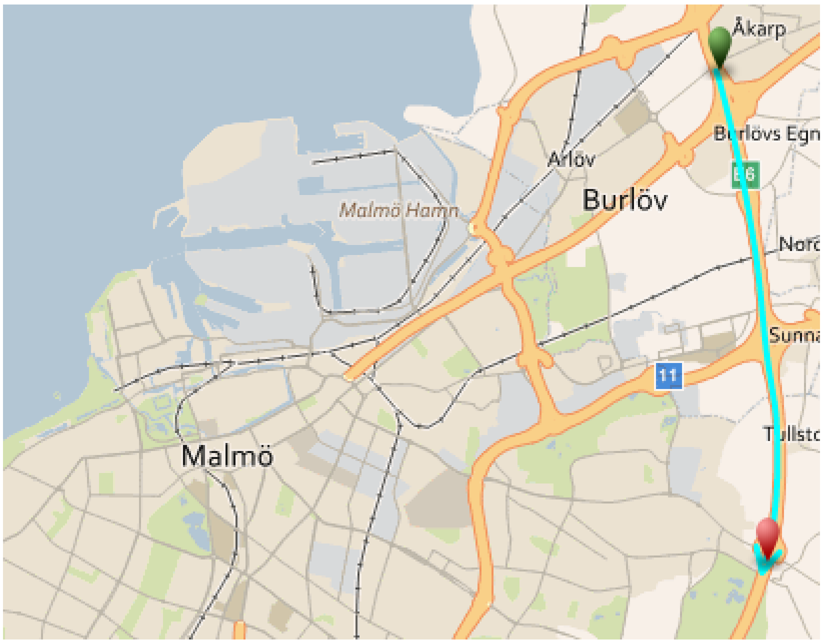


Figure 37: E6 Kronetorp- Salerup, 98965-105524 (Trafikverket PMSV3, 2015)

KF10

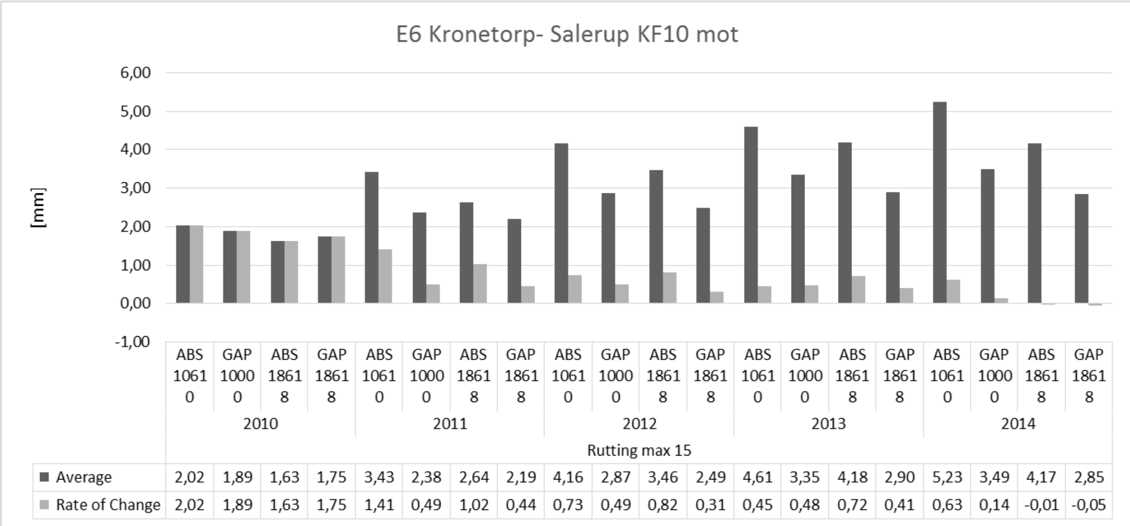


Figure 38: Average values and rate of change for rutting on GAP and ABS

From Figure 38 above it is possible to see that the ABS has higher rut depths than the GAP at both traffic volumes and all years, except for 2010 where the rubber modified asphalt has higher initial rutting. Another observation is that the rut depth is higher for the GAP at lower traffic volumes.

According to Figure 100, Figure 101 and Figure 102 in Appendix III: E6 Kronetorp-Salerup the MPD values for the left, middle and the right part of the lane are excellent for GAP according to VTI (>0.71 mm), approximately 1.1 mm. The ABS (0.55 mm) is under the lower limit required by VTI and classified as bad. Both however fulfil Trafikverket's requirements to be larger than 0.4 mm.

In Table 10 the tracks are evaluated according to Trafikverket's and VTI's classification system. The rubber modified asphalt offers better texture and rut resistance according to the calculated values. Comparing it to the standard asphalt it has 16 years longer lifetime at 18618 vehicles per day and 14.1 years longer lifetime at 10000 vehicles per day.

Table 10: Current state and classification for E6 Kronetorp- Salerup KF10 mot, according to VTI and Trafikverket

Section	**Trafikverket**		**VTI (0.71-2.00 mm)**	**Years to next maintenance**
	Rutting (≤13mm)	**MPD (≥0.40mm)**		
GAP 18618	Yes	Yes	Excellent	26.3
ABS 18618	Yes	Yes	Bad	10.3
GAP 10000	Yes	Yes	Excellent	23.8
ABS 10610	Yes	Yes	Bad	9.7

KF20

For the second lane measurements are made each second year. The results are presented in the figures and tables below. From the data it can be seen that for the second lane, the results are the other way round (Figure 39). The ABS indicates lower rut depths for both traffic volumes throughout the years.

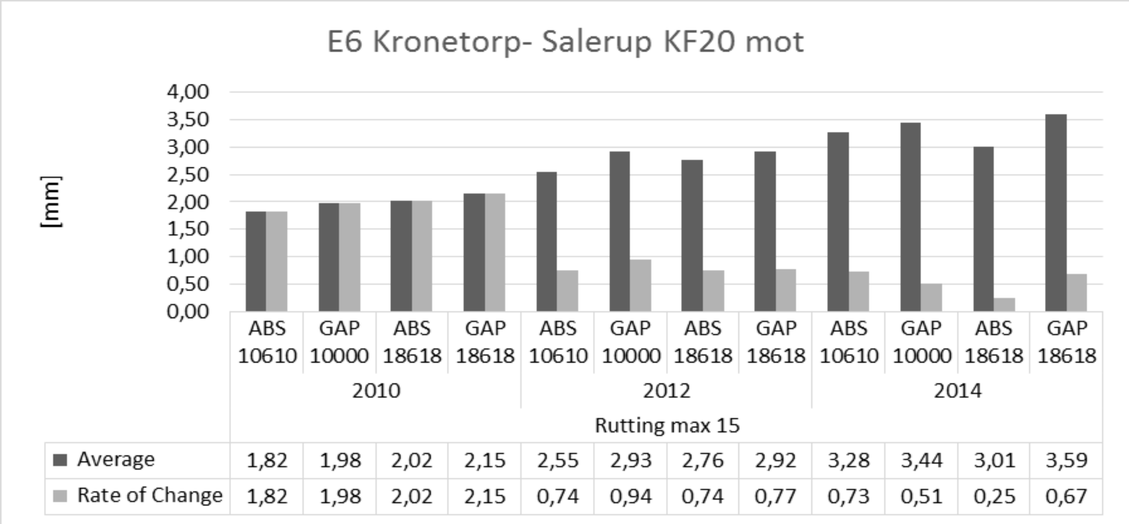


Figure 39: Average values and rate of change for rutting on ABS and GAP

Both asphalt types fulfil Trafikverket's and VTI's requirements for excellent texture. The rubber modified asphalt has yet greater MPD's. As Figure 103, Figure 104 and Figure 105 in Appendix III: E6 Kronetorp-Salerup indicate, the ABS and GAP have similar quality in the section with 10000 vehicles per day. Table 11 below summarizes the results. At the section with 18618 vehicles per day the standard asphalt lasts almost 14 years longer, while the lifetime is the same (26.4 years) at 10000 vehicles per day.

Table 11: Current state and classification for E6 Kronetorp- Salerup KF20 mot, according to VTI and Trafikverket

Section	**Trafikverket**		**VTI (0.71-2.00 mm)**	**Years to next maintenance**
	Rutting (≤13mm)	**MPD (≥0.40mm)**		
GAP 18618	Yes	Yes	Excellent	26.1
ABS 18618	Yes	Yes	Excellent	40.4
GAP 10000	Yes	Yes	Excellent	26.4
ABS 10610	Yes	Yes	Excellent	26.4

4.1.4 E6 Petersborg- Vellinge KF10 & 20 mot

This track is located in Skåne, in the South of Malmö with coordinates between 115947 and 125955 (Figure 40). The road has two lanes with a speed limit of 110 km/h (Trafikverket, 2015). A standard ABS 70/100 B and a rubber modified asphalt GAP 70/100 B were used and placed in 2009. The traffic varies between 3250 vehicles per day and 19364 vehicles per day. The sections with equal traffic are at 17132 vehicles per day, which is the reason why only this section will be analysed and compared. On this section the length of the GAP part is 600 meters and 600 meters for the ABS.

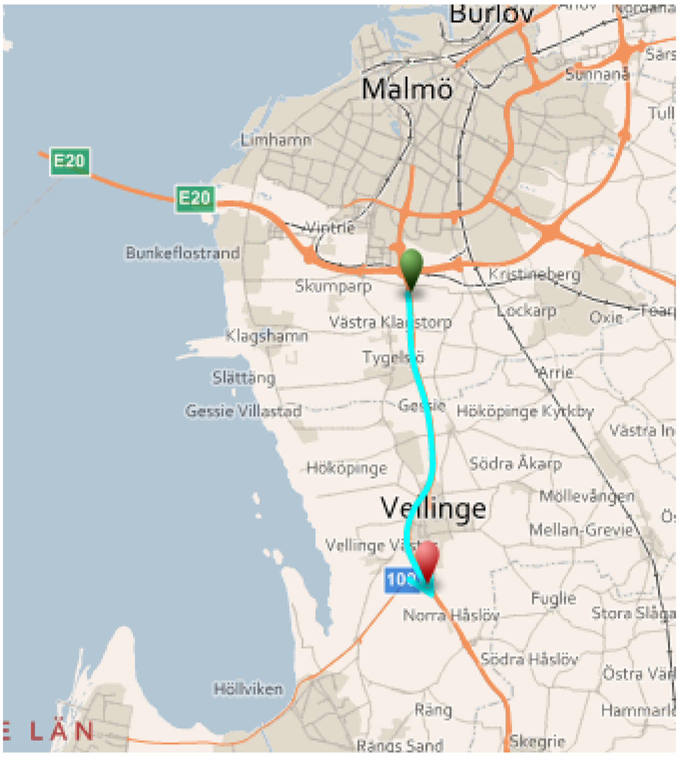


Figure 40: E6 Petersborg- Vellinge, 115947-125955 (Trafikverket PMSV3, 2015)

KF 10

For the first lane measurements are made each year in the summer between June and September.

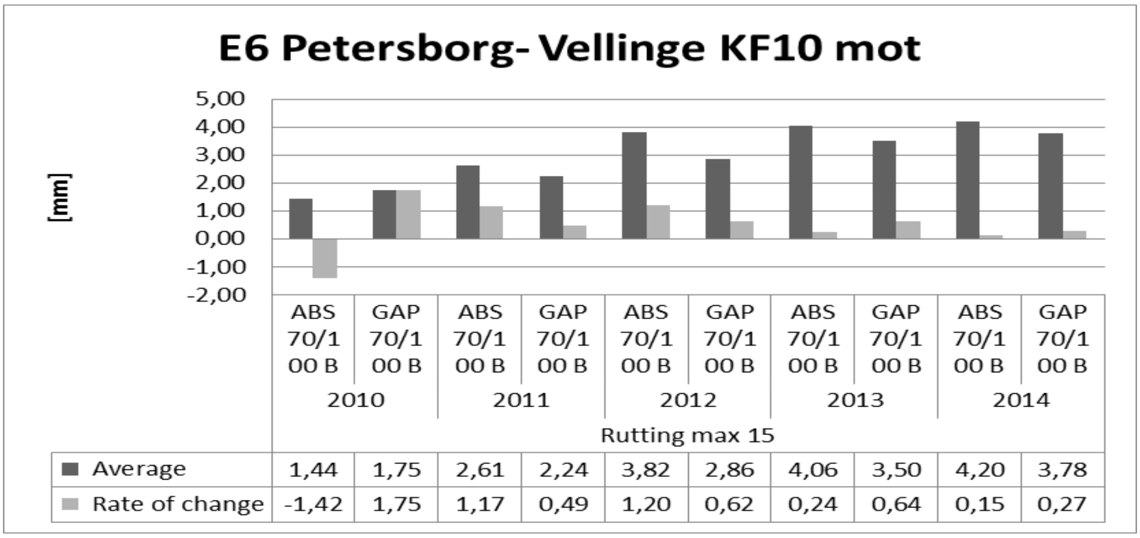


Figure 41: Average values and rate of change for rutting on GAP and ABS

In 2010 the GAP had a higher initial rutting than ABS, which changes over the following years. According to the rate of change the ABS deteriorates faster than the GAP, see Figure 41.

Figure 106 in Appendix IV: E6 Petersborg-Vellinge presents the MPD values for the left part of the lane. The values indicate that the road surface is in excellent condition according to both VTI and Trafikverket for both ABS and GAP, although the ABS has slightly lower values.

Figure 107 in Appendix IV: E6 Petersborg-Vellinge presents the MPD values for the middle part of the lane. The MPD values for the ABS are lower than for the GAP, however both are excellent according to the VTI classification and fulfil Trafikverket's requirements.

In Figure 108 (Appendix IV: E6 Petersborg-Vellinge) the same observations are made as in Figure 107.

The results are gathered in Table 12. After calculations the rubber modified asphalt has a longer lifetime than the standard asphalt by one year.

Table 12: Current state and classification for E6 Petersborg- Vellinge KF10 mot, according to VTI and Trafikverket

Section	**Trafikverket**		**VTI (0.71-2.00 mm)**	**Years to next maintenance**
	Rutting (≤13mm)	**MPD (≥0.40mm)**		
GAP 17132	Yes	Yes	Excellent	14.8
ABS 17132	Yes	Yes	Excellent	13.8

KF20

On the second lane the road is measured each second year.

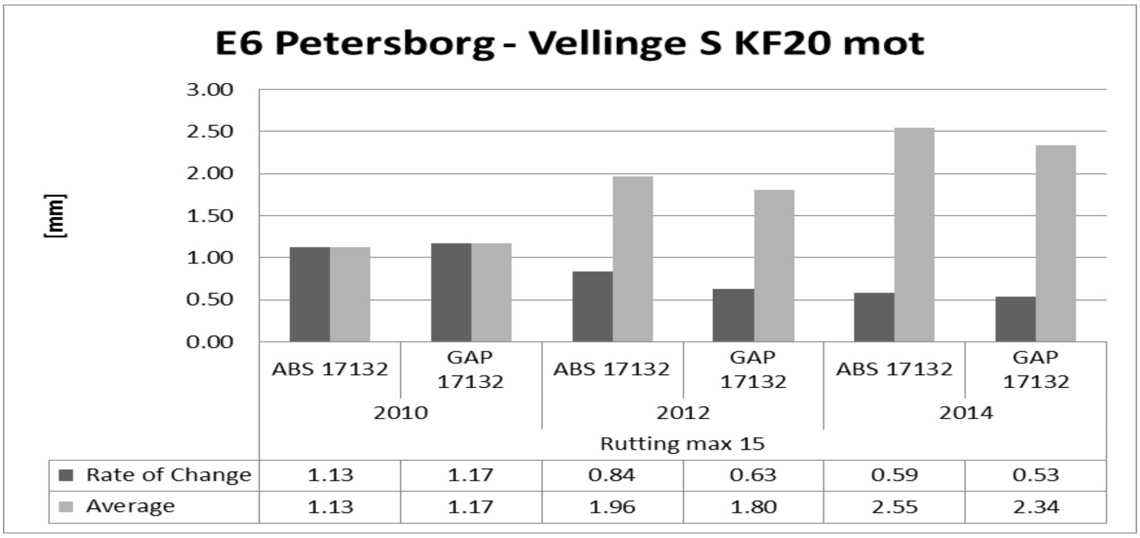


Figure 42: Average values and rate of change for rutting on GAP and ABS

Figure 42 above provides the same results as in Figure 41. Here as well, the rubber-modified asphalt has lower rutting than the ABS, in addition to a lower rate of change

Figure 109, Figure 110 and Figure 111 in Appendix IV: E6 Petersborg-Vellinge prove the same results as the MPD values in the first lane. Both asphalt types fulfil Trafikverket's and VTI's requirements except the ABS in the middle part, which is lower than the VTI requirements.

Table 13: Current state and classification for E6 Petersborg- Vellinge KF20 mot, according to VTI and Trafikverket

Section	Trafikverket		VTI (0.71-2.00 mm)	Years to next maintenance
	Rutting (≤13mm)	MPD (≥0.40mm)		
GAP 17132	Yes	Yes	Excellent	36.8
ABS 17132	Yes	Yes	Excellent	29.2

Both asphalt types offer a good performance according to Trafikverket's requirements and fulfil the VTI requirements for excellent classification, regarding MPD as well (Table 13). The rubber modified asphalt proved to be more resilient than the ABS both in rutting and texture on both lanes and lasts 7.6 years longer.

4.1.5 E6 Sunnanå- Kronetorp KF10 & 20 med

This track is located in the north of Malmö going in the north direction (Figure 43). The coordinates stretch from 36016 to 41005 with a standard asphalt ABS 70/100 B and a rubber modified asphalt GAP 70/100 B. The speed limit is 110 km/h along the whole track and has a traffic volume varying between 6000 and 20683 vehicles per day (Trafikverket, 2015). It is only relevant to compare sections with the same or similar traffic, therefore a section with 17012 vehicles per day was chosen for the ABS and a section with 18294 for the GAP. At these traffic volumes the ABS section is 1020 meters long and the GAP section is 886 meters long. The ABS was placed in 2006 and the GAP was placed in 2009.

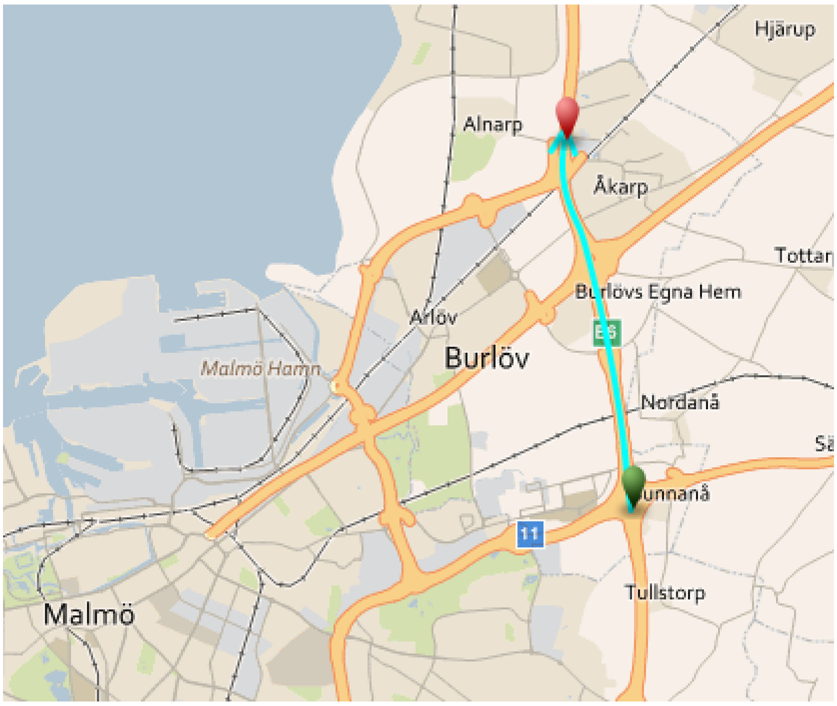
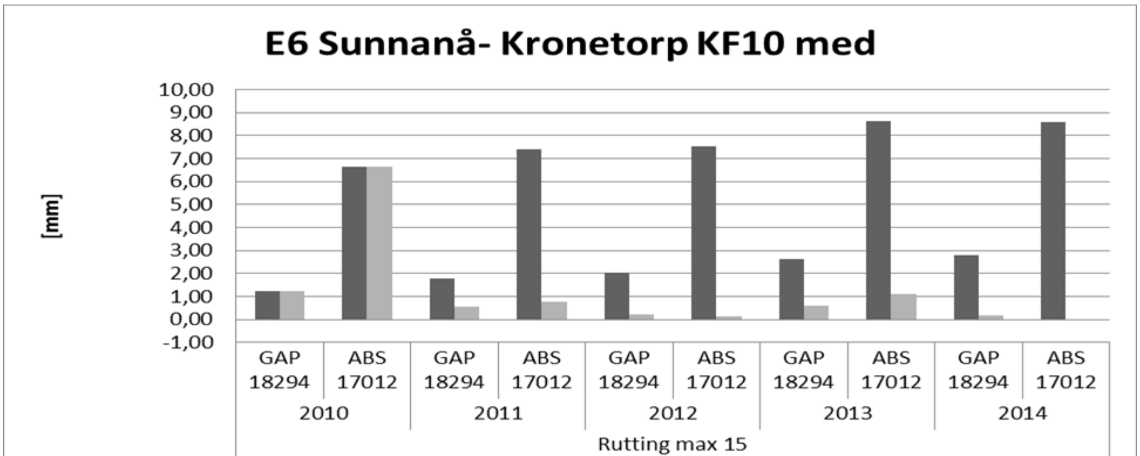


Figure 43: E6 Sunnanå- Kronetorp, 36016-41005 (Trafikverket PMSV3, 2015)

KF 10



	2010 GAP 18294	2010 ABS 17012	2011 GAP 18294	2011 ABS 17012	2012 GAP 18294	2012 ABS 17012	2013 GAP 18294	2013 ABS 17012	2014 GAP 18294	2014 ABS 17012
Average	1,25	6,65	1,80	7,41	2,02	7,53	2,63	8,65	2,80	8,60
Rate of Change	1,25	6,65	0,55	0,77	0,22	0,12	0,61	1,11	0,17	-0,04

Figure 44: Average values and rate of change for rutting on GAP and ABS

In Figure 44 the rate of change is presented for GAP and ABS in addition to the rut depths. A comparison for the rut depths on these sections is difficult due to the different paving dates. Another way to compare them is analysing the rates of change. In 2011 and 2013 the rate of change on ABS is higher than on GAP. In 2012 and 2014 however it is the other way around.

Figure 112, Figure 113 and Figure 114 in Appendix V: E6 Sunnanå-Kronetorp show that the changes in MPD are very small during years.

Table 14: Current state and classification for E6 Sunnanå- Kronetorp KF10 med, according to VTI and Trafikverket

Section	Trafikverket		VTI (0.71-2.00 mm)	Years to next maintenance
	Rutting (≤13mm)	MPD (≥0.40mm)		
GAP 18294	Yes	Yes	Excellent	26.3
ABS 17012	Yes	Yes	Excellent	6.6

In Table 14 the results are gathered. Both types have an excellent texture according to classification by VTI, except for the left MPD on the ABS, which is lower than the limit. Both fulfil Trafikverket's requirements as well. Considering rutting, the rubber modified asphalt would last 20 years longer than the standard asphalt.

KF 20

The traffic on the second lane is the same and even the same materials were used in the same order. Measurements were done each second year. Figure 45 describes the average values and rate of change for rutting from 2010 to 2014. On this lane the results are clearer than on the first one. The rate of change for the GAP is higher than for the ABS indicating that it is deteriorating almost twice as fast. This could once again be related to the higher traffic, which is higher by more than 1200 vehicles per day.

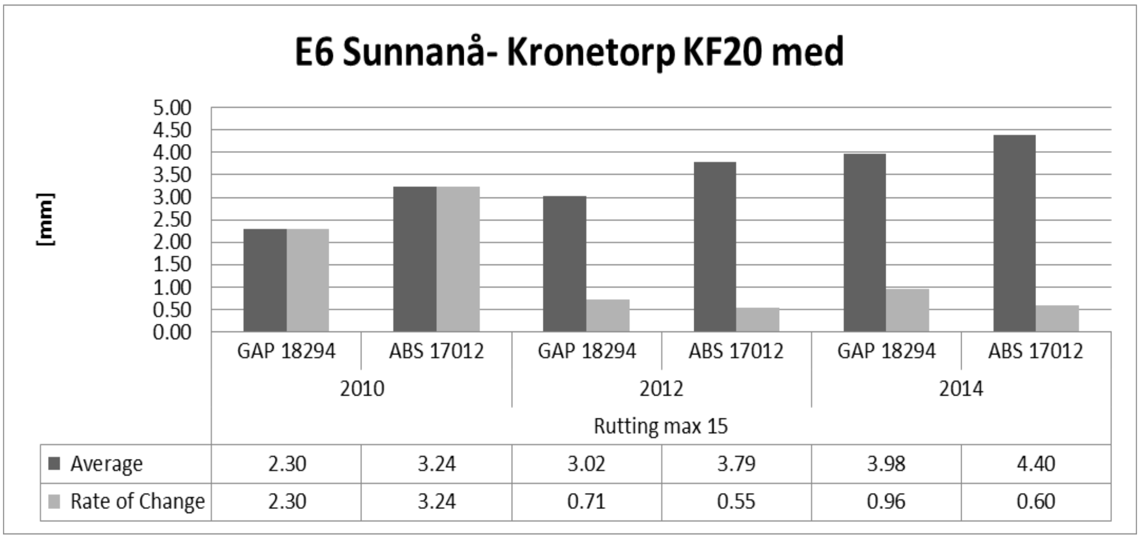


Figure 45: Average values and rate of change for rutting on GAP and ABS

For the MPD values Figure 115, Figure 116 and Figure 117 in Appendix V: E6 Sunnanå-Kronetorp show the same patter as the first lane. The GAP has higher MPD's than the ABS, which means the texture is better and offers better riding quality.

According to Table 15, the ABS lasts over eight years longer than the rubber modified asphalt. The texture on the other hand is better for the GAP although the traffic is higher.

Table 15: Current state and classification for E6 Sunnanå- Kronetorp KF10 med, according to VTI and Trafikverket

Section	Trafikverket		VTI (0.71-2.00 mm)	Years to next maintenance
	Rutting (≤13mm)	MPD (≥0.40mm)		
GAP 18294	Yes	Yes	Excellent	21.6
ABS 17012	Yes	Yes	Excellent	30

4.2 Climate Zone 2

Climate zone 2 is located north of the first zone with a milder temperature. Some of Sweden's largest cities are located in this area such as Stockholm, Gothenburg, Uppsala and Jönköping. These cities have the largest traffic flows which puts the highest demands on the asphalt. In this climate zone both rubber modified and polymer modified asphalts are tested and evaluated.

4.2.1 E6 Ullevi- Kallebäck

The E6 road is located in Gothenburg stretching from Ullevi to Kallebäck junction (Figure 46). The first and second lanes are composed of two asphalt types. The first one is a 70/100- 48 PMB[2] asphalt (placed 2011), followed by a rubber modified asphalt with a 70/100 bitumen binder (placed 2011). The third lane is covered with GAP only and for this reason will not be included in the analysis since it could not be compared to another asphalt type.

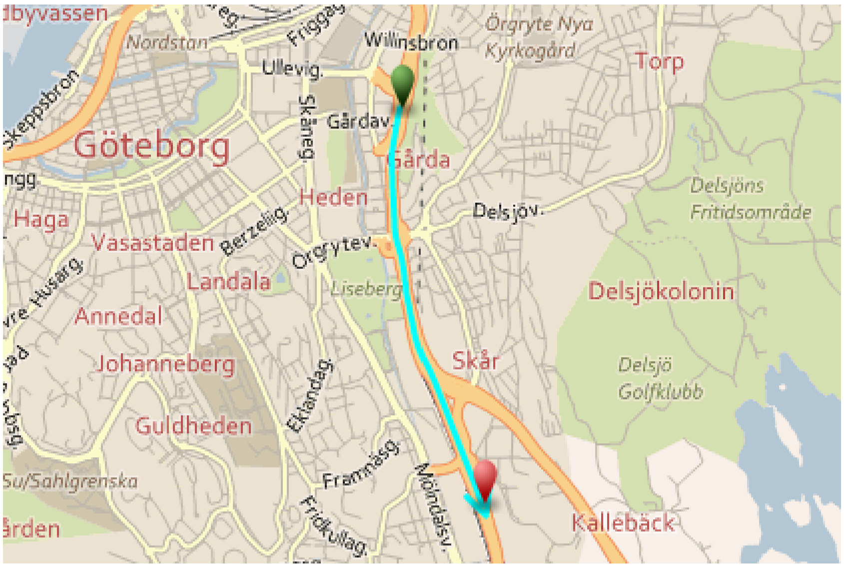


Figure 46: E6 Ullevi- Kallebäck, 176896-179689 (Trafikverket PMSV3, 2015)

The total track length is approximately 2.8 kilometres long and has a speed limit of 70 km/h (Trafikverket, 2015). The traffic volume varies along the track between 30121 and 52640 vehicles per day. For the sake of comparison, sections with the equal traffic of 30121 vehicles per day were used.

[2] Polymer modified bitumen binder

KF10

In Figure 47 below the average values for rut depth and the annual change are presented. The initial rutting is larger for the rubber modified asphalt. The following years, rutting increases for both with different rates of change. The values are slightly higher for the GAP except for 2012.

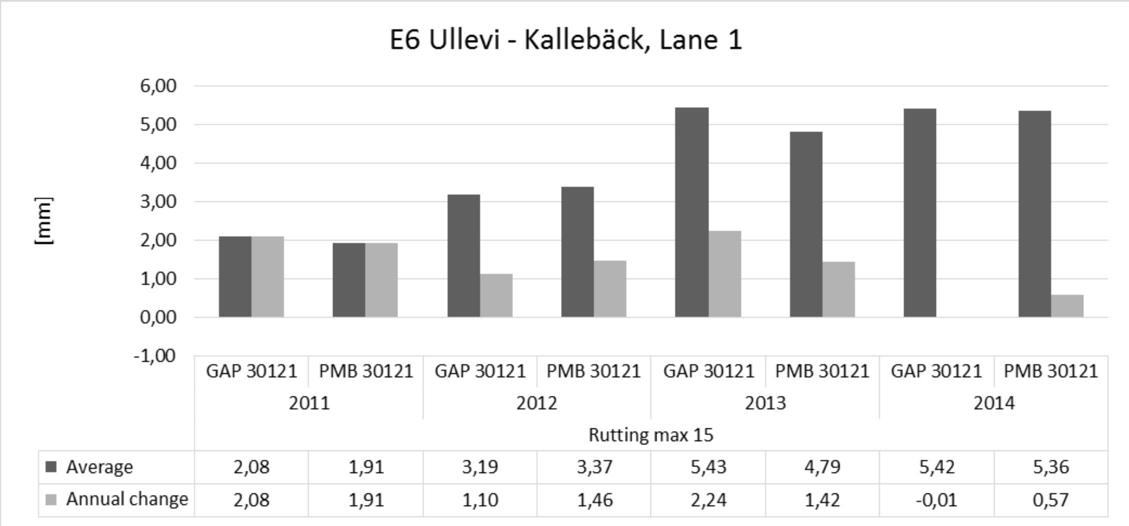


Figure 47: Average value and annual change for rutting on PMB and GAP, lane 1

In Appendix VI: E6 Ullevi-Kallebäck Figure 118, Figure 119 and Figure 120 the differences for MPD for the left, mid and the right parts of the lanes are presented. All three figures clarify that the MPD did not change remarkably after 2012, which could mean that excessive binder or aggregates were worn out and that the surface has come to a uniform state. From Figure 118 it is possible to see that the values for texture on the left side are higher for the PMB during all years.

On the mid part the texture is higher for the PMB until 2013, and on the right side it is higher until 2011. After these years the texture values become higher for the GAP, mainly due to the faster decrease by the PMB (Figure 119 & Figure 120).

KF 20

The second lane indicates a different behaviour (Figure 48). The high value for PMB in 2011 is from the measurement before the new pavement was placed and cannot be interpreted as initial rutting. Starting the comparison from 2012 the PMB has a higher rut depth despite being placed after the GAP.

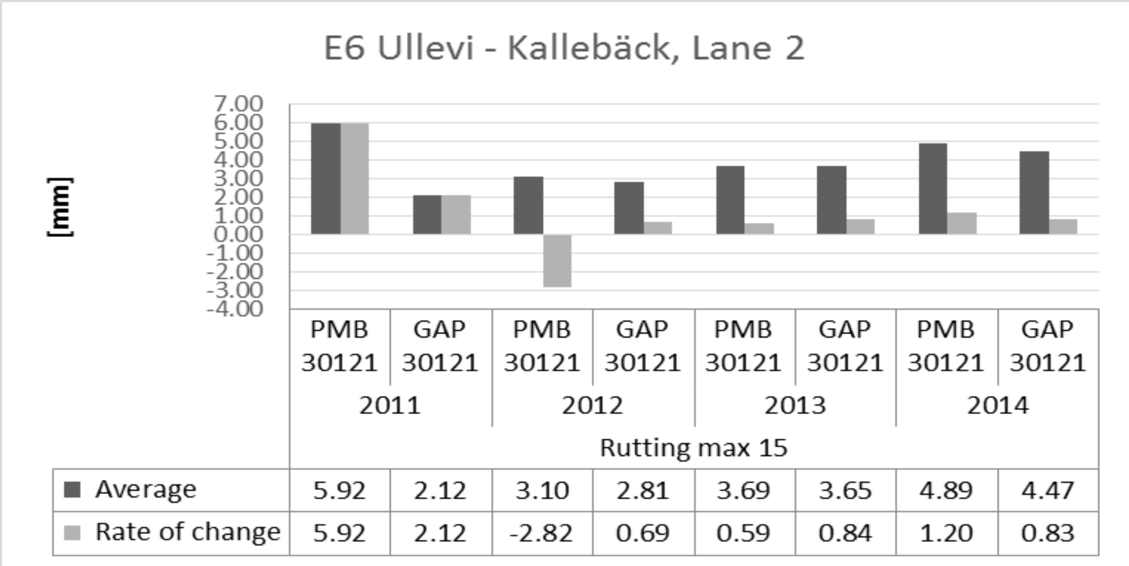


Figure 48: Average value and annual change for rutting on PMB and GAP, lane 2

For the second lane the results are different. The left and middle textures are higher for the PMB throughout all years (Figure 121 & Figure 122 in Appendix VI: E6 Ullevi-Kallebäck). On the right side the texture varies from year to year, which does not provide a clear picture to compare the surface condition between GAP and PMB, see Figure 123.

In the Table 16 below the MPD values from the latest measurement were used for the classifying the sections.

Table 16: Current state and classification for E6 Ullevi- Kallebäck, KF10 and 20 med, according to VTI and Trafikverket

Section	**Lane**	**Trafikverket**		**VTI (0.51- 0.70, 0.71- 1.00 mm)**	**Years to next maintenance**
		Rutting (≤16mm)	**MPD (≥0.35mm)**		
PMB 30121	10	Yes	Yes	Acceptable	9.3
	20	Yes	Yes	Acceptable	12.4
GAP 30121	10	Yes	Yes	Acceptable	9.5
	20	Yes	Yes	Acceptable	14.7

According to Table 16 the asphalt types have a similar life length in the first lane. In the second lane the rubber modified asphalt would last two years more than the PMB. The texture on this section is acceptable for both types according to VTI and are above the required 0.35 mm by Trafikverket.

4.2.2 RV47 Falköping med

The RV47 is located in Falköping on the western side of Lake Vättern (Figure 49) was paved in 2011. The analysed test track is divided into six sections with polymer-modified bitumen, each with a different material composition. The first and last sections are standard asphalts, which are used as references during the comparison of the modified sections. The speed limit on the tested track is 80 km/h and has a total length of 2500 meters (Trafikverket, 2015).

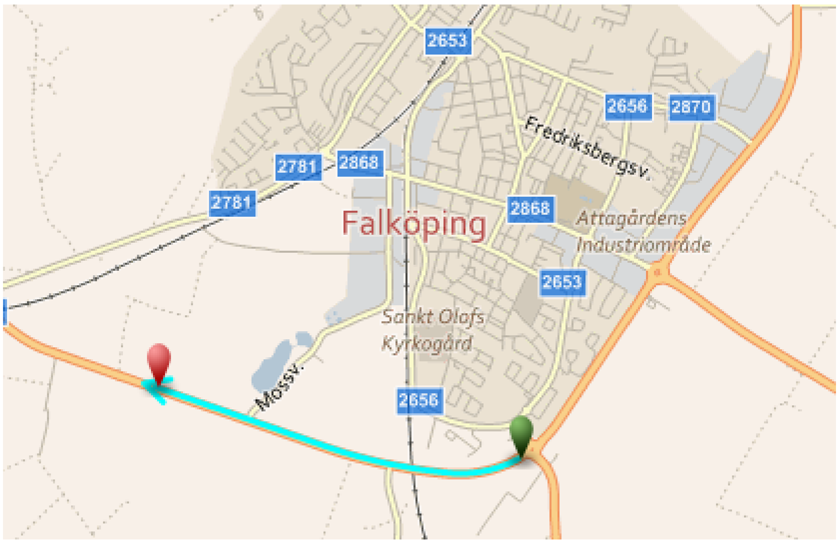


Figure 49: RV47 Falköping, 21220-23720 (Trafikverket PMSV3, 2015)

The purpose of the analysis of this road was to evaluate the suitability of PMSV3 as an analysis tool, which was assessed by comparing the measurements from PSMV3 with the detailed measurements from VTI. The texture (MPD) was not included in this analysis as previously in this report, since the VTI report only focused on rut depth and loss of aggregates (Karlsson, 2015).

The test tracks have different material compositions (Table 17) and therefore offer different performance properties. In the table below, the sections are sorted by traffic and will be compared in the same order later on.

Table 17: Material composition of test sections on RV47 Falköping

Track	Traffic	Asphalt	Binder	Stone abrasion test
1- Reference	5111	ABT 16, + 10% recycling	B70/100 11/16	25% quartzite
2	5111	Inormix 16	Endura F1	Diabase
3	4489	ABT 16	Nypol 76 – 28	<17 mm,Gneiss
4	4489	ABT 16	B70/100	<17 mm, Gneiss
5	4489	ABT 16	Nypol 76-28 11/16	25% Quartzite
6- Reference	4489	ABT, + 10% recycling	B70/100 11/16	25% Quartzite

Rutting comparing PMSV3 vs. VTI

In Figure 50 and Figure 51 the rut depths and annual changes are presented, based on the data from PMSV3. According to Figure 50 in the sections with 5111 vehicles per day Track 2 shows similar rut depths compared to the reference track except for 2013. That year the difference is almost 1 mm.

In the sections where the traffic flow is 4489 vehicles/day, the rut depths for tracks 3, 4 and 5 are higher than the reference track as well. The only exception is track 5 in years 2012 and 2013 where the rut depths were lower. In general the modified asphalts were more sensitive to rutting compared to the reference asphalts. The difference between modified and conventional PMB asphalt covers a large range and varies between -4.4% and 54%.

