

Jon Eric Westerlund

# ITS SOLUTIONS FOR DETECTION OF REDUCED MOBILITY

Master's thesis in Bygg- og miljøteknikk  
Supervisor: Arvid Aakre  
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Faculty of Engineering  
Department of Energy and Process Engineering



## **Abstract**

Prioritising technology development in the field of Intelligent Transport Systems, ITS, will be crucial for the long-term goals of a safer and environmental friendly transport sector. With the current advancements made in automation, increased computing power, analytic processing, communications and cooperative systems, ITS will secure a more efficient utilisation of the transport system for all road users and personnel carrying out transports. Building a physical and digital infrastructure with intelligent roadside units will provide the required foundations for communication coverage, positional accuracy, sensor data and situation awareness during the transition period of mixed fleet operations (varying levels of automation). The intelligent road providing infrastructure-to-vehicle (I2V) and infrastructure-to-cloud (I2C) communications. These innovative technologies for ITS solutions are already available and with automated vehicles approaching fast in the rear-view mirror it is important that the foundation is there for the overtake.

This report presents the use of three different Intelligent Transport Systems (ITS) to detect reduced mobility and stop in traffic due to varying winter conditions in uphill gradients. Providing an efficient and cost effective approach to securing safe use of winter roads by alert messaging to road users, traffic managers and dynamic road condition warning signs. Large scale field trials of the technologies in an arctic climate have produced promising results to secure situation awareness and sensor data to the digital infrastructure of an intelligent winter road.

## Summary

In this master thesis speed profile analysis has been brought forward as a potential parameter for detection of reduced mobility among heavy vehicles in grades. Three new ITS technologies were tested for detection of equilibrium speed at a steep incline on the European highway, E8, in northern Norway. These three are:

1. C-ITS platform by Aventi.
2. In-roadway magnetic detector by Q-free.
3. LiDAR sensors by ITS-Perception.

The test was conducted with the intentions to answer the following research questions:

- RQ 1: Can speed profile analysis of equilibrium speed be used for detection of reduced mobility?
- RQ 2: Can in-roadway magnetic detectors, C-ITS or LiDAR produce the desired result of real-time detection of equilibrium speed or stop in traffic?
- RQ 3: How will these sensors function during an arctic winter?

Analysis of weather and traffic data showed that speed levels decreased significantly with precipitation and reduced road surface friction at the test site in northern Norway. It was also noticed that speeds decrease only slightly when there is no visual aids that would indicate lower friction. A friction reduction decreased equilibrium speed where the vehicles deceleration is zero and utilised power output is equal to power output needed to overcome all running resistance. Having logged 31 heavy vehicles a baseline for equilibrium speed was established. Using this baseline in monitoring of speed profiles, trends of lower equilibrium speeds with low road surface friction values can be used to trigger alert systems

## II

for winter maintenance personnel, traffic management and other on-coming traffic.

In summary the in-roadway magnetic detectors did not have conclusive results to show detection of equilibrium speeds. However, the observations indicate that the technology can detect stop in traffic and continuously monitor speed of each individual vehicle.

C-ITS proved to be a good candidate for speed profile analysis. Giving results equal to the baseline profile used for comparison.

LiDAR sensors showed promising results for alerting slow and stopped traffic. However, it is not possible with the current instalments to safely secure equilibrium speeds of vehicles. It is further described how this can be obtained and tested for LiDAR sensors in future research.

## Preface

This Master Thesis was submitted spring 2019 as part of the civil engineering course Bygg- og Miljøteknikk at NTNU. The thesis is submitted under the study program road, railway and transport.

The thesis was made in cooperation with the Norwegian public road administration (NPRA), Statens Vegvesen, as part of their initiated Borealis project. They helped with collecting data and administering surveys to the project site.

The thesis was funded by NTNU in cooperation with the NPRA.

Associate professor Arvid Aakre at NTNU, has been the main supervisor. Chief engineer Torbjørn Haugen from the NPRA has been co-supervisor and contact channel for the cooperation between the NPRA and NTNU.

This thesis is a report on new technologies within ITS for mobility detection and are all in a research and technological development (RTD) phase. Any results or conclusions from this thesis should not be used to judge the companies mentioned or their products.

Trondheim, 2019-06-11

A handwritten signature in black ink that reads "Jon Eric Westerlund". The signature is written in a cursive style and is positioned above a horizontal dotted line.

Jon Eric Westerlund



## Acknowledgement

I would like to express my sincere gratitude to NTNU and the NPRA for funding my thesis work; and special thanks to my supervisors, Assoc. Professor Arvid Aakre and Chief Engineer Torbjørn Haugen for helping me tailor my first ideas of this thesis to my interests.

Arvid Aakre has been of great guidance along the way to make sure enough data is available in a short six month thesis time span.

Torbjørn Haugen has been my go-to-guy for all general discussions, big or small. He helped me collect data and gave pointers on how to write this thesis.

*I would also like to thank the following people:*

Torgeir Vaa, Senior Principal Engineer and contact person for the Borealis project; for giving me access to the Borealis project, test site, companies with relevant contacts and making sure project results are shared with me.

Jorunn Levy Riddervold for sending me all the data from NPRA sensors immediately when requesting certain dates, and discussing programming code for visualising data.

Tomas Levin for help with ACC testing and every time I got stuck in a programming error.

This thesis was only made possible by the people at the different technology companies opening their doors and sharing data and taking time to let me interview them and ask questions throughout the thesis work. These people include:

- Hans Petter Flugstad, ITS Perception.
- Ola Martin Lykkja, Q-free.
- Bjørn Elnes and Karl Svantorp, Aventi.

Johannes Andre Solberg, Falck Redning AS, for taking time off to make a statistical report on vehicle rescues in Norway.

My colleague and friend Joachim Spange for the many discussions and inputs on data sampling. Most of the time while sitting in the sauna after a game of squash.

Last but not least, I would like to thank my wife Hangi and my son Noam for giving me the love and support to finish my masters degree.

J.W.

## Map

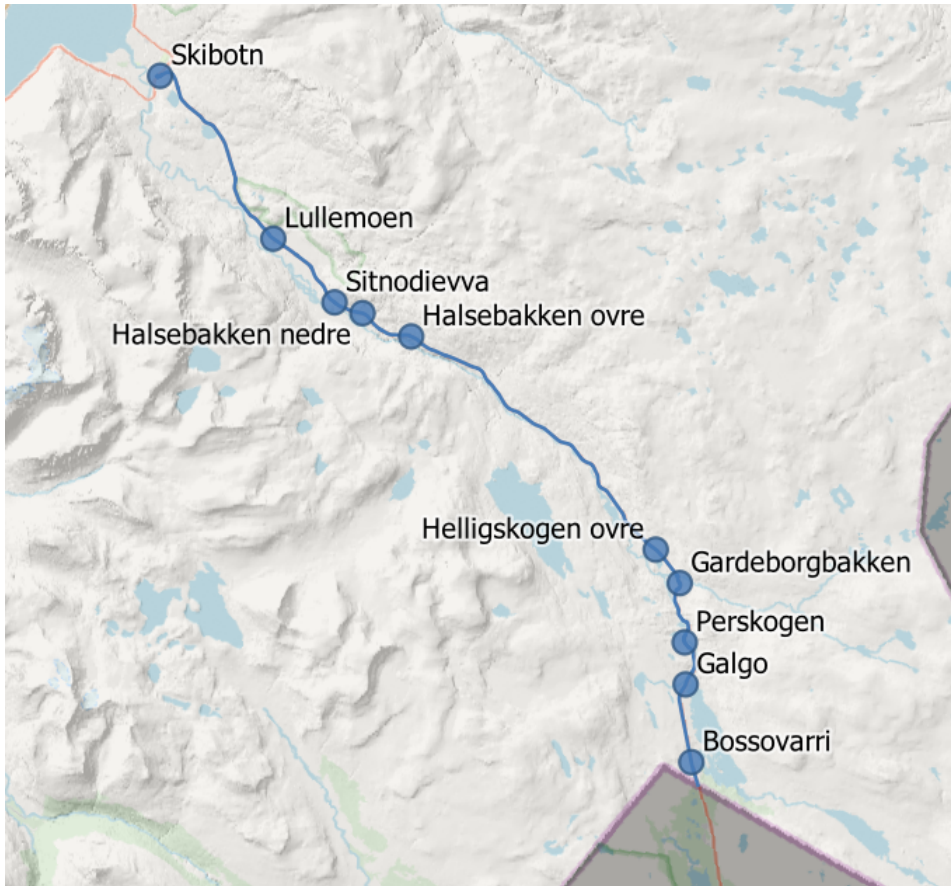


Figure 1: Reference map of test site and sensor locations.

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# Chapter 1

## Introduction

### 1.1 Background

Aurora-Borealis is the name of a cross border project between Norway and Finland to test different Intelligent Transport Systems (ITS) during winter conditions. With the Norwegian project site located on the European highway, E8, in northern Norway, Troms county. ITS can be categorised as solutions that use information and communication technology in a traffic or transport system in order to improve traffic safety, pollution, mobility, efficiency and user satisfaction. This can be found in the project's main goals[1], which intend to implement and test road infrastructure technologies that can help to: increase –

- safety through awareness of weather, traffic, road conditions and environment (wildlife).
- efficiency through traffic following, driver communication and alert systems, along the road and on board.
- environmental sustainability through improved road maintenance and traffic efficiency.

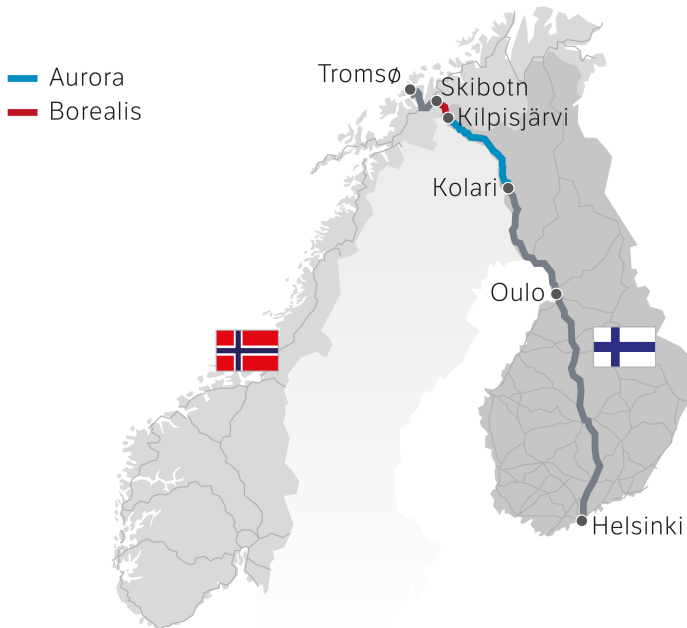


Figure 1.1: Map of Aurora Borealis project site.

The Norwegian project site, Borealis, starts in Tromsø, but the main focus is the 38 km stretch from Skibotn to the Finnish border. E8, a European highway of high importance to the Norwegian fish industry, growing northern light tourism and local business. It is also the bypass road in case E6 to the county of Finnmark is closed. 22 km of the site has a speed limit of 90 km/h, an average annual daily traffic of 700 vehicles with 26% being heavy goods vehicles [2]. The fish industry contributing around 16 trucks a day [3]. Norway exported 2,6 million tons of fish to Asia in 2017, contributing 94,5 billion NOK [4]. From this one can clearly see the socio-economic importance of this highway corridor between Norway and Finland.

Situated above the arctic circle, E8 is prone to many of the problems that come with harsh winters. Slippery road surface due to ice and/or snow



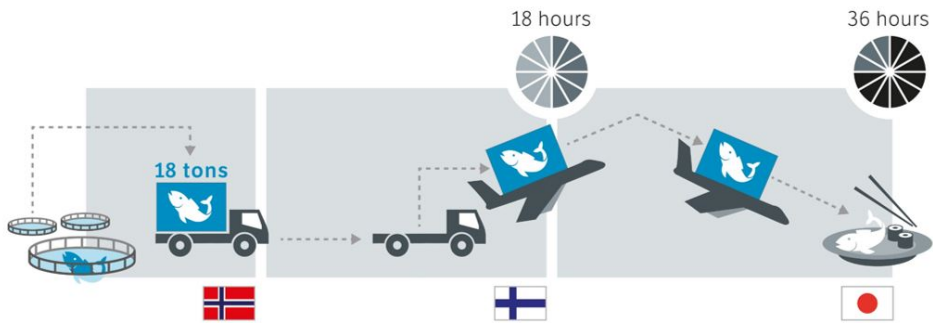


Figure 1.2: A product line from sea to consumer

and snow drifts are the main concerns, but in addition to snow and ice we have reduced visibility due to wetness and darkness. A total of 59 days without sunlight, 22<sup>nd</sup> of November to 20<sup>th</sup> of January [5]. Reindeer and moose are also a risk factor in the area. Being especially hazardous during low visibility. In 2018 15 wildlife collisions were recorded in the county of the Borealis test site, whereof five of these collisions were on the same road section[6]. Global warming and the consequential climate change is causing more extreme weather and rapid weather changes. Rain during winter season, increased frost heave and severe snowfall are all becoming more common.

Falck, a Norwegian recovery service company, revealed in their 2017-2018 statistics report for Norway a 43% increase in vehicle assistance between summer months July-August 2017 and winter months January-February 2018. However, only a 5% increase was found in heavy vehicle assistance for the same period [7]. Eight accidents have been reported to the police on E8 between the months of November to April with the latest being from 2009. Six of these are reported with slippery road surface conditions, and four being single vehicle run-off-road collisions.