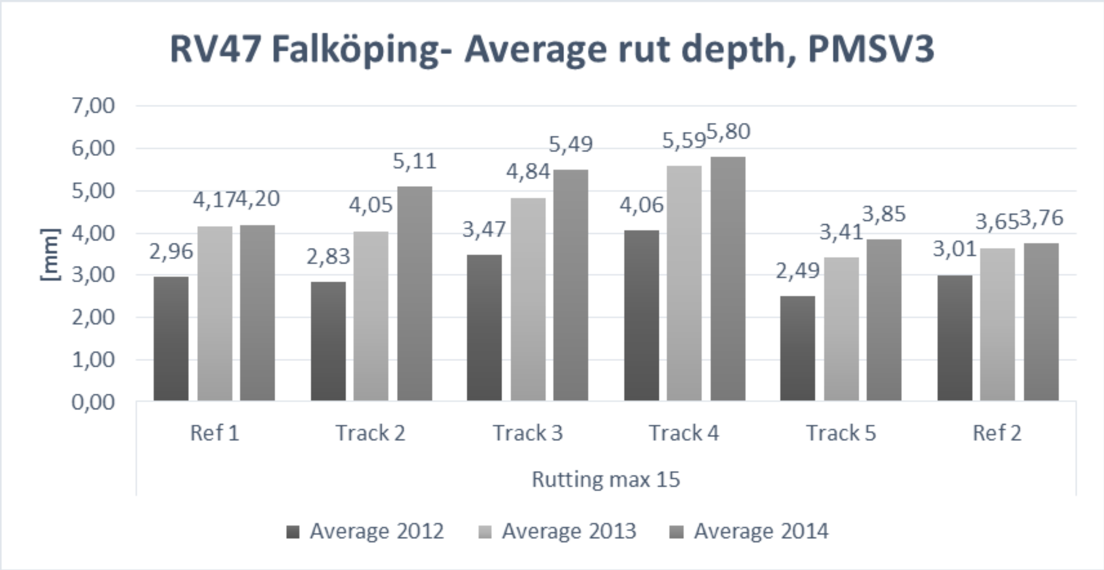


Figure 50: Average rut depth for test track on RV47, Falköping- PMSV3

Figure 51 below supports the results in Figure 50 by presenting the annual increase in rut depth. The annual changes are highest for the modified asphalts. The sections with highest annual increase are tracks 2 and 3.

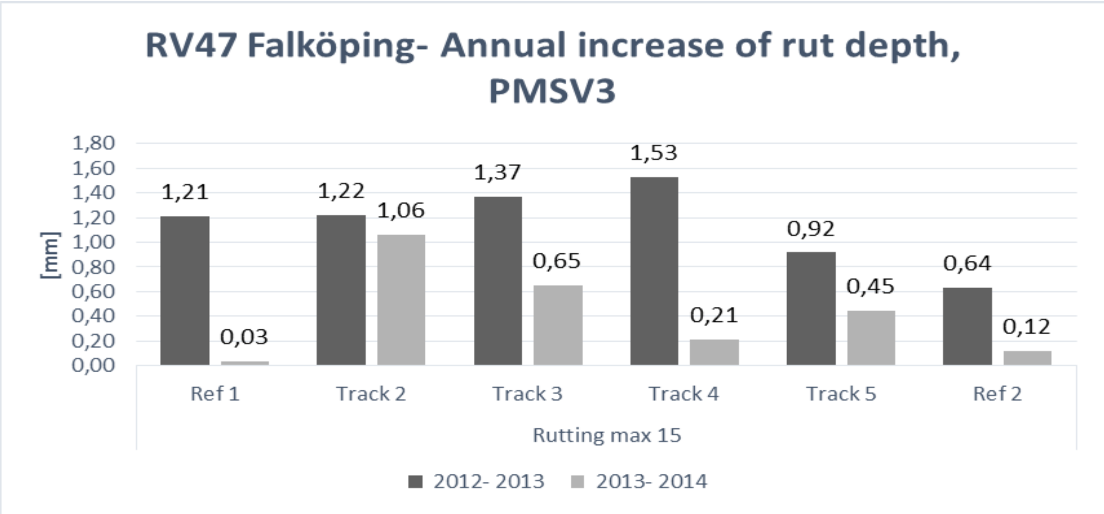


Figure 51: Annual increase of rut depth for test track on RV47, Falköping- PMSV3

Figure 52 and Figure 53 represent the results from the VTI measurement for the same road. The results are similar to those from PMSV3, regarding the modified asphalts, which had higher rut depths than the reference tracks. Only in 2011 and 2012 track 2 was lower in rutting than reference track 1. The increase in rut depth (Figure 53) also supports the fact that the modified tracks are on an average more sensitive to rutting.

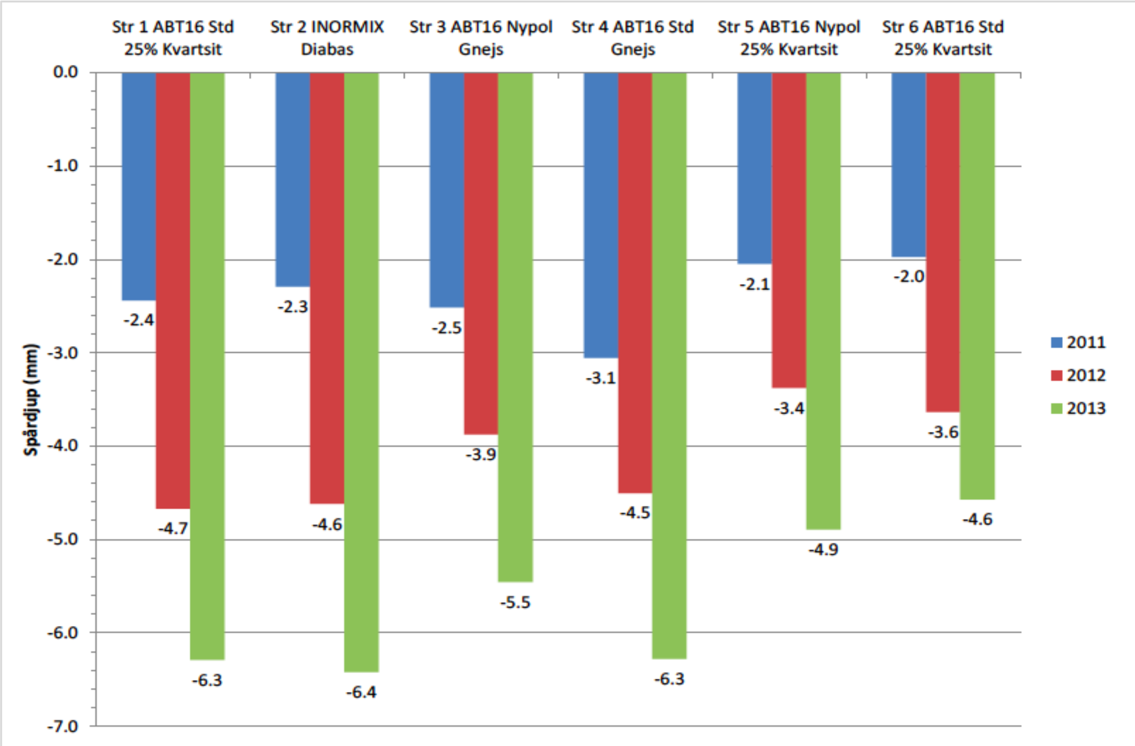


Figure 52: Average value for rut depth for each section 2011, 2012 and 2013 (Karlsson, 2015)

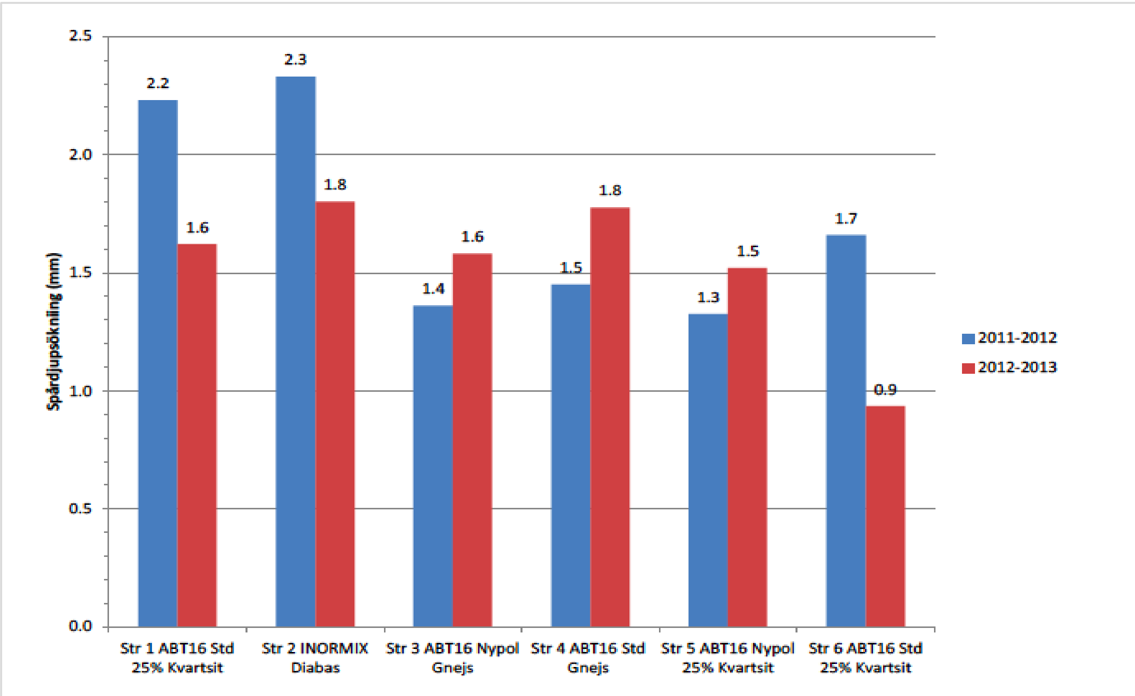


Figure 53: Rut depth increase from 2011- 2012 and 2012- 2013 for each track (Karlsson, 2015)

Differences

Due to the fact that the data for PMSV3 and VTI was collected with different techniques and equipment, differences in the results were expected. In Table 18 below these differences were calculated for each year and section, where the VTI data was compared in relation to the PSMV3 data.

Table 18: Result comparison between data from PSMV3 and VTI

	Ref 1	Track 2	Track 3	Track 4	Track 5	Ref 2
2011	19%	19%	28%	24%	16%	34%
2012	-13%	-14%	19%	19%	0%	1%
2013	-50%	-25%	0%	-9%	-27%	-22%

There is a large range for how much the results differ, such as -50% for reference Track 1 in 2013 and 34% in 2011 for the second reference track. On some occasions there is no difference at all such as the measurement on Track 3 in 2013 and Track 5 in 2012. Nevertheless, the measured data varies on an average by ± 18% on this road.

The average value for texture is measured in Figure 124, Figure 125 and Figure 126 in Appendix VII: RV47 Falköping on the left middle and right part of the lane. The main behaviour for most of the sections on the left and right side is the increase of texture in 2013 followed by a decrease in 2014. In the mid part the texture increases for each year. Reference tracks 1 and 2 and test track 2 show the highest values for texture, which are very high compared to the requirements from Trafikverket and VTI. They show a texture sufficient for speeds at 90-100 km/h.

According to Table 19 the tested sections have a bad or acceptable texture, since the measured values are above the recommended values. Considering lifetime the reference tracks and track 5 have the longest lifetime, especially the second reference track with 32.2 years.

Table 19: VTI's proposed classification of MPD with speed limits, considering friction and aquaplaning, RV 47 Falköping

Section	Trafikverket		VTI (0.51- 0.70, 0.71- 1.00 mm)	Years to next maintenance
	Rutting (≤16mm)	MPD (≥0.35mm)		
Ref 1	Yes	Yes	Bad/Acceptable	19.3
Track 2	Yes	Yes	Excellent	9.6
Track 3	Yes	Yes	Bad/Acceptable	10.4
Track 4	Yes	Yes	Acceptable/Acceptable	11.7
Track 5	Yes	Yes	Bad/Bad	17.7
Ref 2	Yes	Yes	Bad/Bad	32.2

4.2.3 E4 Uppsala-Knivsta

The analysed part of the E4 is located in climate zone 2 and stretches from Uppsala to Knivsta towards Stockholm in the south direction. The speed limit is 110 km/h (Trafikverket, 2015) and the total length is 16725 meters (Figure 54).

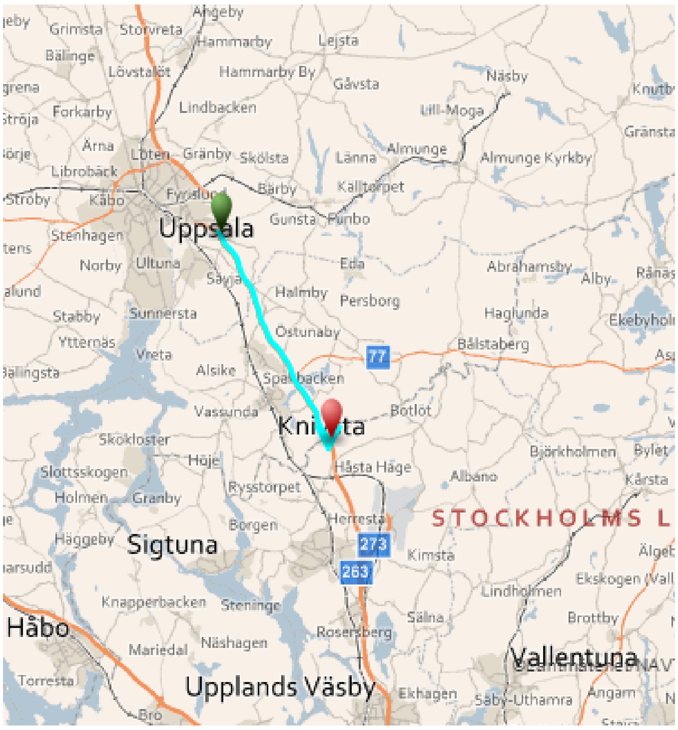


Figure 54: E4 Uppsala- Knivsta, 84720-101329 (Trafikverket PMSV3, 2015)

Several types of rubber- modified asphalt were placed in addition to two standard types of ABS, which were used as reference tracks for comparison (Table 20) in year 2011. The traffic varies between 10500, 13797 and 16971 vehicles per day. In the table below the sectioning of the test track is presented according to Svevia, who placed the asphalt in 2010 (Nordgren, 2015). The whole track was built as a test road in order to evaluate the modified sections in relation to standard asphalt.

Table 20: Sectioning of test track according to material order

Track	Start [m]	Stop [m]	Length [m]	Asphalt type	Properties
1	84720	86640	1920	GAP 16	0,6% Wetfix AP17[3]
Bridge	86740	87121	381	GAP 16	0,6% Wetfix AP17
2	87221	87770	549	GAP 16	0,6% Wetfix AP17 Part 2
3	87970	92120	4150	GAP 16	0,3% Wetfix AP17, 1% Cement
4	92320	94311	1991	GAP 16	Increased Temp.
Ref 70/100	94511	95817	1306	ABS 16	Reference 70/100
Ref 50/70	96017	97129	1112	ABS 16	Reference 50/70
5	97329	101445	4116	GAP 16	Increased Temp. Part 2

[3] Wetfix AP 17 is an additive for increasing the binder's ability to stick to the aggregates (Nordgren & Tykesson, 2011)

In this part of the report not only the GAP was compared to the ABS, but also PMSV3 was compared to Objektsmätning and evaluated for its accuracy and suitability as an analytic tool. This comparison was based on the values for rut depth. Moreover a standardized value was determined with the goal of calculate how much rutting studded tires caused during the winter period. This value was calculating based on the traffic and annual increase of rut depth and modified to 1 million wheel passages according to the Equation 12. In Sweden it is assumed that 70% of all cars have studded tires during winter period (Nordgren, 2015). On this sections also 90% of all traffic was car traffic and 10% was heavy traffic.

Equation 12: Wearing per 1 million wheel passages with studded tyres during the winter period

$$\frac{annual\ rut\ depth\ increase \times 1000000}{2 \times total\ traffic \times winter\ days \times 0.7 \times 0.9}$$

Rutting

The rut depths were compared in sections with equal traffic. In Figure 55 and Figure 56 the first four GAP tracks were compared to the reference track with a 70/100 bitumen binder with a traffic flow of 16971 vehicles per day. According to the measurements all four tracks experienced larger rut depths than the reference track. The highest rutting occurred on tracks 1 and 3 among all the tested sections.

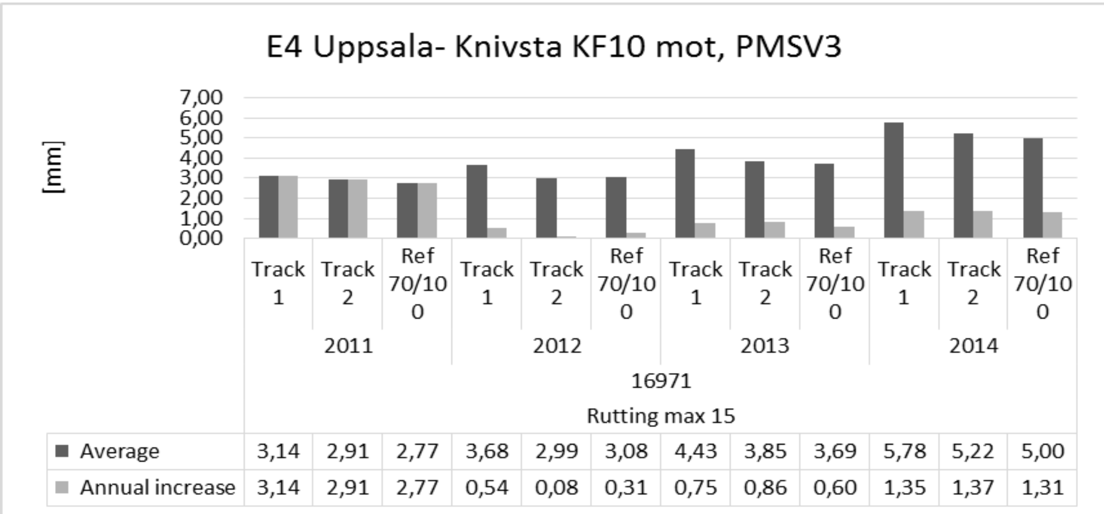


Figure 55: Average values and annual increase of rut depth on Tracks 1, 2 and Reference track 70/100 at 16971 vehicles/day

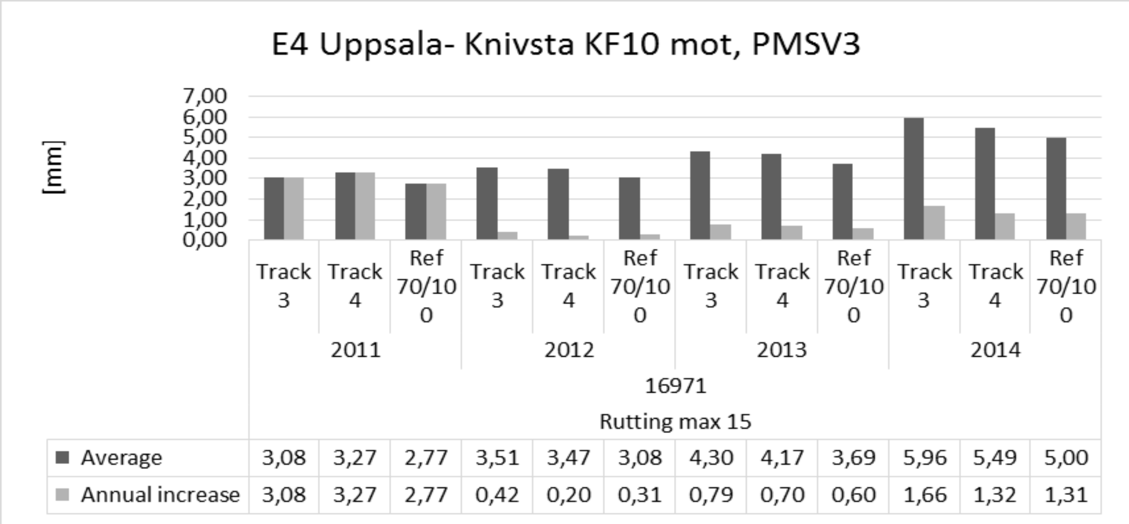


Figure 56: Average values and annual increase of rut depth on Tracks 3, 4 and Reference track 70/100 at 16971 vehicles/day

In Figure 57 the average rut depths for test track 5 were compared to the second reference track with a 50/70 binder. In this section the traffic flow was 13979 vehicles per day. According to the measurements the rut depths were higher for test track 5, just as it was for the other test tracks on the section with 16971 vehicles per day.

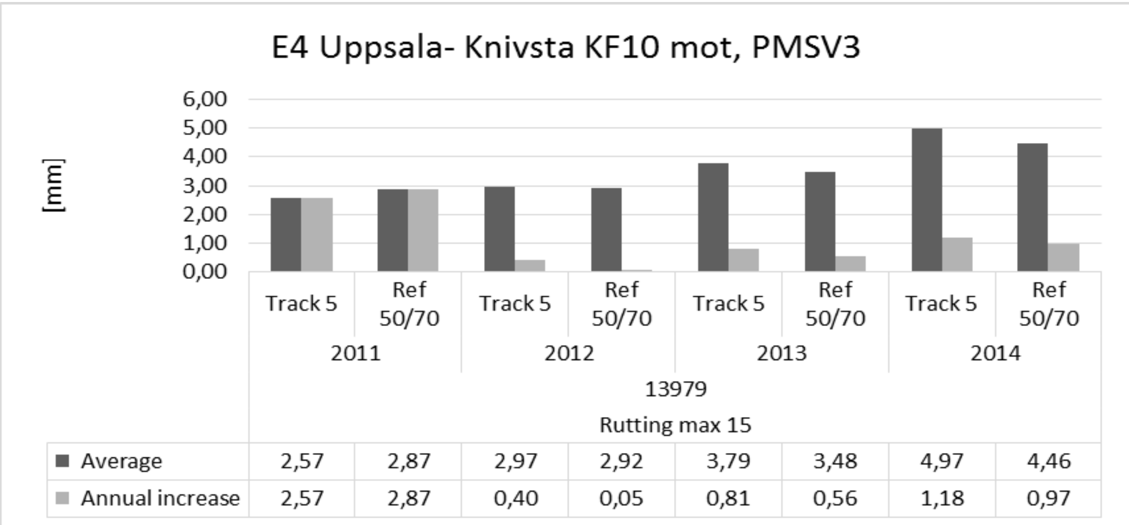


Figure 57: Average values and annual increase of rut depth on Track 5 and reference track 70/100 at 13979 vehicles/day

In order to evaluate the degree of how much the measured rut depths on the test tracks vary from the reference track, these differences were calculated and gathered in Table 21 and Table 22. The largest differences were calculated for track 1, where the rut depths were on an average 0.62 mm larger than the reference track. The rut depths on Track 2, 3 and 4 were 0.15mm, 0.58mm and 0.47mm respectively larger than the reference track throughout the measured years.

Table 21: Comparison of test tracks with reference track 70/100, rutting

	2011	2012	2013	2014
Ref 70/100	2,77	3,08	3,69	5,00
Track 1	3.14	3.68	4.43	5.78
Track 2	2.91	2.99	3.85	5.22
Track 3	3.08	3.51	4.30	5.96
Track 4	3.27	3.47	4.17	5.49

For the fifth test track the differences were smaller than in the previous section. The rut depths on this track were on an average 0.28 mm larger than the reference track except for 2012 where the rutting was larger in the reference track.

Table 22: Comparison of test track 5 with reference track 50/70, rutting

	2011	2012	2013	2014
Ref 50/70	2,87	2,92	3,48	4,46
Track 5	2.57	2.97	3.79	4.97

Texture

On the E4 in Uppsala, the highest measured traffic flow was 16971 vehicles per day. Since high traffic flow usually implies higher wearing it was most interesting to focus on this section. Previously the rut depth was measured to analyse deformation and wearing. To add extra information on the surface condition the texture was analysed using the MPD values from PMSV3.

Figure 127, Figure 128 and Figure 129 in Appendix VIII: E4 Uppsala-Knivsta present the current texture condition on the left, middle and right parts of the first lane. All three figures indicate the highest values in Tracks 2 and 3, while the lowest texture refers to Track 4 and the reference track. The same pattern can be followed for all years from 2012.

In Table 23 all tracks were analysed according to Trafikverket's and VTI's classification system. Each track fulfils the requirements for rutting to be lower than 13 mm and a MPD value higher than 0.4 mm. According to VTI all sections offer an excellent texture. In the last column of the table the years before next maintenance were calculated. The results show that the reference tracks last longer (at least one year) than the rubber modified asphalts regarding rutting.

Table 23: Classification of E4- Uppsala according to Trafikverket and VTI

Section	Trafikverket		VTI (0.71- 2.00 mm)	Years to next maintenance
	Rutting (≤13mm)	MPD (≥0.4mm)		
Track 1	Yes	Yes	Excellent	5.0
Track 2	Yes	Yes	Excellent	5.9
Track 3	Yes	Yes	Excellent	4.7
Track 4	Yes	Yes	Excellent	5.5
Ref 70/100	Yes	Yes	Excellent	6.4
Ref 50/70	Yes	Yes	Excellent	7.7
Track 5	Yes	Yes	Excellent	6.5

Comparison of PMSV3 to Objektsmätning

For the Objektsmätning, data from measurements done in the autumn and spring of each year was used. Measuring at these occasions enabled identifying the wearing caused by studded tires and distinguishing it from the wearing caused by normal tires. These differences could then be evaluated in a direct comparison.

The data used PMSV3 was retrieved from annual measurements in the summer period between June and September. For this reason a direct comparison for studded and normal tires was not possible. The data therefore provides a figure over the asphalt's overall deformation and will be used to determine the rutting during winter in comparison to a whole year.

In Appendix VIII: E4 Uppsala-Knivsta Figure 130 and Figure 131 present the average values for each track are in form of diagrams from both Objektsmätning and PMSV3. The measured values are to a large extend in the same magnitude. For a better understanding the differences were calculated and summarized in the table below.

Table 24: Differences between PMSV3 and Objektsmätning for rut depths on the E4 in Uppsala

	2011	**2012**	**2013**	**2014**
GAP16 0.6% Wetfix	25%	19%	0%	7%
GAP16 0.6% Wetfix Pt2	4%	-2%	-12%	-4%
GAP 16% 0.3% Wetfix 1% Cement	8%	3%	-10%	3%
GAP 16% Increased Temp	11%	6%	-7%	3%
ABS 70/100	13%	7%	-7%	10%
ABS 50/70	6%	-5%	-12%	0%
GAP 16 Increased Temp Pt2	16%	1%	-8%	3%

As Table 24 above shows there is large range for the variation in the measured values. The largest difference was on the first track in 2011 with 25% and the last track with 16% when comparing measurements from PMSV3 to Objektsmätning. Otherwise the differences lie within a range of ±7% on an average.

<u>Wearing per 1,000,000 passage during winter</u>

As previously described it was of interest to analyse the degree of influence from studded tires on rutting. The data in Objektsmätning enabled studying wearing during one winter season on the E4. In order to collect the necessary data the road condition was measured in fall 2011, before the use of studded tires and in spring 2012 when the winter season was over. The results are presented in the figures below.

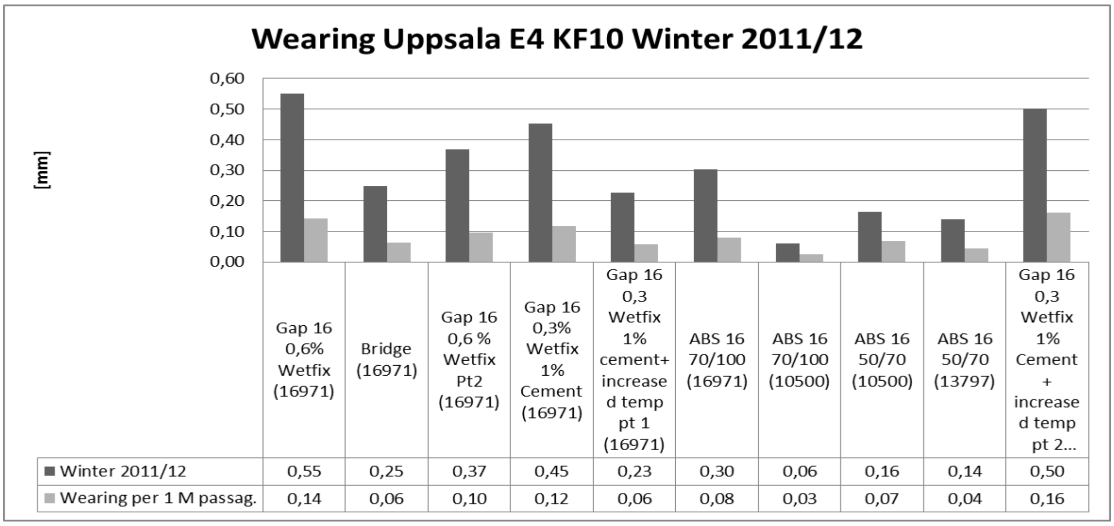


Figure 58: Wear of studded tyres caused by 1million wheel passages during winter 2011/2012, lane 1

In the first lane, the first and last sections indicated to be most sensitive to wearing (Figure 58). According to calculations, the wearing for these sections would be 0.14 mm and 0.16 mm per million wheel passage. Wearing was lowest on the reference tracks on which rutting was half the size and even less than the values on the first and last section.

Comparing the wearing caused in winter with the rut depth of a whole year provides a picture on the effect of studded tires on the road.

Table 25: Proportion between rutting during winter and whole year

	Rutting 2011-2012 [mm] PMSV3	**Wear of studded tyres winter 2011-2012 [mm] Objektsmätning**	**Difference**
Gap 16 0,6% Wetfix (16971)	0.54	0.55	-0.01
Gap 16 0,6 % Wetfix Pt2 (16971)	0.08	0.37	-0.29
Gap 16 0,3% Wetfix 1% Cement (16971)	0.42	0.45	-0.03
Gap 16 0,3 Wetfix 1% cement+ increased temp Pt1 (16971)	0.2	0.23	-0.03
ABS 16 70/100 (16971)	0.31	0.30	0.01
ABS 16 70/100 (10500)	0.15	0.06	0.09
ABS 16 50/70 (10500)	0.16	0.16	0
ABS 16 50/70 (13797)	0.05	0.14	-0.09
Gap 16 0,3 Wetfix 1% Cement + increased temp Pt2 (13797)	0.40	0.50	-0.1

Table 25 above shows the proportion between the winter and the whole year. Most of the values are negative, meaning that the rutting during winter was larger than the rutting for the whole year in total. In the sections with a positive difference (mainly ABS) the wearing during winter was smaller than the total rutting during one year. This fact could be interpreted that these sections are more resistant to wearing than the others. In the other sections the results mean that all rutting is caused by studded tyres.

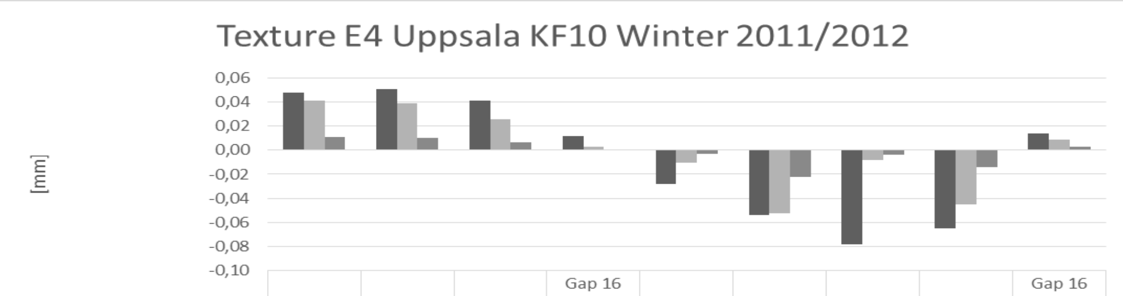
Texture changes per 1 million wheel passage during winter

It was also interesting to analyse the texture changes for each million wheel passage and what information it would provide. The same formula as for the wearing was used, Equation 13, with the difference that the MPD values were used instead, as in the formula below.

Equation 13: Texture change per 1 million wheel passages with studded tyres during the winter period

$$\frac{annual\ texture\ change \times 1000000}{2 \times total\ traffic \times winter\ days \times 0.7 \times 0.9}$$

In Figure 59 the results are presented for texture changes on the different test sections. The changes on sections with the rubber modified asphalt have a positive change, which means the profile depth is increasing. The MPD's on the standard asphalt sections show a negative change, i.e. the profile depth is decreasing over time. The largest changes happen on the left part of the road (MPD left) and the least changes happen on the right side (MPD right).



	Gap 16 0,6% Wetfix (16971)	Gap 16 0,6 % Wetfix Pt2 (16971)	Gap 16 0,3% Wetfix 1% Cement (16971)	Gap 16 0,3 Wetfix 1% cement+ increased temp pt 1 (16971)	ABS 16 70/100 (16971)	ABS 16 70/100 (10500)	ABS 16 50/70 (10500)	ABS 16 50/70 (13797)	Gap 16 0,3 Wetfix 1% Cement + increased temp pt 2 (13797)
MPD left/1M passage	0,05	0,05	0,04	0,01	-0,03	-0,05	-0,08	-0,06	0,01
MPD middle/1M passage	0,04	0,04	0,03	0,00	-0,01	-0,05	-0,01	-0,05	0,01
MPD right/1M passage	0,01	0,01	0,01	0,00	0,00	-0,02	0,00	-0,01	0,00

Figure 59: Texture change during the winter 2011/2012, E4 Uppsala KF10

4.2.4 E4 Viby- Sollentuna (Stockholm) KF30 mot

The track is located in climate zone 2 and stretches from Viby to Sollentuna in the north of Stockholm in the south direction (Figure 60). The speed limit is 110 km/h along the whole track (Trafikverket, 2015), which is covered with standard ABS 70/100 B (2010) and rubber modified asphalt GAP 70/100 B (2012). The traffic varies from 33510 and 42380 vehicles per day; however for the comparison the sections with 33510 vehicles per day were used. The difference in time needs to be considered since ABS already has been deformed for two years before the GAP was placed. The total length is 4533 meters including the reference ABS.

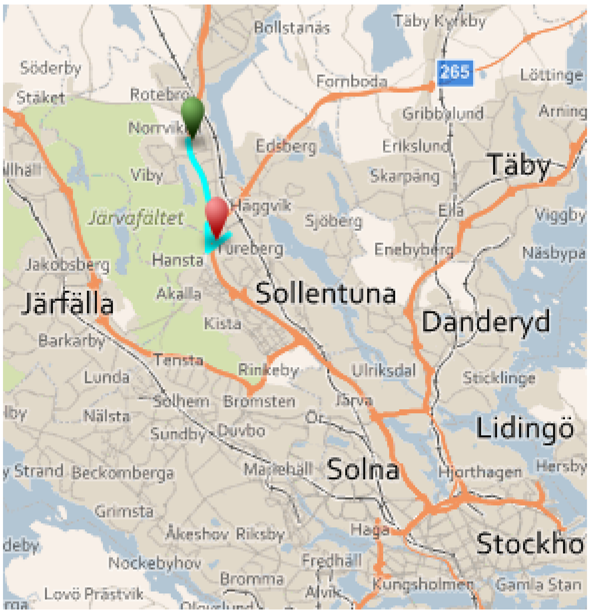


Figure 60: E4 Viby- Sollentuna, 27317-30873 (Trafikverket PMSV3, 2015)

According to the data in PMSV3 the ABS was place in 2004, however in Figure 132 in Appendix IV: E4 Viby-Sollentuna (Stockholm) the rutting for ABS is decreased significantly in 2011, probably due to maintenance. Figure 132 illustrates the measurements along the track and its variation.

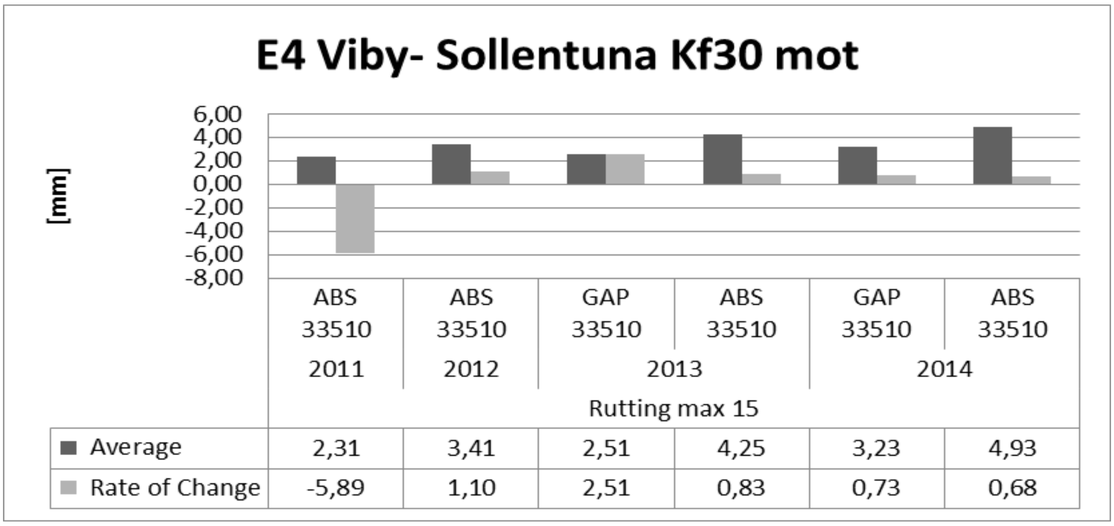


Figure 61: Average values and rate of change for rutting on GAP and ABS

Comparing the initial rutting for ABS (2011) and GAP (2013) clarifies that the GAP deforms more in the beginning. After the second year the rate of change is larger for ABS (1.10) compared to GAP (0.73), which could mean that it deforms at a higher rate (Figure 61).

In Figure 133 in Appendix IV: E4 Viby-Sollentuna (Stockholm) the left MPD values are compared for ABS and GAP. The initial values are more or less the same for both materials. From the rate of change one can conclude that the ABS deteriorates faster, 0.24 mm per year for ABS compared to 0.12 mm per year for GAP. The same results even apply to Figure 134 and Figure 135 for the middle and right MPD.

Both types fulfil Trafikverket's and VTI's requirements and standards for the least and maximum limits. VTI classifies the sections to excellent considering MPD see Table 26 below.

Table 26: Current state and classification for E4 Stockholm, Viby- Sollentuna KF30 mot, according to VTI and Trafikverket

Section	**Trafikverket**		**VTI (0.71-2.00 mm)**	**Years to next maintenance**
	Rutting (≤13mm)	**MPD (≥0.40mm)**		
GAP 33510	Yes	Yes	Excellent	6.0
ABS 33510	Yes	Yes	Excellent	6.6

The results in the table above imply that the ABS is more resistant than the GAP and that it is better suited for this section on the road. On the other hand, data from three years measurements are not enough data to base a decision on.

4.3 Climate Zone 4

Climate zone 4 is situated in the middle and along the east coast of Sweden. Here the cities Umeå and Sundsvall are located.

4.3.1 Västerbotten - E4 Broänge-Hökmark K10

The asphalt for the track in Västerbotten E4 between Broänge and Hökmark, through Mångbyn, see Figure 62, was placed in the beginning of July 2012, however in PMSV3 the track was registered with the date of pavement in the beginning of September 2012.

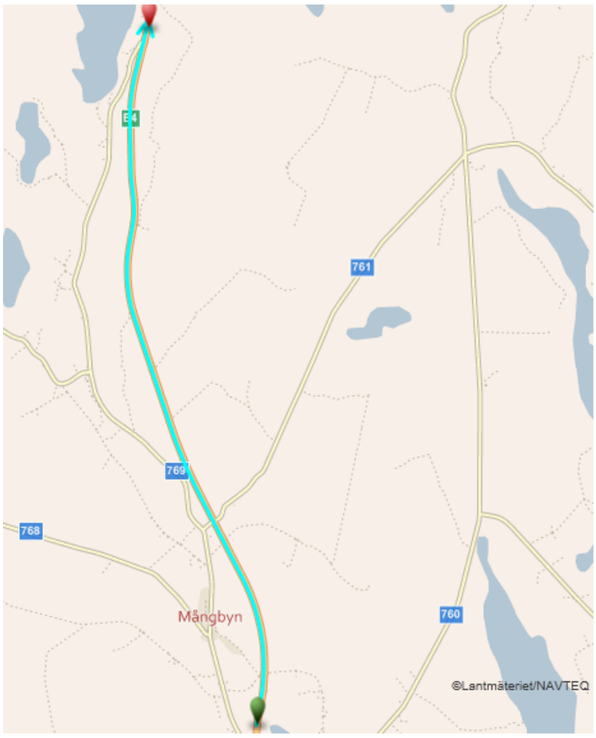


Figure 62: Mångbyn E4 156720 to 164260 (Trafikverket PMSV3, 2015)

The track consists of GAP 16 100/150 and a reference track of ABS 16 100/150 paved by the same company over the course of two days. On the road the traffic load is 3808 cars per day including heavy traffic of 885 cars per day. For the analysis the tracks were divided into type of asphalt. In PMSV3 measurements from the years 2012, 2013 and 2014 for med direction can be found. The track is approximately 6.8 km long and the road consists mainly of one lane, partially a second overtaking lane and overtaking within one lane.

On the track the speed limit is 90 km/h and the measurement car had a speed varying from 55 to 85 km/h with an average of 85 km/h (Trafikverket PMSV3, 2015). The measurements were done in 1 to 20 m steps, with an average of every 19 m.

Furthermore, the reference track shall be from the starting point 156720 to 157540 and the GAP track from point 157540 to 164260. These points are also registered in PMSV3 however when looking at the measured data the reference track shows unexpectedly high values, see Figure 63. It is assumed that the registration is wrong. Therefore no proper analysis and comparison between the tracks can be done due to the unknown starting point of the reference track.

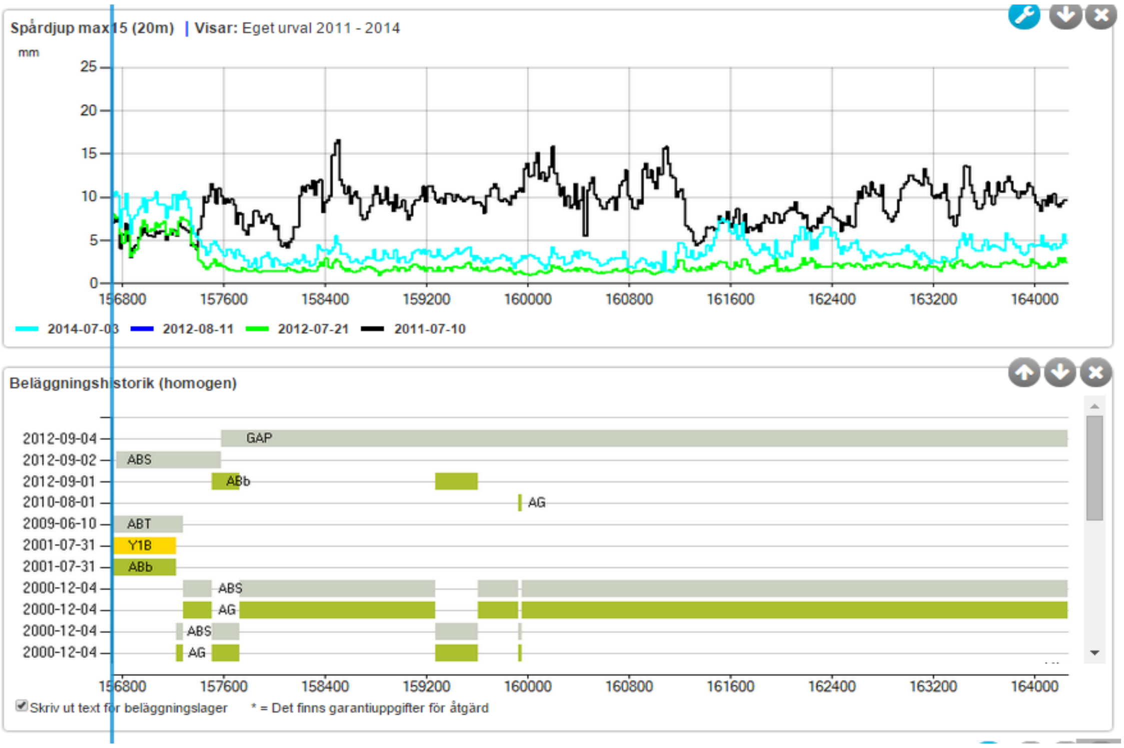


Figure 63: PMSV3 history graph and rutting max 15 for E4 med track 156720 to 164260

However to analyse the Gap it was assumed that the track is in the correct position, further on the transition parts between pavement types were taken away.

Values for the annual change of MPD and rut depth are shown in Figure 64. When looking at the values for the different MPD tracks it can be seen that MPD right is higher than middle and left. The changes within the middle track can be due to overtaking of cars and changing lanes. However after one year the left and right track increased similar and the middle track value decrease and after the second year all MPD values increased similar.

For the change of rut depth after the first month the value increased by 1.8 mm and in the following years the values increased each year by approximately 0.8 mm.

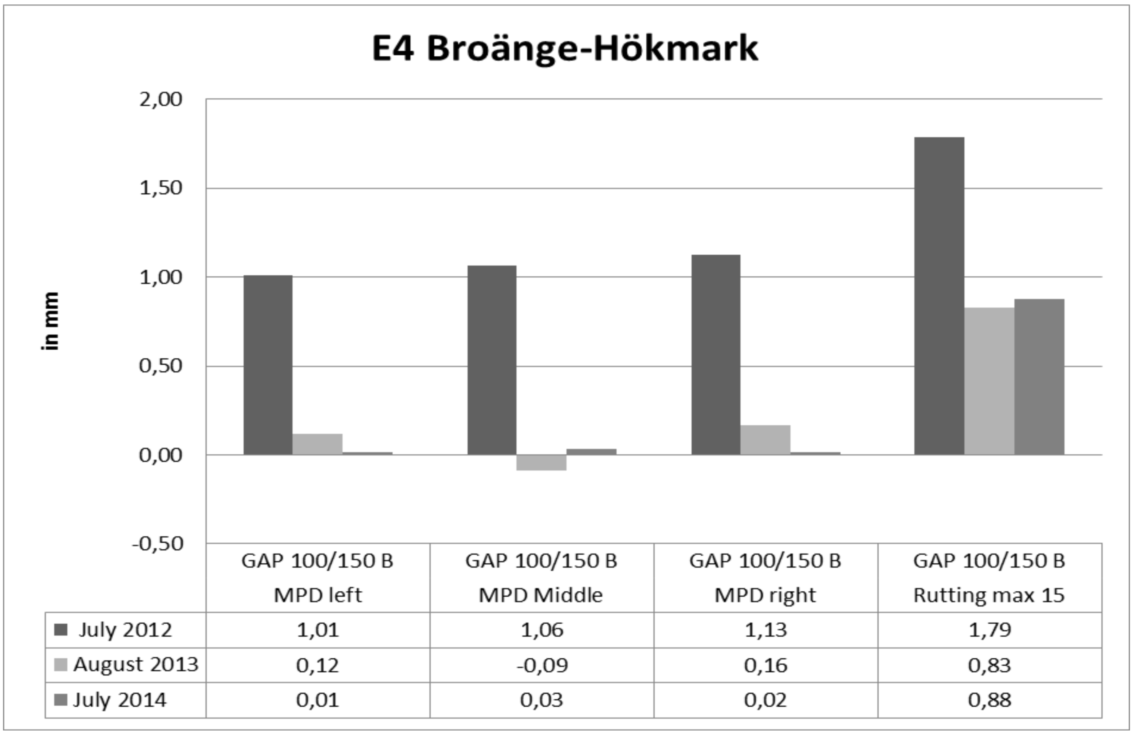


Figure 64: E4 Broänge- Hökmark - Annual change for MPD and Rutting

All values are within the limitations of Trafikverket requirements. For the MPD the values can be classified by VTI requirements, see Table 27. For the traffic load of 3800 cars and speed limit of 90 km/h all MPD values are classified as excellent.

Table 27: Classifications for MPD following VTI

		GAP 100/150 B (3800) 90 km/h
MPD left	2012	Excellent
	2013	Excellent
	2014	Excellent
MPD middle	2012	Excellent
	2013	Excellent
	2014	Excellent
MPD right	2012	Excellent
	2013	Excellent
	2014	Excellent

Table 28 shows the current state for the investigated track, as well as the track will need maintenance in approximately 15 years.

Table 28: Current state and classification for E4 Broänge-Hökmark KF10 according to VTI and Trafikverket

Section	**Trafikverket**		**VTI (0.71-1,5 mm)**	**Years to next maintenance**
	Rutting (≤14mm)	**MPD (≥0.35mm)**		
GAP (3800)	Yes	Yes	Excellent	15

4.4 Climate Zone 5

Climate zone 5 is the most north zone of Sweden. Here cities such as Luleå, Kiruna and Lycksele are situated. Within this climate zone the demand on asphalt and bitumen are higher due to colder and rougher climate. As well as the widespread use of studded tyres requires different properties of the pavement.

4.4.1 Västerbotten - E12 Lycksele K10

Med direction

The asphalt for the track in Västerbotten E12 through Lycksele was placed in July 2012. For the med direction the track starts at point 151932 until 158798, see Figure 65. The track consists of ABTS 11 GMB and a reference track of ABTS 11. On the road the traffic varies from 1000 up to 5000 cars per day including heavy traffic.

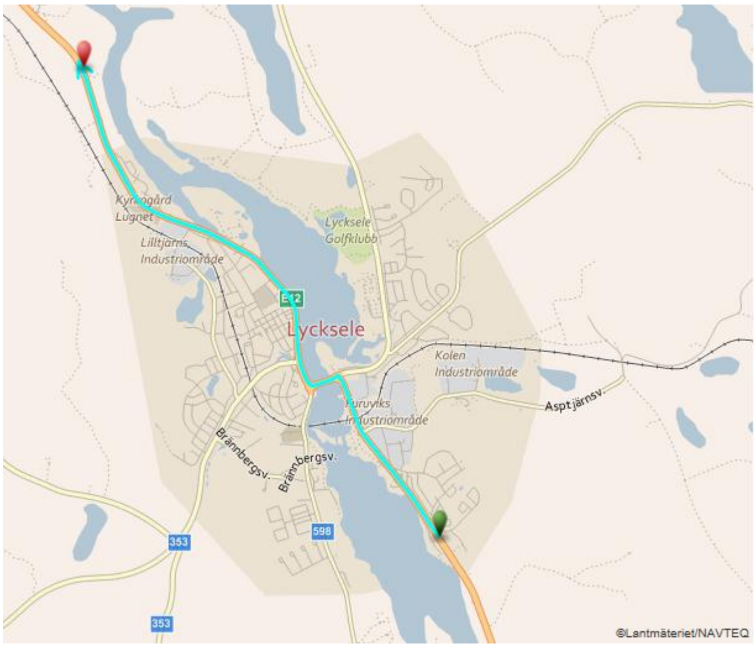


Figure 65: Lycksele med direction 151932 to 158798 (Trafikverket PMSV3, 2015)

In PMSV3 measurements in year 2012 and 2014 were done. Additionally, Destia has made measurements approximately three weeks after asphalting the tracks. The analysed track is approximately 6.8 km long in both directions.

However, in PMSV3 the pavement types and year are not registered correctly. Therefore data from the construction company Svevia and the Objektsmätning from Destia were taken to choose the exact points of the pavement types.

Furthermore, it should be mentioned that the data collected can vary depending on the testing method for example the speed of the measuring car. Destia used a speed of around 47 km/h, however at some places the speed had to be reduced to 20 km/h and the measurements are done in 20 m steps. This is in contrast to the measurements of PMSV3 where the speed of the measurement car varied from 20 to 70 km/h and the measurements were done in 1 to 20 m steps, with an average of every 15 m. The speed limits on the track vary from 50 until 90 km/h. Where the highest amount of traffic is found the speed limit varies from 50 to 70 km/h.

Table 29 shows a comparison of the data of PMSV3 and Destia for the speed and rutting max15. Here it can be seen that there are differences between the values, especially for the speed of the measuring cars the values vary. However, the values for rutting vary a lot at the maximum where the difference is over 2 mm. This can be due to the speed variance and length of the measuring distance. Within the measurement distance of 20 m values can be missed, therefore data measured within shorter distances can be more accurate.

Table 29: Speed and Rutting from PMSV3 and Destia for med

	Speed PMSV3	Speed Destia	Rutting Max15 PMSV3	Rutting Max15 Destia
Average	49,7	45,8	1,6	1,5
Maximum	64,0	49,6	9,1	7,3
Median	51,0	47,5	1,8	1,4
Minimum	15,0	18,4	0,8	0,6
Standard deviation	8,7	5,2	0,8	0,5

For a further comparison the data for rutting max 15 from PMSV3 and from Destia are shown in Figure 66 and Figure 67. Here it is visible that the data from PMSV3 and Destia are close to each other; however in Table 29 it can be seen that the values vary at some spots.

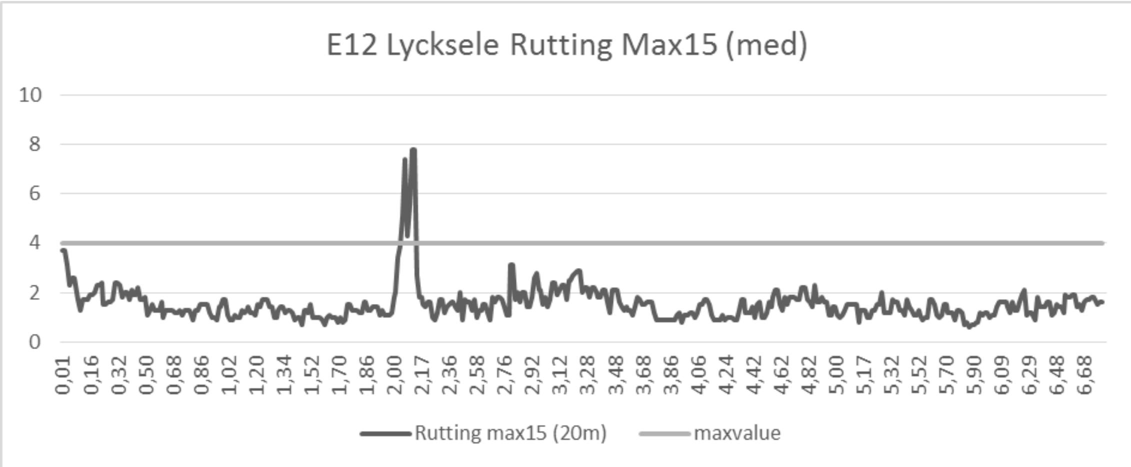


Figure 66: Rutting Max 15 and acceptable level of 4 mm from PMSV3

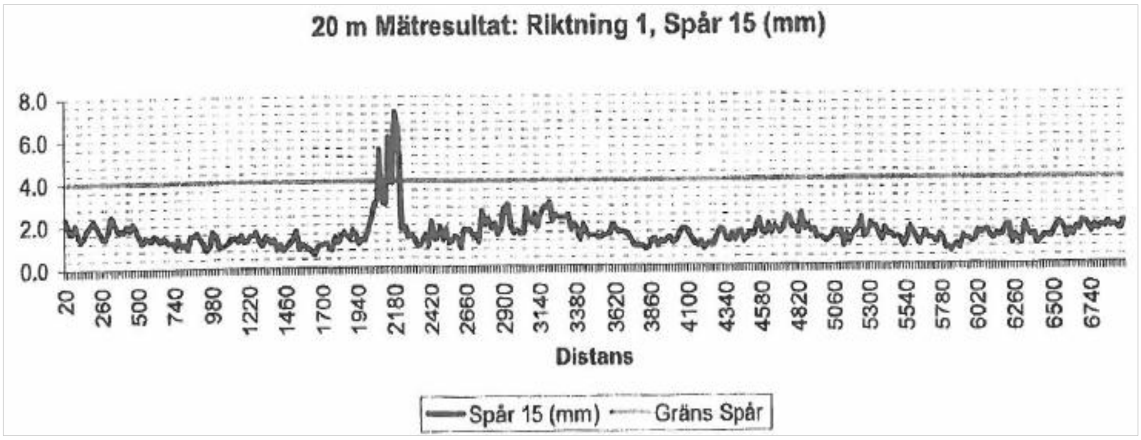
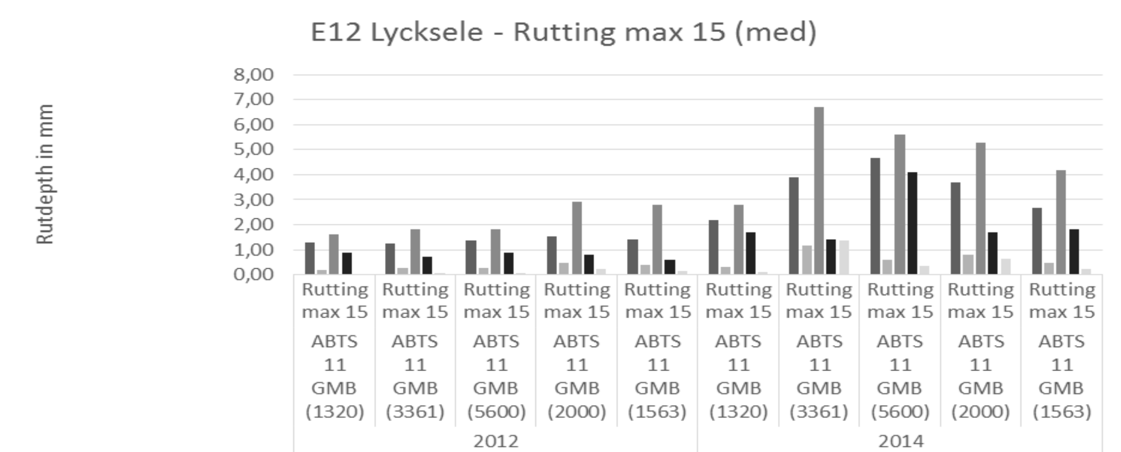


Figure 67: Rutting Max 15 and acceptable level of 4 mm from Destia

For further analysis, data that was unusual and not on a straight track within junctions, crossings, rail tracks, roundabouts or bridges was excluded. This was because these values give not exact average values for a comparison with other tracks.

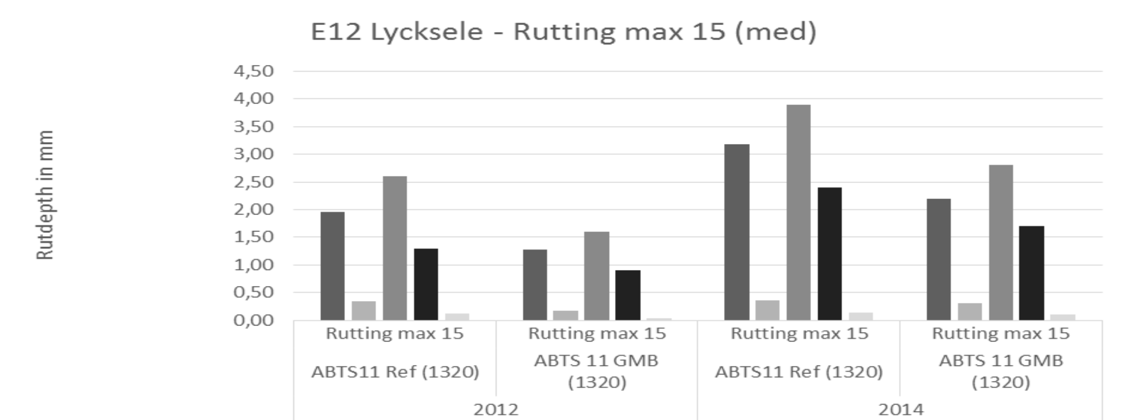
Figure 68 shows the average, standard deviation, maximum, minimum and variance of rut depth max 15 for the ABTS 11 tracks with rubber for different amounts of traffic and for years 2012 and 2014. The graphs show that during the first months after asphalting the average value varies only a little, however the highest value is found at the track with the highest amount of traffic. After two years the values show a similar change. This means that parts with the highest traffic have also the highest average values. Here it must be mentioned that the track with traffic of 3361 has the highest maximum value and the lowest minimum value and a standard deviation of 1.17, where for the track with the highest average the standard deviation is only 0.58.



	Rutting max 15 ABTS 11 GMB (1320)	Rutting max 15 ABTS 11 GMB (3361)	Rutting max 15 ABTS 11 GMB (5600)	Rutting max 15 ABTS 11 GMB (2000)	Rutting max 15 ABTS 11 GMB (1563)	Rutting max 15 ABTS 11 GMB (1320)	Rutting max 15 ABTS 11 GMB (3361)	Rutting max 15 ABTS 11 GMB (5600)	Rutting max 15 ABTS 11 GMB (2000)	Rutting max 15 ABTS 11 GMB (1563)
	2012					2014				
Average value	1,27	1,23	1,37	1,53	1,41	2,20	3,89	4,65	3,68	2,69
Standarddeviation value	0,18	0,25	0,27	0,49	0,37	0,32	1,17	0,58	0,80	0,47
Maximum value	1,60	1,80	1,80	2,90	2,80	2,80	6,70	5,60	5,30	4,20
Minimum value	0,90	0,70	0,90	0,80	0,60	1,70	1,40	4,10	1,70	1,80
Variance	0,03	0,06	0,07	0,24	0,14	0,10	1,37	0,33	0,65	0,23

Figure 68: Rutting max 15 (med) for ABTS11 with GMB and different traffic load

Figure 69 shows the reference track and the rubber track, both have the same amount of traffic. Here it can be seen that during the first months after paving the average values for rutting changed differently.



	Rutting max 15 ABTS11 Ref (1320)	Rutting max 15 ABTS 11 GMB (1320)	Rutting max 15 ABTS11 Ref (1320)	Rutting max 15 ABTS 11 GMB (1320)
	2012		2014	
Average value	1,96	1,27	3,19	2,20
Standarddeviation value	0,35	0,18	0,37	0,32
Maximum value	2,60	1,60	3,90	2,80
Minimum value	1,30	0,90	2,40	1,70
Variance	0,12	0,03	0,14	0,10

Figure 69: Rutting max15 for ABTS11 reference track and ABTS 11 with GMB

Moreover, Figure 70 shows values for the annual change of the average values for the rutting. The reference track has higher values than the rubber track. Further on, when comparing the ABTS 11 tracks with rubber and different traffic loads the track with the highest amount of traffic has the highest annual change of rutting.

However, as mentioned above the track with 3300 cars per day has the highest maximum value and highest standard deviation in values, yet the track with the highest traffic has values distributed more evenly over the track.

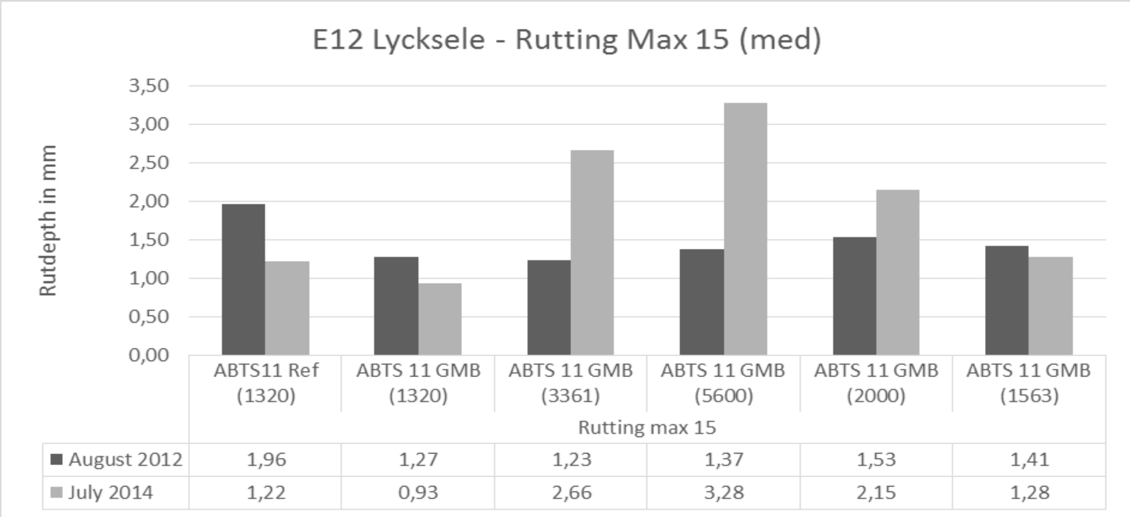


Figure 70: Rutting max 15- annual rate of change for ABTS11 reference track and ABTS 11 with GMB

In Figure 136 in Appendix X: E12 Lycksele the annual change of the MPD left and right track are illustrated. For the ABTS11 track the change is really low for the second year and the highest change for the rubber track with the highest traffic. Figure 137 in Appendix X: E12 Lycksele shows the MPD values for the middle track.

Table 30 shows the classification of the MPD values corresponding to the VTI requirements. The reference track is excellent and all other values vary from bad to excellent expect the GMB with highest traffic has only a bad value during the first year on the left side.

Table 30: Classifications for MPD following VTI (med)

		ABTS11 Ref (1320) 70 km/h	ABTS11 GMB (1320) 70 km/h	ABTS11 GMB (3361) 50-70 km/h	ABTS11 GMB (5600) 50 km/h	ABTS11 GMB (2000) 50-70 km/h	ABTS11 GMB (1563) 50-70 km/h
MPD left	2012	Excellent	Bad	Bad-Good	Bad	Bad-Good	Bad-Good
	2014	Excellent	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
MPD middle	2012	Excellent	Bad	Bad-Good	Good	Bad-Good	Bad-Good
	2014	Excellent	Excellent	Excellent	Excellent	Excellent	Bad-Good
MPD right	2012	Excellent	Bad	Bad-Good	Good	Bad-Good	Bad-Good
	2014	Excellent	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

Table 31 shows how long each track has until next maintenance. Comparing the reference track and the GMB track with the same traffic load the GMB will last 14 % longer than the reference track.

Table 31: Current state and classification for E12 Lycksele med, according to VTI and Trafikverket

Section	Trafikverket		Years to next maintenance
	Rutting	MPD	
ABTS 11 (1320)	Yes	Yes	30
ABTS 11 GMB (1320)	Yes	Yes	41
ABTS 11 GMB (1563)	Yes	Yes	30
ABTS 11 GMB (2000)	Yes	Yes	17,5
ABTS 11 GMB (3361)	Yes	Yes	11,5
ABTS 11 GMB (5600)	Yes	Yes	9

Mot direction

In PMSV3 data is only available between a starting point of 307155 to an end point of 309235 and only for the years 2012 and 2013, see Figure 71.

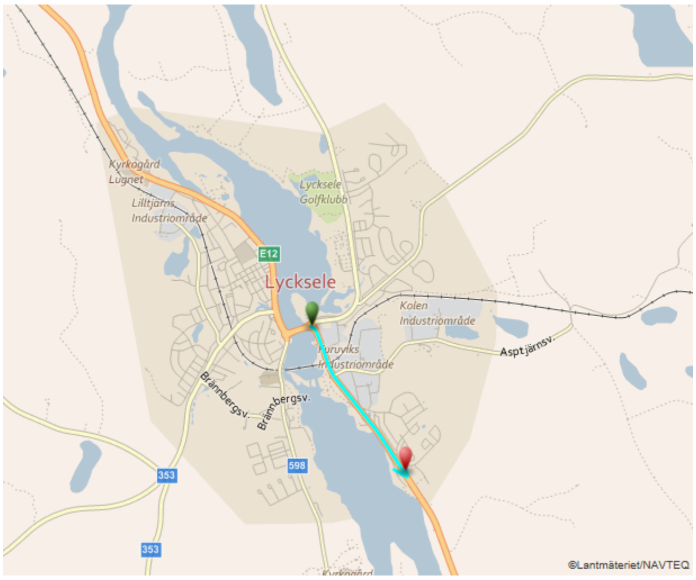


Figure 71: Lycksele mot 307155 to 309235 (Trafikverket PMSV3, 2015)

Figure 72 shows the annual rate of change of the MPD tracks and the rut depth. Here it can be seen that the values for MPD in all tracks for the reference track changes during the first month more than for the tracks with rubber, whereas during the first year the change is lower for the reference track than for the rubber track.

When looking at the rut depth the change for the reference track is lower during the first year and a greater during the second year compared for the rubber track with the same traffic. Furthermore it should be noted that the part with the rubber has a varying speed limit from 50 to 70 km/h, whereas on the reference track the speed limit is 70 km/h. For the extra rubber track with a higher traffic load the initial rutting is lower than for the part with higher traffic, however the change after one year is much higher.

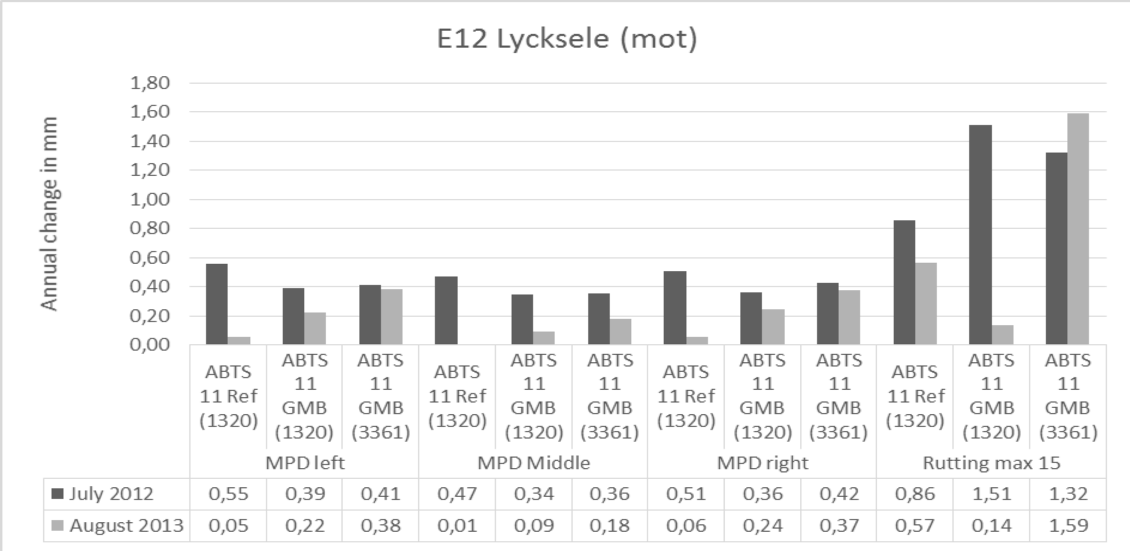


Figure 72: Annual rate of change mot

Table 32 illustrates the classifications after VTI for the MPD values as mentioned. The classification shows that for the reference track and rubber track the values for MPD left and right are mostly classified as excellent after one year. During the first year the values for both rubber tracks are classified as good to bad. Moreover, for the second track with higher traffic the values are acceptable and excellent after one year.

Table 32: Classifications for MPD following VTI (mot)

		ABTS11 Ref (1320) 70 km/h	ABTS11 GMB (1320) 50-70 km/h	ABTS11 GMB (3361) 50-70 km/h
MPD left	2012	Excellent	Good- Bad	Good- Bad
	2013	Excellent	Excellent	Acceptable
MPD middle	2012	Bad	Good- Bad	Good- Bad
	2013	Bad	Good- Bad	Excellent
MPD right	2012	Excellent	Good- Bad	Good- Bad
	2013	Excellent	Excellent	Acceptable

Table 33 shows that the track matches the Trafikverket requirements and the remaining years until maintenance. Here it is seen that the reference track has a much shorter life time than the GMB track. This could be due to different speed limits and change of speed. However, this high value could be due to the reason that only one year of measurement was available after the initial rutting.

Table 33: Current state and classification for E12 Lycksele mot, according to VTI and Trafikverket

Section	**Trafikverket**	
	Rutting	**MPD**
ABTS 11 (1320)	Yes	Yes
ABTS 11 GMB (1320)	Yes	Yes
ABTS 11 GMB (3361)	Yes	Yes

4.4.2 Västerbotten - E12 Storuman- Stensele K10 med

The asphalt for the track in Västerbotten E12 through Stensele and Storuman was placed in May 2011 (Nordgren & Tykesson, 2011). The track consists of Gap 16, ABT 16 GMB and a reference track with ABT 16 B 160/220. On the road the traffic is varying from 500 to 3000 cars per day including heavy traffic and the track with GMB is divided into three parts due to a change of traffic.

In PMSV3 measurements from year 2012 and 2014 for med direction are available. The analysed track is approximately 4.7 km long from starting point 252081 to the endpoint 259558.

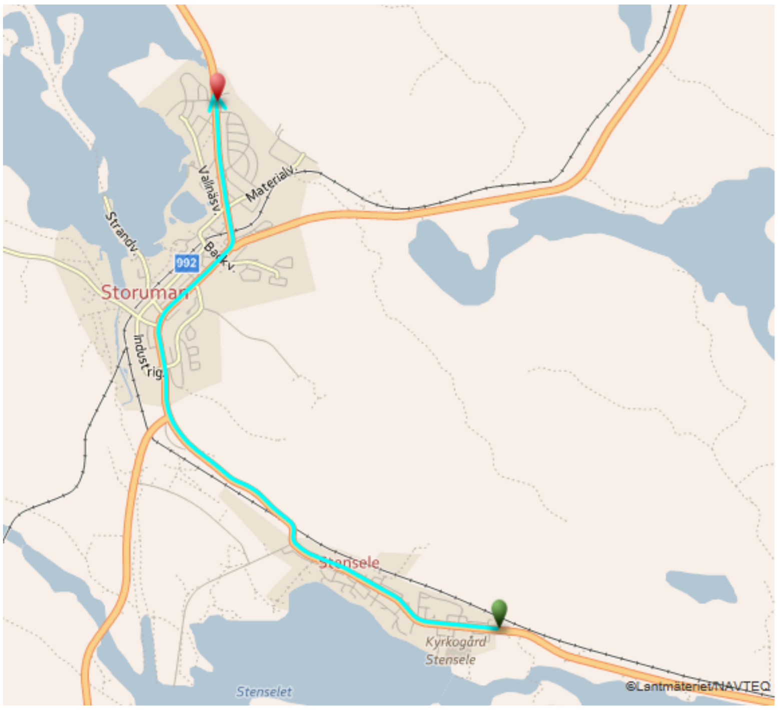
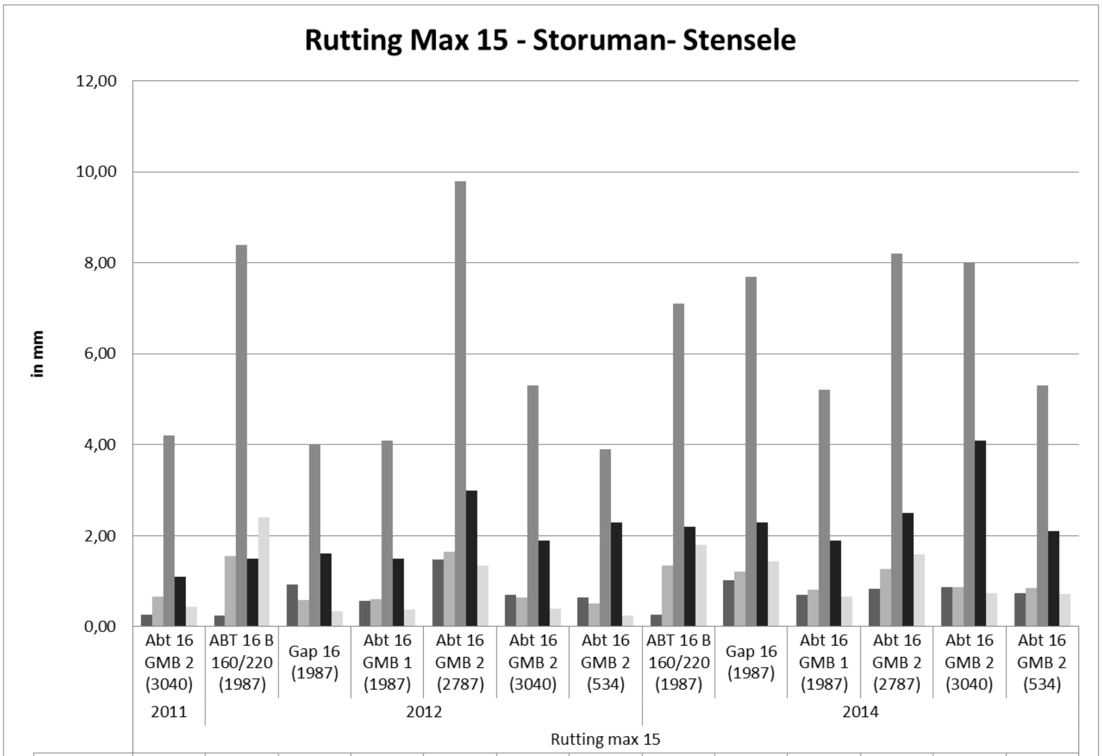


Figure 73: Stensele to Storuman 252081 to 259558. (Trafikverket PMSV3, 2015)

However, within PMSV3 the pavement types and year are not registered correctly. Therefore data from Svevia, pictures from PMSV3 and the Report from Nordgren & Tykesson, 2011 were taken to choose the exact track of the pavement types, see Figure 73.

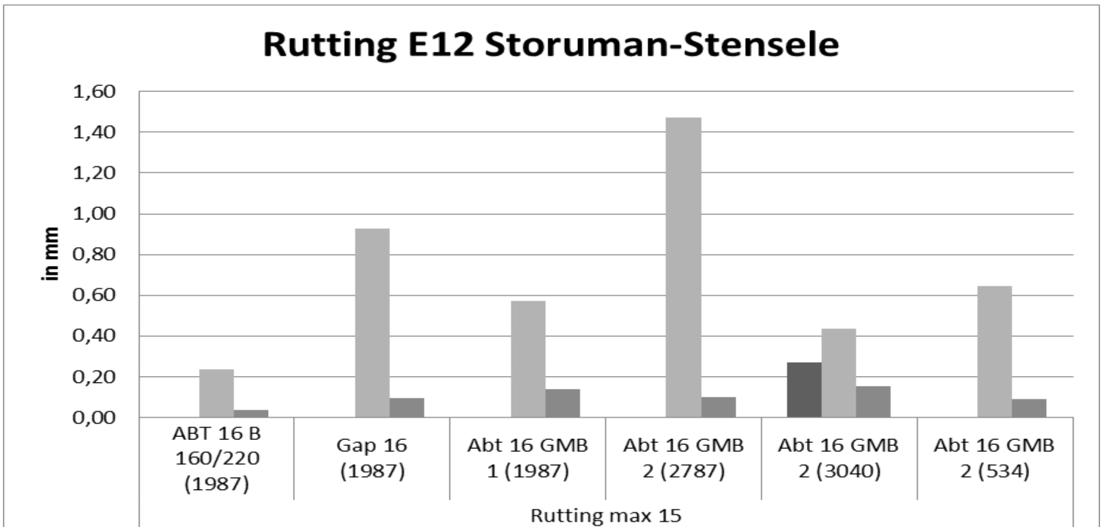
Furthermore, the data measured in PMSV3 was measured at a speed of approximately 45 km/h. As well this, the measurements are done in steps between 1 and 21 m, with an average of 14 m steps. The speed limit on the track is 50 to 90 km/h.



	Abt 16 GMB 2 (3040) 2011	ABT 16 B 160/220 (1987) 2012	Gap 16 (1987) 2012	Abt 16 GMB 1 (1987) 2012	Abt 16 GMB 2 (2787) 2012	Abt 16 GMB 2 (3040) 2012	Abt 16 GMB 2 (534) 2012	ABT 16 B 160/220 (1987) 2014	Gap 16 (1987) 2014	Abt 16 GMB 1 (1987) 2014	Abt 16 GMB 2 (2787) 2014	Abt 16 GMB 2 (3040) 2014	Abt 16 GMB 2 (534) 2014
Aver.	0,27	0,24	0,93	0,57	1,47	0,71	0,65	0,27	1,02	0,71	0,84	0,86	0,74
Stdev	0,66	1,55	0,58	0,61	1,64	0,64	0,50	1,34	1,20	0,81	1,26	0,86	0,84
Maximum	4,20	8,40	4,00	4,10	9,80	5,30	3,90	7,10	7,70	5,20	8,20	8,00	5,30
Minimum	1,10	1,50	1,60	1,50	3,00	1,90	2,30	2,20	2,30	1,90	2,50	4,10	2,10
Variance	0,44	2,40	0,33	0,37	1,35	0,40	0,25	1,79	1,45	0,66	1,60	0,74	0,71

Figure 74: Rutting max 15 (med) with different traffic loads

Figure 74 shows the main values for rutting of the different pavements divided by traffic loads for year 2012 and 2014. Here it can be seen that pavement with ABT has the lowest average value and a high maximum value after the first year. In 2014 the lowest average value has also the ABT track. It is also shown that the GAP track has the highest average value for 2012 and 2014.