Assistance Heavy	Month	Month
Weight class	July	Aug
3.5 - 4.5 tonne	98	76
3.5 - 5 tonne	162	151
5 - 12 tonne	75	198
5 - 7.5 tonne	67	89
7.5 - 12 tonne	224	286
> 12 tonne	296	316
Total	922	1116

(a) Summer Assistance

Assistance Heavy	Year	
Weight Class	Dec 2017	Jan – March 2018
3.5 - 5 tonne	107	396
5 - 12 tonne	89	374
5 - 7.5 tonne	157	254
7.5 - 12 tonne	308	935
> 12 tonne	389	1248
Total	1050	3207

(b) Winter Assistance

Figure 1.3: Heavy vehicle assistance statistics report.

E8 from Skibotn has a winter maintenance classification of DkC, in a grading system from A-E. Set by the Norwegian Public Road Administration (NPRA), figure 1.4, DkC sets a requirement for: "Clear road surface, dry or wet, during mild periods around 0°C and hard packed snow/ice during cold periods. Sanding shall be used on complete cover of snow and ice, also as a preventive measure. Preventive salting shall be used to hinder a slippery road surface due to a thin cover of snow, ice or surface hoar. During periods with no snow precipitation, salt should be used to maintain a clear road surface" [8].

The winter maintenance classification is mainly derived from the average annual daily traffic with consideration taken to the composition of traffic (light/heavy), the geometric standard of the road, climate, topography, environmental considerations, etc. On E8 winter maintenance personnel live on site to be available on demand. Having personnel and equipment available on short notice out on rural highways is necessary

Maintenance-class	AADT							
	0	500	1500	3000	5000	10000	15000	20000
DkA								
DkB								
DkC								
DkD								
DkE								

Figure 1.4: Advised Norwegian Maintenance classification (grey), based on AADT

to meet the standards and ensure a reliable road network.

The main factors for having the Norwegian Borealis project on E8 from Tromsø to the Finnish border and Finland’s project Aurora onward to Kolari, is to increase cross border cooperation for ITS solutions during winter conditions. The idea being that if you can make it in an arctic climate you will make it anywhere. The two national road departments intend to cooperate to forward good ITS solutions, based on equal, mutual and collected benefits. Stress testing different solutions that can help operation and maintenance keep a consistent level year-round and ensuring the safety and functionality of winter traffic. Choosing a site with high socio-economic value is important to ensure both local and political interest, and the combination of low AADT<sup>1</sup> and high AADT-HV<sup>2</sup> makes it easier to control a project site and secure data collection. Though less data is available it will be easier to study the data on a microscopic level and look at the combination of sensors for best result.

In the last few years hardware advancements like increased processing power and memory, coupled with advancement in communication and cloud computing technology [9] has made companies and politicians see the upcoming importance and demand for smarter infrastructure. Buzz

<sup>1</sup>Average annual daily traffic

<sup>2</sup>Average annual daily traffic - heavy vehicles exceeding 3,5 tonnes

words like "big data" and "internet-of-things" have become synonymous with the wave of future thinking and Norwegian politicians have not been slow to understand this. Several laws have been brought up for reform to accommodate the future of self-driving vehicles and Norway has taken a leading role for testing and implementing autonomous vehicles and ships. Norway's National Transport Plan, NTP, 2018-2029 [10], sets the 12-year framework to achieve long-term goals in transport politics. Here we can clearly see an increased focus on ITS solutions with;

One of the main priorities set as a basis for NTP 2018-2029:

"Greater use of ITS and new technologies to increase effectiveness and reach the transport political goals." page.23

And;

The government will:

"Investigate the potential for new technological solutions through use of tests and pilot projects." page.35

Deputy Director-General Matthew Baldwin of the European Commission department for mobility and transport opened the 2018 ITS conference, Aurora Summit, saying that we cannot reach the goal of vision zero (zero killed and zero seriously injured in traffic) without autonomous vehicles. This vision of the future from the European Commission with connected and automated driving is shared by many, but to reach it, we must first set the foundations of a digital infrastructure; intelligent road side units providing required communication coverage, positional accuracy, sensor data and situation awareness.

This political interest in ITS resulted in 2.5 million NOK to ITS Norge

in the state budget 2018 [11]. ITS Norway is a national association for promoting "new technology in a multi-modal way for the transport sector. The objective is achieving smarter, safer and more sustainable transport solutions as well as increased business opportunities for Norwegian companies" [12]. The NPRA has also set aside 450 million NOK for implementing test pilots for coordinated ITS and automated transport in the period 2018-2023 [13]. Borealis being one of these.

## 1.2 Objectives

The challenges mentioned in chapter 1.1 are key areas for supportive infrastructures. Gaining the ability to collect in-situ, real time information and predicaments. Securing that correct actions are made in a shorter time frame. The two national transport agencies in Norway and Finland

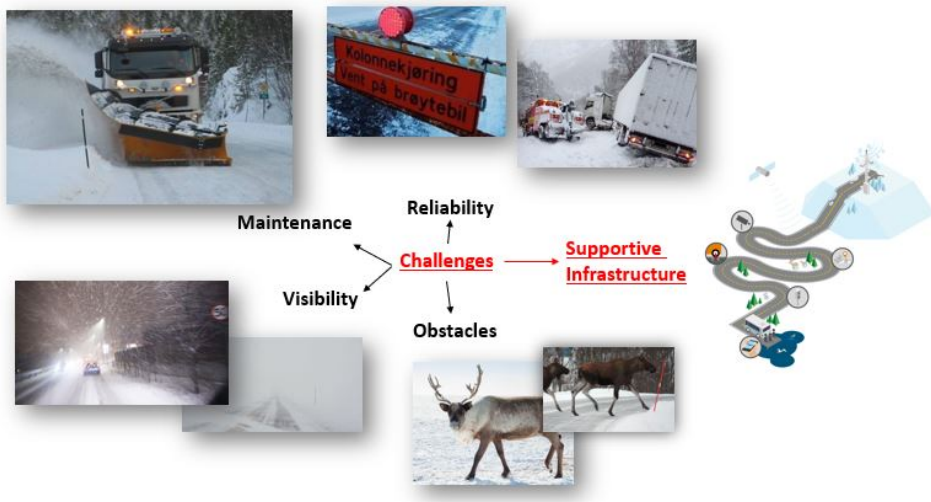


Figure 1.5: Challenges with winter roads.

have chosen different technologies and aim to learn from each other after project completion. This joint effort will help stress test more ITS

solutions for northern climate and high standards, and contribute in collecting more data to achieve a flow of information between systems and across national borders. Securing the best possible result from the set goals.

### **1.2.1 ITS-systems to be implemented**

The ITS technologies listed below are installed at the Borealis test site and briefly described in this subsection:

1. C-ITS and its communication platform by Aventi.
2. Weather stations.
3. In-roadway vehicle detection sensors by Q-free.
4. Weigh-in-Motion sensors by Kistler (WIM).
5. Inductive-loop traffic detectors.
6. LiDAR sensors by ITS Perception.
7. Distributed Acoustic Sensing (DAS) by CMR

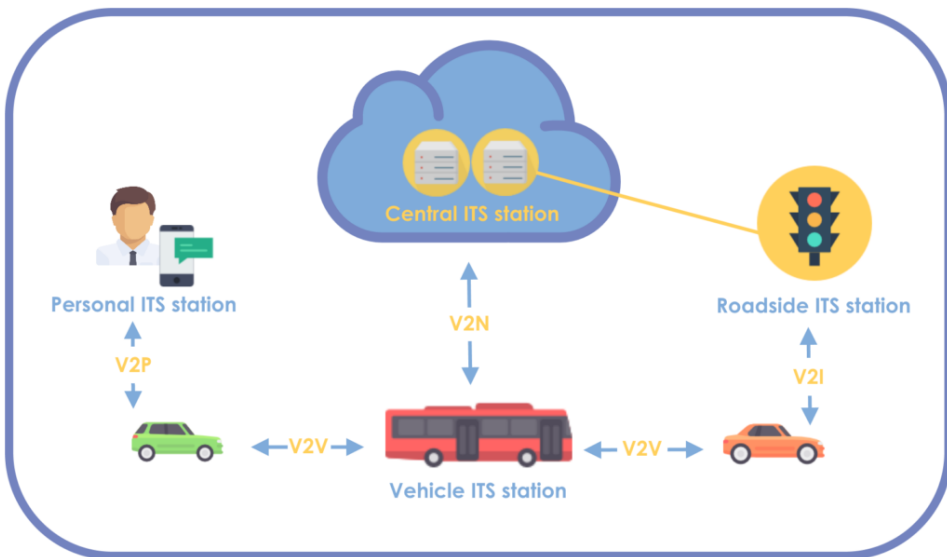


Figure 1.6: C-ITS communication channels. *Source:*[14]

1. C-ITS. Cooperative ITS collects information from vehicles and road infrastructure to communicate and alert road users and traffic managers. This digital interaction improves traffic coordination, safety and comfort of driving by distributing the collected information to the correct users. Either as messages and alerts on an ITS-OBU (on-board unit) or through dynamic message signs (DMS) [15][16].

2. Weather stations situated along the road will allow for precise and local weather information and road conditions to be available on demand at all time. Intelligent sensors report precipitation, wind direction and speed, visibility and temperature in addition



Figure 1.7: Weather Station. *Source:*[17]

to road surface conditions such as coverage, road temperature and friction. This data with the contribution of weather forecasts will secure higher mobility and regularity of traffic as well as increased safety [18].

3. In-roadway magnetic detectors (magnetometers). Simple on/off data registry by detecting vehicles above the sensor. Changes in the earth's natural magnetic field by overhead iron objects calibrated for vehicles is detected and sent wire-

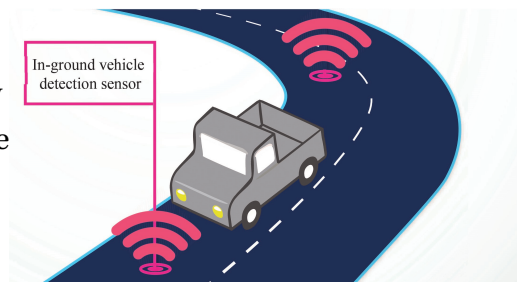


Figure 1.8: *Source:*[14]

less to a nearby base station. This technology is most common in parking lots for dynamic parking space availability information to the user, but an innovative new idea is to connect several sensors together, evenly spaced in a line. Combining the data, one can retrieve travel time information, traffic count and stop in traffic. Which again can be used to give an early indication of reduced mobility and high accident risk [19][20].



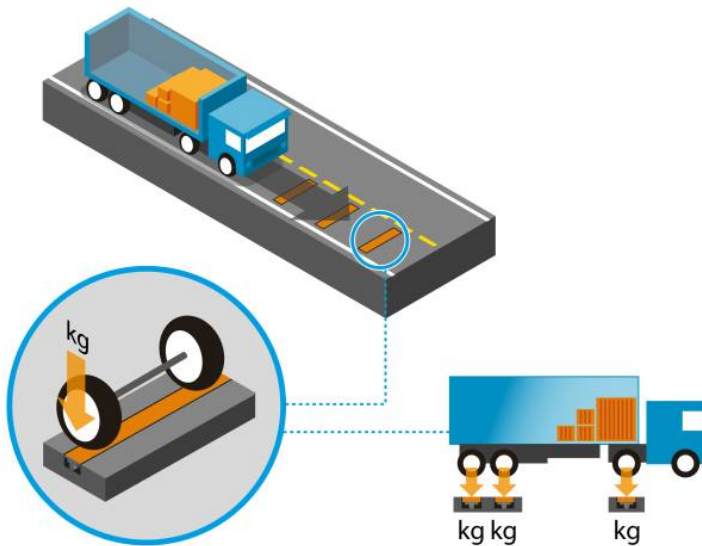


Figure 1.9: Weigh-In-Motion. *Source:*[17]

4. Weigh-In-Motion (WIM) is a well-used technology to detect vertical axle loads from vehicles, compared to static weighing stations. It's an efficient way to retrieve axle weights and gross vehicle weights from vehicles travelling at normal traffic speeds. The Kistler sensors are Lineas quartz sensors. They are similar to piezoelectrical cables, but use quartz elements that yield an electrical charge signal in response to applied stress. The quartz signal is amplified into a proportional voltage output that can further be used as direct measurement of the applied axle force. The sensors can be used for size and weight enforcement, advice tire chains messaging to heavy trucks and administration and planning for cargo operators. Implementing WIM-technology helps increase road safety and reducing maintenance costs [21].

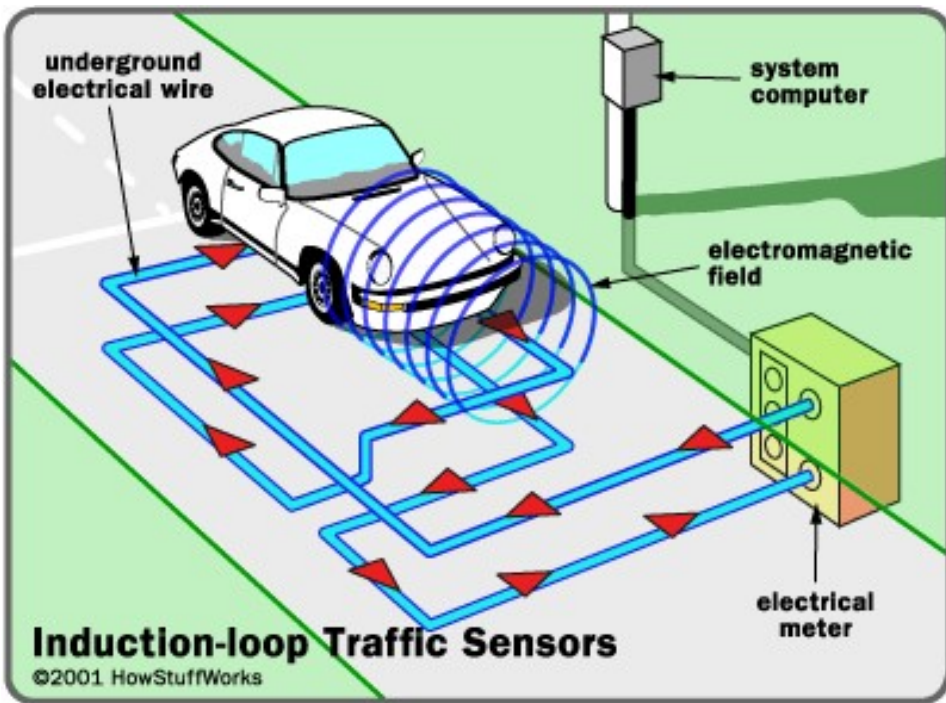


Figure 1.10: Induction-loop. *Source:*[22]

5. Inductive-loop traffic detectors, an electromagnetic detection system registering the decrease of induction in a looped wire from passage or presence of vehicles above it. This technology was introduced already in the early 1960's and is now one of the most used sensor equipment's for traffic management. Due to it being embedded in the pavement it is insensitive to weather conditions and road maintenance as well as low "false-positive" registers. This versatility and being a well proven technology over many years has made it a preferable sensor for traffic counting, vehicle classification, vehicle actuated control of light signals, bus priority, parking guidance and information systems to name a few. This technology helps retrieve traffic information and improve mobility, efficiency, pollution and user satisfaction [23].

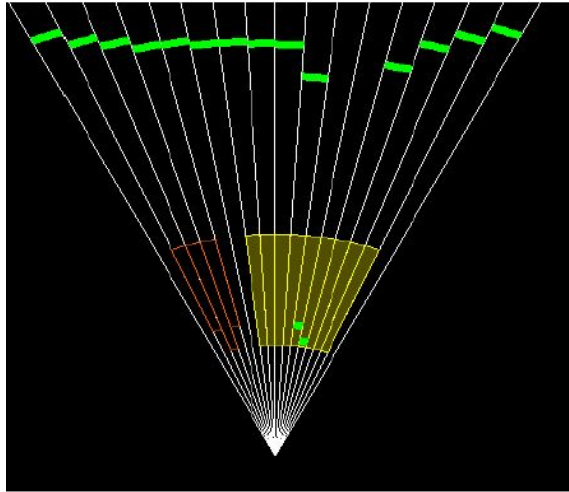


Figure 1.11: LiDAR beam with registered reflections in green. *Source:*[24]

6. LiDAR, Light Detection and Ranging, is an optical sensing technology using pulsed laser light. Light, having an almost constant speed in air across normal climate temperatures and pressure gradients, enables use of round trip time-of-flight measurements for distance calculations between sensor and object; signal and reflection. This remote sensing of objects without physical contact is similar to that of radio waves (radar) and sound waves (sonar). LiDAR has been used since the 1960's, but has only recently become cheap enough for wide use. Mostly due to the technology being favoured in self driving vehicles. Using LiDAR in roadside infrastructure will detect passing vehicles and their speed. Alerts can be sent when detecting slow moving and stopping traffic. Having several sensors, e.g. one at the bottom of a hill and one at the top, will improve detection and allow speed profiles to be calculated between the sensors. Further development will enable categorisation of objects and alerts to be sent for pedestrians or wildlife on the road. This technology has the potential to greatly increase traffic safety and improve traffic mobility, efficiency and pollution.[23].

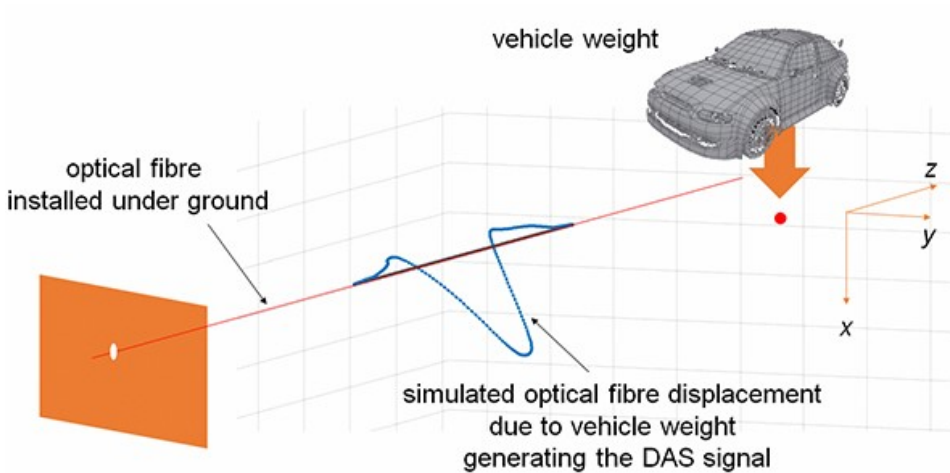


Figure 1.12: Acoustic Sensing. *Source:*[25]

7. DAS, Distributed Acoustic Sensing. A fiber optic-based instrument that allows for continuous acoustic measurements along the length of an individual optical fiber. A pulse of laser light is transmitted through an optic cable where some of this light is scattered back to its source due to inhomogeneities in the fiber. Any measured optical path length changes in this back scatter due to local acoustic energy, in our case a vehicle, will be detected by an interrogator unit. This makes it possible to individually follow vehicles along a continuous cable next to the road. Detect the vehicles direction and speed and if the vehicle stops. It is also possible to count vehicles and have vehicle classifications at point sensors, a single sensor location, by having the cable bored across the road. This sensory equipment can greatly improve traffic safety by quickly detecting stop in traffic or ghost drivers. And as the inductive-loop traffic detectors in point five; retrieve traffic information and improve mobility, efficiency, pollution and user satisfaction [25][26].

### 1.2.2 Research Questions

WIM, induction loops and roadside weather stations are categorised as conventional in-situ technologies for traffic data collection. All giving important data for traffic management and the future intelligent road. LiDAR, magnetometer, DAS and C-ITS are in a research and development phase (R&D). The companies providing these sensors and technologies show positive concept descriptions for real time monitoring of traffic flow and alerting abnormal events like slow moving traffic or full stop.

Data from the conventional ITS stations have been collected during one winter season from November 2018 to end of April 2019. Data from the R&D technologies were gathered from a large scale field trial in March 2019. However, DAS data was not collected due to the company not being available in March. The field trial data will be compared to known speed profiles of 31 heavy vehicles and mathematical speed profile model. Speed profile analysis will also be done using WIM and induction-loop data and comparing it to weather reports to see if a visual change in speed curvature can be detected with varying weather.

From analysis of above mentioned data collection, this thesis will aim towards answering the following research questions:

- RQ 1: Can speed profile analysis of equilibrium speed be used for detection of reduced mobility?
- RQ 2: Can in-roadway magnetic detectors, C-ITS or LiDAR produce the desired result of real-time detection of equilibrium speed or stop in traffic?
- RQ 3: How will these sensors function during an arctic winter?

### 1.3 Limitations

Some limiting factors should be noted for this thesis. With the first and foremost being lack of control and ownership of the project site, sensors and data collection. Resulting in having to wait for sensors to be installed, tested or activated for data collection.

The fact that the thesis is on reduced mobility during winter operations require that data is collected and ongoing as early as possible to retrieve a viable sample size from a low AADT road. And that data collection coincides with change in weather and road conditions to secure the possible detection of reduced mobility. The lack of control on environmental conditions within a short time frame has led to a smaller sample size of test data than wanted.

The three technologies under testing are all in a research and development phase with limited information found from previous studies during literature review. Finding the information and knowledge in this thesis has therefore relied more on the companies own information, with possibility of being biased.

# Chapter 2

## Methodology and Data

This chapter describes the approach chosen for data collection and analysis during this thesis.

Section one consists of data collected from the conventional ITS sensors, WIM, induction loops and weather station. It further details how this data was analysed and filtered for the purpose of this thesis.

Section two describes the test site, Gardeborgbakken, where the full scale field test was conducted. It further details the scientific approach to test signal outputs from the LiDAR and magnetometer sensors and C-ITS. This data will be compared to the speed profiles logged manually and a mathematically modelled speed profile; also described in this section. Results are given in chapter [4](#) on page [37](#).

### 2.1 Data Collection

A personal library was created with the data retrieved from ITS sensors that have been online since the beginning of winter 2018. These include:

1. Weigh-In-Motion - Haslebakken
2. Inductive loops - Haslebakken and Gardeborgbakken
3. Weather sensors - Gardeborgbakken

The complete library includes 8132 heavy vehicles across one winter season, November 2018 until end of April 2019. A self made script was made to identify matching vehicles between the two sensor locations Haslebakken and Gardeborgbakken, joining their metadata and timestamps. The identification was made on the assumption that a vehicle will have a travel time between the two sensor points calculated as distance between the sensors divided by the speed registered with WIM at Haslebakken and inductive loops and Gardeborgbakken. The speed is found as the rolling mean of the previous five heavy vehicles at both points, evening out single vehicle speed differences at the two locations. From looking at the data it is assumed that local drivers tend to speed up over Haslebakken knowing that there is an incline ahead. This speed is therefore not representative for the whole distance. Likewise, the speed at Gardeborg is too slow for what an average speed would be. Using a rolling mean compared to the mean of all vehicles is also done to comprise weather variations with time. Many tests were performed, tweaking the window for rolling mean and if both points should be used as basis for speed in the travel time calculations. A window of five vehicles was found to give a good vehicle identification between the two data sets while not giving a too long time span for possible weather change. This is especially noticeable at night when only a few trucks are registered. The calculated travel time is added to the Haslebakken timestamp and is the assumed time to arrive at Gardeborg. A time window of plus minus four minutes is added to compensate for variations. Any single vehicle registered with a timestamp at Gardeborgbakken within the time interval is automatically matched. Where more than one option is available for possible heavy vehicles, manual identification had to be made. Manually



comparing length and timestamps at the two sensors, logical identification was made. Where no logical identification could be made the heavy vehicle was removed from the data set.

<b>Registered Vehicles</b>	Nov	Dec	Jan	Feb	March	April	<b>Total</b>
Haslebakken	1184	1217	1440	1370	1520	1401	<b>8132</b>
Gardeborg	1014	1111	1044	1202	1351	1256	<b>6978</b>
Automatic matching	637	711	617	724	879	777	<b>4345</b>
After manual matching	967	1071	879	1074	1266	1183	<b>6440</b>

Table 2.1: Table of registered heavy vehicles

Due to technological differences and how vehicles are registered at the two sensor locations, it is not possible to filter out heavy vehicles based on the same properties. The filter for the weigh-in-motion sensor at Haslebakken was set to vehicles with gross weight greater than 3500 kg and more than 3 axles. The filter for the inductive loops at Gardeborbakken was set using the built in type identification. The manual did not specify how these classifications are made, but it's assumed they are length dependent. Filter was set for 8: Vogntog (truck) and 9. Semitrailer (semi-truck). Before filtering roughly 5% more vehicles are registered at Haslebakken. After filtering Haslebakken has 14% more registered heavy vehicles. Different filters were tested with axle configurations and including vehicle classification types for small trucks. However, this included the winter maintenance vehicles which often only drive parts of the section and do not fit the travel time estimates. This often lead to incorrect matchings. The filter used in this thesis reduced viable data samples for speed curve analysis, but made automation and checking of data easier in the time available. Roughly 60% of the vehicles were automatically matched and after manual crosschecking only a handful were found to be incorrect, mostly due to an overtake between the sensors. 8% of the registered vehicles at Gardeborbakken did not find a match and was removed from the data set. A total of 6440 heavy vehicles have been

matched between the two sensors creating the basis for the thesis speed curve analysis and analysing speed change with weather.

## 2.2 Test site

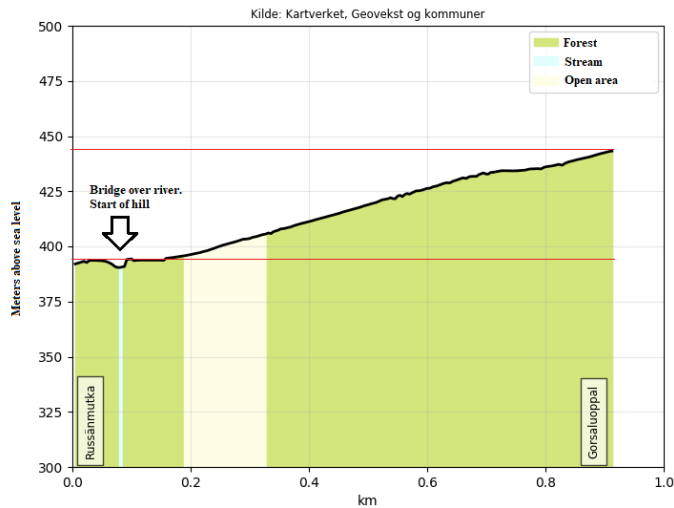


Figure 2.2: Elevation profile at Gardeborgbakken.