	ABT 16 B 160/220 (1987)	Gap 16 (1987)	Abt 16 GMB 1 (1987)	Abt 16 GMB 2 (2787)	Abt 16 GMB 2 (3040)	Abt 16 GMB 2 (534)
2011					0,27	
2012	0,24	0,93	0,57	1,47	0,44	0,65
2014	0,04	0,09	0,14	0,10	0,15	0,09

Figure 75: Annual rate of change for rutting max15

In Figure 75 the annual change of the average values are shown. The highest average value is for the pavement with GMB with medium traffic, however the speed limit is here 90 km/h and 70 km/h for the rest of track. For the reference track the second year showed the lowest increase.

In Appendix XI: E12 Storuman-Stensele Figure 138, Figure 139 and Figure 140 show the annual change of the MPD. Table 34 shows a classification of the MPD values for this track. All values are according to Trafikverket's standards. Table 34 shows the classification referring to VTI. Here it can be seen that the ABT reference has bad values compared to the rest. The best values are for the track with the lowest traffic. As well this, all values for the right side are classified as bad.

Table 34: Classifications for MPD following VTI (med)

		ABT16 B 160/220 Ref (1987) 50–70 km/h	GAP 16 (1987) 50 km/h	ABTS 16 GMB 1 (1987) 50 km/h	ABTS 16 GMB 2 (2787) 90 km/h	ABTS 16 GMB 2 (3040) 50 km/h	ABTS 16 GMB 2 (534) 50 km/h
MPD left	2012	Bad	Acceptable	Excellent	Excellent	Excellent	Excellent
	2014	Bad	Acceptable	Acceptable	Acceptable	Acceptable	Excellent
MPD middle	2012	Bad	Acceptable	Good	Excellent	Good	Excellent
	2014	Bad	Acceptable	Good	Excellent	Good	Excellent
MPD right	2012	Bad	Bad	Bad	Bad	Bad	Bad
	2014	Bad	Bad	Bad	Bad	Bad	Bad

Table 35 shows that the pavements meet the requirement from Trafikverket and VTI.

Table 35: Current state and classification for E12 Storuman-Stensele med, according to VTI and Trafikverket

Section	**Trafikverket**	
	Rutting	**MPD**
ABTS 16 160/220 (1987)	Yes	Yes
Gap 16 (1987)	Yes	Yes
ABTS 16 GMB 1 (1987)	Yes	Yes
ABTS 16 GMB 2 (2787)	Yes	Yes
ABTS 16 GMB 2 (3040)	Yes	Yes
ABTS 16 GMB 2 (534)	Yes	Yes

4.4.3 Norrbotten - E4 Gäddvik-Nickbyn K10

Med direction

The asphalt for the track in Norrbotten E4 between Gäddvik and Nickbyn passing Luleå was placed in June 2013. The first measurement for PMSV3 was done in August 2013.

The track consists of Gap16 100/150 and a reference track of ABS 16 100/150. The traffic load on the road varies from 1810 to 4012 cars per day including heavy traffic (280 to 563 trucks per day). For the analysis the tracks were divided into type of asphalt and traffic load.

In PMSV3 measurements are found from year 2013 and 2014 for med direction can be found. The analysed track is approximately 10 km long from the starting point 72795 to the end point 89450, see Figure 76. The road consists of mainly two lanes and partially of one lane.

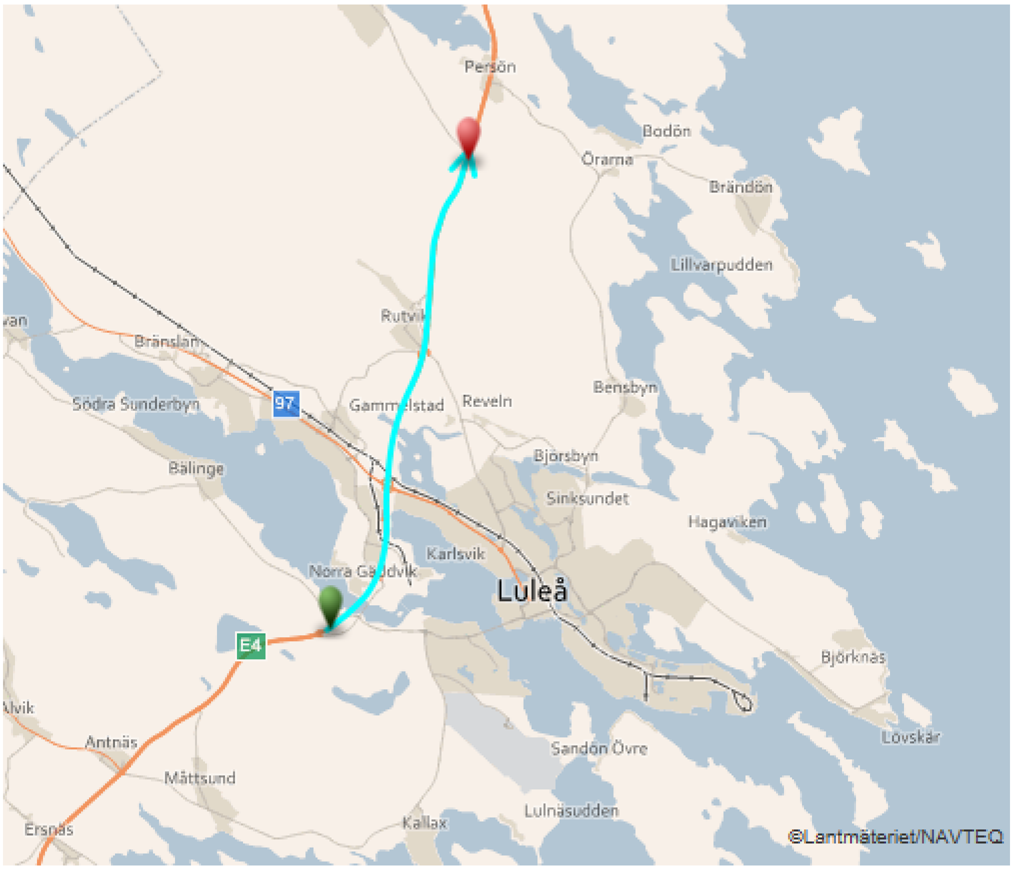
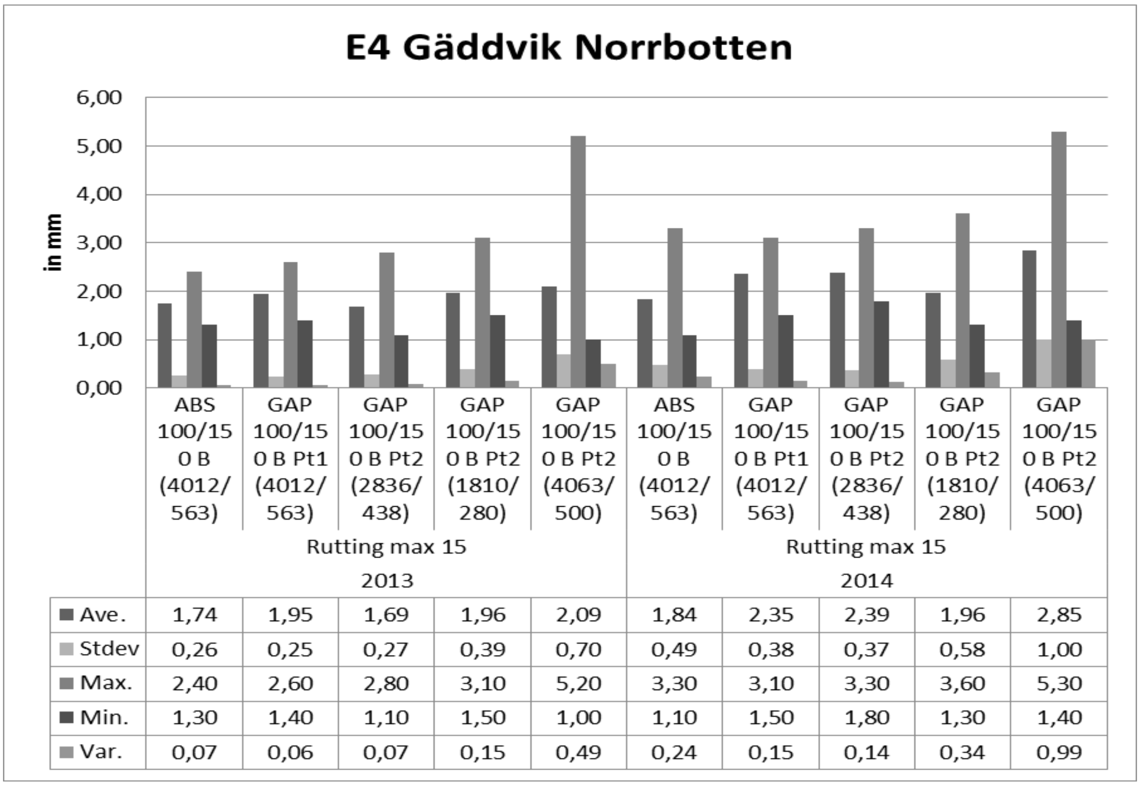


Figure 76: E4 Gäddvik to Nickbyn 72798 to 89450 (Trafikverket PMSV3, 2015)

The speed limit on the road is 110 km/h and the measurement car had a varying speed from 65 to 90 km/h. The measurements were done in 1 to 20 m steps, with an average of every 16 m.

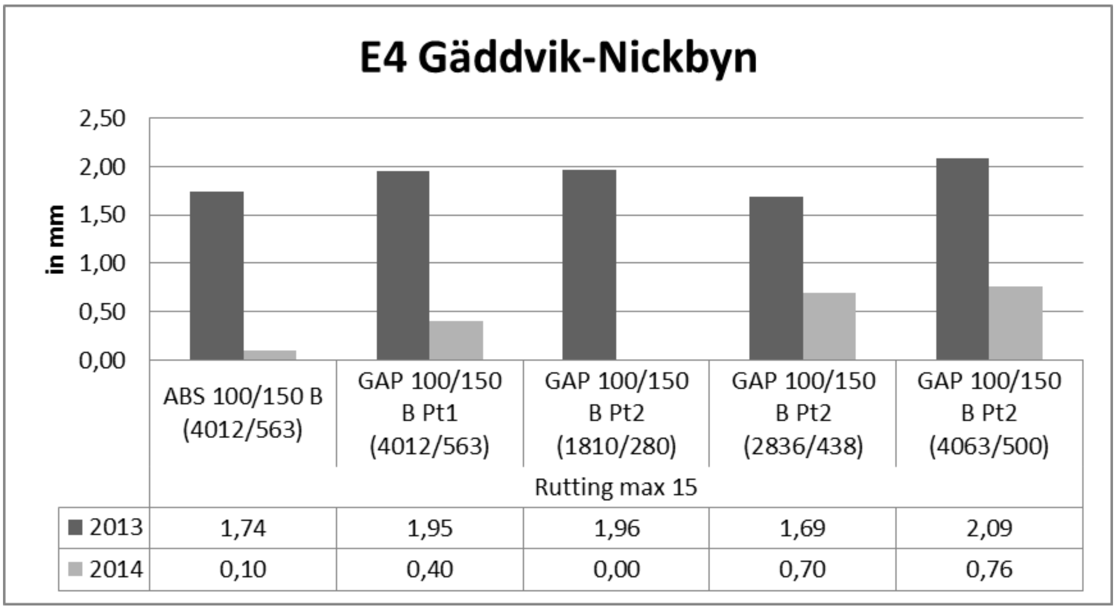
Figure 77 and Figure 78 show the values for the rut depth of the reference track and the Gap tracks divided by traffic loads. When comparing the reference track and the Gap track with the same traffic load it can be seen that the Gap shows higher initial rutting after the first month and increased four times more than the ABS reference track. However the reference track has higher minimum and maximum values than the Gap track after the first year and a higher standard deviation than the Gap track.



	ABS 100/150 B (4012/563) 2013	GAP 100/150 B Pt1 (4012/563) 2013	GAP 100/150 B Pt2 (2836/438) 2013	GAP 100/150 B Pt2 (1810/280) 2013	GAP 100/150 B Pt2 (4063/500) 2013	ABS 100/150 B (4012/563) 2014	GAP 100/150 B Pt1 (4012/563) 2014	GAP 100/150 B Pt2 (2836/438) 2014	GAP 100/150 B Pt2 (1810/280) 2014	GAP 100/150 B Pt2 (4063/500) 2014
Ave.	1,74	1,95	1,69	1,96	2,09	1,84	2,35	2,39	1,96	2,85
Stdev	0,26	0,25	0,27	0,39	0,70	0,49	0,38	0,37	0,58	1,00
Max.	2,40	2,60	2,80	3,10	5,20	3,30	3,10	3,30	3,60	5,30
Min.	1,30	1,40	1,10	1,50	1,00	1,10	1,50	1,80	1,30	1,40
Var.	0,07	0,06	0,07	0,15	0,49	0,24	0,15	0,14	0,34	0,99

Figure 77: Rutting max 15 (med) with different traffic loads – E4 med

Furthermore, when looking at the Gap depending on traffic load it is shown that the values vary even with a similar traffic load, for example when looking at the first and the last Gap track with an similar traffic load of 4000 cars per day the values are also similar during the first month and after the first year values are varying by 0.50 mm. The annual change of the last track is nearly double when compared to the first Gap track. However as seen in Figure 77 these values show a big difference in variance and standard deviation.



	ABS 100/150 B (4012/563)	GAP 100/150 B Pt1 (4012/563)	GAP 100/150 B Pt2 (1810/280)	GAP 100/150 B Pt2 (2836/438)	GAP 100/150 B Pt2 (4063/500)
2013	1,74	1,95	1,96	1,69	2,09
2014	0,10	0,40	0,00	0,70	0,76

Figure 78: Annual rate of change for rutting max15- E4 med

For the MPD the annual change seen in Appendix XII: E4 Gäddvik-Nickbyn Figure 141 and Figure 142 show that the annual change after one year is lower for the reference track compared to the GAP. The largest increase can be found at the Gap track with the highest traffic load.

The values are all within the requirements for Trafikverket and Table 36 shows the classification of the values according to VTI. All values are classified as excellent, however the MPD right value after the first month for the reference track is the only one classified as bad.

Table 36: Classifications for MPD following VTI (med)

		ABS 100/150 B Pt1 (4012/563)	GAP 100/150 B Pt1 (4012/563)	GAP 100/150 B Pt2 (2836/438)	GAP 100/150 B Pt2 (1810/280)	GAP 100/150 B Pt2 (4063/500)
MPD left	2013	Excellent	Excellent	Excellent	Excellent	Excellent
	2014	Excellent	Excellent	Excellent	Excellent	Excellent
MPD middle	2013	Excellent	Excellent	Excellent	Excellent	Excellent
	2014	Excellent	Excellent	Excellent	Excellent	Excellent
MPD right	2013	Bad	Excellent	Excellent	Excellent	Excellent
	2014	Excellent	Excellent	Excellent	Excellent	Excellent

Table 37 shows the performance of the pavement. The best performance shows the reference track with longer life time than the Gap track. However, when comparing the Gap tracks, the parts with lower traffic have a shorter life time than the part with 4000 cars per day.

Table 37: Current state and classification for E4 Gäddvik- Nickbyn med, according to VTI and Trafikverket

Section	Trafikverket		Years to next maintenance
	Rutting	MPD	
ABS Pt 1 (4012)	Yes	Yes	129
Gap Pt 1 (4012)	Yes	Yes	31,5
Gap Pt 2 (1810)	Yes	Yes	Not possible
Gap Pt 2 (2836)	Yes	Yes	17,6
Gap Pt 2 (4063)	Yes	Yes	16

Mot direction

For the mot direction the track was also placed in June 2013. The first measurement in PMSV3 was done in August 2013.

The track consists also of ABS 16 GMB and according to PMSV3 is there also a reference track of ABS 16 100/150 following the GMB. However, when analysing the data it was visible that the track was already paved in year 2007 and not 2013 see Figure 79. This example shows that the registration in PMSV3 is not always correct and reliable.

The traffic load varies from 1810 to 4012 cars per day including heavy traffic from 280 to 563 trucks per day. In PMSV3 measurements are found from year 2013 and 2014 for mot direction. The analysed track is approximately 14.7 km long from the starting point 112038 to the end point 130608. The road consists of mainly two lanes and partially of one lane.

The speed limit on the road is 110 km/h and the measurement car had a varying speed from 78 to 90 km/h, with an average of 80 km/h. The measurements were done in 1 to 21 m steps, with an average of every 16 m.

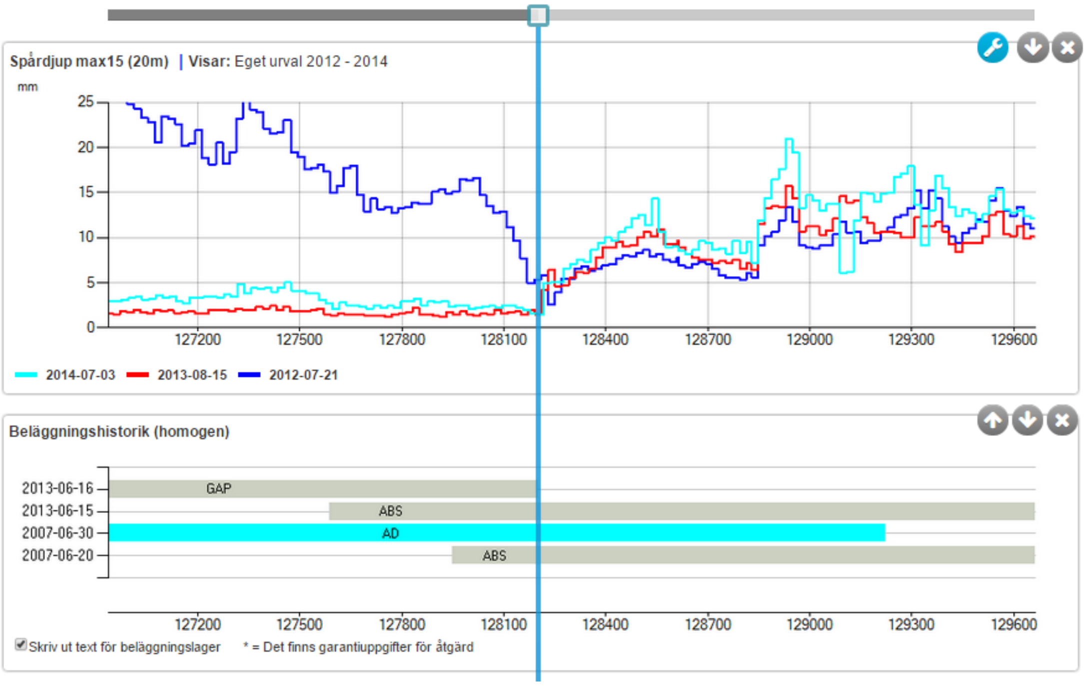
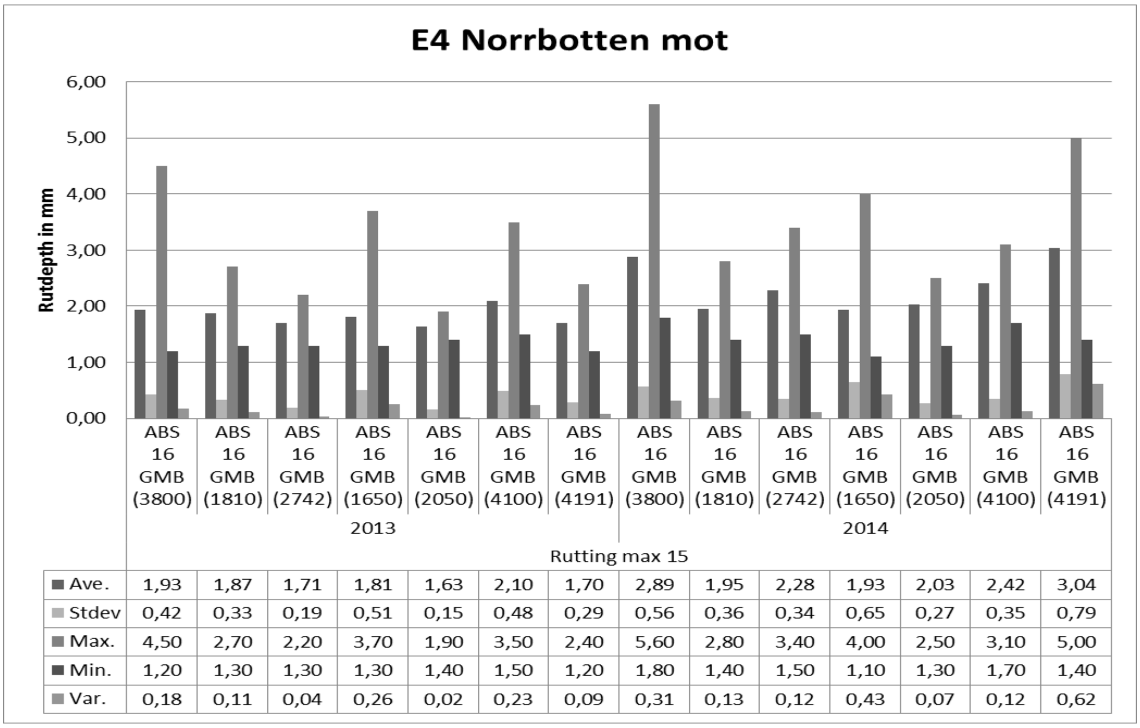


Figure 79: Pavement history for track 112038 to 130608, Norrbotten E4

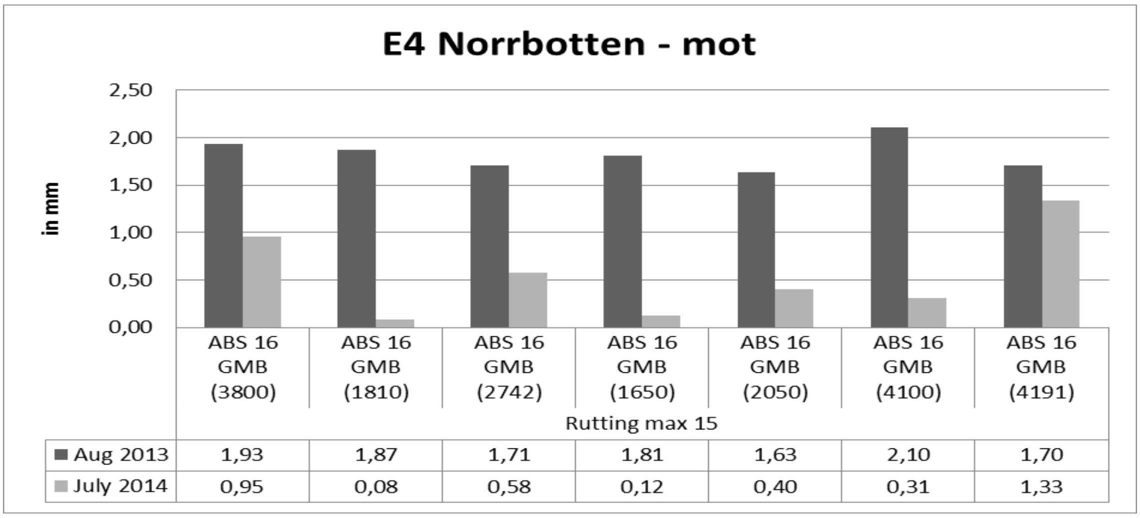
The values for the rut depth of this track are shown in Figure 80 and Figure 81, in this case no reference track is available from met direction, however to be able to make an comparison the reference track from med direction is used, see Figure 78.

The parts with the highest traffic show also the highest rutting after the first measurement, however the parts with medium traffic of 2000 until 3000 cars per day show the lowest initial rut depth. After one year the lowest values are for the tracks with the lowest traffic load. This means that the parts with traffic loads from 2000 until 3000 cars per day have less variation in initial rutting and the highest annual change after the first year.



	ABS 16 GMB (3800)	ABS 16 GMB (1810)	ABS 16 GMB (2742)	ABS 16 GMB (1650)	ABS 16 GMB (2050)	ABS 16 GMB (4100)	ABS 16 GMB (4191)	ABS 16 GMB (3800)	ABS 16 GMB (1810)	ABS 16 GMB (2742)	ABS 16 GMB (1650)	ABS 16 GMB (2050)	ABS 16 GMB (4100)	ABS 16 GMB (4191)
	2013							2014						
Ave.	1,93	1,87	1,71	1,81	1,63	2,10	1,70	2,89	1,95	2,28	1,93	2,03	2,42	3,04
Stdev	0,42	0,33	0,19	0,51	0,15	0,48	0,29	0,56	0,36	0,34	0,65	0,27	0,35	0,79
Max.	4,50	2,70	2,20	3,70	1,90	3,50	2,40	5,60	2,80	3,40	4,00	2,50	3,10	5,00
Min.	1,20	1,30	1,30	1,30	1,40	1,50	1,20	1,80	1,40	1,50	1,10	1,30	1,70	1,40
Var.	0,18	0,11	0,04	0,26	0,02	0,23	0,09	0,31	0,13	0,12	0,43	0,07	0,12	0,62

Figure 80: Rutting max 15 (med) with different traffic loads – E4 mot



	ABS 16 GMB (3800)	ABS 16 GMB (1810)	ABS 16 GMB (2742)	ABS 16 GMB (1650)	ABS 16 GMB (2050)	ABS 16 GMB (4100)	ABS 16 GMB (4191)
Aug 2013	1,93	1,87	1,71	1,81	1,63	2,10	1,70
July 2014	0,95	0,08	0,58	0,12	0,40	0,31	1,33

Figure 81: Annual rate of change for rutting max15- E4 mot

Figure 143 and Figure 144 in Appendix XII: E4 Gäddvik-Nickbyn show the MPD values for all tracks.

The values for rutting and MPD are due to Trafikverket requirements being fulfilled, for further classification of the MPD values the VTI requirements are taken into account, see Table 38. Here most of the results are classified as excellent, except for one the MPD right for the traffic load of 4100. This value was only achieved directly after the paving and after one year the values area all excellent.

Table 38: Classifications for MPD following VTI (mot)

		ABS 16 GMB (3800)	ABS 16 GMB (1810)	ABS 16 GMB (2742)	ABS 16 GMB (2050)	ABS 16 GMB (4100)	ABS 16 GMB (4191)
MPD left	2013	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	2014	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
MPD middle	2013	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
	2014	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
MPD right	2013	Excellent	Excellent	Excellent	Excellent	Bad	Excellent
	2014	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent

Table 39 shows the performance of the tracks, when comparing the reference track and GMB with the same traffic load the reference track shows much higher life time. However, when only comparing the GMB depending on traffic, the ones with the lowest amount of traffic show a better performance. This could also be due to only one available measurement.

Table 39: Current state and classification for E4 Gäddvik- Nickbyn mot, according to VTI and Trafikverket

Section	**Trafikverket**		**Years to next maintenance**
	Rutting	**MPD**	
ABS Pt 1 (4012)	Yes	Yes	129
GMB (4100)	Yes	Yes	41
GMB (4191)	Yes	Yes	8,77
GMB (3800)	Yes	Yes	12,7
GMB (2742)	Yes	Yes	21,4
GMB (2050)	Yes	Yes	31,5
GMB (1810)	Yes	Yes	186,5

4.5 Result overview

Table 40 shows the pavement type, traffic and needed years until maintenance of all analysed tracks. CZ is an abbreviation for climate zone.

Table 40: Result overview

CZ	Road no.	Location	Lanes	Speed limit [km/h]	Traffic	Asphalt type	Years until maintenance
1	E4	Kropp-Hyllinge	10	110	11734	ABS 70/100 B	7
					13383	GAP 70/100 B	7
					4500	ABS 70/100 B	23
					4500	GAP 70/100 B	14.5
			20		11734	ABS 70/100 B	28.1
					13383	GAP 70/100 B	27.8
					4500	ABS 70/100 B	22.9
					4500	GAP 70/100 B	33.4
	E6	Fredriksberg - Lockarp	10	110	7157	ABS 70/100 B	21.6
						GAP 70/100 B	24.2
					19089	ABS 70/100 B	13
					17064	GAP 70/100 B	29.6
			20		7157	ABS 70/100 B	50.3
						GAP 70/100 B	46.5
					19089	ABS 70/100 B	26.2
					17064	GAP 70/100 B	55
	E6	Kronetorp-Salerup	10	110	18618	ABS 70/100 B	10.3
						GAP 70/100 B	26.3
					10610	ABS 70/100 B	9.7
					10000	GAP 70/100 B	23.8
			20		18618	ABS 70/100 B	40.4
						GAP 70/100 B	26.1
					10610	ABS 70/100 B	26.4
					10000	GAP 70/100 B	26.4
	E6	Petersborg-Vellinge South	10	110	17132	ABS 70/100 B	13.8
						GAP 70/100 B	14.8
			20		17132	ABS 70/100 B	29.2
						GAP 70/100 B	36.8
	E6	Sunnanå-Kronetorp	10	110	17012	ABS 70/100 B	6.6
					18294	GAP 70/100 B	26.3
			20		17012	ABS 70/100 B	30
					18294	GAP 70/100 B	21.6
2	E6	Ullevi-Kallebäck	10	70	30121	ABS 70/100 PMB	9.3
						GAP 70/100 B	9.5
			20		30121	ABS 70/100 PMB	12.4
						GAP 70/100 B	14.7

	E4	Uppsala-Knivsta	10 20	110	16971	GAP16 0.6% Wetfix	5.0
					16971	GAP16 0.6% Wetfix Pt2	5.9
					16971	GAP 16% 0.3% Wetfix 1% Cement	4.7
					16971	GAP 16% Increased Temp	5.5
					16971	ABS 70/100	6.4
					13979	ABS 50/70	7.7
					13979	GAP 16 Increased Temp Pt2	6.5
	E4	Viby-Sollentuna Stockholm	30	110	33510	ABS 70/100 B	6.6
					33510	GAP 70/100 B	6
4	**E4**	Broänge - Hökmark	10	90	3800	GAP 16 100/150	15
	E12	Lycksele	10 med	70	1320	ABTS 11	30
				50-70	1320	ABTS 11 GMB	41
				50-70	1563	ABTS 11 GMB	30
				50-70	2000	ABTS 11 GMB	17,5
				50-70	3361	ABTS 11 GMB	11,5
				50	5600	ABTS 11 GMB	9
			10 mot	70	1320	ABTS 11	
				50-70	1320	ABTS 11 GMB	
				50-70	3361	ABTS 11 GMB	
	E12	Storuman-Stensele	10	50-70	1987	ABTS 16 160/220	
				50	1987	Gap 16	
				50	1987	ABTS 16 GMB 1	
				90	2787	ABTS 16 GMB 2	
				50	3040	ABTS 16 GMB 2	
				50	534	ABTS 16 GMB 2	
5	**E4**	Gäddvik-Nickbyn	10 med	110	4012	ABS 100/150	
					4012	Gap Pt 1	
					1810	Gap Pt 2	
					2836	Gap Pt 2	
					4063	Gap Pt 2	
			10 mot	110	4012	ABS 16 GMB	
					4100	ABS 16 100/150	
					4191	ABS 16 100/150	
					3800	ABS 16 100/150	
					2742	ABS 16 100/150	
					2050	ABS 16 100/150	
					1810	ABS 16 100/150	

5 Discussion

The discussions were made for each track individually and then gathered together in order to achieve an overall picture of which asphalt type is more suitable regarding texture and rutting

E4 Kropp- Hyllinge KF10

In this section the lifetime was equal for both the GAP and the ABS, despite more traffic on the GAP. From it can be concluded that the GAP is more resistant to rutting than ABS. On the section with 4500 vehicles per day the ABS lasts 8.5 years longer than the GAP, meaning it is better suited for this section and traffic volume. The texture for the standard asphalt is better in both sections.

On this road the use of standard ABS is recommended more regarding rut resistance and texture. Additional measurements are recommended, since the long- term use of GAP has not been evaluated yet.

E4 Kropp- Hyllinge KF20

In this section the ABS has a longer lifetime than the GAP at the high traffic volumes. However, the results would need further consideration since the traffic volumes are not equal. On the section with 4500 vehicles per day the GAP lasts 10.5 years longer than the ABS and is clearly better suited for this road with this traffic volume. The texture was excellent for both, nevertheless higher for ABS.

E6 Fredriksberg- Lockarp KF10 mot

The calculation showed that the GAP provides a longer lifetime at both traffic volumes. In the section with lower traffic further measurements are necessary for a clearer result. To judge from the annual changes the wearing varies for each year.

The rubber modified asphalt provided even a better texture and at the higher traffic the ABS was even rated as bad by the VTI classification. This could however be related to the higher traffic, which was more by over 2000 vehicles per day on the ABS section. Both types fulfil Trafikverket’s requirements.

E6 Fredriksberg- Lockarp KF20 mot

All sections fulfilled Trafikverket’s requirements for maximum rut depth and texture. Compared to the VTI requirements all types have an excellent texture. Judging by the values the GAP provides a slightly better texture. On the section with ABS at 19089 vehicles per day the texture is lowest compared to the others, which may depend on the high traffic volume.

E6 Kronetorp- Salerup KF10 mot

The GAP fulfilled Trafikverket’s and VTI’s requirements for rut depth and texture at both traffic volumes. The ABS on the other hand fulfilled Trafikverket’s requirements, but had a bad texture according to VTI. The rut depths were much higher for the ABS and is expected to last 16 years less than the GAP at 18618 vehicles per day and 14 years less at 10000 vehicles per day.

Another observation is that the rut depth is higher for the GAP at lower traffic volumes. The reason for this could be related to the use of less resistant aggregates on sections with lower traffic volumes.

E6 Kronetorp- Salerup KF20 mot

The results for this lane differ from the first lane. On the sections with 10000 vehicles per day the remaining time before maintenance is the same for both types. Since the traffic for the ABS is 10610 vehicles per day, i.e. slightly higher than for the GAP, one can say that the ABS is better on this section. At the section with 18618 vehicles per day the ABS clearly has a greater advantage with an almost 14 years longer lifetime. In terms of texture the GAP provides a better texture and in addition to this all sections fulfil Trafikverket and VTI's requirements.

E6 Petersborg- Vellinge KF10 mot

On this road the rubber modified asphalt has proven to provide better resistance against rutting and a better texture than the ABS. The GAP is expected to last 1 year longer than the standard asphalt. Weather this is an advantage sufficient enough to compensate for the additional cost is something that still has to be investigated. Both types fulfil Trafikverket's requirements and are rated as excellent according to VTI's requirements.

E6 Petersborg- Vellinge KF20 mot

On the second lane the results resemble the ones in the first lane. The GAP provides better texture and rut resistance here as well. The GAP is expected to last for more than seven years longer than the ABS. Both types fulfil Trafikverket's requirements and are rated as excellent by VTI.

E6 Sunnanå- Kronetorp KF10 med

From 2009 until 2014 the rut depth for rubber-modified asphalt increased with 2.80 mm. After the same time period the standard asphalt's rut depth was 7.41 mm in 2011. The difference between the two materials' rut depth is 4.61 mm, which is almost double the rut depth for the GAP. Considering rutting, the rubber modified asphalt would last 20 years longer than the standard asphalt, or 17 years if the paving date is taken into consideration.

Considering texture, the better values are associated with the GAP, although the traffic is higher on that section. On the other hand the ABS has been placed three years previously, meaning that it has been exposed for wearing for a longer period. The rate of change indicates that the ABS has decreased by less than 0.03 mm per year, which could indicate that the MPD for the ABS has been low from the beginning. Both types have an excellent texture according to classification by VTI, except for the left MPD on the ABS, which is lower than the limit. Both fulfil Trafikverket's requirements as well.

E6 Sunnanå- Kronetorp KF20 med

On this lane the standard asphalt provides the better material in terms of rutting. The ABS lasts more than eight years longer than the GAP. Considering texture the rubber asphalt provides a better surface, despite the higher traffic. One explanation for the low texture on the ABS could be that it was placed three years earlier. To be more certain, additional measurements are necessary and time should pass in order to show which type lasts longer since deterioration changes with time. Both fulfil Trafikverket's requirements and have an excellent texture according to the VTI rating.

E6 Ullevi- Kallebäck KF10 & 20

On the first lane of the E6 in Gothenburg the measured data was very similar for both asphalt types. The GAP had a slightly longer life span (by 0.2 years) than the PMB. On the second lane the difference was clearer, where the rubber modified asphalt indicated grater resistance against rutting on an average (3 years longer lifetime). The annual increases in Figure 47 and Figure 48 have a high variation from year to year, which does not provide an accurate representation of the pavement's behaviour. There is no clear picture of how the asphalt types will behave with time, hence further measurements are needed in order to determine the better suited asphalt type for this road.

Considering MPD no significant differences were observed in the comparison between GAP and PMB in lane 1. For lane 1 the MPD values are between 0.55- 0.91 mm for both types. These values fulfil Trafikverket's requirements for texture larger than 0,35 mm at 70 km/h. Larger differences were indicated in lane 2 as the MPD value was much higher for the PMB. Even these values fulfil Trafikverket's requirements and are on an average classified as acceptable by VTI.

E 47 Falköping

VTI uses advanced techniques and equipment and closes down the road in order to achieve very precise measurements. For PMSV3 on the other hand the data is collected with a single reading with the laser-equipped car. These differences show in the results with a large variation up to 50% at certain instances. However, regarding the expense in the measuring procedure and that most of the readings from PMSV3 differed by ±18% from VTI's measurements it is possible to conclude that PMSV3 is a feasible tool for road surveys. Since rutting is measured in millimetres it is acceptable to have a difference of 18%, which otherwise may appear to be a high value. The VTI survey is more suited for researchers or if certain properties of an asphalt type/mixture are requested.

As well as being in agreement with the rutting reference tracks 1 and 2 as well as track 2 (which had the lowest rutting), they also appear to have the highest values for texture. According to the values and the patterns there is a correlation between texture and wearing on these asphalt types. The asphalt types with good wear resistance offer a better texture as well. All sections had higher texture than recommended by both Trafikverket and VTI which in other words means the asphalt types offer a skid resistance which is too high. This affects the noise emission and fuel consumption, which increase with too high texture.

Considering lifetime the second reference track offers the best quality by far. From an economical point of view this asphalt type is the most recommended one.

E4 Uppsala- Knivsta

<u>Evaluation of PMSV3 in comparison to Objektsmätning (Rutting)</u>

The results indicated differences between the two road surveys, regarding rut depths. On average the data from PMSV3 deviated by ±7% from the data in Objektsmätning, which is a very acceptable range regarding the expense in the survey method and equipment. Bearing in mind that the measured values are in millimetres, ±7% is a very small difference and affects the outcome to a small extent. Many aspects can influence the measurements such as equipment, driving style, traffic and most important in that case the different occasions.

The most important factor for differences is the different measuring occasions. While the Objektsmätning was implemented during spring and autumn, the measurements for PMSV3 were implemented in summer meaning that the surveys were done either before or after Objektsmätning. Considering that most of the deformation occurs during winter time, this time difference has a minor influence on the measurements.

These differences however affected the results when comparing the rutting caused in winter with the rutting during the whole year. In the calculations almost all measurements were larger for the winter period to a small degree, which is not logical. One explanation for why the results are differing is the difference in the measuring methods. Moreover the small difference indicates that most of the wearing is caused during the winter period by studded tires.

Conclusion

According to the measurements and results PMSV3 is a feasible analysis tool. In general there is one drawback with PMSV3, which is the extra editing work in the data files before the data can be used for analysis.

Comparison of GAP to ABS

Texture

There is a clear difference in texture (MPD) between GAP and ABS. The texture in the sections with modified asphalt was much higher than the texture for the standard asphalt. On the GAP sections the MPD values were all above 1 mm during the period between 2011 and 2014, while MPD on the reference sections was below 1 mm. Furthermore, the rate of change was higher for the reference sections, meaning the texture decreased faster.

Rutting

On the test road the rubber modified asphalt was more sensitive to rutting than the standard asphalts. The standard types would last at least one year longer with the two traffic volumes according to the last measurement and the average changing rate.

Conclusions

The modified asphalt is more suited for this section regarding texture since the measured values were larger than the reference track and decreased slower. Therefore it is possible to conclude that the texture on GAP is more stable and does not change extremely. The standard ABS on the other hand is more resistant to wearing by studded tyres, which results in less rutting.

Wearing per 1 million wheel passages

The wearing which was calculated for one million wheel passages enables the comparison between asphalt types independent of traffic volumes. In this calculation the number of cars was neutralized. The effect of this neutralization becomes clear when the values are compared to the results in Figure 56 and Figure 57. In these figures tracks 3 and 4 have the greatest rutting, however in Figure 58 the last track has the largest rutting, which only became clear when the traffic amount was neutralized.

Texture change per 1 million wheel passages

The results in Figure 59 indicate that the texture for GAP increases, while it decreases for the ABS. As long as the values are within the required range there is no large difference between increase and decrease. The values matter when they become extreme, which may indicate the wearing of the aggregates if the MPD decreases, and the loss of aggregates if the MPD increases.

In order to verify in which direction the texture is moving it is possible to compare it to the MPDs in Figure 127, Figure 128 and Figure 129 in Appendix VIII: E4 Uppsala-Knivsta. In these figures the textures behave in the same way they did in Figure 59. They decrease for the reference track and increase for the modified tracks. The following years it starts to decrease for all sections in different degrees. The tracks are still within the recommendations from Trafikverket according to Figure 127, Figure 128 and Figure 129 in Appendix VIII: E4 Uppsala-Knivsta, hence no judgment can be made with the present data and further measurements are needed.

The data however provides a hint in which direction the asphalt types are going and in what way the deterioration occurs. In this case the aggregates in the standard asphalt seem to be worn out and crushed, while they would loosen and fall out in the rubber modified asphalt.

Conclusions

Transforming the wearing to a neutral number independent of traffic enables the comparison of asphalt types in sections with different traffic volumes. In our opinion this number is an effective way of evaluating wearing on a road.

E4 Viby- Sollentuna (Stockholm) KF30 mot

The results in Table 26 imply that the ABS is more resistant to rutting than the GAP and that it is better suited for this section on the road. In terms of texture the rubber modified asphalt was better. On the other hand, there were too few measurements on this road. Data from three years' worth of measurements are not enough data to base a decision on.

E4 Broänge-Hökmark K10 med

In this case the Gap meets the requirements of Trafikverket and is classified as excellent for all three measurements for approximately 3800 cars per day and 90 km/h. However due to the incorrectly registered data it is unsure if these values are correct and a reference track was missing for comparison.

E12 Lycksele K10 med

For the med direction the reference track shows worse results for rutting than the GMB even with lower traffic load. The track would need maintenance 10 years before the GMB track. However the texture for the reference track is better classified than for the GMB.

For the PMSV3, the correct data regarding pavement type and pavement date should be registered correctly. The modified asphalt could not be found only using the search function in PMSV3 and no further information.

Additional measurements are recommended, since the long- term use of GMB has not been evaluated yet.

E12 Lycksele K10 mot

For the mot direction the reference track shows lower values after the first month of pavement, however during the first year the initial rutting is higher in total for the reference track than for the GMB.

On the reference track the texture ranks higher in the classification than the GMB.

Additional measurements are recommended since the long- term use of GMB could not be evaluated with the present amount of data.

E12 Storuman- Stensele K10 med

Here three different pavements could be compared. After the first year the reference track followed by the GMB show the best results. However in the following two years the GAP has a lower annual change than the GMB.

For the texture the reference track is classified worst and GMB best. However, for all three pavements the right side is classified as bad.

For texture and rutting additional measurements are recommended, since the long term use of GAP and GMB could not been evaluated yet.

Furthermore, for the PMSV3 the correct data regarding pavement type and pavement date should be registered correctly. The modified asphalt could not be found only using the search function in PMSV3 or without additional information.

E4 Gäddvik-Nickbyn K10 med and mot

For the med direction the rut depth values vary in some parts more than others and therefore have a higher range of values concluding in higher average values with similar traffic load.

While comparing the reference and Gap track, the reference track shows better results for initial rutting.

For the texture, the classification is excellent according to VTI, it must be mentioned that the classification ranges are only for speed limit up to 100 km/h, however for this track the speed limit is 110 km/h. Therefore the classification might be only good for an overview and not for an actual classification.

For texture and rutting additional measurements are recommended since the long- term use could not be evaluated yet.

For PMSV3 again it is important to register the pavements correctly due to misunderstandings if no additional data is provided. In this case, data from the construction company was available and it was therefore known that no additional reference track was paved in mot direction.

6 Conclusions and future recommendations

During the analysis of the measured data several observations were made regarding asphalt types, deformation patterns and the use of PMSV3. We expected the RMA to be more resistant to rutting than our results showed, since the studies from Arizona clearly promised better performance. The different outcome can mainly be related to the use of studded tires in Sweden and difference in climate.

The use of PMSV3 for our analysis was helpful. It was both easy to use and straightforward and provided a high amount of useful data, not only about rut depth and texture but also about traffic, prognoses, statistics and many other parameters. The system has the advantage that information on each road is provided with pictures and graphs and can be changed directly during use, besides the map that shows the current location. Another advantage is its price efficiency compared to surveys from VTI which can be three to five times the price of analysis with PMSV3.

There were a few disadvantages as well, such as incorrect reporting in the data base about pavement type. For some roads there was no information about the pavement type or it did not correspond to the information provided by the contractors. The same problem applies to the coordinates for a few sections. Finally, the data editing is time consuming, especially when there are many different asphalt types and many different traffic volumes.

<u>Rubber modified asphalt</u>

The evaluation of rubber modified asphalt could have been more comprehensive, if all information had been available in PMSV3. Most of the tracks that provided data from many years for a good comparison were located in climate zone 1. In climate zone 2 the available data was limited and no conclusion for which asphalt type is better could be made. For instance, the E6 in Gothenburg was compared to ABS with PMB, not the standard binder. Other roads are the E18 and E20 in Örebro, where many different products can be found as it was in Uppsala. The data from these roads would have been an important aspect for our comparison; however it was left out since the road was placed recently and no data was available in PMSV3. These tracks are however good examples for this kind of analysis in the future.

The surface properties for the GAP showed an increased rut resistance and higher texture than conventional asphalt, especially in climate zone 1. On the E6 in Fredriksberg the lifetime of the rubber modified asphalt was up to 29 years longer than the conventional asphalt. On the E6 in Gothenburg, located in climate zone 2 it performed better than polymer modified asphalt, which is supposed to be a better option than conventional asphalt. In Uppsala and Stockholm on the other hand the standard asphalt only provided better rut resistance. For climate zone 2 it is therefore not clear which asphalt type performs better and more measurements are necessary in the future. In the north the provided data was insufficient for a conclusion. Most tracks were measured only once so would make a good starting point for future studies.

As a last step the wearing for one million wheel passages was calculated, which enabled the comparison for wearing independent of traffic. This number is very useful for roads with different traffic volumes and asphalt types. This calculation was applied on the E4 in Uppsala and verified that the GAP was more sensitive to wearing there.

Future recommendations

A clearer reporting of pavement data regarding type and start and stop coordinates would facilitate the work on a large scale. PMSV3 is a very suitable tool for road surveys and recommended for future use regarding accuracy and cost. Rubber modified asphalt has a great potential and could compensate for the extra cost of 20% with longer lifetime. However, additional measurements are necessary to evaluate GAP for a long term perspective.

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8 List of figures

9 List of tables

10 List of equations

Appendix

Appendix I: E4 Kropp-Hyllinge

KF 10

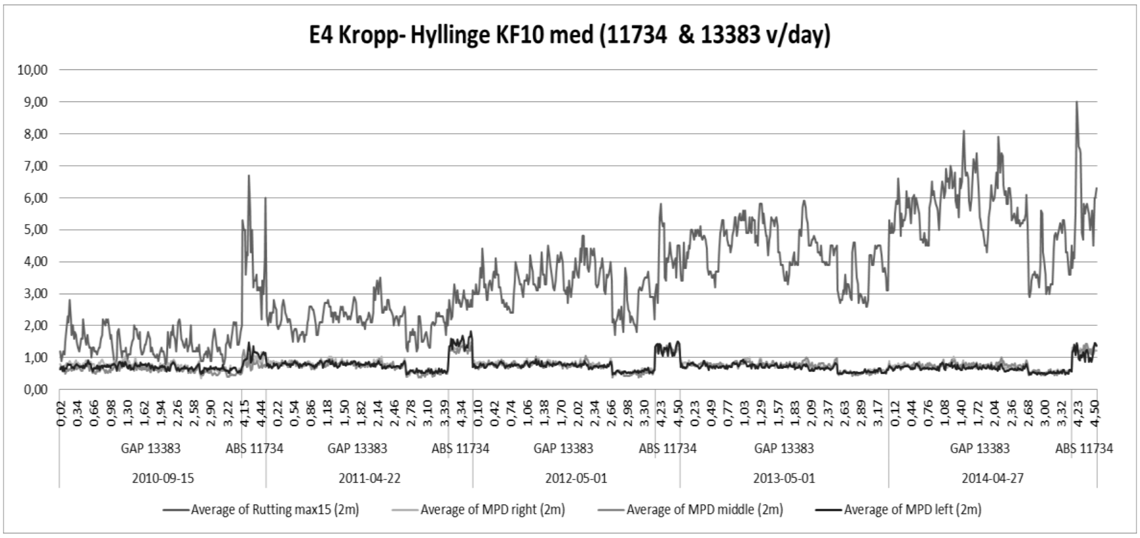


Figure 82: Average values for rutting, MPD left, middle and right between 2010 and 2014

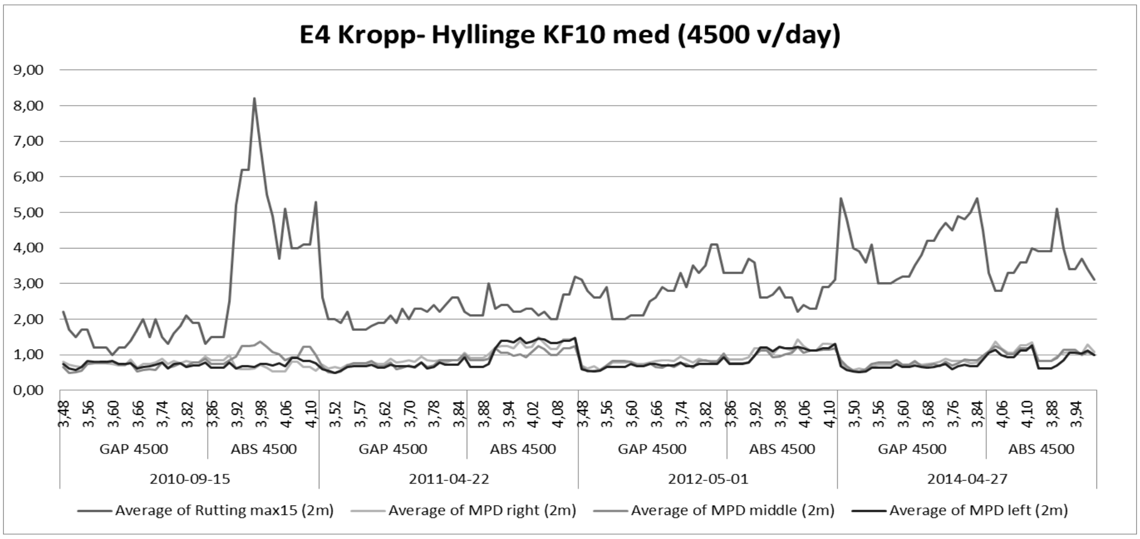


Figure 83: Average values for rutting, MPD left, middle and right between 2010 and 2014

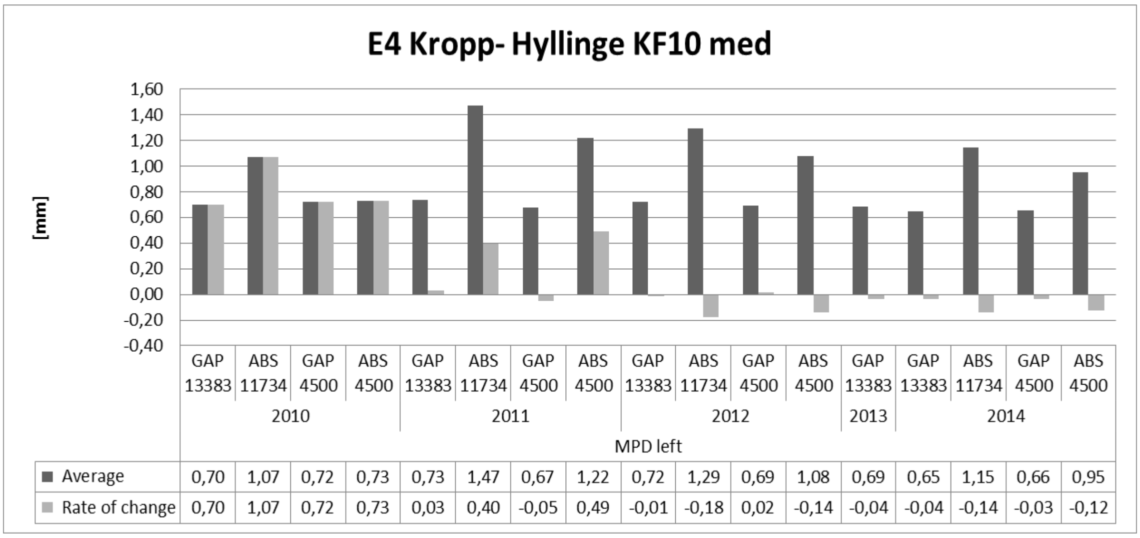


Figure 84: Average values and annual change for MPD left for standard ABS and GAP

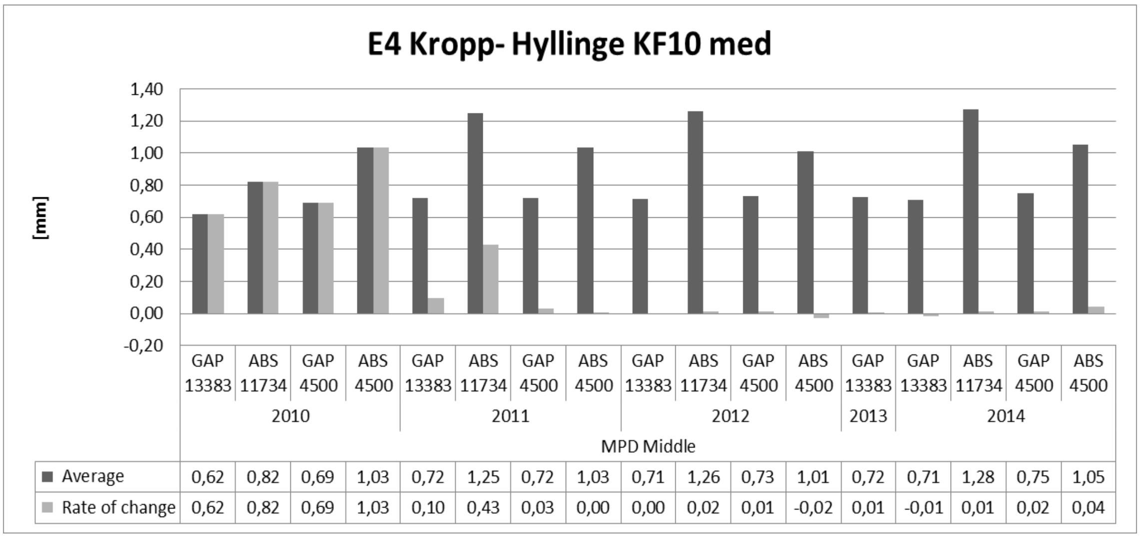


Figure 85: Average values and annual change for MPD middle for standard ABS and GAP

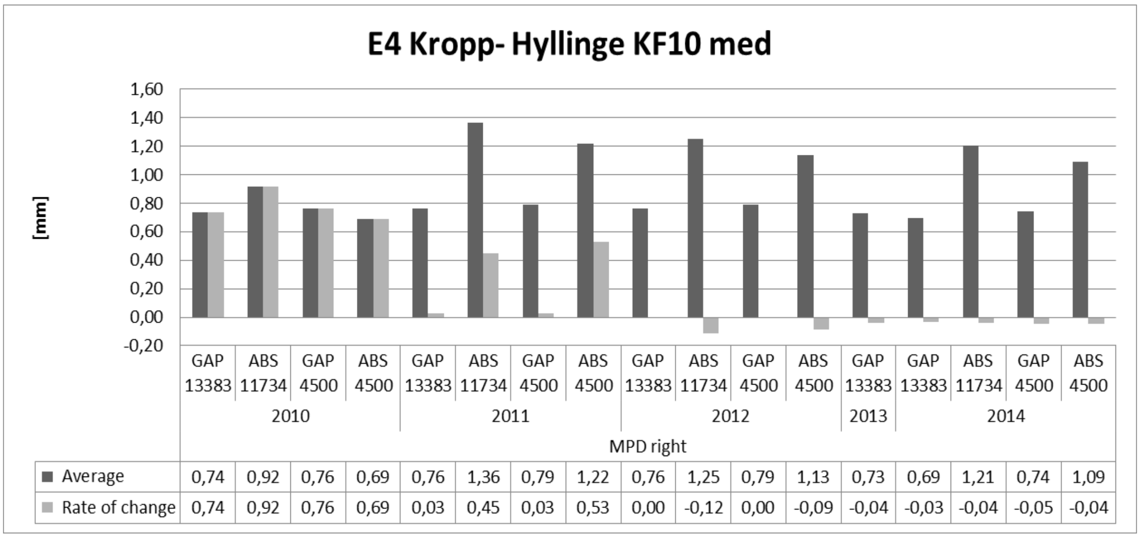


Figure 86: Average values and annual change for MPD right for standard ABS and GAP

KF 20

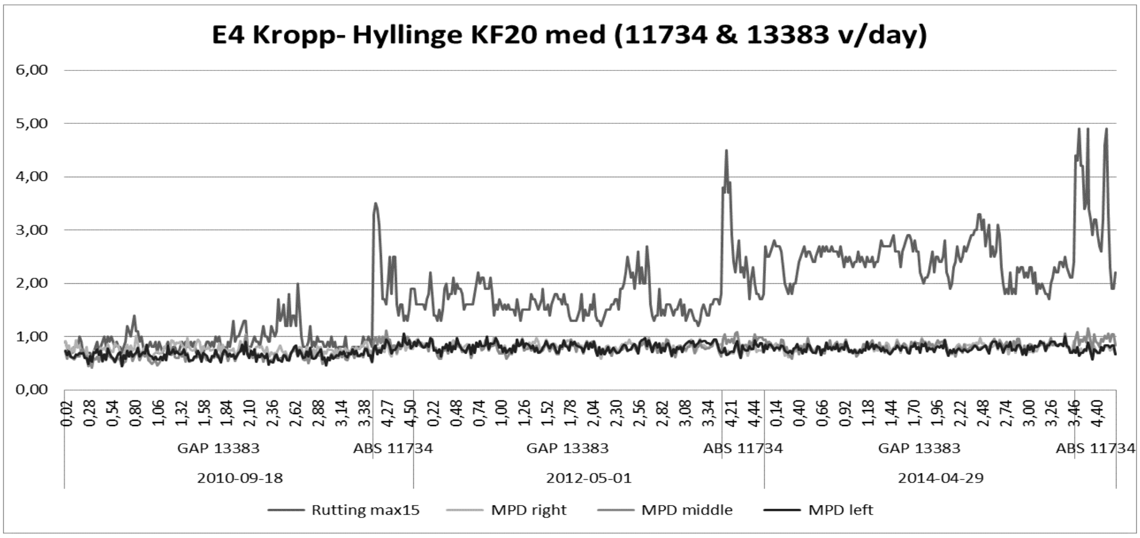


Figure 87: Average values for GAP and ABS along the test track, 11734 & 13383 vehicles per day

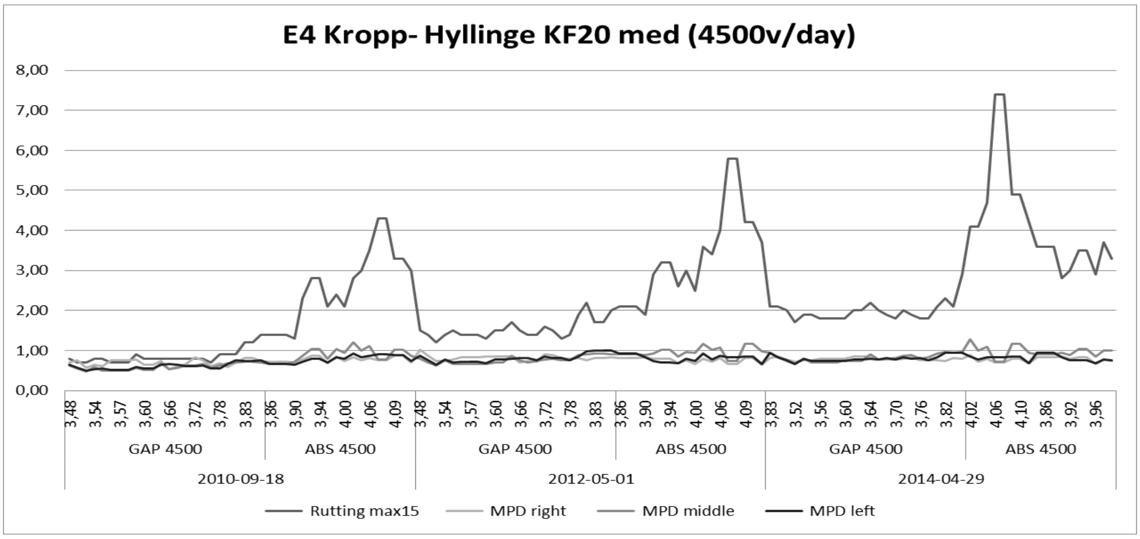
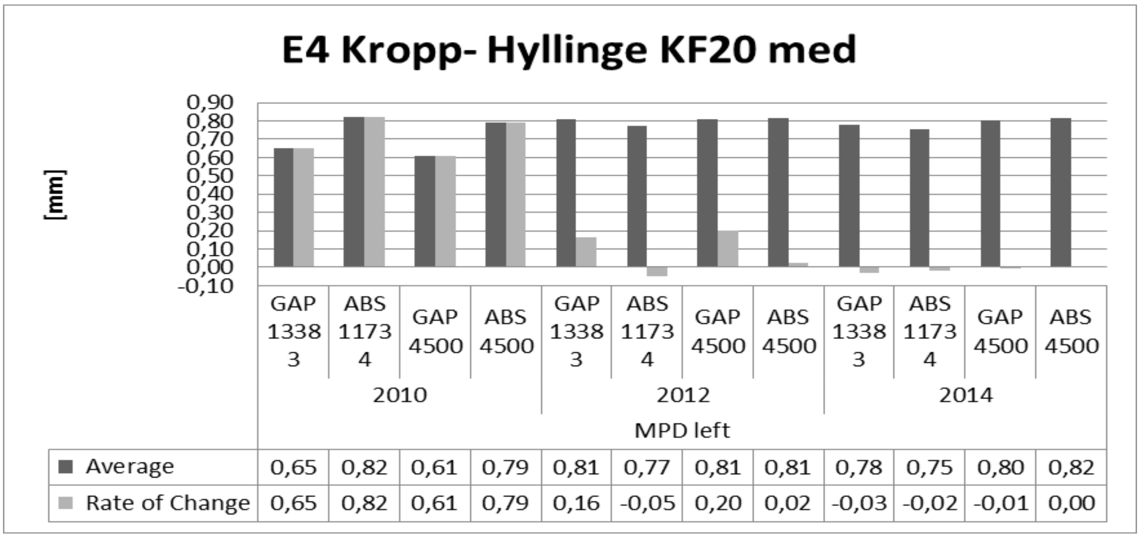
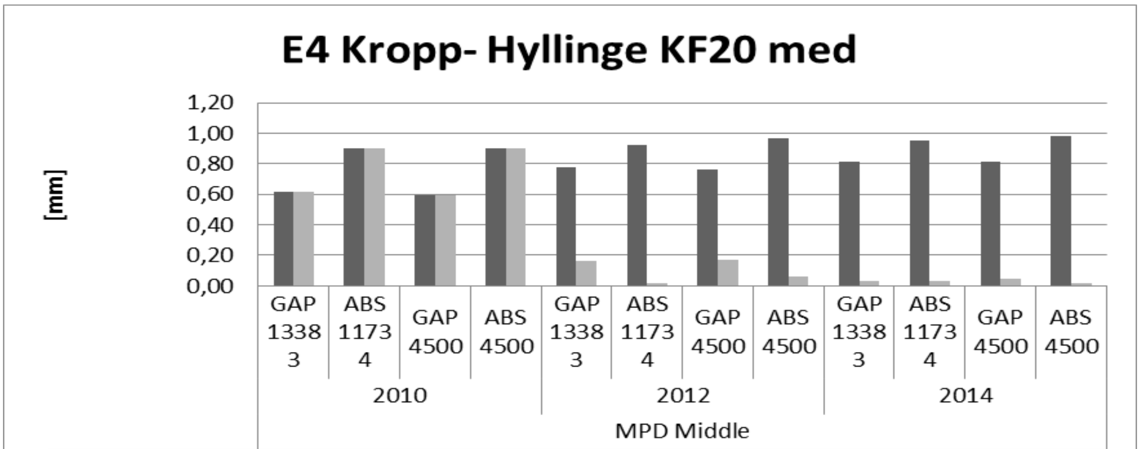


Figure 88: Measured values for GAP and ABS along the test track, 4500 vehicles per day



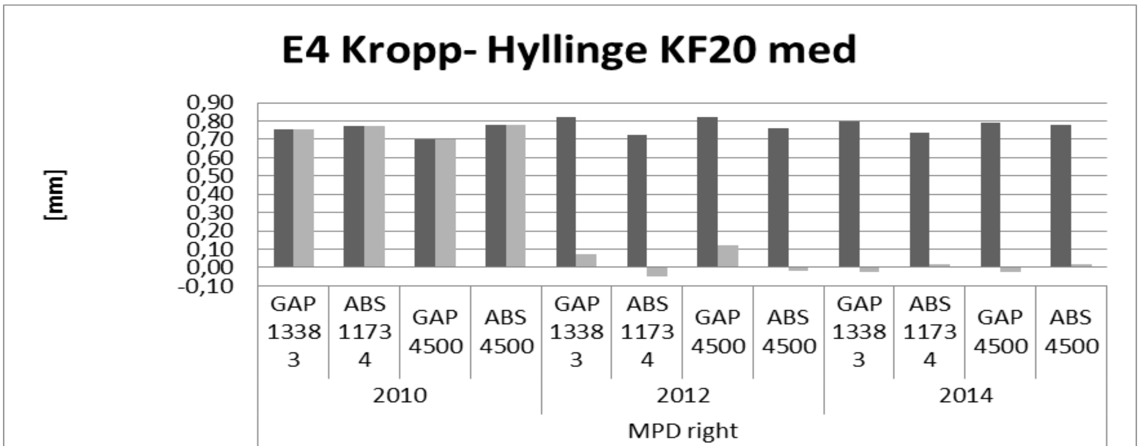
	2010				2012				2014			
	GAP 13383	ABS 11734	GAP 4500	ABS 4500	GAP 13383	ABS 11734	GAP 4500	ABS 4500	GAP 13383	ABS 11734	GAP 4500	ABS 4500
Average	0,65	0,82	0,61	0,79	0,81	0,77	0,81	0,81	0,78	0,75	0,80	0,82
Rate of Change	0,65	0,82	0,61	0,79	0,16	-0,05	0,20	0,02	-0,03	-0,02	-0,01	0,00

Figure 89: Average values and rate of change for MPD left on GAP and ABS



	GAP 13383 (2010)	ABS 11734 (2010)	GAP 4500 (2010)	ABS 4500 (2010)	GAP 13383 (2012)	ABS 11734 (2012)	GAP 4500 (2012)	ABS 4500 (2012)	GAP 13383 (2014)	ABS 11734 (2014)	GAP 4500 (2014)	ABS 4500 (2014)
Average	0,62	0,90	0,60	0,90	0,78	0,92	0,76	0,96	0,81	0,95	0,81	0,98
Rate of Change	0,62	0,90	0,60	0,90	0,16	0,02	0,17	0,06	0,03	0,03	0,05	0,01

Figure 90: Average values and rate of change for MPD middle on GAP and ABS



	GAP 13383 (2010)	ABS 11734 (2010)	GAP 4500 (2010)	ABS 4500 (2010)	GAP 13383 (2012)	ABS 11734 (2012)	GAP 4500 (2012)	ABS 4500 (2012)	GAP 13383 (2014)	ABS 11734 (2014)	GAP 4500 (2014)	ABS 4500 (2014)
Average	0,75	0,77	0,70	0,78	0,82	0,72	0,82	0,76	0,80	0,74	0,79	0,78
Rate of Change	0,75	0,77	0,70	0,78	0,07	-0,05	0,12	-0,02	-0,02	0,02	-0,03	0,02

Figure 91: Average values and rate of change for MPD right on GAP and ABS

Appendix II: E6 Fredriksberg-Lockarp

KF 10

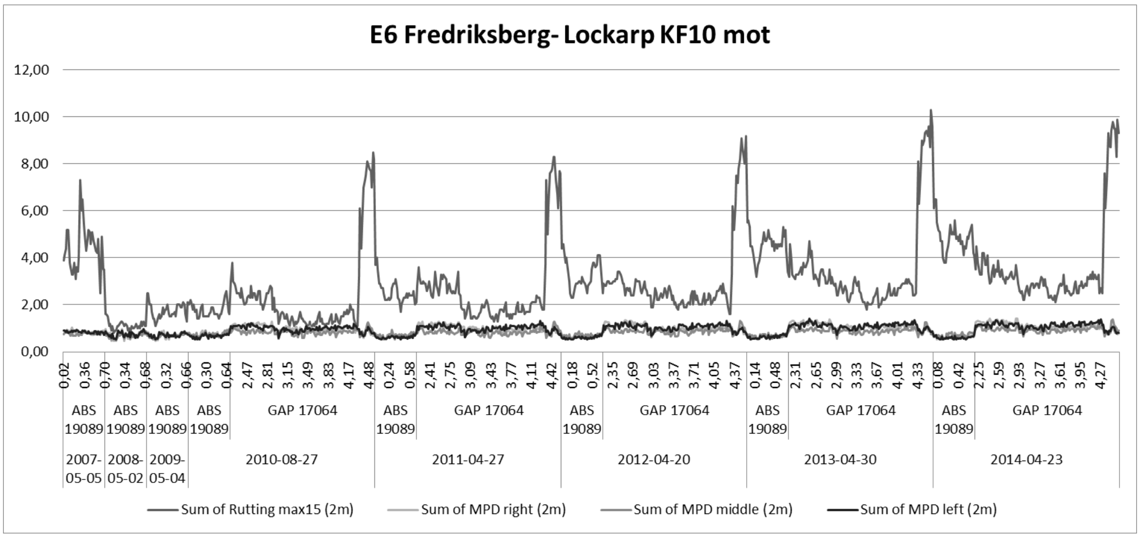


Figure 92: Rutting and MPD left, middle and right with traffic volumes 17064 and 19089 vehicles per day

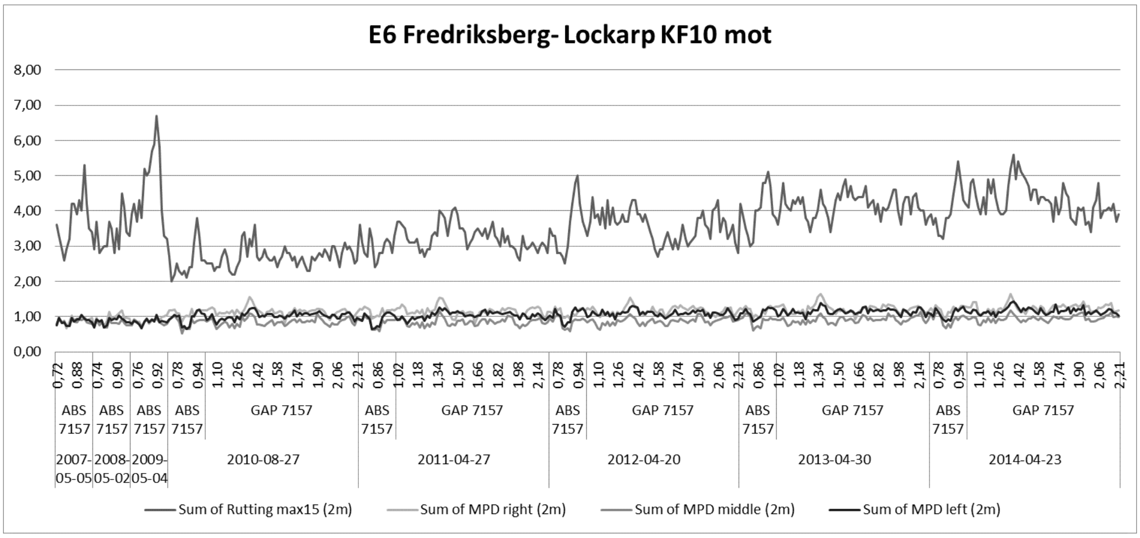
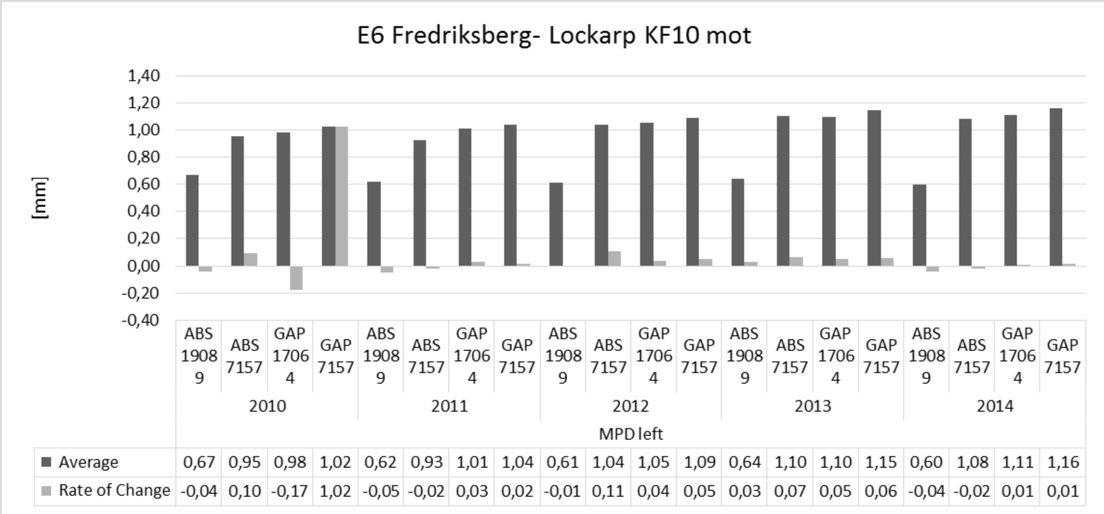
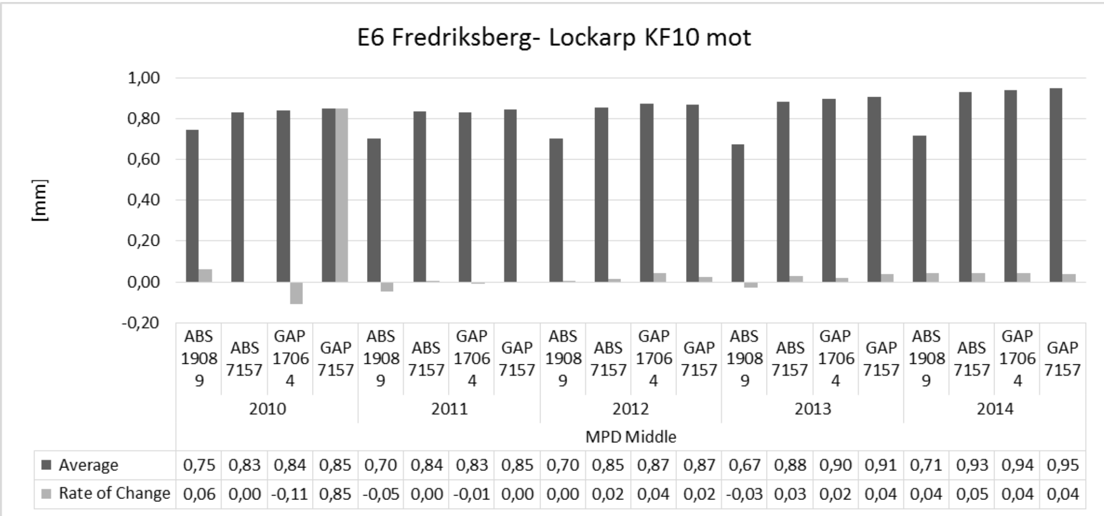


Figure 93: Rutting and MPD left, middle and right with traffic volume 7157 vehicles per day



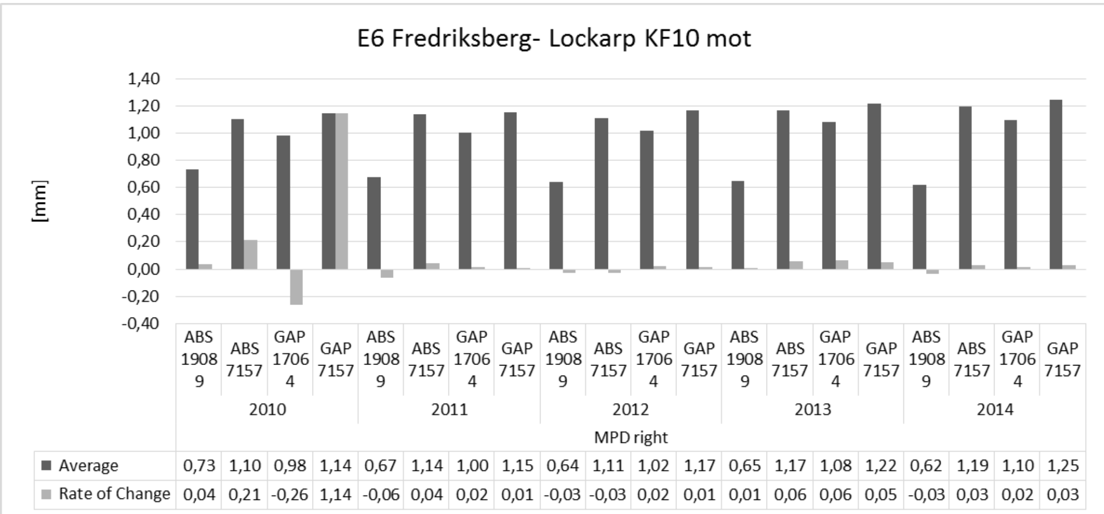
MPD left	2010 ABS 19089	2010 ABS 7157	2010 GAP 17064	2010 GAP 7157	2011 ABS 19089	2011 ABS 7157	2011 GAP 17064	2011 GAP 7157	2012 ABS 19089	2012 ABS 7157	2012 GAP 17064	2012 GAP 7157	2013 ABS 19089	2013 ABS 7157	2013 GAP 17064	2013 GAP 7157	2014 ABS 19089	2014 ABS 7157	2014 GAP 17064	2014 GAP 7157
Average	0,67	0,95	0,98	1,02	0,62	0,93	1,01	1,04	0,61	1,04	1,05	1,09	0,64	1,10	1,10	1,15	0,60	1,08	1,11	1,16
Rate of Change	-0,04	0,10	-0,17	1,02	-0,05	-0,02	0,03	0,02	-0,01	0,11	0,04	0,05	0,03	0,07	0,05	0,06	-0,04	-0,02	0,01	0,01