The main focus in this thesis has been on the uphill road at Gardeborgbakken. A 900 meter stretch with a maximum incline of 7,3%. See figure 2.1 for curvature visualisation. This section is known for being demanding during winter conditions, mainly due to braking before a sharp left turn at the beginning of the incline, depleting all momentum and making the trucks rely solely on engine power and friction to get them up safely. At this section, 31 heavy vehicle's speed was mapped manually to secure a baseline for speed profile comparisons. This was done by logging speed, altitude and position with a video data logger [27] in a personal car, following behind with adaptive cruise control (ACC) locked

on to the heavy vehicle. For most of the runs at least two people were present in the vehicle. Making observations and taking notes on times, driving (ACC mode and power utilisation) and other traffic conditions. The speed curve mapping took place over four days of driving. February 4<sup>th</sup> and 12<sup>th</sup> to 14<sup>th</sup> of March. All runs were filmed to visually assist in data control. Speed curves logged was compared against calculation models for "Estimating Speed Profiles of Heavy Vehicles in Grades" [28]. Model version 2009-03-22 by Arvid Aakre was used during this thesis. A detailed model description can be found in a SINTEF report [29], but in short, a heavy vehicle will drive up a steady incline and loose its initial speed until deceleration stops and required running power equals utilised power. This state will be the vehicles equilibrium speed,  $V_{eq}$ .

$$V_{eq} = \frac{P_{util}}{F_{climb} + F_{air} + F_{roll}} \quad (2.1)$$

$P_{util}$  = utilised power output by the vehicle.

$F_{climb}$  = climbing resistance [N]

$F_{roll}$  = rolling resistance [N]

$F_{air}$  = aerodynamic drag [N]

More on this can be found in chapter 3: "Theoretical Background".

Four cameras were set up next to the road at the two sensor locations. One tripod Sony handheld camera and one GoPro with external battery pack taped to a nearby pole was used at each location. This to secure that good footage was captured to aid in vehicle recognition and to get license plate numbers for extracting engine power statistics. These statistics can be found in a public online database on the NPRA website. However, due to many trucks having foreign registration plates and most vehicles not being filmed, speed curves have also been made with standard engine parameters set by the NPRA [30]. See figure 2.3

Tabell 2.12: Parametere som inngår i beregning av akselerasjon for vogntog (VT)

Parameter	Enhet	Verdi
Rullemotstand	-	0.015
Luftmotstand	-	0.6
Areal, front	m <sup>2</sup>	8.0
Masse	kg	40000
Motoreffekt	kW	360

Figure 2.3: Standardised Norwegian truck parameters.

In addition to the video data logger mentioned above, a hybrid cooperative ITS station was installed in the vehicle from 12<sup>th</sup> to 14<sup>th</sup> of March. Combining ITS G5 and cellular communication, the on board unit continuously sent live information in Cooperative Awareness Messages (CAM) to a cloud server. Within the CAM lies, among many things, information on the vehicles position, direction, altitude and speed which can be used to produce a speed profile and detect lower speeds than normal in an area. Similar to our own data logger, the CITS station logged all movement of our car following 27 heavy vehicles.

On March 13<sup>th</sup> Gardeborgbakken was closed for normal traffic in both directions to undergo controlled testing of the ITS equipment. A three axle winter maintenance truck had a tank filled with slurry on the open-box bed, resulting in a total gross weight of 17240 kg. The truck was to perform nine runs up the hill undergoing different tasks for each run. The ITS equipment could then be checked for detection and if correct output was shown for each run.



Figure 2.4: Test truck with weight distribution

The different runs were as follows:

Starting at bottom of hill	Test case
	<b>Bogie down on all runs</b>
11:13	Slow driving, 3 stops waiting roughly 2 min at each point 1-3
11:26	Same
11:37	Same
12:50	Slow driving, 4 stops waiting roughly 1 min at each point 1-4
13:02	20 km/h up the hill
13:08	40 km/h up the hill
13:14	Normal speed (unfortunately slowed by vehicle in front)
13:20	Normal speed
13:27	Slow driving, 4 stops, backing up 10-20 meters after each stop
13:39	Middle of the road, 20 km/h <b>down the hill</b>
13:43	Middle of the road, 20 km/h <b>up the hill</b>
13:53	20 km/h up the hill

Figure 2.5: Test case drive schedule

The main focus for several of the companies testing their technologies this day was to detect the test vehicle driving uphill and, foremost, if full stop is registered. Here only registering the stop and not necessarily why it is stopping. However, one can see the potential and possibilities from the technologies from the results during this test. To detect full stop a CITS station was installed in the test vehicle for this purpose. The other technologies are roadside infrastructures and were monitored during the test runs.

For road information a curvature analyzing program called KurvGen was loaded with FKB vector data from the Norwegian Road Data Base (NRDB). Both horizontal and vertical curvature can be calculated and visualised, figure 2.1. The resulting data of hill gradients (percentage and length) and curvature radius have been used in this thesis.

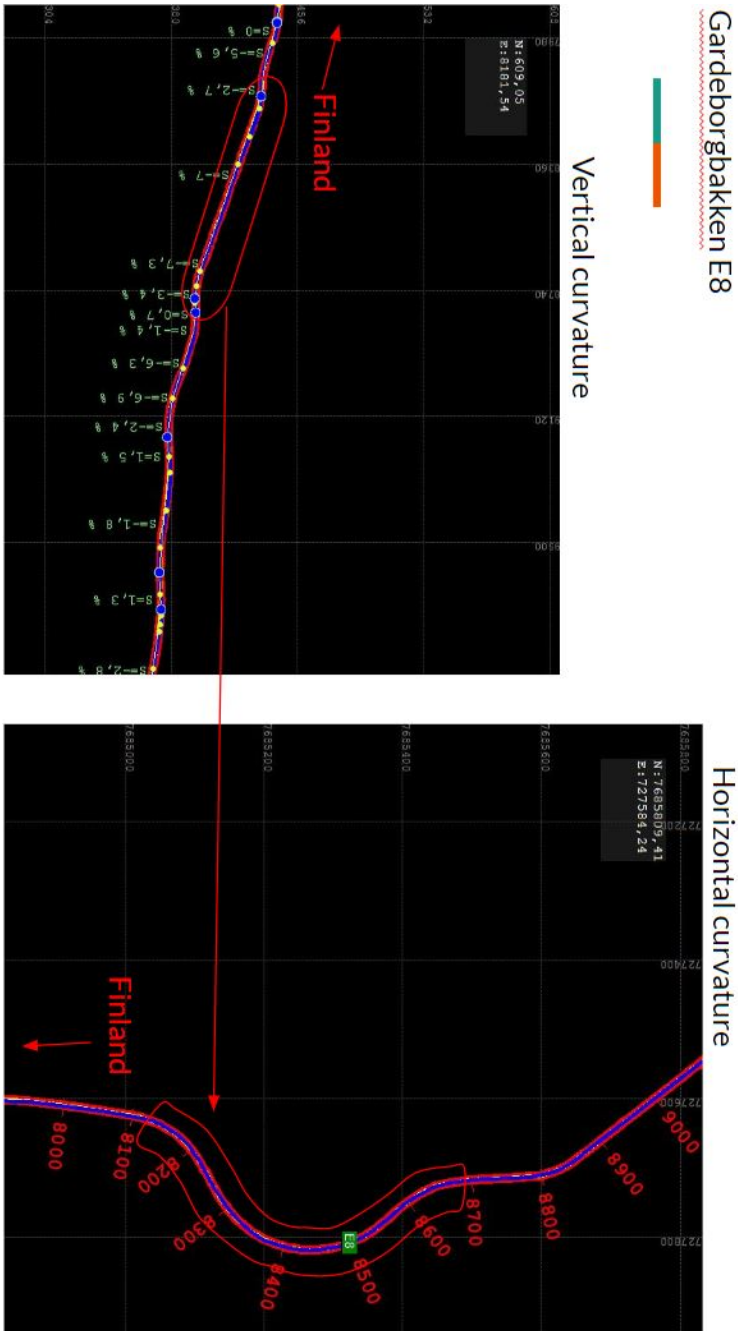


Figure 2.1: Horizontal and vertical curvature at Gardeborgbakken. Larger figures can be found in appendix C

# Chapter 3

## Theoretical Background and Technology Description

The theory for this master thesis has been gathered through research on the topic of ITS. Substantial and viable information has been found to conclude that ITS will be important to secure a safer and more efficient infrastructure while reducing the environmental footprint of the transport sector as a whole. Technical specifications of these technologies have also been gathered through interviews and communication with the companies and use of company website.

This chapter will give a more detailed theory description of the three R&D technologies tested during this thesis.

1. Mathematical speed profile model.
2. LiDAR.
3. In-roadway magnetic detectors.
4. C-ITS.

DAS was not available for testing during this thesis and therefore not ex-

plained further. The first section explains the physical laws and equations behind the mathematically modelled speed profile used for evaluation. WIM, induction loops and weather stations will not be described further than the short description given in chapter 1, section 1.2.1. This is due to the sensors being well-known industry standards for the past twenty years and are not the main focus of this thesis.

### **3.1 Speed Profile**

The theory behind the model used to validate logged speed profiles, is in principal based on natural laws. It has been shown to fit well with real life situations of heavy vehicles in grades even though it simplifies and does not include all parameters that would normally affect a vehicle while driving. Following equations is inspired from Automotive Handbook[31] and the paper where the speed profile model was created[28].



First and foremost, the interest of the speed profile is to identify equilibrium speed,  $V_{eq}$ , where utilized power by the vehicle is equal to power needed to overcome running resistance.

$$v_{eq} = \frac{P_{util}}{F_{climb} + F_{air} + F_{roll}} \quad (3.1)$$

Running resistance is the sum of all forces working in opposite direction of the forward movement:

$$F_{run} = F_{climb} + F_{roll} + F_{air} \quad (3.2)$$

where,

$F_{climb}$  = climbing resistance [N]

$F_{roll}$  = rolling resistance [N]

$F_{air}$  = aerodynamic drag [N]

$$F_{climb} = m * g * \sin \alpha \quad (3.3)$$

approximated to:

$$F_{climb} \approx m * g * 0.01 * s_i \quad (3.4)$$

for gradient  $s_i \leq 20\%$ , giving an error of less than 2%. [m] mass of vehicle in kg.

$$F_{roll} = f_r * m * g * \cos \alpha \quad \left| \angle \alpha \right. \quad (3.5)$$

$f_r$  = rolling resistance coefficient [dimensionless]

$m$  = mass of vehicle [kg]

$$F_{air} = 0.5 * \rho * c_w * A * (v + v_0)^2 \quad (3.6)$$

$\rho$  = air density [ $kg/m^3$ ]

$c_w$  = drag coefficient [dimensionless]

$A$  = front area of vehicle [ $m^2$ ]

$v$  = vehicle speed [m/s]

$v_0$  = headwind speed [m/s]

Power needed to overcome total rolling resistance is then:

$$P_{run} = F_{run} * v \iff P_{run} = (F_{climb} + F_{roll} + F_{air}) * v \quad (3.7)$$

With resulting power unit in Watt [W]

Maximum engine power output available from the engine to drive the wheels,  $P_{max}$  given in [kW], will be reduced by power transmission losses. The grade of utilised power by the vehicle can be described as:

$$P_{util} = P_{max} * u \quad (3.8)$$

$u$  = degree of utilisation of max engine power[%]

Utilised power will further be consumed in overcoming the power needed for total rolling resistance. If  $P_{util} > P_{roll}$  the surplus will accelerate the vehicle. Or decelerate if  $P_{util} < P_{run}$ . If  $P_{util} = P_{run}$  acceleration will be zero and a constant speed is reached. Equilibrium speed,  $v_{eq}$ . This brings us back to our first equation 3.1:

$$\begin{aligned} P_{util} &= P_{run} \\ \iff P_{util} &= F_{run} * v \\ \iff P_{util} &= (F_{climb} + F_{roll} + F_{air}) * v \\ \iff v_{eq} &= \frac{P_{util}}{F_{climb} + F_{roll} + F_{air}} \quad \square \end{aligned}$$

## 3.2 LiDAR

The light detection and ranging technology (LiDAR) uses continuous laser light pulses at a 905nm wavelength. The pulses are sent from sensor emitters with different angles to illuminate an area for desired mapping and detection. The laser light is bounced off objects, returned and registered in the sensor by a multi-channel receiver. Based on time-of-flight between emitter and receiver, distance to the object can be calculated with cm precision.

$$d = \frac{C * t}{2} \quad (3.9)$$

$d$  = distance [m]

$C$  = speed of light [m/s]

$t$  = time to and from object [s]

The division by two accounts for time being to and from object. With millions of pulses being sent every second a huge data sample is collected for signal processing. Using data filters for mitigation of interference and nuisance signals from environmental conditions, such as snow, rain, dust etc, a high quality detection and ranging can be achieved. Further configurations can be made to define how much reflection is needed to be classified as a relevant object, and machine learning is also utilised to recognise certain objects such as heavy vehicles, pedestrians or wildlife. Machine learning is thought to be the best solution for quickly discarding background images to focus on the relevant object, so called "object specific focus-of-attention mechanism" [32]. When an object is detected and classified, distance, position and speed is sent to a server. Here specific configurations for each ITS sensor location can be set. At Gardeborbakken slow moving traffic has recently been changed to 12km/h and needs to be kept for a certain time period before it is reported. Stop is reported when object has not moved for 10 seconds. The LiDAR sensors

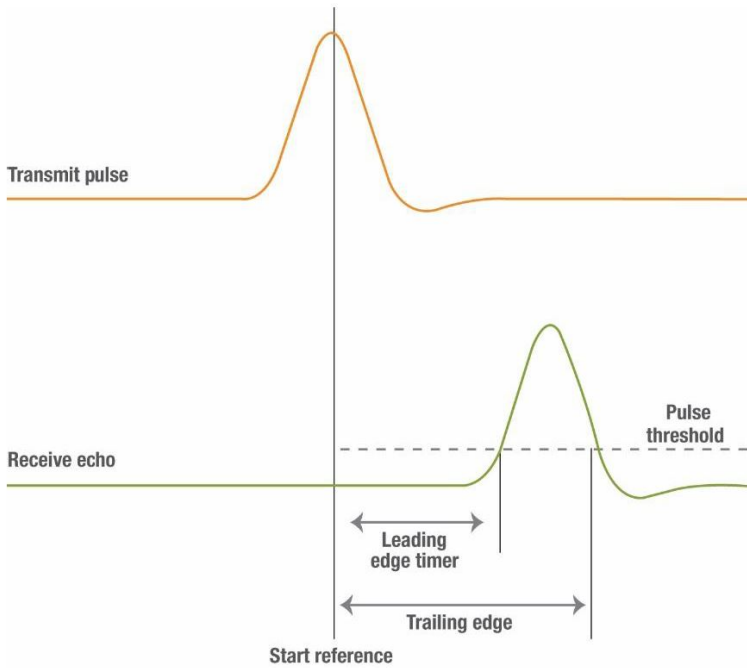


Figure 3.1: Light pulse and echo.

also include a camera that starts recording whenever an event is reported. A timeline of events with graphical interface of the video footage is saved and simplifies human interaction when validating reports.