Figure 94: Average values and rate of change for MPD left on GAP and ABS



MPD Middle	2010 ABS 19089	2010 ABS 7157	2010 GAP 17064	2010 GAP 7157	2011 ABS 19089	2011 ABS 7157	2011 GAP 17064	2011 GAP 7157	2012 ABS 19089	2012 ABS 7157	2012 GAP 17064	2012 GAP 7157	2013 ABS 19089	2013 ABS 7157	2013 GAP 17064	2013 GAP 7157	2014 ABS 19089	2014 ABS 7157	2014 GAP 17064	2014 GAP 7157
Average	0,75	0,83	0,84	0,85	0,70	0,84	0,83	0,85	0,70	0,85	0,87	0,87	0,67	0,88	0,90	0,91	0,71	0,93	0,94	0,95
Rate of Change	0,06	0,00	-0,11	0,85	-0,05	0,00	-0,01	0,00	0,00	0,02	0,04	0,02	-0,03	0,03	0,02	0,04	0,04	0,05	0,04	0,04

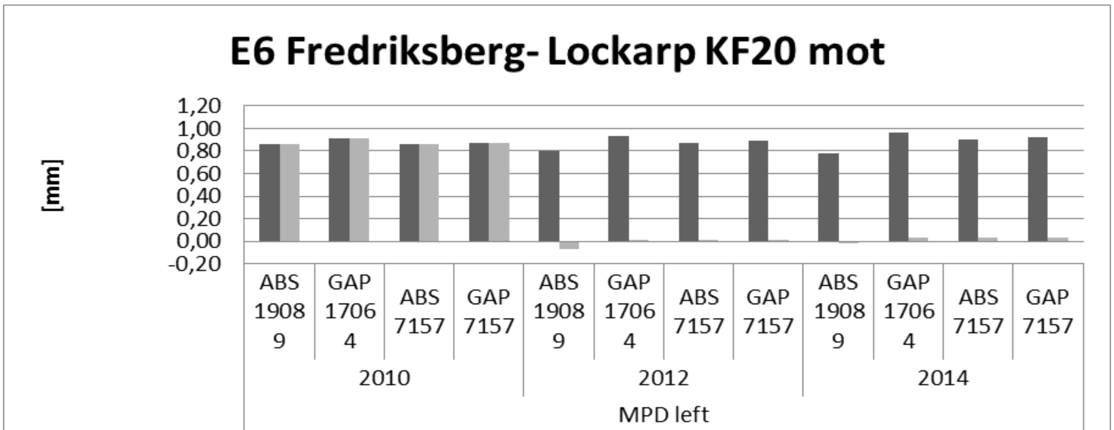
Figure 95: Average values and rate of change for MPD middle on GAP and ABS



MPD right	2010 ABS 19089	2010 ABS 7157	2010 GAP 17064	2010 GAP 7157	2011 ABS 19089	2011 ABS 7157	2011 GAP 17064	2011 GAP 7157	2012 ABS 19089	2012 ABS 7157	2012 GAP 17064	2012 GAP 7157	2013 ABS 19089	2013 ABS 7157	2013 GAP 17064	2013 GAP 7157	2014 ABS 19089	2014 ABS 7157	2014 GAP 17064	2014 GAP 7157
Average	0,73	1,10	0,98	1,14	0,67	1,14	1,00	1,15	0,64	1,11	1,02	1,17	0,65	1,17	1,08	1,22	0,62	1,19	1,10	1,25
Rate of Change	0,04	0,21	-0,26	1,14	-0,06	0,04	0,02	0,01	-0,03	-0,03	0,02	0,01	0,01	0,06	0,06	0,05	-0,03	0,03	0,02	0,03

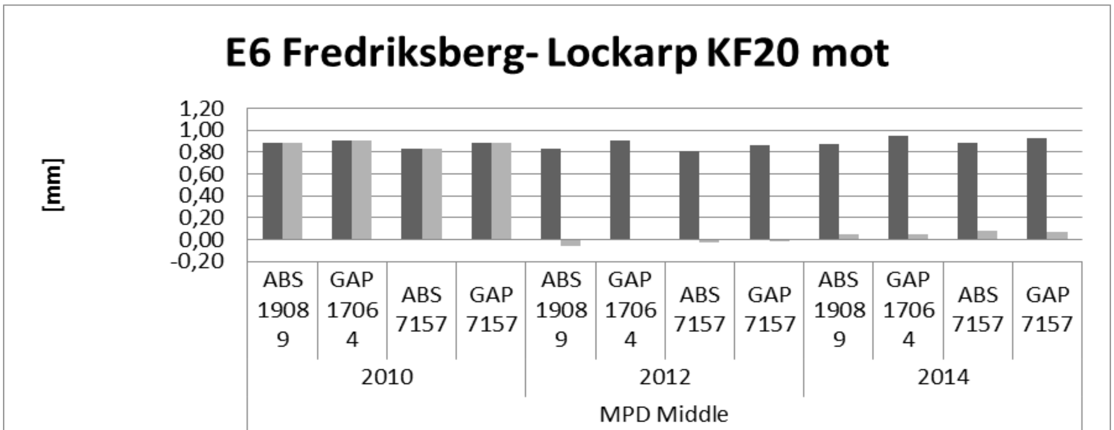
Figure 96: Average values and rate of change for MPD right on GAP and ABS

KF 20



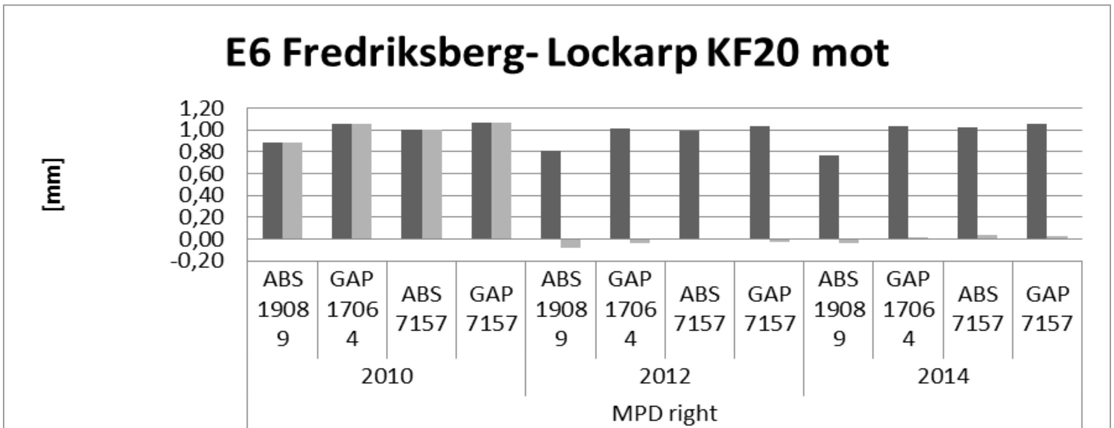
	ABS 19089 (2010)	GAP 17064 (2010)	ABS 7157 (2010)	GAP 7157 (2010)	ABS 19089 (2012)	GAP 17064 (2012)	ABS 7157 (2012)	GAP 7157 (2012)	ABS 19089 (2014)	GAP 17064 (2014)	ABS 7157 (2014)	GAP 7157 (2014)
Average	0,87	0,91	0,86	0,87	0,80	0,93	0,87	0,89	0,78	0,97	0,90	0,92
Rate of Change	0,87	0,91	0,86	0,87	-0,07	0,02	0,01	0,02	-0,02	0,03	0,03	0,03

Figure 97: Average values and rate of change for MPD left on GAP and ABS



	ABS 19089 (2010)	GAP 17064 (2010)	ABS 7157 (2010)	GAP 7157 (2010)	ABS 19089 (2012)	GAP 17064 (2012)	ABS 7157 (2012)	GAP 7157 (2012)	ABS 19089 (2014)	GAP 17064 (2014)	ABS 7157 (2014)	GAP 7157 (2014)
Average	0,88	0,91	0,83	0,88	0,83	0,90	0,80	0,86	0,87	0,95	0,88	0,93
Rate of Change	0,88	0,91	0,83	0,88	-0,06	-0,01	-0,02	-0,02	0,04	0,05	0,08	0,07

Figure 98: Average values and rate of change for MPD middle on GAP and ABS

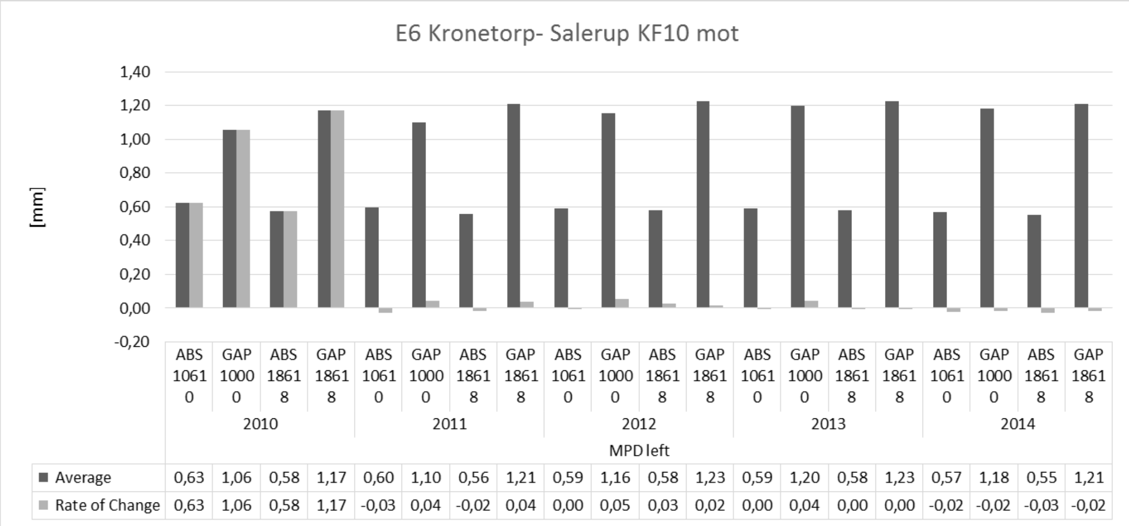


	ABS 19089 (2010)	GAP 17064 (2010)	ABS 7157 (2010)	GAP 7157 (2010)	ABS 19089 (2012)	GAP 17064 (2012)	ABS 7157 (2012)	GAP 7157 (2012)	ABS 19089 (2014)	GAP 17064 (2014)	ABS 7157 (2014)	GAP 7157 (2014)
Average	0,89	1,05	1,00	1,06	0,81	1,02	0,99	1,03	0,77	1,04	1,03	1,06
Rate of Change	0,89	1,05	1,00	1,06	-0,08	-0,04	-0,01	-0,03	-0,04	0,02	0,04	0,02

Figure 99: Average values and rate of change for MPD right on GAP and ABS

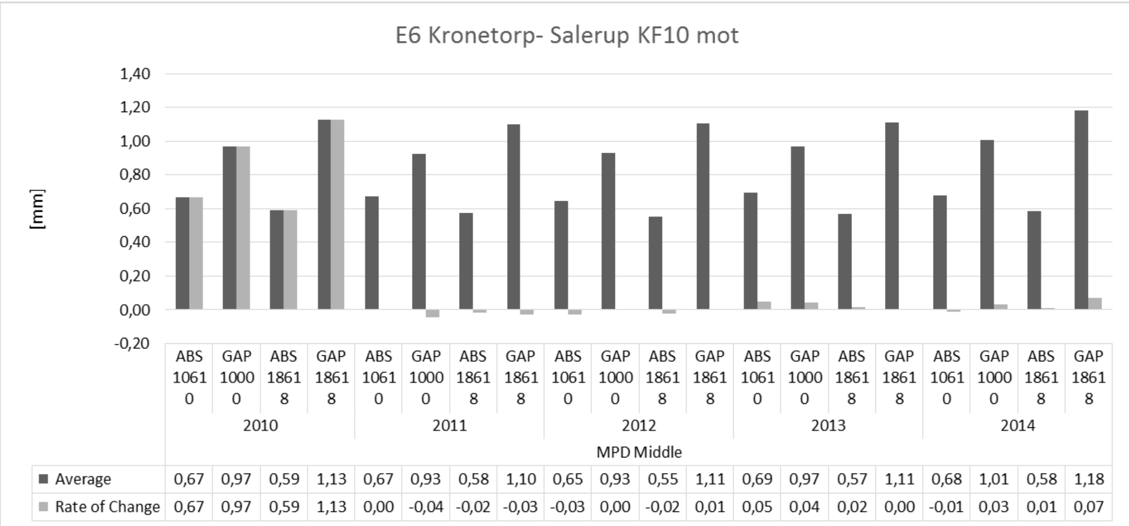
Appendix III: E6 Kronetorp-Salerup

KF 10



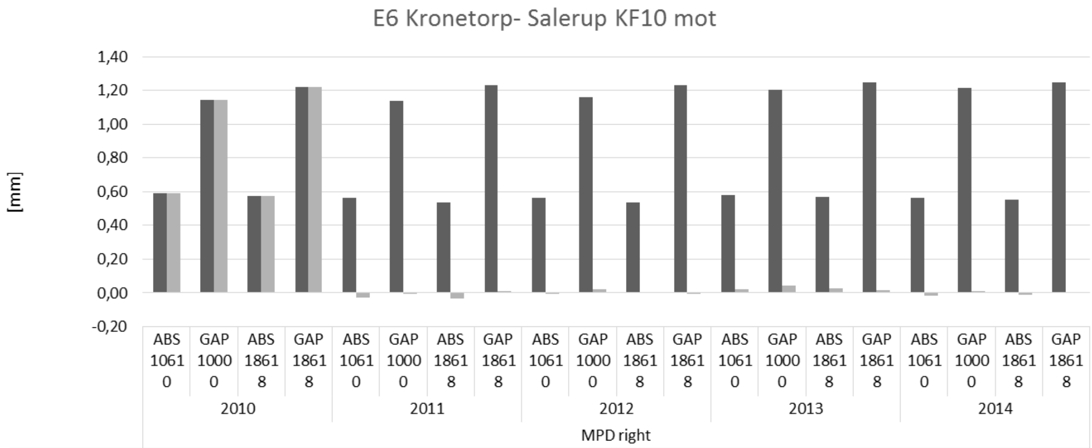
MPD left	2010 ABS 10610	2010 GAP 10000	2010 ABS 18618	2010 GAP 18618	2011 ABS 10610	2011 GAP 10000	2011 ABS 18618	2011 GAP 18618	2012 ABS 10610	2012 GAP 10000	2012 ABS 18618	2012 GAP 18618	2013 ABS 10610	2013 GAP 10000	2013 ABS 18618	2013 GAP 18618	2014 ABS 10610	2014 GAP 10000	2014 ABS 18618	2014 GAP 18618
Average	0,63	1,06	0,58	1,17	0,60	1,10	0,56	1,21	0,59	1,16	0,58	1,23	0,59	1,20	0,58	1,23	0,57	1,18	0,55	1,21
Rate of Change	0,63	1,06	0,58	1,17	-0,03	0,04	-0,02	0,04	0,00	0,05	0,03	0,02	0,00	0,04	0,00	0,00	-0,02	-0,02	-0,03	-0,02

Figure 100: Average values and rate of change for MPD left on GAP and ABS



MPD Middle	2010 ABS 10610	2010 GAP 10000	2010 ABS 18618	2010 GAP 18618	2011 ABS 10610	2011 GAP 10000	2011 ABS 18618	2011 GAP 18618	2012 ABS 10610	2012 GAP 10000	2012 ABS 18618	2012 GAP 18618	2013 ABS 10610	2013 GAP 10000	2013 ABS 18618	2013 GAP 18618	2014 ABS 10610	2014 GAP 10000	2014 ABS 18618	2014 GAP 18618
Average	0,67	0,97	0,59	1,13	0,67	0,93	0,58	1,10	0,65	0,93	0,55	1,11	0,69	0,97	0,57	1,11	0,68	1,01	0,58	1,18
Rate of Change	0,67	0,97	0,59	1,13	0,00	-0,04	-0,02	-0,03	-0,03	0,00	-0,02	0,01	0,05	0,04	0,02	0,00	-0,01	0,03	0,01	0,07

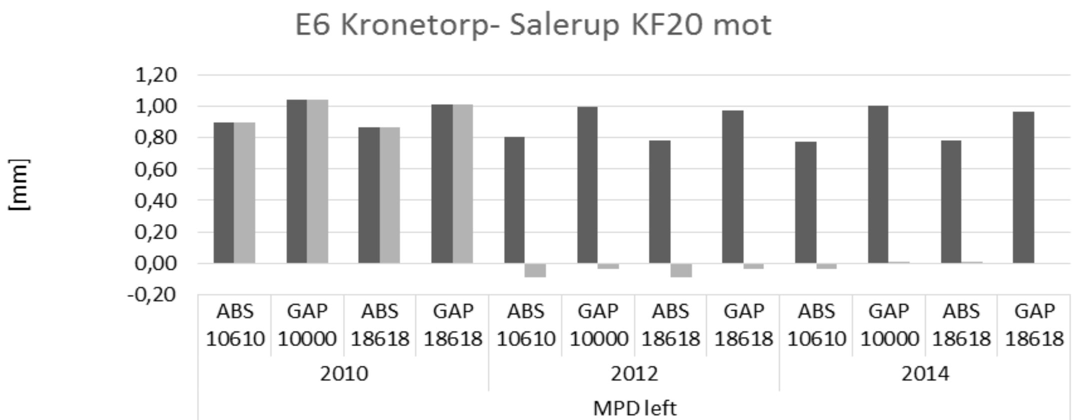
Figure 101: Average values and rate of change for MPD middle on GAP and ABS



MPD right	2010 ABS 10610	2010 GAP 10000	2010 ABS 18618	2010 GAP 18618	2011 ABS 10610	2011 GAP 10000	2011 ABS 18618	2011 GAP 18618	2012 ABS 10610	2012 GAP 10000	2012 ABS 18618	2012 GAP 18618	2013 ABS 10610	2013 GAP 10000	2013 ABS 18618	2013 GAP 18618	2014 ABS 10610	2014 GAP 10000	2014 ABS 18618	2014 GAP 18618
Average	0,59	1,14	0,57	1,22	0,56	1,14	0,54	1,23	0,56	1,16	0,54	1,23	0,58	1,20	0,57	1,25	0,56	1,21	0,56	1,25
Rate of Change	0,59	1,14	0,57	1,22	-0,03	-0,01	-0,03	0,01	0,00	0,02	0,00	0,00	0,02	0,05	0,03	0,02	-0,02	0,01	-0,01	0,00

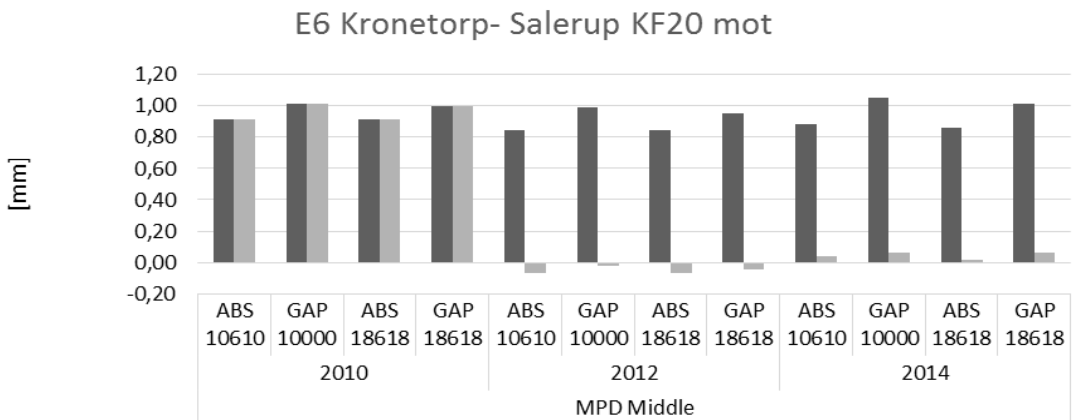
Figure 102: Average values and rate of change for MPD right on GAP and ABS

KF 20



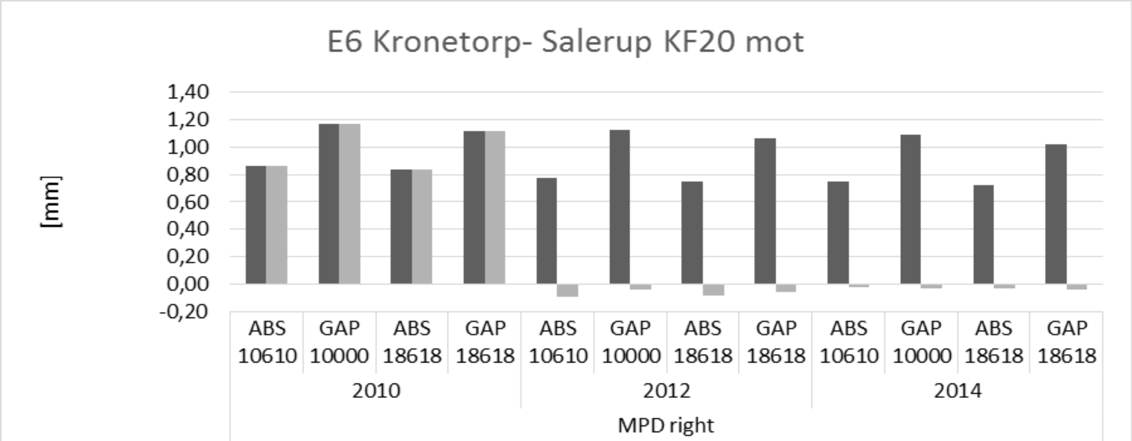
MPD left	2010 ABS 10610	2010 GAP 10000	2010 ABS 18618	2010 GAP 18618	2012 ABS 10610	2012 GAP 10000	2012 ABS 18618	2012 GAP 18618	2014 ABS 10610	2014 GAP 10000	2014 ABS 18618	2014 GAP 18618
Average	0,90	1,04	0,87	1,02	0,81	1,00	0,78	0,98	0,77	1,01	0,79	0,97
Rate of Change	0,90	1,04	0,87	1,02	-0,09	-0,04	-0,09	-0,04	-0,04	0,01	0,00	0,00

Figure 103: Average values and rate of change for MPD left on GAP and ABS



MPD Middle	2010 ABS 10610	2010 GAP 10000	2010 ABS 18618	2010 GAP 18618	2012 ABS 10610	2012 GAP 10000	2012 ABS 18618	2012 GAP 18618	2014 ABS 10610	2014 GAP 10000	2014 ABS 18618	2014 GAP 18618
Average	0,91	1,01	0,92	1,00	0,84	0,99	0,85	0,95	0,88	1,05	0,86	1,01
Rate of Change	0,91	1,01	0,92	1,00	-0,07	-0,02	-0,07	-0,04	0,04	0,06	0,02	0,06

Figure 104: Average values and rate of change for MPD middle on GAP and ABS



	2010				2012				2014			
	ABS 10610	GAP 10000	ABS 18618	GAP 18618	ABS 10610	GAP 10000	ABS 18618	GAP 18618	ABS 10610	GAP 10000	ABS 18618	GAP 18618
Average	0,87	1,17	0,84	1,12	0,77	1,13	0,75	1,06	0,75	1,09	0,72	1,02
Rate of Change	0,87	1,17	0,84	1,12	-0,09	-0,04	-0,09	-0,05	-0,02	-0,03	-0,03	-0,04

Figure 105: Average values and rate of change for MPD right on GAP and ABS

Appendix IV: E6 Petersborg-Vellinge

KF 10

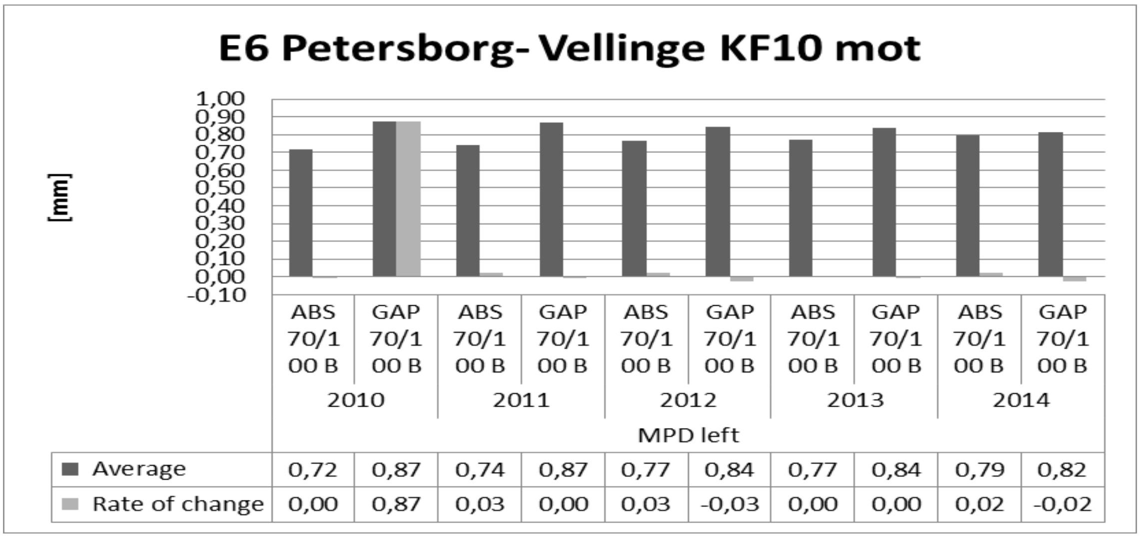


Figure 106: Average values and rate of change for MPD left on GAP and ABS

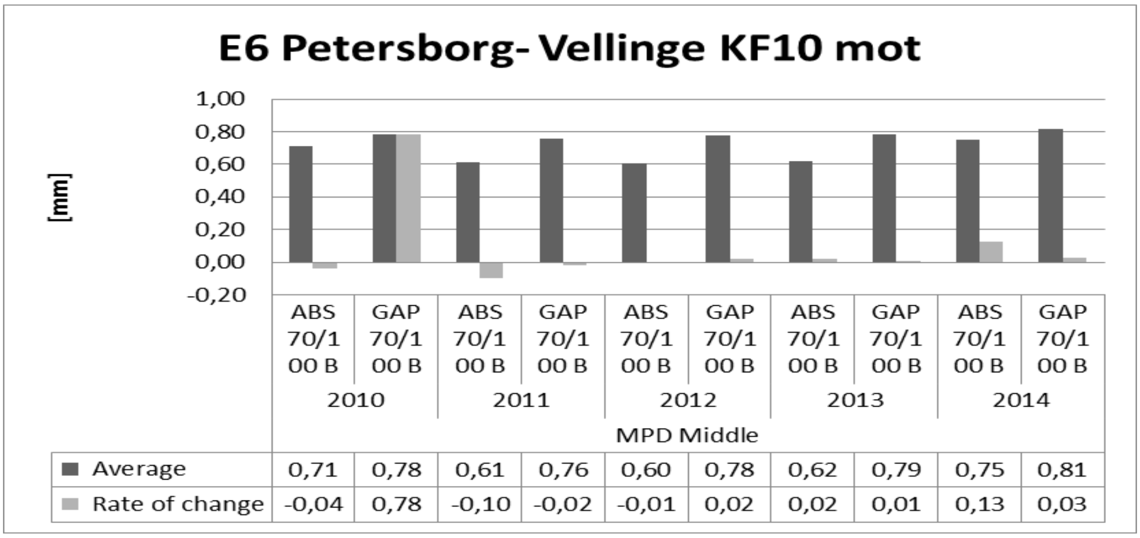


Figure 107: Average values and rate of change for MPD middle on GAP and ABS

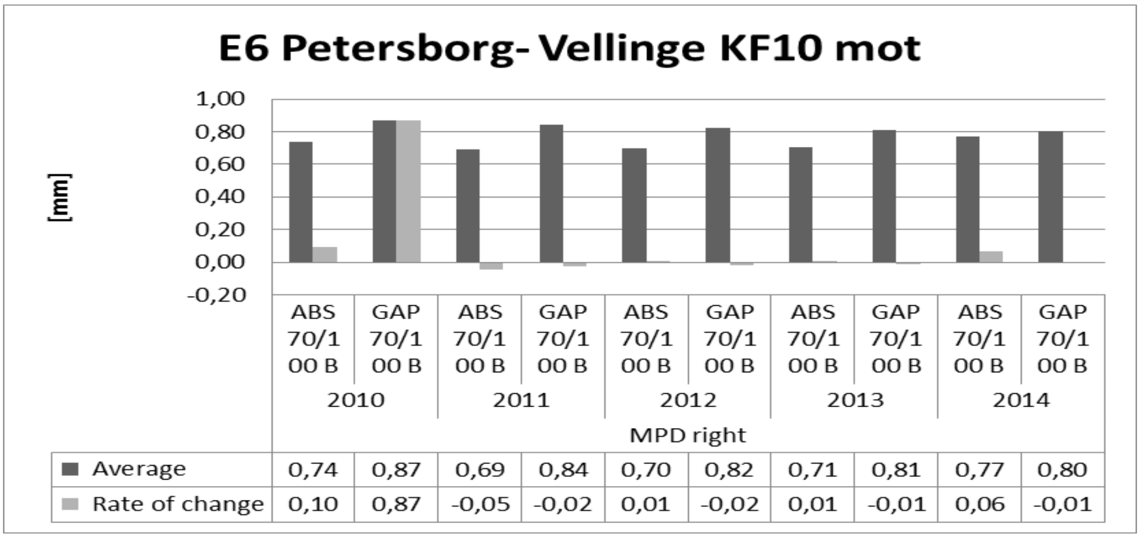


Figure 108: Average values and rate of change for MPD right on GAP and ABS

KF 20

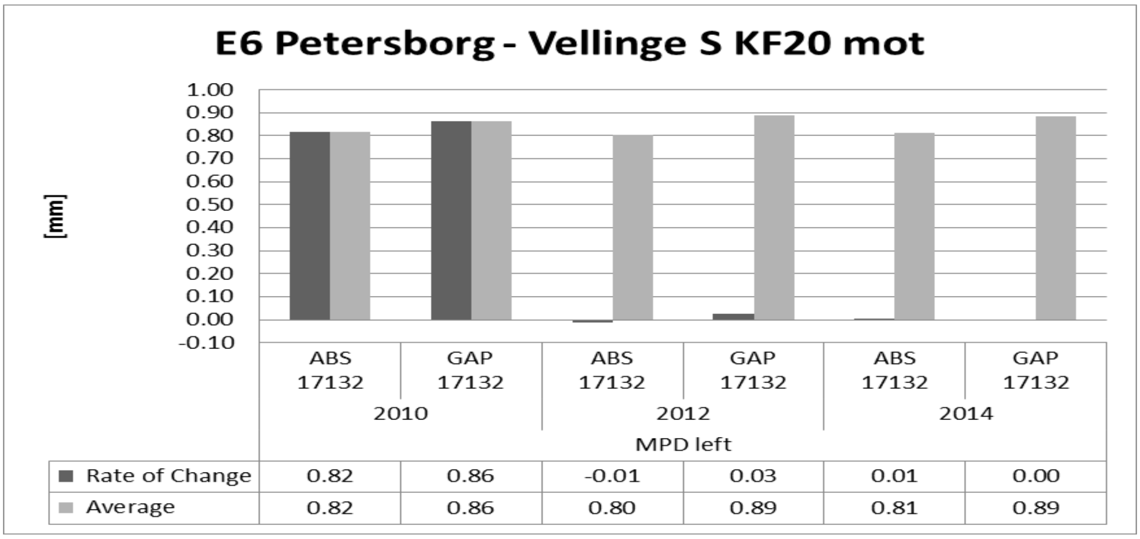


Figure 109: Average values and rate of change for MPD left on GAP and ABS

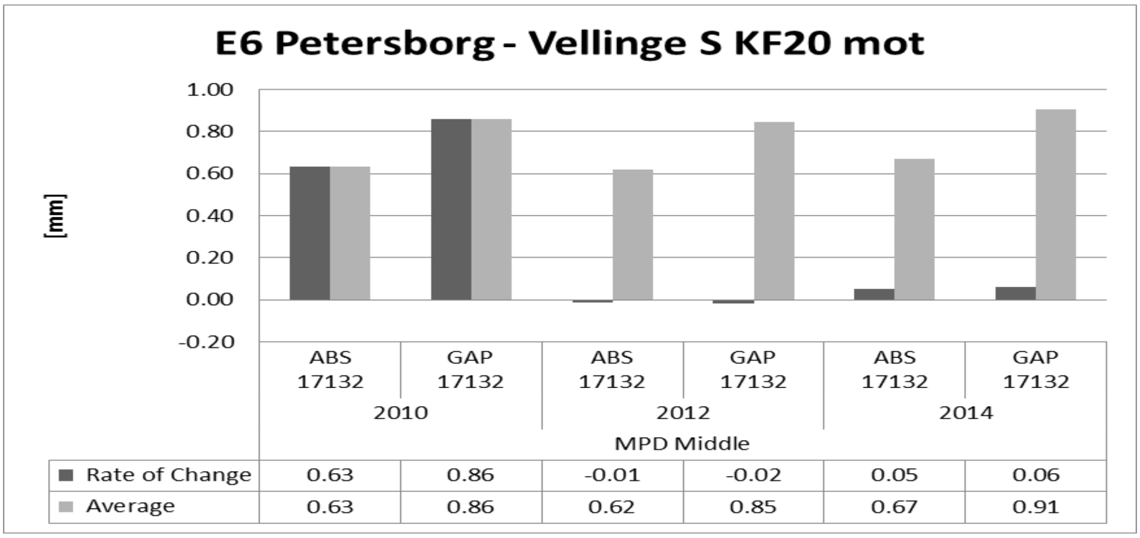


Figure 110: Average values and rate of change for MPD middle on GAP and ABS

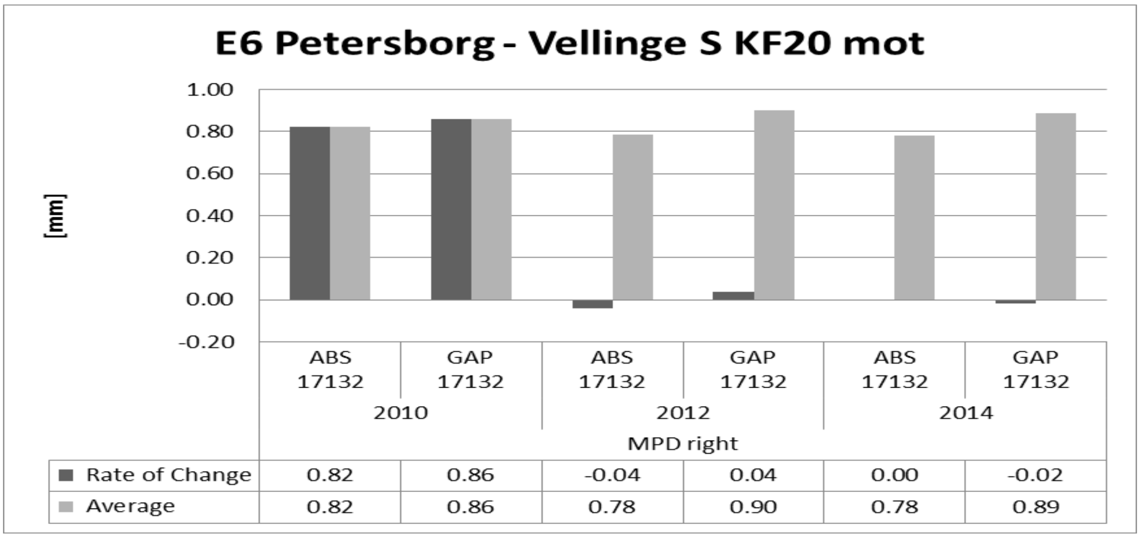
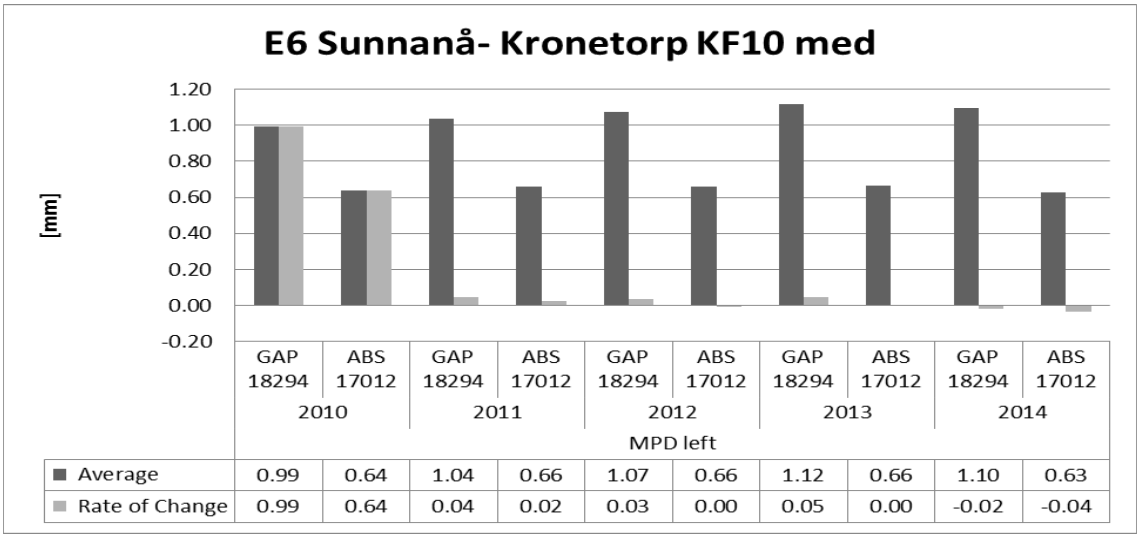


Figure 111: Average values and rate of change for MPD right on GAP and ABS

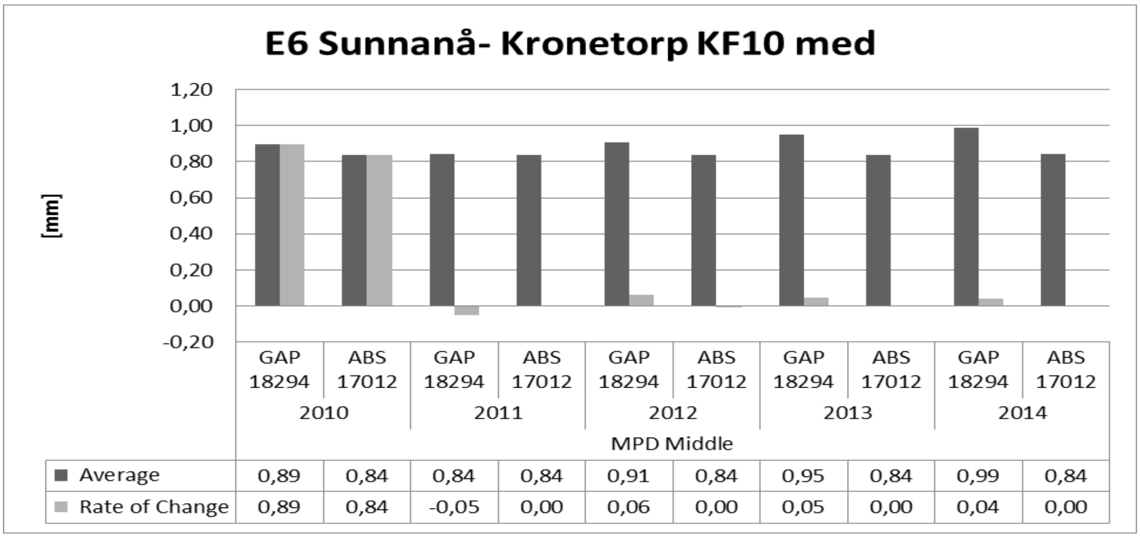
Appendix V: E6 Sunnanå-Kronetorp

<u>KF 10</u>



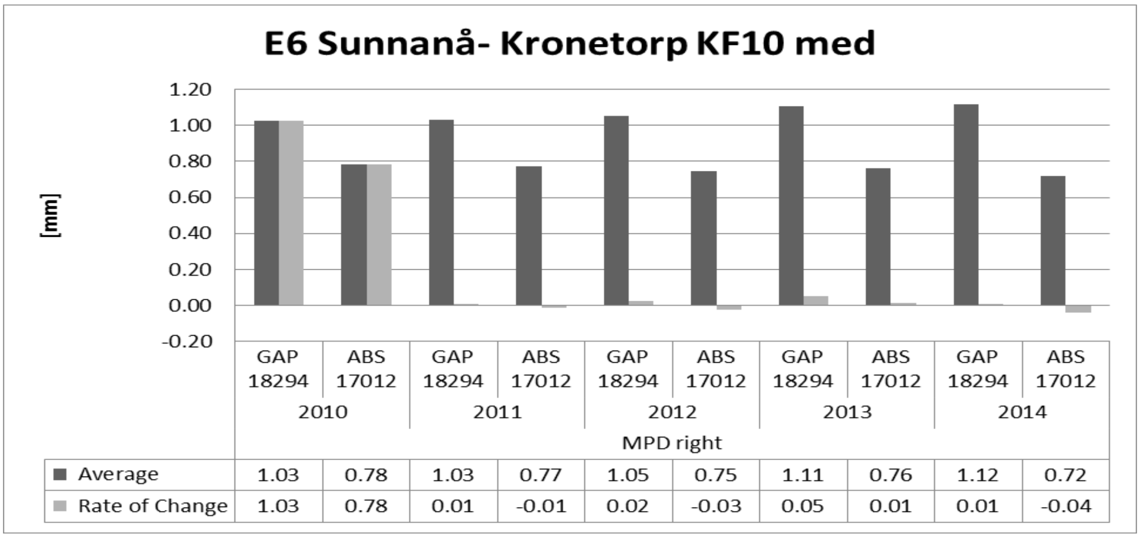
	GAP 18294 (2010)	ABS 17012 (2010)	GAP 18294 (2011)	ABS 17012 (2011)	GAP 18294 (2012)	ABS 17012 (2012)	GAP 18294 (2013)	ABS 17012 (2013)	GAP 18294 (2014)	ABS 17012 (2014)
Average	0.99	0.64	1.04	0.66	1.07	0.66	1.12	0.66	1.10	0.63
Rate of Change	0.99	0.64	0.04	0.02	0.03	0.00	0.05	0.00	-0.02	-0.04

Figure 112: Average values and rate of change for MPD left on GAP and ABS



	GAP 18294 (2010)	ABS 17012 (2010)	GAP 18294 (2011)	ABS 17012 (2011)	GAP 18294 (2012)	ABS 17012 (2012)	GAP 18294 (2013)	ABS 17012 (2013)	GAP 18294 (2014)	ABS 17012 (2014)
Average	0,89	0,84	0,84	0,84	0,91	0,84	0,95	0,84	0,99	0,84
Rate of Change	0,89	0,84	-0,05	0,00	0,06	0,00	0,05	0,00	0,04	0,00

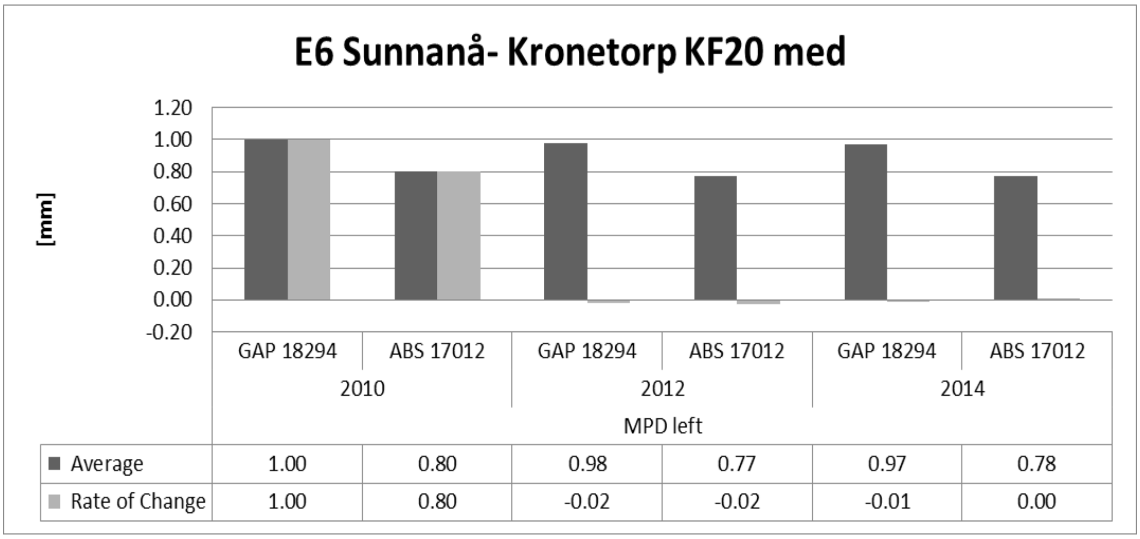
Figure 113: Average values and rate of change for MPD middle on GAP and ABS



	GAP 18294 2010	ABS 17012 2010	GAP 18294 2011	ABS 17012 2011	GAP 18294 2012	ABS 17012 2012	GAP 18294 2013	ABS 17012 2013	GAP 18294 2014	ABS 17012 2014
Average	1.03	0.78	1.03	0.77	1.05	0.75	1.11	0.76	1.12	0.72
Rate of Change	1.03	0.78	0.01	-0.01	0.02	-0.03	0.05	0.01	0.01	-0.04

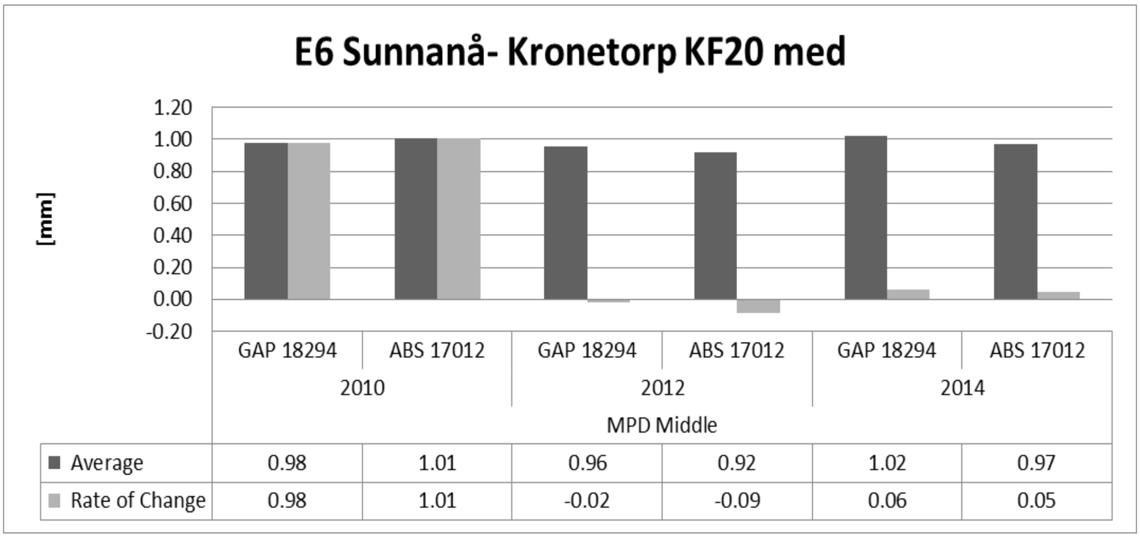
Figure 114: Average values and rate of change for MPD right on GAP and ABS

KF 20



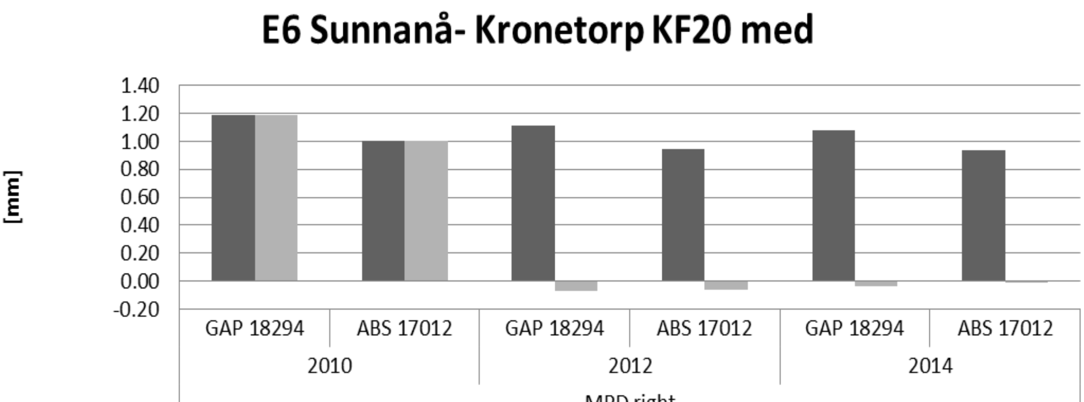
	GAP 18294 2010	ABS 17012 2010	GAP 18294 2012	ABS 17012 2012	GAP 18294 2014	ABS 17012 2014
Average	1.00	0.80	0.98	0.77	0.97	0.78
Rate of Change	1.00	0.80	-0.02	-0.02	-0.01	0.00

Figure 115: Average values and rate of change for MPD left on GAP and ABS



	GAP 18294 2010	ABS 17012 2010	GAP 18294 2012	ABS 17012 2012	GAP 18294 2014	ABS 17012 2014
Average	0.98	1.01	0.96	0.92	1.02	0.97
Rate of Change	0.98	1.01	-0.02	-0.09	0.06	0.05

Figure 116: Average values and rate of change for MPD middle on GAP and ABS

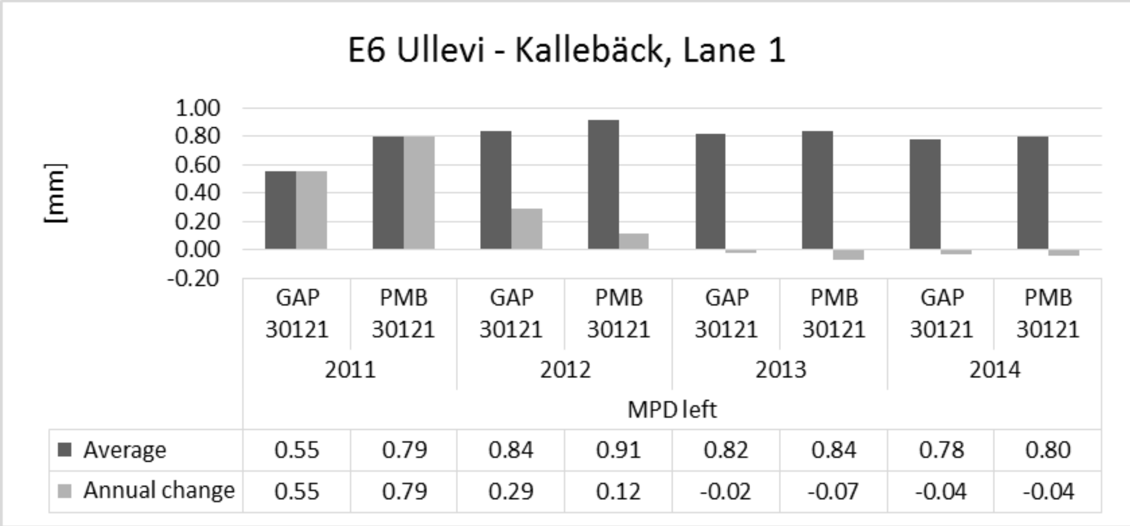


	2010		2012		2014	
	GAP 18294	ABS 17012	GAP 18294	ABS 17012	GAP 18294	ABS 17012
Average	1.18	1.01	1.12	0.94	1.08	0.94
Rate of Change	1.18	1.01	-0.07	-0.06	-0.04	0.00

Figure 117: Average values and rate of change for MPD right on GAP and ABS

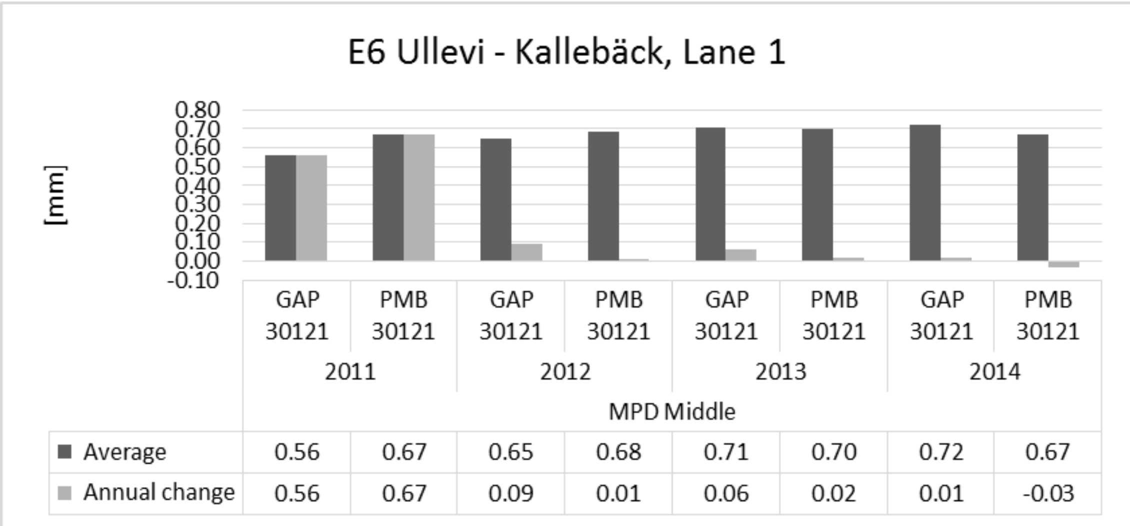
Appendix VI: E6 Ullevi-Kallebäck

KF 10



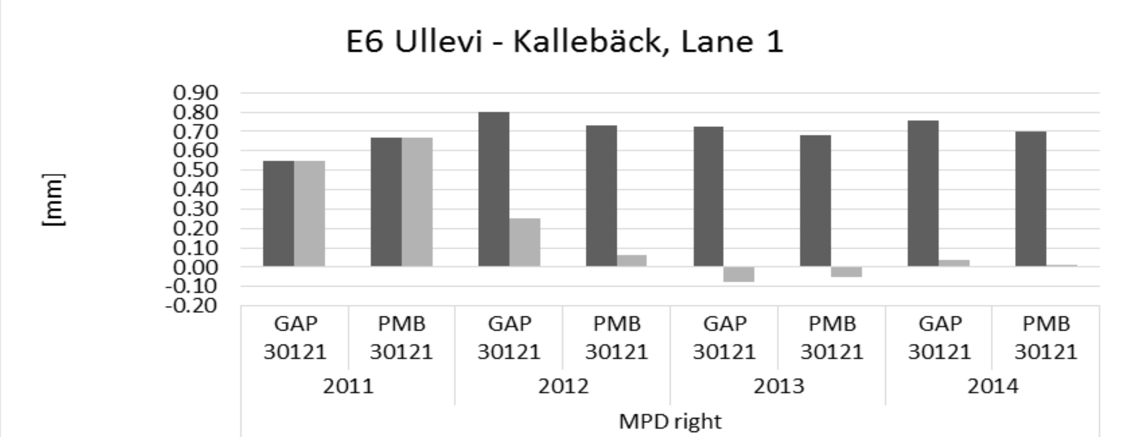
	GAP 30121 (2011)	PMB 30121 (2011)	GAP 30121 (2012)	PMB 30121 (2012)	GAP 30121 (2013)	PMB 30121 (2013)	GAP 30121 (2014)	PMB 30121 (2014)
Average	0.55	0.79	0.84	0.91	0.82	0.84	0.78	0.80
Annual change	0.55	0.79	0.29	0.12	-0.02	-0.07	-0.04	-0.04

Figure 118: Average value and annual change for MPD left on PMB and GAP, lane 1



	GAP 30121 (2011)	PMB 30121 (2011)	GAP 30121 (2012)	PMB 30121 (2012)	GAP 30121 (2013)	PMB 30121 (2013)	GAP 30121 (2014)	PMB 30121 (2014)
Average	0.56	0.67	0.65	0.68	0.71	0.70	0.72	0.67
Annual change	0.56	0.67	0.09	0.01	0.06	0.02	0.01	-0.03

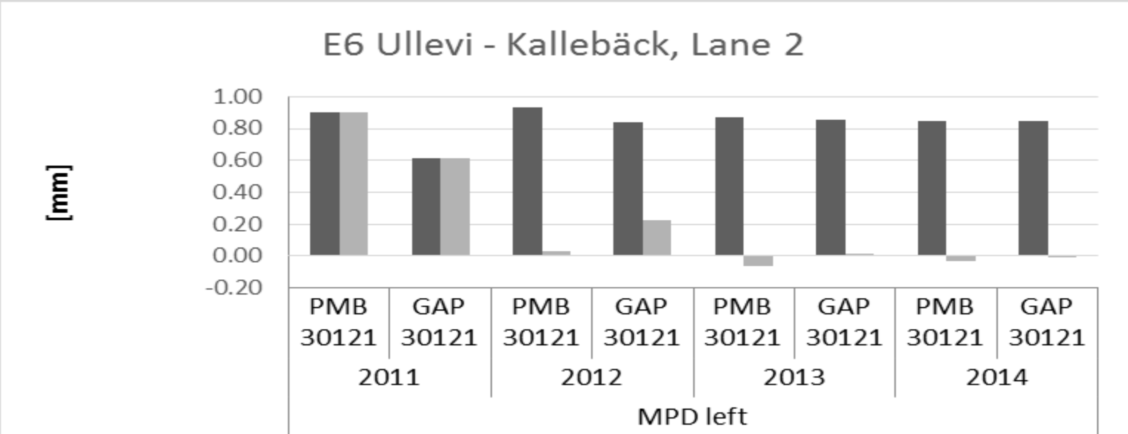
Figure 119: Average value and annual change for MPD middle on PMB and GAP, lane 1



	GAP 30121 (2011)	PMB 30121 (2011)	GAP 30121 (2012)	PMB 30121 (2012)	GAP 30121 (2013)	PMB 30121 (2013)	GAP 30121 (2014)	PMB 30121 (2014)
Average	0.55	0.67	0.80	0.73	0.72	0.68	0.76	0.70
Annual change	0.55	0.67	0.25	0.06	-0.08	-0.05	0.04	0.01

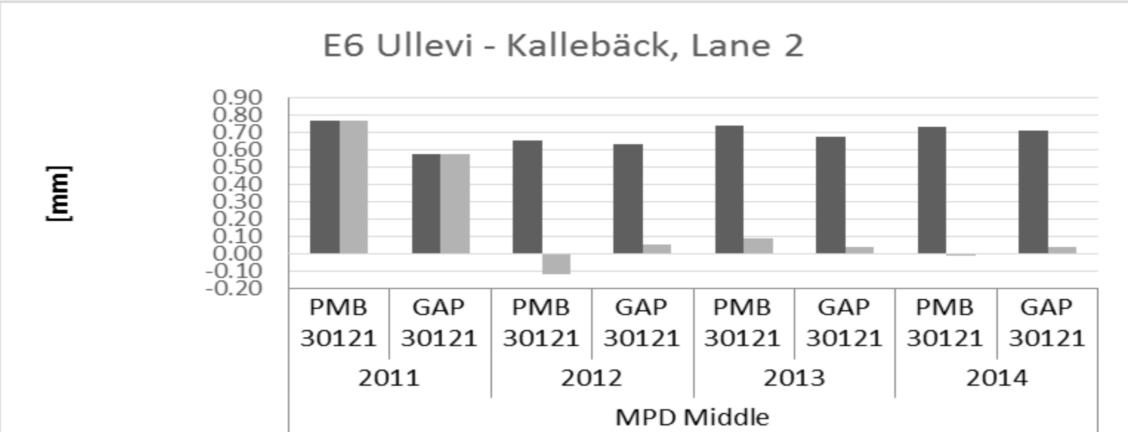
Figure 120: Average value and annual change for MPD right on PMB and GAP, lane 1

KF 20



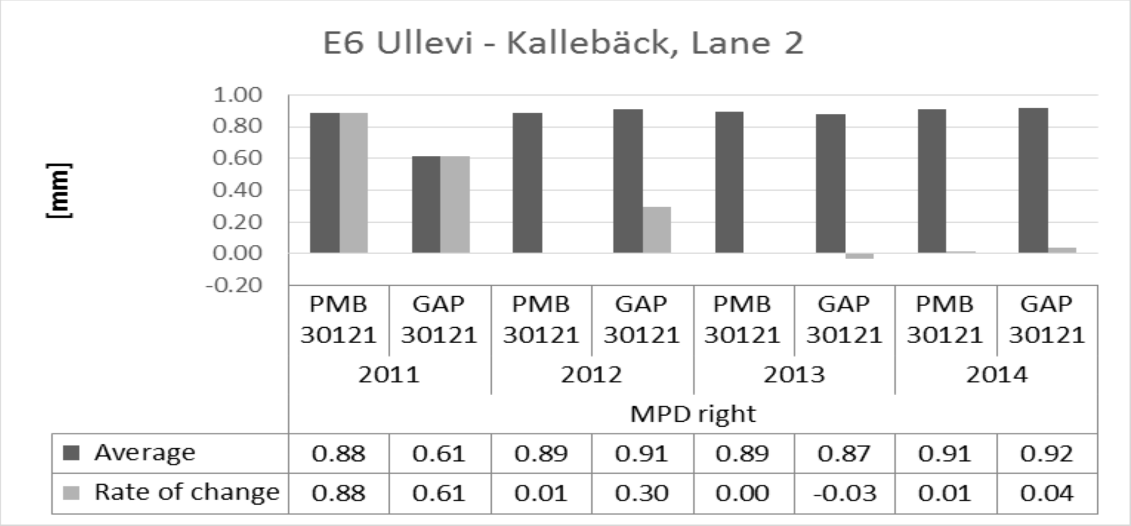
	PMB 30121 (2011)	GAP 30121 (2011)	PMB 30121 (2012)	GAP 30121 (2012)	PMB 30121 (2013)	GAP 30121 (2013)	PMB 30121 (2014)	GAP 30121 (2014)
Average	0.90	0.61	0.93	0.84	0.87	0.85	0.84	0.84
Rate of change	0.90	0.61	0.03	0.23	-0.06	0.01	-0.03	-0.01

Figure 121: Average value and annual change for MPD left on PMB and GAP, lane 2



	PMB 30121 (2011)	GAP 30121 (2011)	PMB 30121 (2012)	GAP 30121 (2012)	PMB 30121 (2013)	GAP 30121 (2013)	PMB 30121 (2014)	GAP 30121 (2014)
Average	0.77	0.58	0.65	0.63	0.74	0.67	0.73	0.71
Rate of change	0.77	0.58	-0.12	0.05	0.09	0.04	-0.01	0.04

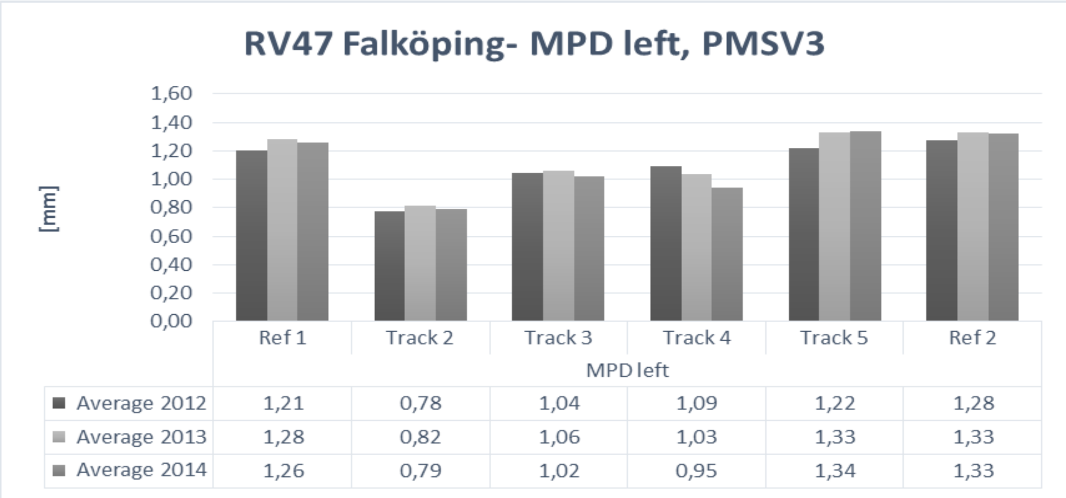
Figure 122: Average value and annual change for MPD middle on PMB and GAP, lane 2



	PMB 30121 (2011)	GAP 30121 (2011)	PMB 30121 (2012)	GAP 30121 (2012)	PMB 30121 (2013)	GAP 30121 (2013)	PMB 30121 (2014)	GAP 30121 (2014)
Average	0.88	0.61	0.89	0.91	0.89	0.87	0.91	0.92
Rate of change	0.88	0.61	0.01	0.30	0.00	-0.03	0.01	0.04

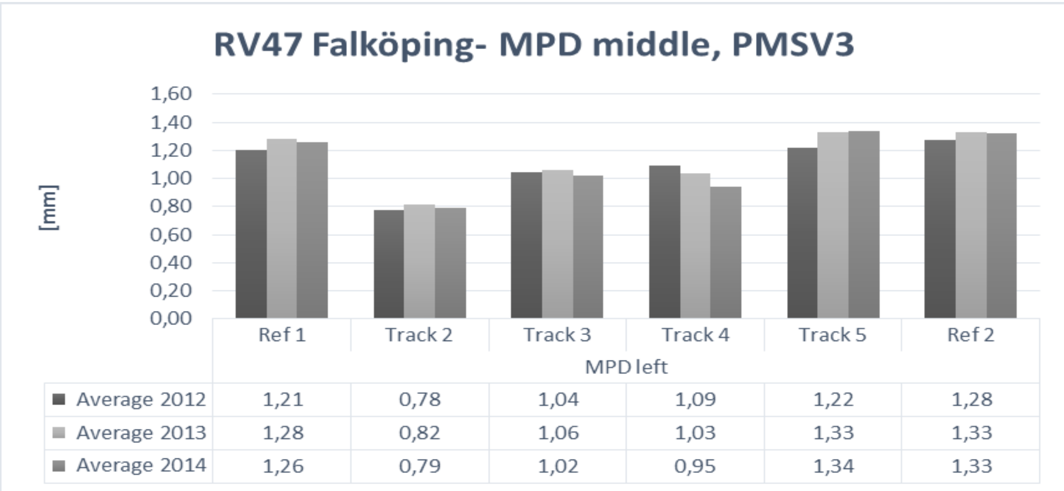
Figure 123: Average value and annual change for MPD right on PMB and GAP, lane 2

Appendix VII: RV47 Falköping



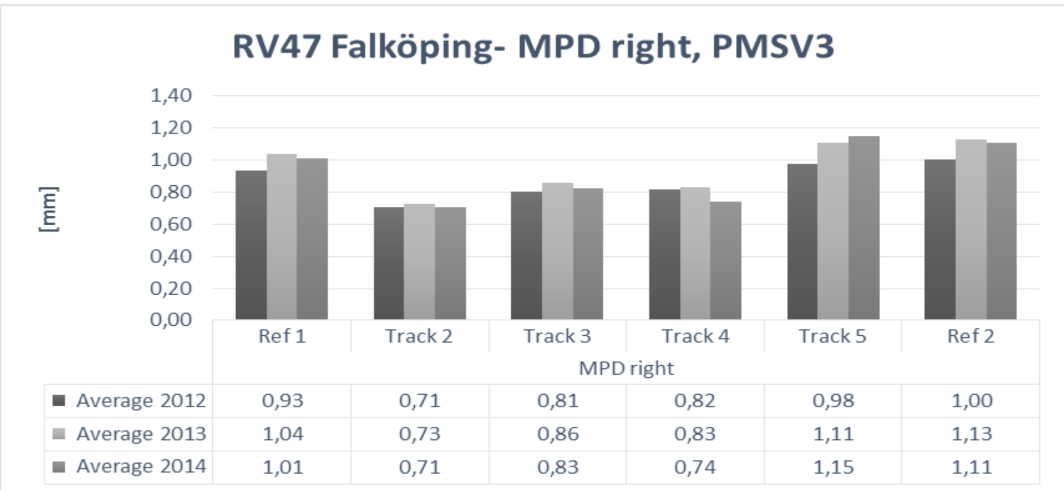
	Ref 1	Track 2	Track 3	Track 4	Track 5	Ref 2
Average 2012	1,21	0,78	1,04	1,09	1,22	1,28
Average 2013	1,28	0,82	1,06	1,03	1,33	1,33
Average 2014	1,26	0,79	1,02	0,95	1,34	1,33

Figure 124: Average values for left MPD on test sections on RV 47 Falköping



	Ref 1	Track 2	Track 3	Track 4	Track 5	Ref 2
Average 2012	1,21	0,78	1,04	1,09	1,22	1,28
Average 2013	1,28	0,82	1,06	1,03	1,33	1,33
Average 2014	1,26	0,79	1,02	0,95	1,34	1,33

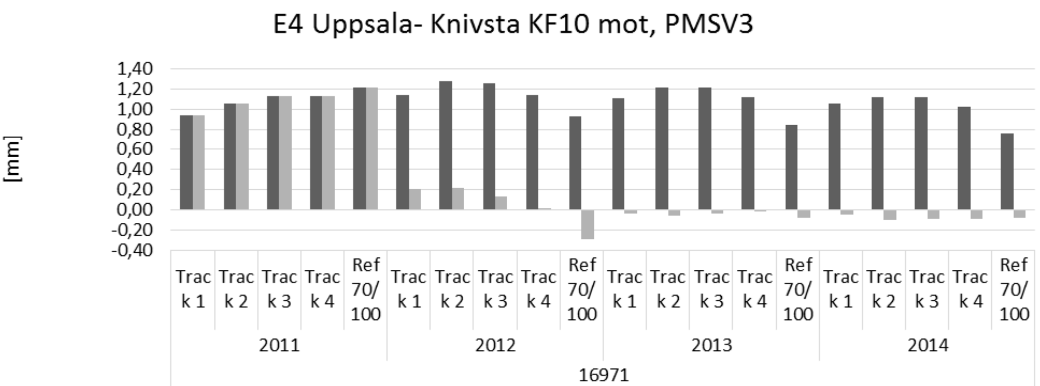
Figure 125: Average values for middle MPD on test sections on RV 47 Falköping



	Ref 1	Track 2	Track 3	Track 4	Track 5	Ref 2
Average 2012	0,93	0,71	0,81	0,82	0,98	1,00
Average 2013	1,04	0,73	0,86	0,83	1,11	1,13
Average 2014	1,01	0,71	0,83	0,74	1,15	1,11

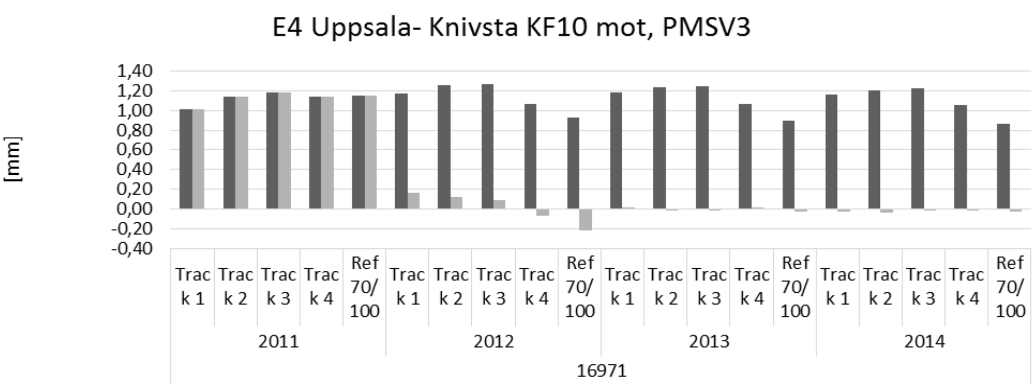
Figure 126: Average values for right MPD on test sections on RV 47 Falköping

Appendix VIII: E4 Uppsala-Knivsta



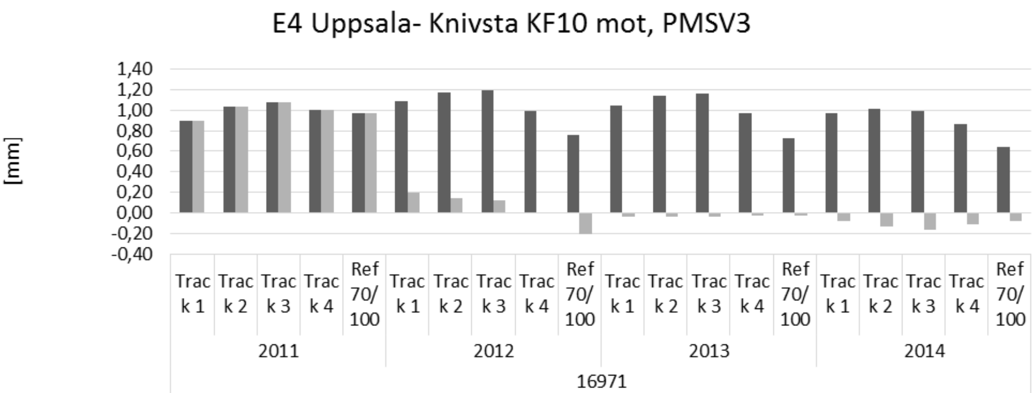
Year	2011					2012					2013					2014				
	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100
Average	0,94	1,06	1,13	1,13	1,22	1,14	1,28	1,26	1,14	0,92	1,10	1,22	1,22	1,12	0,84	1,06	1,11	1,12	1,03	0,75
Annual increase	0,94	1,06	1,13	1,13	1,22	0,21	0,22	0,13	0,02	-0,3	-0,0	-0,0	-0,0	-0,0	-0,0	-0,0	-0,1	-0,1	-0,1	-0,0

Figure 127: Average values and annual increase for MPD left on GAP and ABS 70/100



Year	2011					2012					2013					2014				
	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100
Average	1,01	1,14	1,18	1,14	1,15	1,18	1,26	1,27	1,07	0,92	1,18	1,24	1,25	1,07	0,89	1,16	1,21	1,22	1,06	0,86
Annual increase	1,01	1,14	1,18	1,14	1,15	0,16	0,12	0,08	-0,0	-0,2	0,01	-0,0	-0,0	0,00	-0,0	-0,0	-0,0	-0,0	-0,0	-0,0

Figure 128: Average values and annual increase for MPD middle on GAP and ABS 70/100



Year	2011					2012					2013					2014				
	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100	Track 1	Track 2	Track 3	Track 4	Ref 70/100
Average	0,90	1,03	1,08	1,01	0,97	1,09	1,18	1,20	1,00	0,76	1,05	1,14	1,16	0,97	0,73	0,96	1,01	0,99	0,86	0,64
Annual increase	0,90	1,03	1,08	1,01	0,97	0,19	0,15	0,12	-0,0	-0,2	-0,0	-0,0	-0,0	-0,0	-0,0	-0,0	-0,1	-0,1	-0,1	-0,0

Figure 129: Average values and annual increase for MPD right on GAP and ABS 70/100

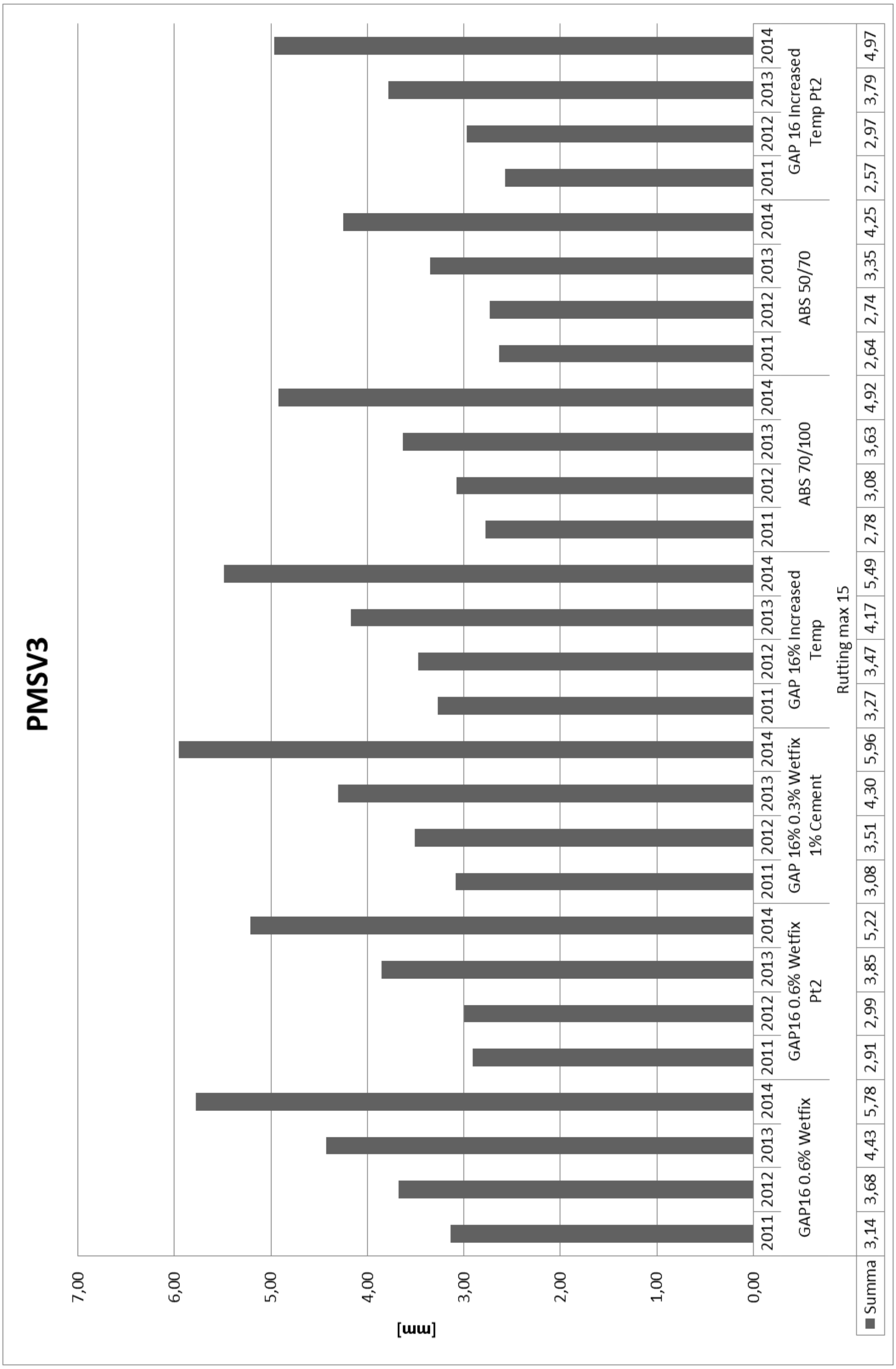


Figure 130: Average measurements for rutting on E4 in Uppsala, PMSV3

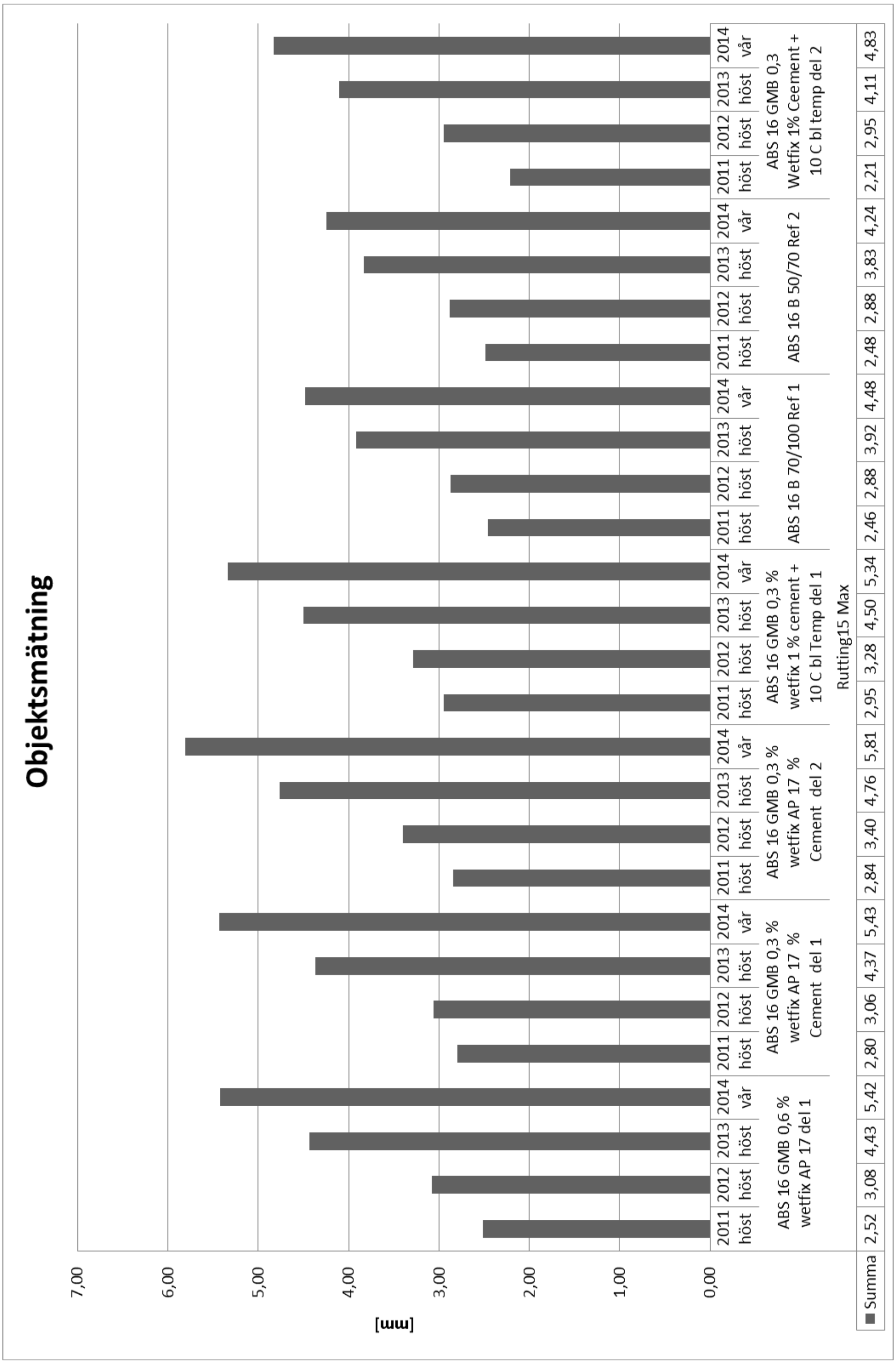


Figure 131: Average measurements for rutting on E4 in Uppsala, Objektsmätning

Appendix IV: E4 Viby-Sollentuna (Stockholm)