The ITS-Perception LiDAR sensor has been developed in Quebec with year round rigorous testing. Filters have been implemented where pulses hitting snow crystals will be filtered out since the next pulse does not hit the same point. Using the 905nm wavelength also reduces absorption by water compared to other LiDAR wavelengths. The overall picture will be weaker with heavy rain or snowfall reducing amount of pulses able to be used for analysis, but for recognition of vehicles this is not reported as an issue [33].

### 3.3 In-roadway magnetic detector

The in-roadway magnetic detector, also known as a magnetometer, is a single self contained unit with a diameter of 110mm and height of 75mm. The sensor is a 3-axis magnetometer measuring the magnitude and direction of the earth's magnetic field. Any changes in height, width or length of the magnetic field by a metal mass, moving or stationary, is referenced around the sensors X, Y and Z axis, figure 3.3. The sensors are calibrated to the normal ambient magnetic conditions upon installation and any anomaly is sent via short range radio waves to a base station. The sample frequency is the most important factor determining the lifespan of the built in lithium

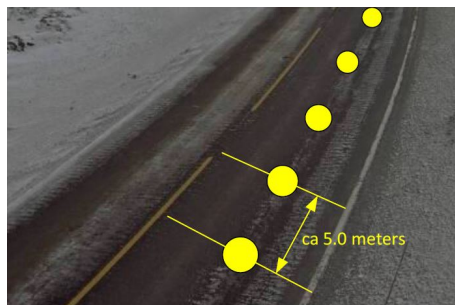


Figure 3.2: Sensor unit and sensor positions in middle of uphill lane.

battery. During this thesis, sample rate was set at 1Hz giving an expected operational lifetime of 10 years. Setting a higher sample rate will increase detection probability, but reduce battery life. As an example: A 12 meter truck driving 50km/h  $\rightarrow$  14m/s will be above a single point of the road surface for  $\frac{12}{14}$  seconds = 0.86 seconds. To reliably detect the vehicle a sensor would need to have a sample rate higher than this. However, for the test site 120 sensors are installed in a line every five meters and every sensor does not need to detect the vehicle. Vehicles able to drive above 50km/h up the hill is also not a concern. Each sensor is unsyn-

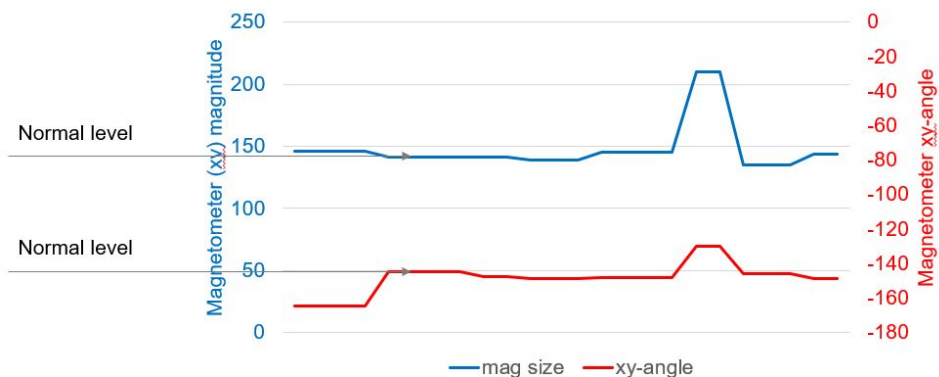


Figure 3.3: Change in magnetic field from passing vehicle.

chronised and each will operate independent of each other. The base station time stamps each input to reduce clock errors and sends data to a cloud server. Here all data is analysed and presented in a combined map and image based interface showing occupied sensors and an image of the vehicle. The technology is robust and able to detect vehicles all year round. Long cold winters will however shorten the battery life. The sensors themselves are drilled 20mm below the road surface and filled with epoxy glue, figure 3.4, to hinder being taken by snow plows.

Literature review on the technology found only a limited amount of related studies. With none having tested a similar set up. Most studies are of single sensors for vehicle detection at signalised intersections or rail-road crossings. Showing that the most common cause of error among magnetometers at multi-lane stop zones are false-positive registrations from vehicles in adjacent lanes. In a study from Newmark Civil Engineering Laboratory at the University of Illinois it was found that this false call error increased during winter conditions. Being 7.6% in favourable weather to 15.4% during winter [34]. Magnetometers placed in advance zones prior to stop lights have reported missed registrations as most frequent error, being up to 9.7% in all weather conditions. Mostly due to traffic driving between the lanes or motorcycles not being registered [34]. ARRB Consulting and La Trobe University have done tests on magneto-

meter lifespans. Estimating the useful battery life to be about 10 years with traffic volumes at 3,500 veh/h. This study was done with favourable weather conditions in Australia [35].

There has not been found any studies relating to increased registration errors with increased snow or ice cover. The winter maintenance class DkC for this road section (page 7 in the Introduction chapter) limits the allowed buildup of thick snow and ice cover, however it will be interesting to see if any registration changes can be noted in upcoming winters with changes in cover thickness. It will also be interesting to see a battery life evaluation from the sensors daily battery status messages during the next couple of years.

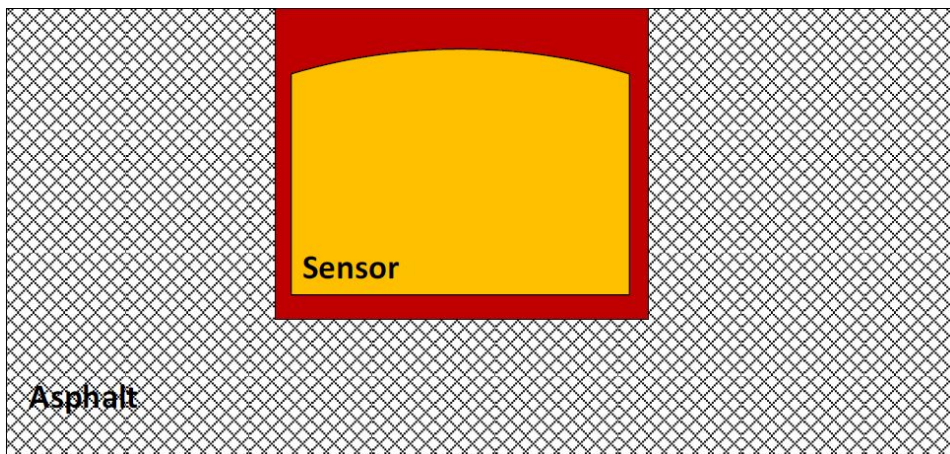


Figure 3.4: Magnetometer within the asphalt and filled with epoxy glue (red).

### 3.4 C-ITS

Cooperative ITS is a service to provide an ad hoc network between online road entities; vehicles-to-vehicles, V2V, and vehicles-to-infrastructure, V2I. The service will provide dynamic exchange of messages between the entities and secure that accurate information is given to the correct users. Mobile

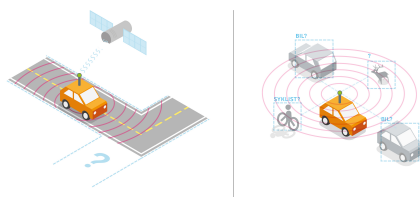


Figure 3.5: C-ITS communication network.

C-ITS stations will in the future be integrated in vehicles to gather information of speed, position, height etc to the cloud where analysis can be made. A hybrid communication platform is used, using cellular towers and wireless short range communications (ITS-G5). ITS-G5 skips the need for a coordinated wired network, sending data packets over multiple hops between the online entities. Data is sent on behalf of each other among the entities, extending the communication range and decreasing latency. Enabling road infrastructure or even vehicles themselves to send information of a slippery road surface to vehicles further down the road. European standards [36] have already been set in place to secure interoperability between technology providers, GPS-position accuracy, end-to-end latency etc. Having cross boarder standards is essential so that vehicles can communicate across national borders.



# Chapter 4

## Results

The key objective for the thesis was to discover and examine new ITS-technologies implemented on the E8 test site and if they are able to be used for speed curve analysis and coinciding reduction in mobility. A preliminary study of weather and traffic data was conducted with the goal to find patterns correlating speed and weather. A basis for speed profile assimilation was manually done using a video logger following heavy vehicles. A controlled test was held on 13<sup>th</sup> of March for testing the ITS-technologies mentioned. A heavy vehicle drove controlled runs at the test site and data from the different technologies have been analysed.

The chapter is split in six sections to systematically structure the results:

- Section 1 - Details the results from the preliminary study of conventional sensor data, WIM, induction loops and weather stations.
- Section 2 - Shows the results from the adaptive cruise control test.
- Section 3 - details the results from the manually logged speed pro-

files and sets up a basis for speed curve analysis with the mathematically modelled speed profile.

- Section 4 - Results from Aventis C-ITS systems.
- Section 5 - Results from Q-frees in-roadway detection sensors.
- Section 6 - Results from ITS-Perceptions LiDAR sensor.

## 4.1 Preliminary study

Climate data from the road weather station, located close to the traffic registration point at Gardeborgbakken, was collected for the period November 2018 to April 2019. The climate data contains 20 different weather parameters updated on 10 minute intervals. Parameters used in this thesis for speed evaluation are: temperature, precipitation, visibility, wind direction and speed, ice and snow cover on road and road surface friction.

Data from matched vehicles at the WIM sensor, Haslebakken, and induction loops, Gardeborgbakken, was collected from November 2018 to April 2019. Daily mean vehicle speed has been calculated for heavy vehicles driving the 18.5 km stretch Haslebakken to Gardeborgbakken. The speed is calculated as distance divided by time. With time being derived from the vehicles matched timestamps at the two sensor locations. Traffic volume is defined as the daily number of heavy vehicles that was registered and matched at both traffic registration stations. Note that only trucks with four plus axles were included in the data as mentioned in section 2.1.

See figure 4.1 and 4.2 for February and March results. Speed and traffic volume from WIM and induction loop sensors is located in top two plots followed by weather station data plots. All months have been plotted and

can be found in appendix B.

From figure 4.1 we get the results for February 2019. The three red lines indicate days of high precipitation and we can observe a clear reduction in speed during the same days. The lines of high precipitation also show reduced visibility and increased snow cover. Highest friction coincide with the days of lowest snow cover and we also find the highest speed values during these days. However, one can also observe that speed fluctuates slightly even when parameters like friction and precipitation are more stable. The fluctuations can be seen throughout all months and are most likely due to the low traffic volume, with as low as ten vehicles registered in the weekends. Each single vehicle will then have a greater impact on the average speed. During work days around 50 heavy vehicles are registered and we can observe smaller fluctuations in speed during these days. The low speed shown with a red circle corresponds with a traffic volume of 50 veh/day, but no weather data explains this speed reduction.

If we look at figure 4.2 for March 2019 we find speed, friction and snow cover to be concurrent with each other. Other observations include:

- Speeds average around 70-75km/h in November and April and dips down to 65km/h in January, February. This coincides well with snow and ice road surface cover.
- The build up of snow show a greater reduction on speed than ice cover.
- During the test period a low friction level combined with precipitation and snow cover significantly reduce speed. Whereas speed can be seen to increase again when snow cover reduces and there is no precipitation even though friction levels remain constant at a low level.

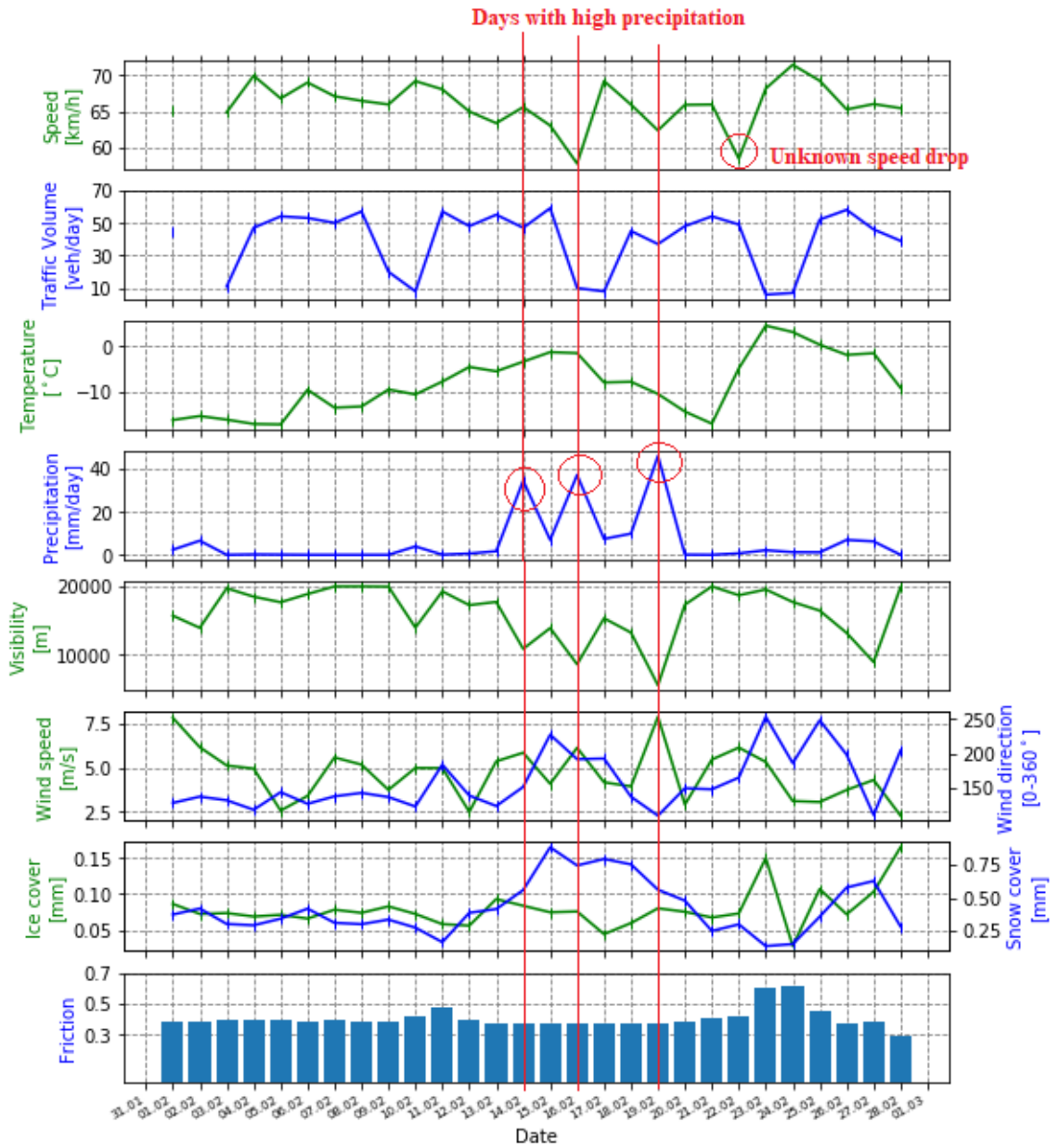


Figure 4.1: Mean daily values for Gardeborgbakken, February 2019

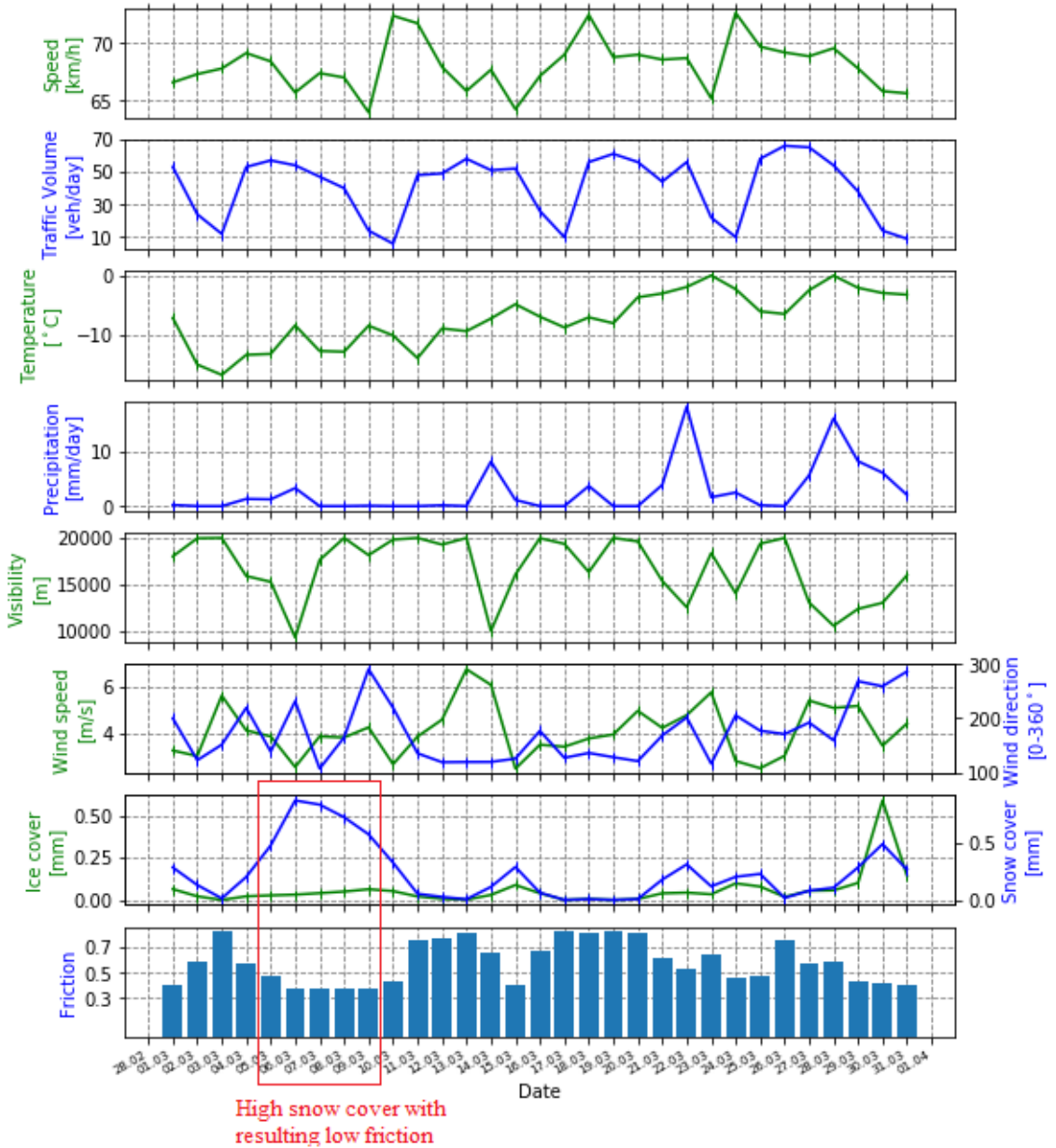


Figure 4.2: Mean daily values for Gardeborgbakken, March 2019

- Highest speeds are all observed during weekends.
- Wind speeds were all within moderate levels and visibility good during the test period. Neither had an effect on speed levels.
- Build up of ice cover does not influence friction values to the same extent as snow cover.

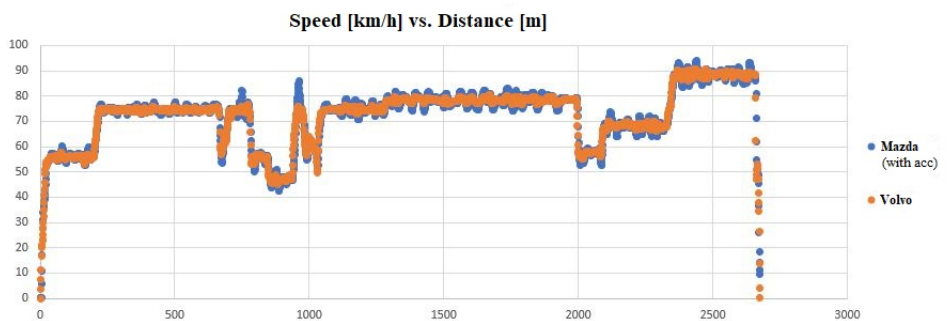
## Conclusions

The following conclusions could be made from the preliminary study of traffic and weather data during the test period November 2018 - April 2019.

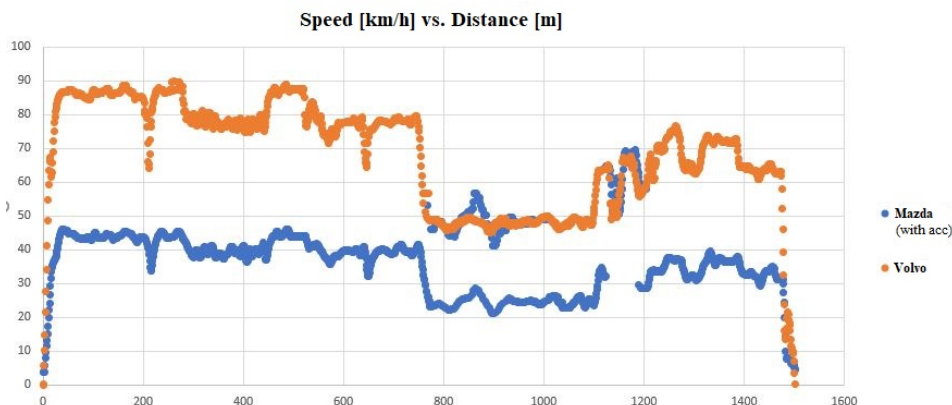
- Speed is foremost affected by road climate changes that are visible to the driver. Firstly snow cover and then precipitation having the greatest impact.
- Build up of ice cover show less effect on both speed and friction values than was anticipated.
- Low friction values alone, without precipitation nor snow cover, showed little effect on speed values. These findings are in accordance to previous observations [37][38]. It should however be noted, that these studies did not use a parameter for road surface snow cover, and therefore have a greater low friction/high speed observation than in this report. Most likely due to snow cover being a visible aid to the driver of low friction values.

## 4.2 Adaptive Cruise Control

On the 13<sup>th</sup> of March a test was done to evaluate the vehicles adaptive cruise control (ACC). Vehicle used was a Mazda 6 rental car mon-



(a) Speed comparison Haslebakken to Finnish border



(b) Speed comparison Nordkjosbotn to Haslebakken

Figure 4.3: ACC speed comparison. Mazda with ACC following Volvo

itored with an Aveni C-ITS station and video logger. The controlled drive was conducted following another personal vehicle, Volvo, also monitored with a separate Aveni C-ITS station. Communication between the vehicles was done via two-way radios. The test route was 78km from Nordkjosbotn to the Finnish border along E8, lasting roughly one hour. The route consisted of several road variations with tight curves, long straight stretches and varying grades. Comparing the positions of each vehicle every second a distance interval would be found in which the ACC drives at different speeds. Evaluating speeds each second would also show the ACCs ability to follow at an even rate. The speed comparison between the two

vehicles, Mazda with ACC following behind Volvo, was split into two sections due to a stop at Haslebakken. This resulted in an interesting speed being logged during the second run, figure 4.3b. Similar curves are noticed, but with the following vehicle, Mazda, having half the speed. Some gaps are also found in the data where speed jumps to being the same as Volvo. This is noted as a C-ITS error and not relevant for the results of the ACC test. The video logger registered similar speeds as the Volvo. An error free data sample can be seen in figure 4.3a representing the first section of the test run, Nordkjosbotn to Haslebakken. Larger spikes are noticed from the following vehicle with ACC than from leading vehicle. Especially where large acceleration/deceleration is made by the leading vehicle.

The distance between vehicles with ACC activated differs depending on the vehicle speed, the faster the vehicle speed, the longer the spatial distance. Mazda 6 has four ACC levels: long, medium, short and extremely short. Distance between vehicle guideline from the manufacturer is, in order as above, at 80km/h: 50, 40, 30 and 25 meters. The "3 second" rule normal amongst Norwegian drivers would at 80km/h equal 67 meters. ACC mode short was used during the test study. Figure 4.4 shows the normal distribution curve of the following vehicles speed with ACC mode short. Vehicle leading was driving with cruise control set to 80km/h on a 8km stretch with few curves.



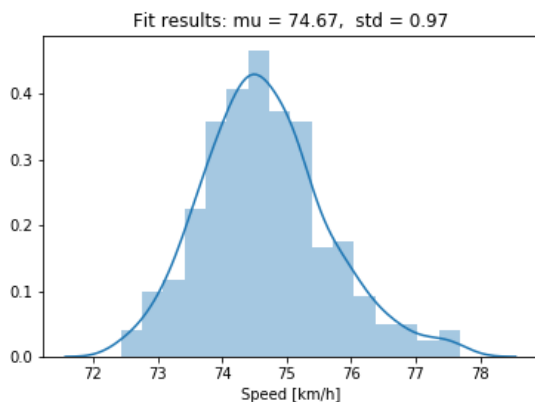


Figure 4.4: Normal distribution of speed with ACC mode short. Leading vehicle with set cruise control at 80km/h.

## Conclusions

As seen in the normal distribution, figure 4.4, ACC is a good tool for following the speed of the vehicle in front. At a steady speed of leading vehicle, speed was maintained with a standard deviation of 1 km/h. However, it is seen and felt when driving that ACC can fluctuate speeds at times. Especially with heavy acceleration/deceleration of vehicle in front or in tight curves. This is taken into consideration when analysing speed profiles.

## 4.3 Basis for speed curve analysis

The basis for the thesis speed profile analysis is derived from in situ observations from heavy vehicles driving up Gardeborgbakken. Following behind with adaptive cruise control, a video logger and GPS [27] collected continuous data along the route. 31 runs were done in

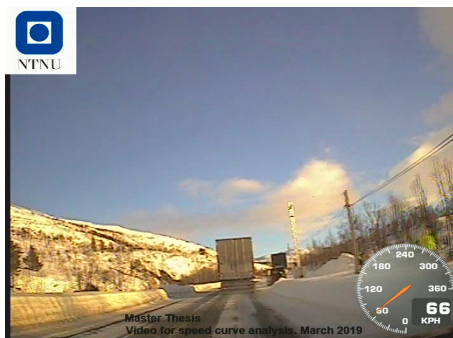


Figure 4.5: Video footage following a heavy vehicle.

total with 28 showing viable results.