KF 30

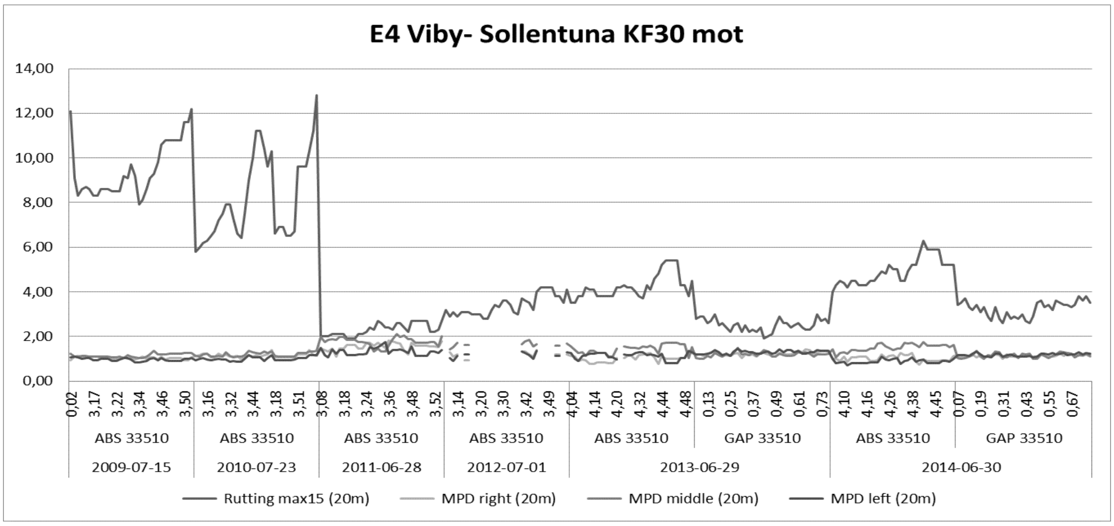


Figure 132: Measurements for rutting, MPD left, middle and right on GAP and ABS

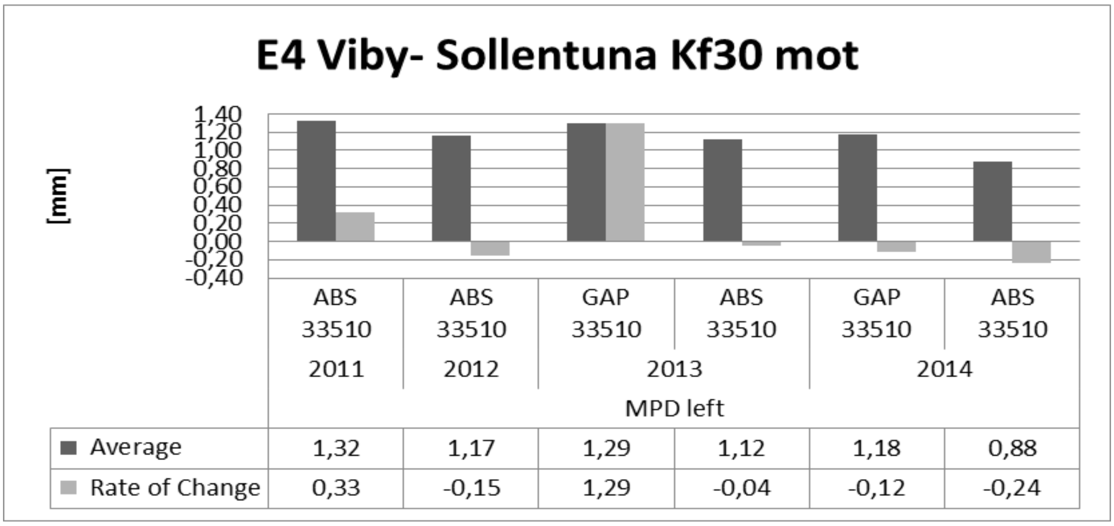


Figure 133: Average values and rate of change for MPD left on GAP and ABS

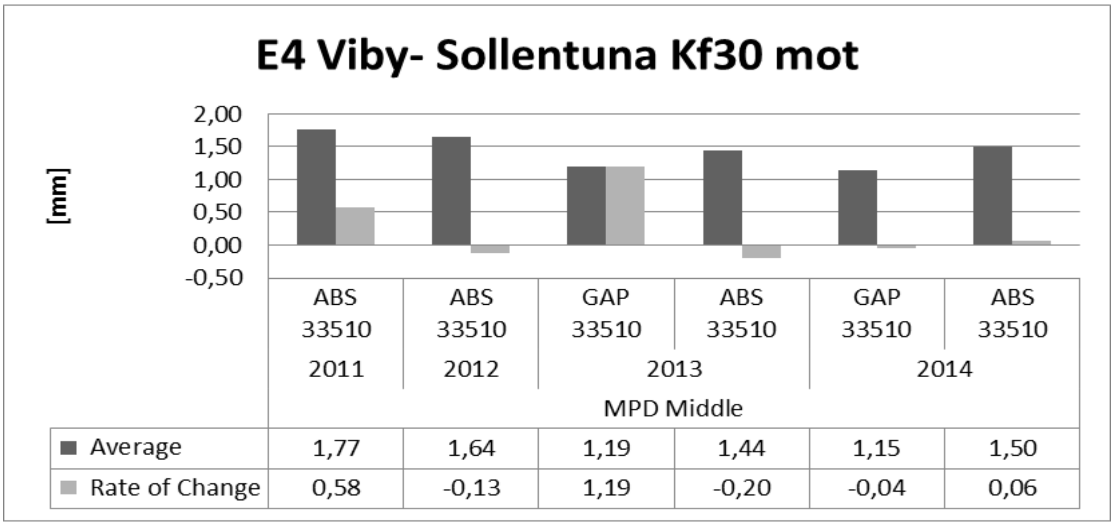


Figure 134: Average values and rate of change for MPD middle on GAP and ABS

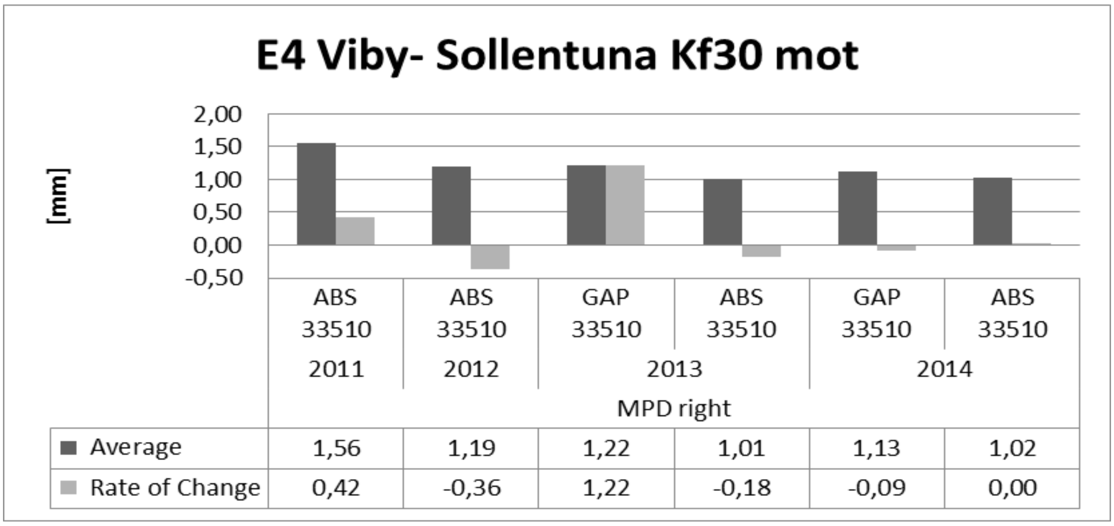


Figure 135: Average values and rate of change for MPD right on GAP and ABS

Appendix X: E12 Lycksele

<u>Med direction</u>

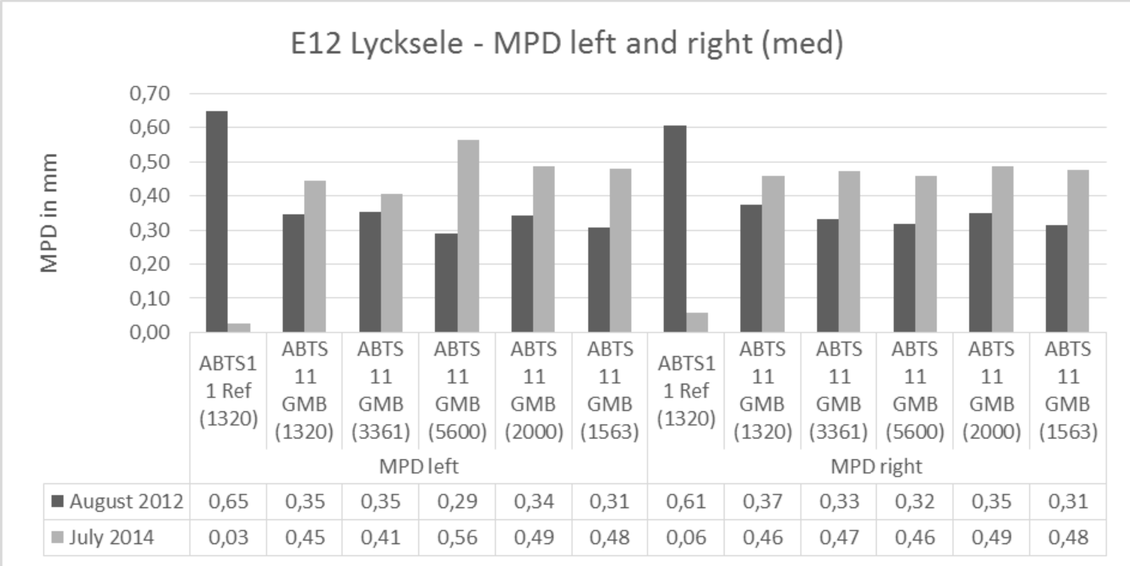


Figure 136: MPD left and right (med) - annual rate of change for ABTS11 reference track and ABTS 11 with GMB

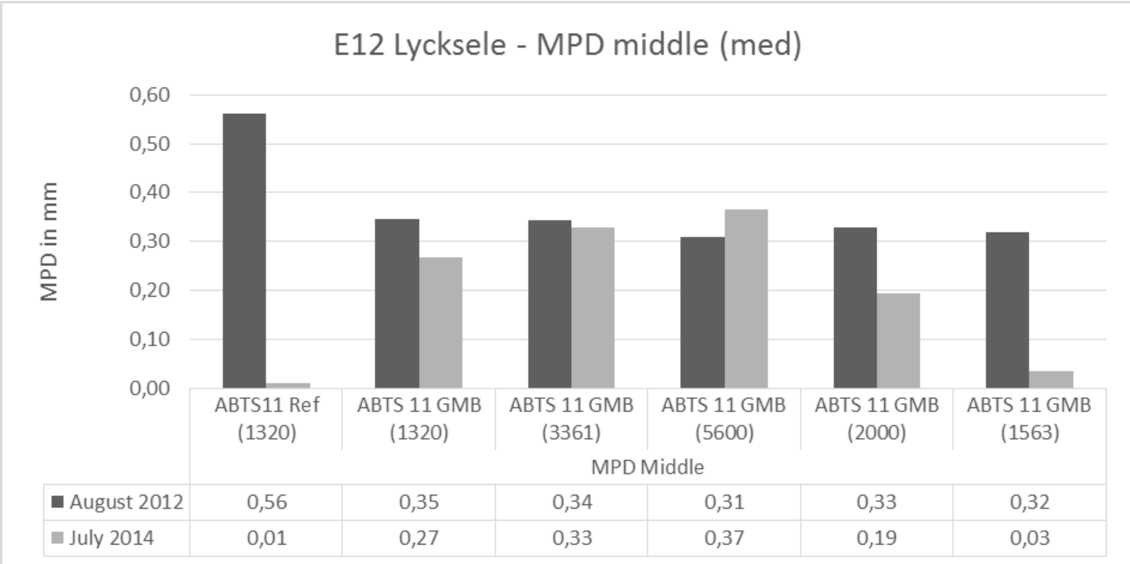
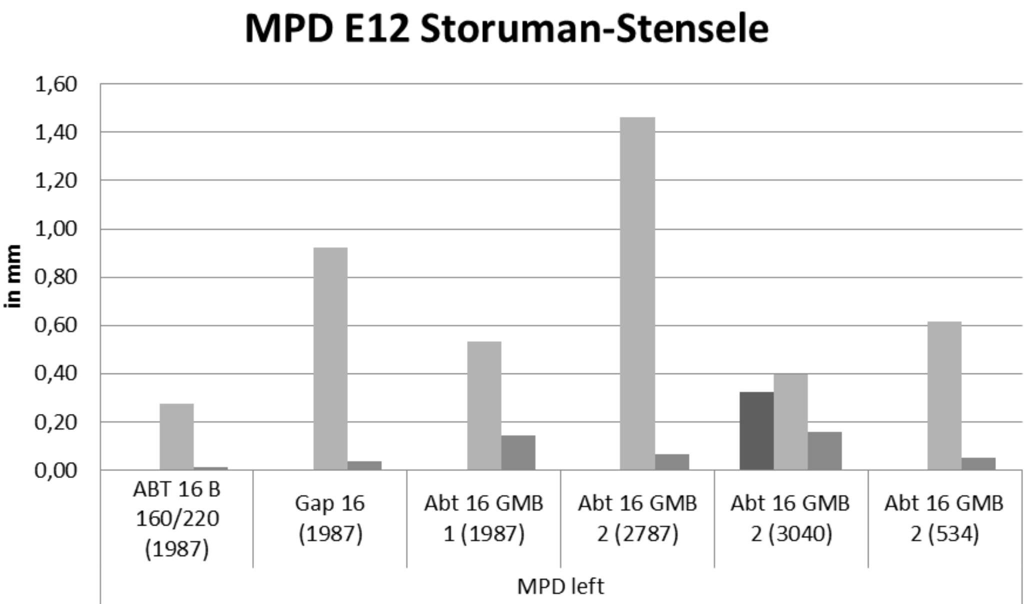


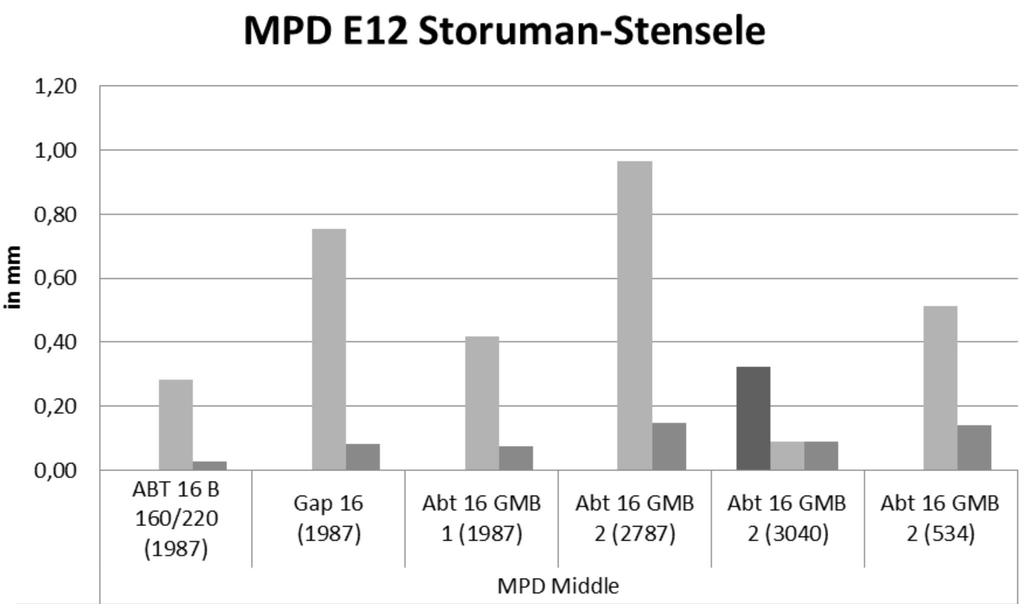
Figure 137: MPD middle (med) - annual rate of change for ABTS11 reference track and ABTS 11 with GMB

Appendix XI: E12 Storuman-Stensele



	ABT 16 B 160/220 (1987)	Gap 16 (1987)	Abt 16 GMB 1 (1987)	Abt 16 GMB 2 (2787)	Abt 16 GMB 2 (3040)	Abt 16 GMB 2 (534)
2011					0,33	
2012	0,28	0,92	0,53	1,46	0,40	0,62
2014	0,01	0,04	0,14	0,07	0,16	0,05

Figure 138: Annual rate of change for MPD left



	ABT 16 B 160/220 (1987)	Gap 16 (1987)	Abt 16 GMB 1 (1987)	Abt 16 GMB 2 (2787)	Abt 16 GMB 2 (3040)	Abt 16 GMB 2 (534)
2011					0,32	
2012	0,28	0,75	0,42	0,96	0,09	0,51
2014	0,03	0,08	0,07	0,15	0,09	0,14

Figure 139: Annual rate of change for MPD middle

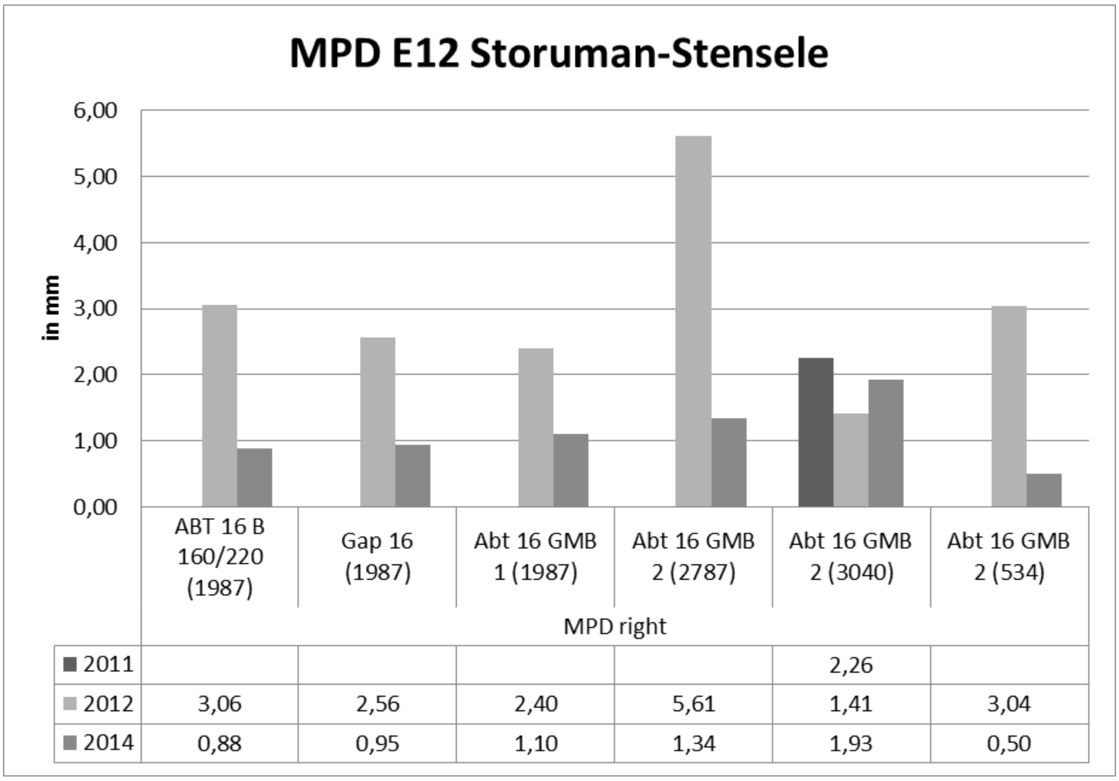
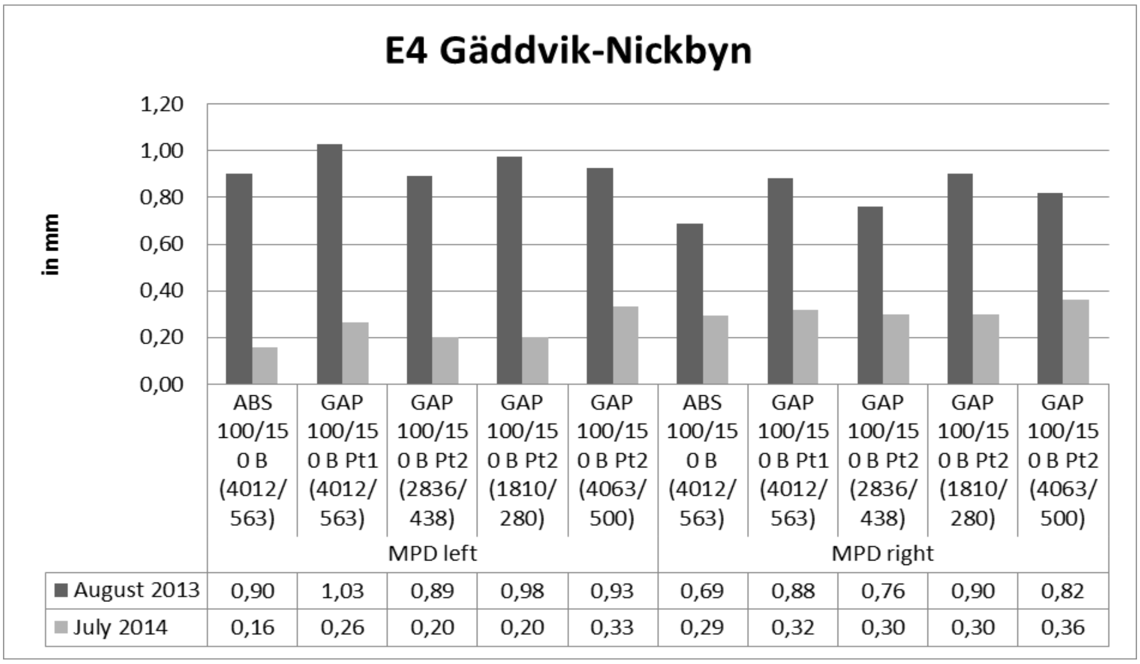


Figure 140: Annual rate of change for MPD right

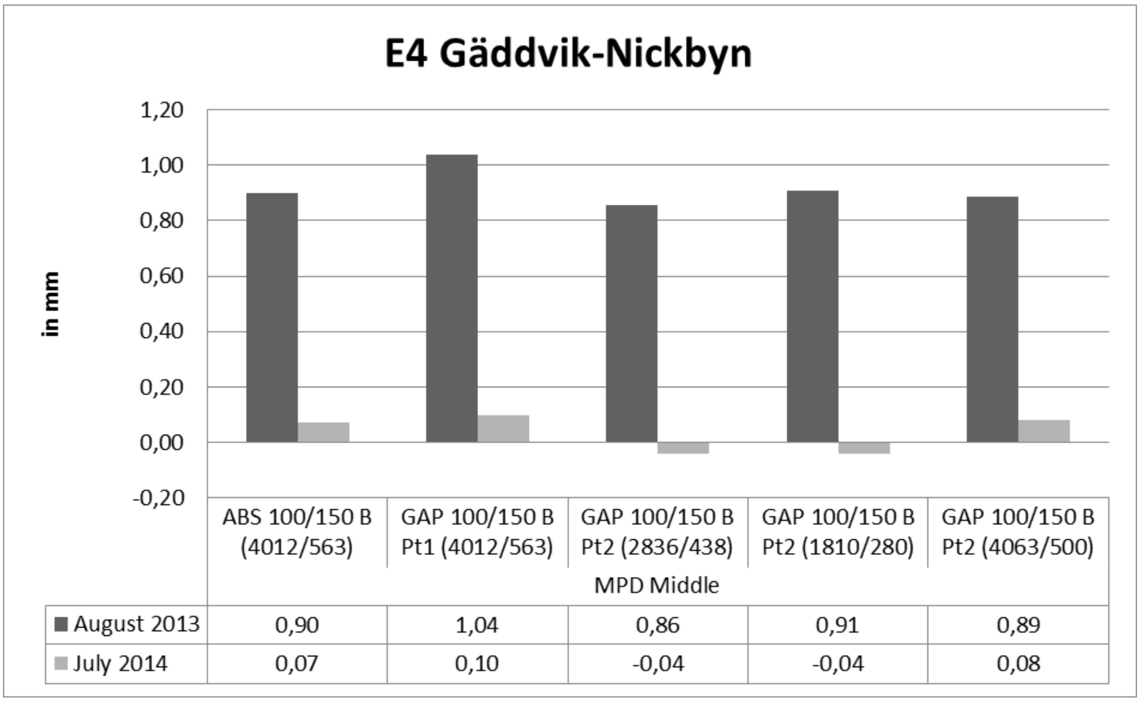
Appendix XII: E4 Gäddvik-Nickbyn

Med direction



	ABS 100/150 B (4012/563)	GAP 100/150 B Pt1 (4012/563)	GAP 100/150 B Pt2 (2836/438)	GAP 100/150 B Pt2 (1810/280)	GAP 100/150 B Pt2 (4063/500)	ABS 100/150 B (4012/563)	GAP 100/150 B Pt1 (4012/563)	GAP 100/150 B Pt2 (2836/438)	GAP 100/150 B Pt2 (1810/280)	GAP 100/150 B Pt2 (4063/500)
	MPD left					MPD right				
August 2013	0,90	1,03	0,89	0,98	0,93	0,69	0,88	0,76	0,90	0,82
July 2014	0,16	0,26	0,20	0,20	0,33	0,29	0,32	0,30	0,30	0,36

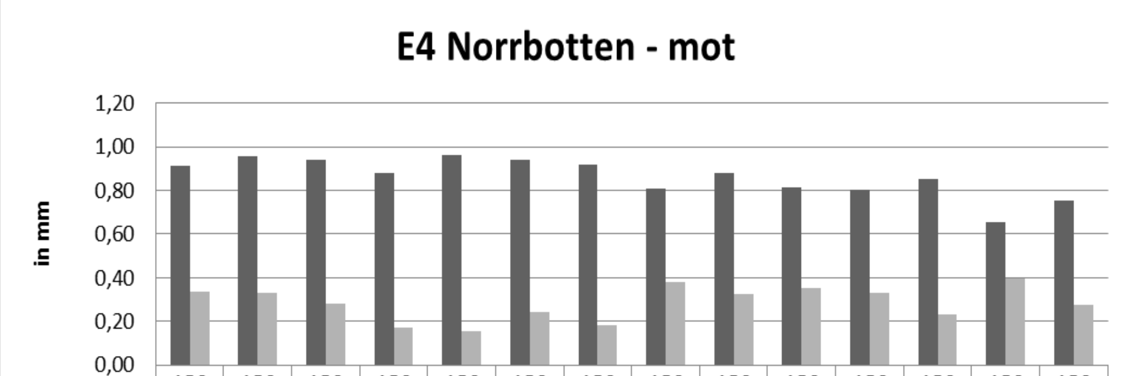
Figure 141: Annual rate of change for MPD left and right- E4 med



	ABS 100/150 B (4012/563)	GAP 100/150 B Pt1 (4012/563)	GAP 100/150 B Pt2 (2836/438)	GAP 100/150 B Pt2 (1810/280)	GAP 100/150 B Pt2 (4063/500)
	MPD Middle				
August 2013	0,90	1,04	0,86	0,91	0,89
July 2014	0,07	0,10	-0,04	-0,04	0,08

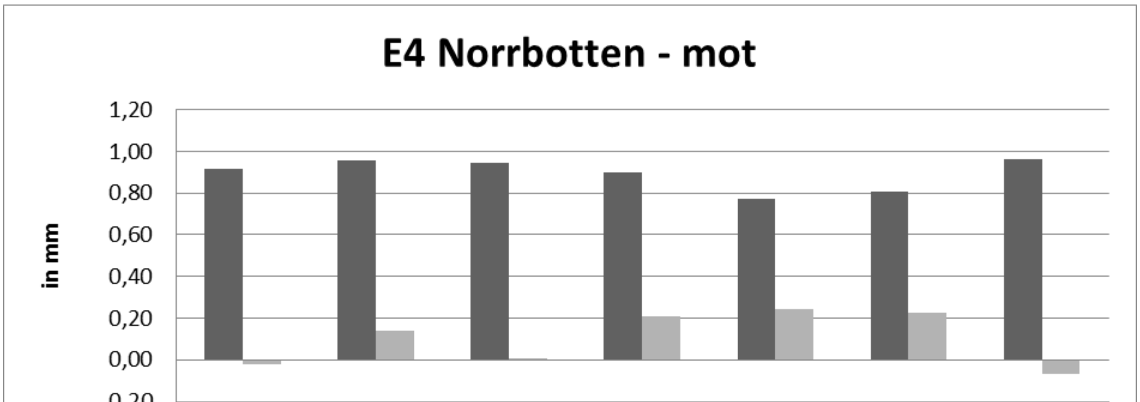
Figure 142: Annual rate of change for MPD middle – E4 med

Mot direction



	MPD left							MPD right						
	ABS 16 GMB (3800)	ABS 16 GMB (1810)	ABS 16 GMB (2742)	ABS 16 GMB (1650)	ABS 16 GMB (2050)	ABS 16 GMB (4100)	ABS 16 GMB (4191)	ABS 16 GMB (3800)	ABS 16 GMB (1810)	ABS 16 GMB (2742)	ABS 16 GMB (1650)	ABS 16 GMB (2050)	ABS 16 GMB (4100)	ABS 16 GMB (4191)
Aug 2013	0,91	0,96	0,94	0,88	0,96	0,94	0,92	0,81	0,88	0,82	0,80	0,86	0,65	0,75
July 2014	0,34	0,33	0,28	0,17	0,16	0,24	0,19	0,38	0,32	0,35	0,33	0,23	0,40	0,28

Figure 143: Annual rate of change for MPD left and right- E4 mot



	MPD Middle						
	ABS 16 GMB (3800)	ABS 16 GMB (1810)	ABS 16 GMB (2742)	ABS 16 GMB (1650)	ABS 16 GMB (2050)	ABS 16 GMB (4100)	ABS 16 GMB (4191)
Aug 2013	0,91	0,96	0,94	0,90	0,77	0,80	0,96
July 2014	-0,02	0,14	0,01	0,21	0,25	0,22	-0,07

Figure 144: Annual rate of change for MPD middle – E4 mot

Appendix XIII

The table below contains information on all analysed roads, whether data was available or not. Not all of them were included in the project, only the ones with enough data and a reference track.

Road no.	Location	Direction	Lane	Start-and Stoppoint	Asphalt type	Date	Reasons
E4	Kropp-Hyllinge	Med	10, 20	15870-20415	ABS 70/100 B GAP 70/100 B	2011 2010	
E6	Fredriksberg-Lockarp	Mot	10, 20	108091-112673	ABS 70/100 B GAP 70/100 B	2009 2010	
E6	Kronetorp-Salerup	Mot	10, 20	98965-105524	ABS 70/100 B GAP 70/100 B	2007 2009	
E6	Petersborg-Vellinge South	Mot	10, 20	115947-125955	ABS 70/100 B GAP 70/100 B	2009	
E6	Sunnanå-Kronetorp	Med	10, 20	36016-41005	ABS 70/100 B GAP 70/100 B	2006 2009	
E22	Blekinge Rosenholm	Med	10	77095-808300	ABS 70/100 B ABS 30/60-55 16 GMB	2014	Not enough data
E22	Blekinge Rosenholm	Mot	10	29405-32700	ABS 70/100 B ABS 30/60-55 16 GMB	2014	Not enough data
H137	Kalmar Öland	Med	10	160-10700	ABS 30/60 55 GMB KGO III ABS 70/100-48 PMB ABS 70/100 B	2014	Not enough data
E4	Ystad-Sandskogen	Med	10	51430-54010	GAP 70/100 B	2008	No reference track
E6	Kropp-Hyllinge	Mot	10, 20	157617-171000	ABS 70/100 B	2010	No modified asphalt
E6	Fredriksberg-Sunnanå	Med	10, 20	30092-36036	GAP 70/100 B	2005/ 2010?	Unclear date No reference
E6	Lockarp-Fredriksberg	Med	10, 20	26394-30052	GAP 70/100 B	2009	No reference track
E6	Vellinge North-Petersborg	Med	10, 20	18733-23762	GAP 70/100 B	2008	No refernce
E6	Vellinge North-Petersborg	Mot	10, 20	0-1000	ABS 70/100 B	2008	No modified asphalt
E6	Vellinge South-Vellinge North	Med	10, 20	13953-18753	GAP 70/100 B PMB (only 60 m section)	2008	No reference track
E6	Ullevi-Kallebäck	Med	10, 20	176896-179689	ABS 70/100 PMB GAP 70/100 B	2011	
RV47	Falköping	Med	10	21220-23720	ABT 70/100 B PMB, 6 types	2011	

E4	Uppsala-Knivsta	Med	10, 20	84720-101445	GAP16 0.6% Wetfix	2011	
					GAP16 0.6% Wetfix Pt2		
					GAP 16% 0.3% Wetfix 1% Cement		
					GAP 16% Increased Temp		
					ABS 70/100		
					ABS 50/70		
					GAP 16 Increased Temp Pt2		
E4	Viby-Sollentuna, Stockholm	Mot	30	27317-30873	ABS 70/100 B GAP 70/100 B	2010 2012	
169	Kubale	Med	10	12490-17604	ABT 70/100 B ABS 30/60-55 GMB	2014	Not enough data
169	Almön	Med	10	100-2600	ABS 30/60-55 GMB	2014	Not enough data
710	Kållekär	Med	10	5616-6777	ABS 30/60-55 GMB ABS 70/100 B	2014	Not enough data
E4	Stockholm Rotsund-Rotenbron	Mot	30	21950-27280	ABS 70/100 B Pt1 GAP 70/100 B Pt1 ABD 90/150-75 PMB HABT	201320122014 1986	Not enough data Ass. wrong registration
E4	Rotebro	Mot	20	26982-32007	ABS 70/100 B ABS 30/60-55 GMB	2010/2013201 4	Only one year measurement No reference Ass. wrong registration
E4	Stockholm Haga Norra	Mot	30	39369-42100	ABS 70/100 B GAP ABS 45/80-55 PMB	201020122014	Not enough data No reference
E4	Stockholm Haga Norra	Mot	10	39369-42100	ABS 70/100 B ABS 45/80-55 PMB	20102014	Not same year Not enough data
E18	Jakobsberg – Hjulsta bygg	Med	10	22200-26000	ABS 70/100 B Gap 70/100	2006 2012	Not same year Not enough data
E18	Jakobsberg – Hjulsta bygg	Med	20	23223-25320	Gap 70/100	2012	No reference track Not enough data
E18	Jakobsberg – Hjulsta nybygge	Med	10	20299-24011	ABS 70/100 Gap 70/100	20062012	Not enough data
E18	Jakobsberg – Hjulsta nybygge	Mot	10	95923-99634	ABS 70/100 Gap 70/100	20062012	Not enough data
226	Huddinge	Mot	10	11030-13322	ABS 70/100 B Gap 70/100 B	2006 2012	Not enough data
226	Huddinge	Mot	20	11030-13322	ABS 70/100 B Gap 70/100 B	2006 2012	Not enough data
226	Huddinge sjukhuset	Med	10	11930-12611	ABS 70/100 B Gap 70/100 B	2006 2012	Not enough data

226	Huddinge sjukhuset	Med	20	11819-12120	ABS 70/100 B Gap 70/100 B	2004 2012	Not enough data
276	Åkersberga	Med	10	6656-7700	ABS 70/100 B Gap 70/100 B	2009 2012	Not enough data
276	Åkersberga	Mot	10	45460-46500	ABS 70/100 B Gap 70/100 B	2009 2012	Not enough data ABS data only one year
E18	Örebro	Med	20	71430-84408	ABS 70/100 B ABS 30/60-55-GMB	2013	No available data
E20	Örebro	Mot	20	0-23136	ABS 70/100 B ABS 30/60-55 GMB	2013	Last measurements in 2012
6.20	Gothenburg, Söderleden	Mot	10, 20	1940-10180	ABS 16 GMB ABS 11 GMB ABS PMB	2013/ 2011	Date not clear
6.20	Gothenburg, Söderleden	Med	10	26432-34688	ABS 16 GMB ABS 11 GMB ABS PMB	2013/ 2011	Date not clear
169	Tjörn	Med	10	13468-17643	ABS 30/60-55 GMB	2014	Last measurements from 2013
E6/ E20	Sävenäsleden	Med	10	15080-20920	ABS GMB ABS B	2003 2002 1980	Unreliable date
E4	Broänge-Hökmark	Med	10	156720-164260	GAP16 100/150 ABS 16 100/150	2012	
E12	Lycksele	Med	10	151932-158798	ABTS 11 ABTS 11 GMB	2012	
E12	Lycksele	Mot	10	307155-309235	ABTS 11 ABTS 11 GMB	2012	
E12	Storuman-Stensele	Med	10	245181-252932	GAP 16 ABT 16 GMB ABT 16 B 160/220	2011	
E4	Gäddvik-Nickbyn	Med	10	72795-89450	GAP 16 ABS 16 100/150	2012	
E4	Gäddvik-Nickbyn	Mot	10	112038-130608	ABS 16 GMB ABS 16 100/150	2013	
356	Boden	Med	10	36079-36989	GAP 50/80-55 GMB	2013	Not enough data