Weight of each vehicle was gathered from the Weigh-in-Motion sensor at Haslebakken. One vehicle did not have its weight registered. Vehicle recognition plate numbers were found from video footage by four cameras set up next to the road. As anticipated, only a few Norwegian registration plates were found. It should also be noted that the Sony cameras did not have good enough focus to read the plates and the GoPro cameras died midday on two of the days due to cold temperatures. This resulted in six registered Norwegian plates used to find engine statistics. From these six, three of the heavy vehicles were also registered with the video logger.

Time	Length [m]	Gross Weight [kg]	Max engine power [kW]	Weight to power ratio [kg/kW]
12.03.2019 10:01	17.36	22030	405	54.395
12.03.2019 10:35	20.77	26020	478	54.435
12.03.2019 12:26	17.82	39800	382	104.188
12.03.2019 14:10	25.90	61040	537	113.669
12.03.2019 14:26	16.81	40570	405	100.173
13.03.2019 09:33	8.76	17240	368	46.848

Table 4.1: Heavy vehicles registered with weight and engine power.

Collectively the input data and information used for speed curve analysis in this thesis includes:

- Road curvature. Vertical used for calculation. Horizontal for analysis.
- Road and traffic conditions. Used in analysis.
- Observed vehicle power utilisation. Used in calculation model.
- Vehicle speed. Logged 20 times a second by GPS. Raw data was shrunk to every second for graphical analysis.
- Positioning by UTM coordinates and elevation. Elevation is mapped against speed in speed profiles. Coordinates used as index key to display several speed profiles on each graph for comparison.

- Vehicle gross weight. Used in calculation model.
- Max engine power. Used in calculation model.
- Weather data. Used for calculating model parameters.

For the calculated speed profile model, used as a comparison in this thesis, several coefficients have been used based on previous studies[37] and from the Automotive Handbook[31]. They have not been altered to suit the test site as it is not the main focus of this thesis. However, where possible, situational parameter changes have been made. The hill is split into five subsections starting at the bridge below Gardeborgbakken. Length and grade for each subsection,  $i$ , found using KurvGen (see 2.1). End speed calculated at each subsection is the start speed for the next.

Parameters set in the calculation model include:

- Air density, based on weather data and elevation at Gardeborgbakken,  $\rho = 1.26 \text{ kg/m}^3$ .
- Front area of truck. Norwegian standard,  $A = 8 \text{ m}^2$ .
- Rolling resistance coefficient,  $f_r = 0.015$ .
- Air resistance coefficient,  $C_w = 0.60$ .
- Maximum acceleration at low speed,  $a = 3 \text{ m/s}^2$ .
- Wind speed, zero.
- Power utilization set to 95(%) at highest section grades. 90(%) used on remaining subsections.
- Initial speed, changed according to vehicles being compared. Mean point speed found at bridge.
- Length and grade of subsection,  $l_i [m], s_i [\%]$ .

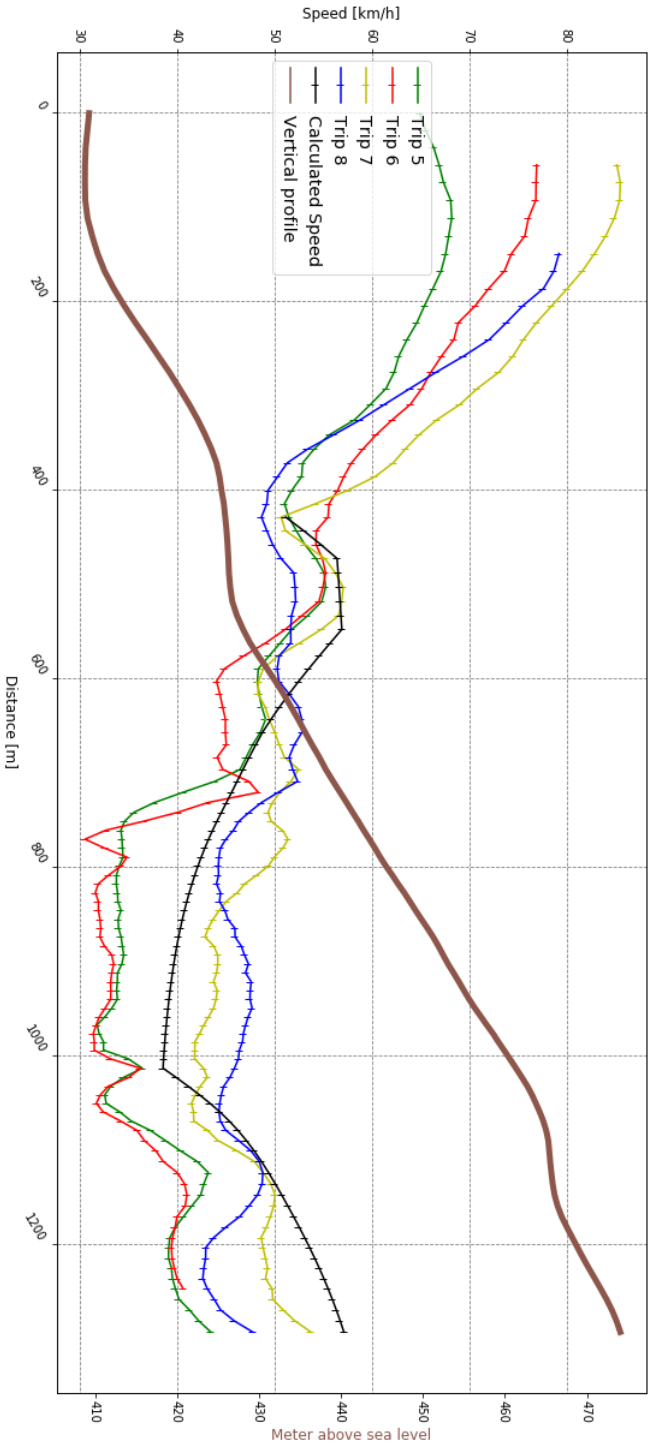


Figure 4.6: Logged speed profiles for vehicles 5 to 8 against a calculated speed profile of a heavy vehicle with Norwegian set standard[30]. Vehicle 5 and 6 were heavy, above 50000kg. Vehicle 7: 40000kg. Vehicle 8: 25000kg.

Figure 4.6 shows the speed curves from heavy vehicle number five to eight on the 12<sup>th</sup> of March. A modelled speed profile is also included. The model is set to Norwegian standards for heavy trucks with gross weight 40000kg and engine output 360kW; resulting in a weight to power ratio of 111.10kg/kW.

The first two vehicles 5 and 6 were heavy, weighing 52080kg and 61040kg respectively. Vehicle 7 and 8 weigh 40570kg and 24220kg respectively. Weight to power ratio is only available for vehicle 6 and 7, having 113.67kg/kW and 100.17kg/kW respectively.

It is evident that the model falls between the two heavy and the two lighter vehicles. The model does not take into account horizontal curvature and gear use which is most likely the cause for the speed drops at around 700m distance. Here Gardeborgbakken goes from a 200m radius left turn to a 160m radius right turn. The model was not calculated for the subsection grade at m1200 and should be disregarded. The spikes seen from vehicle 6 around distance 700 is an adaptive cruise control error where the following vehicle lost contact, accelerated and then applied the brakes shortly afterwards when contact was established. This is noted and can be seen in the video footage. The spike at m1000 is believed to be gear change when approaching the top of the hill. Equilibrium speed is reached at 32km/h for the two heavy vehicles and at 45km/h for the lighter vehicles. Equilibrium speed for the heavy vehicles is low given that road friction had a mean of 0.7 during this time period. The model, even with standard parameters and the mentioned drawbacks, seem to fit well with the vehicles linearity.

From the plots of all logged vehicles it was noted that the heaviest vehicles reach very low equilibrium speeds just above 30km/h, even with road friction values at 0.6 and 0.7 on the logged days. To further look into the

ID	Time	Length [m]	Gross Weight [kg]
Trip 5	12.03.2019 10:23	16.39	52080
Trip 6	12.03.2019 14:10	25.90	61040
Trip 16	13.03.2019 13:53	16.67	55710
Trip 19	14.03.2019 11:44	16.54	58110
Trip 20	14.03.2019 12:11	17.26	49930
Trip 22	14.03.2019 12:56	17.74	50000

Table 4.2: Heavy vehicles registered with weight greater than or equal to 50000kg

equilibrium speed of these vehicles, a data set was made consisting of vehicles with gross weight  $\geq 50000\text{kg}$ , see figure 4.7 and table 4.2. The calculated speed model for this graph was set for mean weight of all six vehicles, 54478kg, and mean engine power output, 450kW. Resulting in a weight to power ratio of 121kg/kW. The result indicates that equilibrium speed lies between 30-35km/h for heavy vehicles  $\geq 50000\text{kg}$ , with one falling slightly below 30km/h and two just above 40km/h. The vehicles with  $v_{eq} = 40\text{km/h}$  are noted to also be the lightest of the six.

## Conclusions

Vehicle six and seven were noted to be refrigerator vehicles and the salmon transport on this section should most likely fall under the speed profiles in figure 4.7 of the six heaviest vehicles. The fact that four of the heaviest vehicles have almost identical equilibrium speeds with road friction values between 0.6 and 0.7 on the respective days indicate that equilibrium speeds falling below 30km/h and low friction values could be set as trigger values for an alert system.

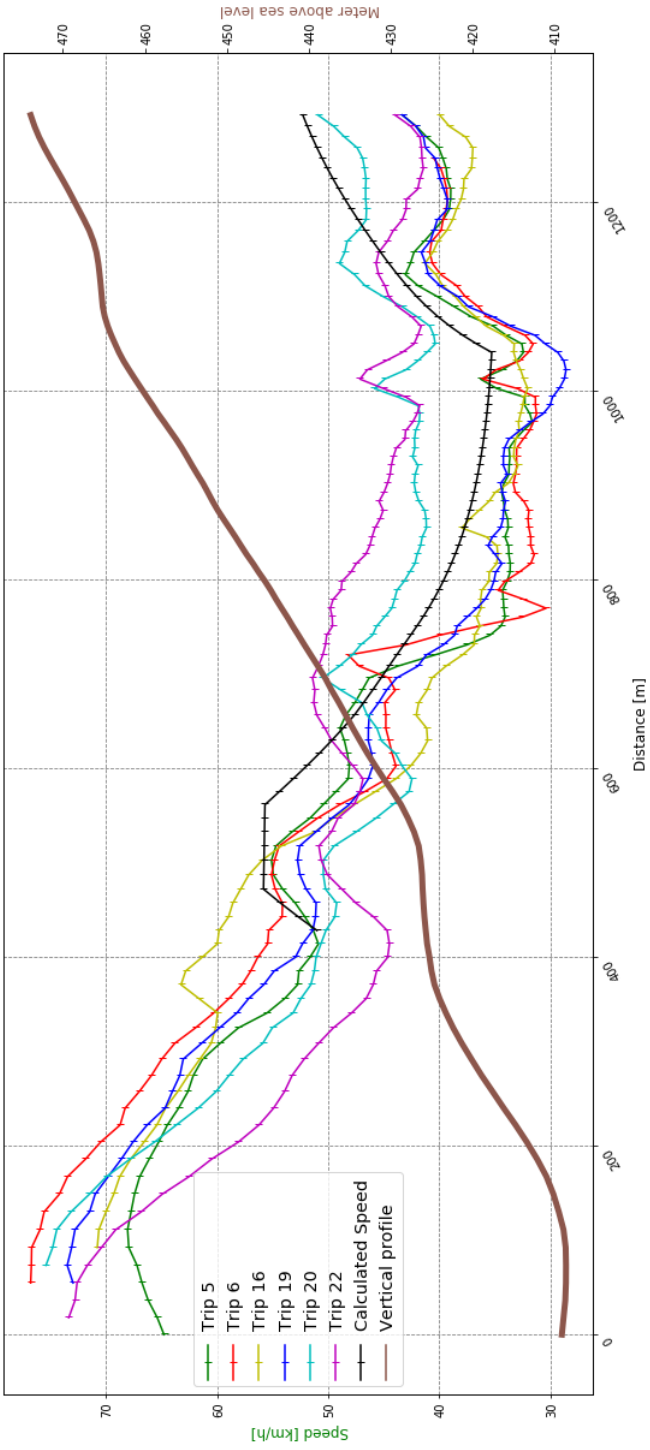


Figure 4.7: Logged speed profiles for vehicles  $\geq 50000\text{ kg}$  against calculated speed model with mean weight and power ratio of the six heavy vehicles.

## 4.4 C-ITS

The C-ITS station uses similar technology as the video VBOX PRO logger that is used as basis for speed profiles. The C-ITS station used in this thesis included a more accurate GPS and advanced technical specifications than the logger. So in theory the C-ITS station should have similar speed profiles.



Figure 4.8: Video logger and C-ITS equipment inside the vehicle during test runs.

### Conclusions

Figure 4.9 shows the resulting speed profile following heavy vehicle number six, also seen in figure 4.7 on p.51. Here the C-ITS data from the same run is compared to the VBOX data resulting in an almost exact copy. Similar results were found on the other speed profiles.



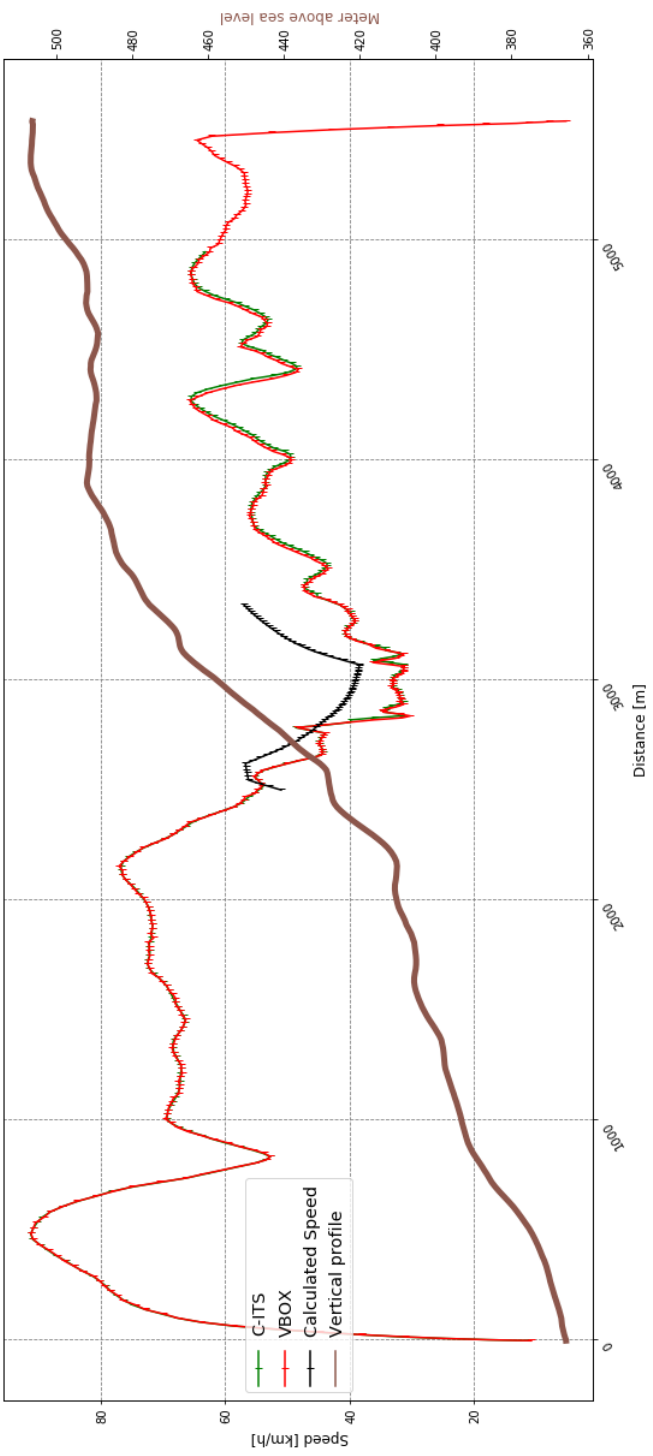


Figure 4.9: Comparing Aventi C-ITS (green) and VBOX (red) speed profiles. Test site, Gardeborgbakken, represented by calculated speed profiles set for Norwegian standard heavy vehicle.

## 4.5 In-roadway magnetic detector

Due to delayed installations, testing and operations of the system the sensors were not online until the test week in march. The raw data retrieved by the company during this week, needed further filtering and tuning and has therefore not been available during this thesis work. The company estimated a four month delay on the data handling. Some results from the test week have been given and can be seen on the right. Figure 4.10 show that the in-roadway detection sensors were active and sending information of passing vehicles overhead. Number of messages sent vary, meaning that the sensors have not registered the same amount of passages. This is reported to be a tuning error and will be fixed. Figure 4.11 show sensor ID as function of time. Higher sensor IDs are activated as the vehicle drives up the hill. Further tuning and filtering is also required here for a good representation.

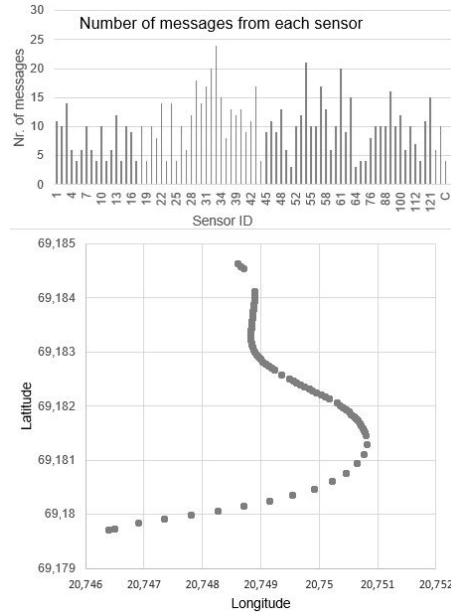


Figure 4.10: Data received from the sensors during test runs.

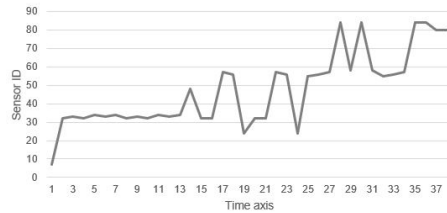


Figure 4.11: Vehicle driving up the hill.

Figure 4.12 show a geographical representation of the vehicle during the 20km/h test drive with three full stops. Here sensors that have been "on" for a longer period are shown as a cluster of sensors indicating that a vehicle has stopped. Due to delayed installations the last section of the road was installed with a spacing between sensors of 20 meters, compared to five meters further down the hill. This is the reason why only two sensors were active at the last full stop shown in bottom right of figure.

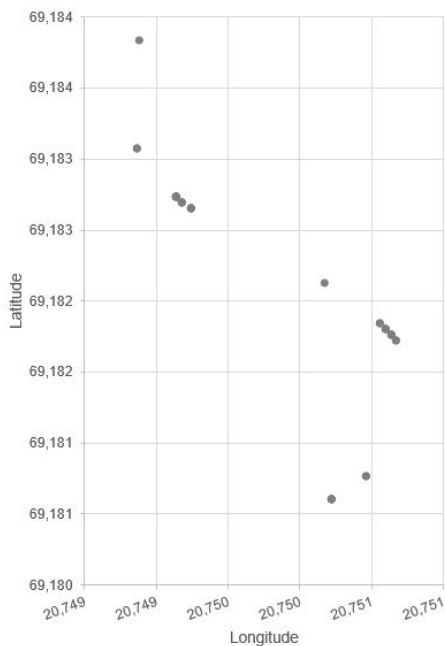


Figure 4.12: Geographical representation of full stop.

## Conclusions

The results from the in-roadway detection sensors at this time, are not enough to make viable conclusions for the technology to be used in a speed profile analysis. However, the results do show that a real time indication of a vehicles speed profile is possible and more so to indicate full stop. It should be of interest to further pursue this technology in future studies to investigate its potential for detection of reduced mobility.

## 4.6 LiDAR

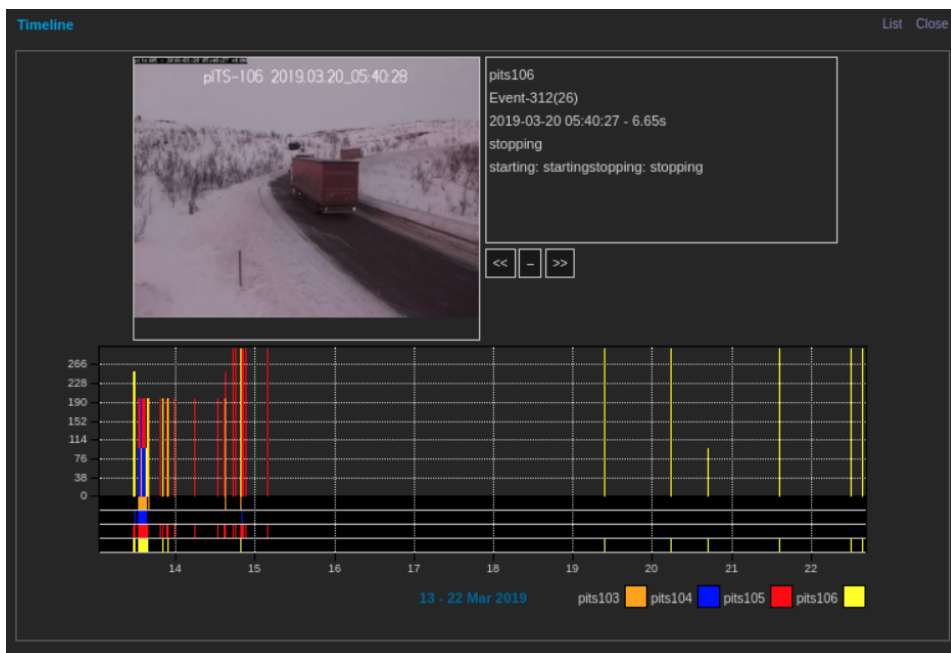


Figure 4.13: Events at Gardeborgbakken 13<sup>th</sup> to 23<sup>rd</sup> of March. Nr. 103 and 105 indicate sensor at top of the hill. 104 and 106 bottom of hill sensor

The LiDAR equipment has been online during the winter 2019 and several events of slow or stopped traffic have been reported during this time. Figure 4.13 shows a visual presentation of these events. During the days of testing at Gardeborgbakken on the 13<sup>th</sup> and 14<sup>th</sup> of March all passing vehicles were logged. After these dates only events classified as slow moving or stopped were logged. A camera is turned on when events are triggered and examining the event from 20<sup>th</sup> of March we see a heavy vehicle having trouble at 05:40 in the morning. The following text shows that the vehicle came to a complete stop, then slowly starting to move again, followed by another complete stop. The alerts triggered around 20<sup>th</sup> to 23<sup>rd</sup> of March coincide with days of precipitation and reduction

in road surface friction.

Examining the data from the test runs with the drive schedule, figure 2.5 we see how the different test runs were classified by the LiDAR equipment. At 13:02 a slow drive of 20km/h was started and the resulting LiDAR output can be seen in figure 4.14.

Lidar position	Time	Cause
Lower	03/13 13:02:47	passing
Lower	03/13 13:03:03	stopping
Lower	03/13 13:03:23	starting
Lower	03/13 13:03:31	stopping
Upper	03/13 13:04:12	passing

Figure 4.14: Driving 20km/h.

From the LiDAR positioned at the bottom of the hill ("lower"), the test truck was categorised as starting-stopping-starting until being registered by the LiDAR at the top of the hill ("upper") as passing. Slow traffic is registered as continuous, short start-stops, which is also found during the other test runs driving slowly, including 40km/h. At normal speed, 60km/h, the truck was registered as passing.

The way slow driving is registered made it difficult to pinpoint the test runs of slow driving with 4 one minute stops. Using the schedule and seeing that each stop should last roughly one minute the results are seen in figure 4.15. Similar results were found in the other test runs with full stop.

Lidar position	Time	Cause
Lower	03/13 12:53:11	passing
Lower	03/13 12:54:45	starting
Lower	03/13 12:54:57	stopping
Upper	03/13 12:55:41	passing
Upper	03/13 12:55:55	stopping
Upper	03/13 12:56:57	starting

Figure 4.15: Slow driving, with 4 one minute stops.

## Conclusions

The LiDAR sensors at this time in Gardeborgbakken can not be used to represent speed profiles. Further instalments of sensors would need to be made along the route to be able to track the vehicle the whole way. However, the reason for a speed profile analysis in this thesis is to detect

trends of reduced mobility. The LiDAR equipment has shown its ability to detect full stop and slow moving traffic, though it will not be able to show reduction in equilibrium speed. Installing a third LiDAR in the middle of the hill and having the one at top pointing down with a narrow scope, should, in theory, make it possible to detect when equilibrium speed is met. Another possibility could be to monitor speed between m800 and m1000 as seen in the speed profile plots, e.g. figure 4.7, representing the area to likely find equilibrium speeds. Further case studies should be made on this topic since the use of LiDAR as a multipurpose ITS sensor show great potential.

# Chapter 5

## Conclusions, Discussion, and Recommendations for Further Work

### 5.1 Conclusions

In this master thesis speed profile analysis has been brought forward as a potential parameter for detection of reduced mobility among heavy vehicles in grades. Analysis of weather and traffic data showed that speed levels decreased significantly with precipitation and reduced road surface friction at the test site in northern Norway. It was also noticed that speeds decrease only slightly when there is no visual aids that would indicate lower friction. A friction reduction decreased equilibrium speed where the vehicles deceleration is zero and utilised power output is equal to power output needed to overcome all running resistance. Having logged 31 heavy vehicles a baseline for equilibrium speed was established. Using this baseline in monitoring of speed profiles, trends of lower equilibrium speeds with low road surface friction values can be used to trigger

alert systems for winter maintenance personnel, traffic management and other oncoming traffic.

Having set a baseline for speed profiles, three ITS technologies recently installed at the test site were used to check if they also could be used for monitoring of speed profiles. These included:

1. C-ITS platform by Aventi.
2. In-roadway magnetic detector by Q-free.
3. LiDAR sensors by ITS-Perception.

The C-ITS data showed very promising results for being used as a monitoring system for reduced mobility. The results from generated speed profiles were almost identical copies of the baseline used as comparison, and equilibrium speeds were easily identifiable. A C-ITS on-board unit needs to be installed in every vehicle for this to have good results. It does however not succumb to weather and climate errors.

The In-roadway magnetic detectors did not have enough data at this time to conclude if the technology can be used for speed profile monitoring. However, the few results found do indicate that it will be possible. Further investigation is advised. In theory, the technology is suited for detection of reduced mobility if good vehicle detection is assured. More studies need to be done focusing on false and missed registration errors with winter conditions and build of snow cover on road surface. This should be done with several magnetometers in a line (along the traffic lane) to detect errors on the whole system, not by single sensors. Battery life needs to be closely monitored at test site during the next couple of years.

The LiDAR results from winter 2019 have been good for detection of stopped vehicles and slow moving traffic. The sensors installed at the test site at this time are not enough to produce speed profiles and identify equi-



librium speeds, however more sensors are planned. From the results found this season, LiDAR equipment has shown to be a viable ITS solution for detection of reduced mobility. Including a third sensor along the roadside, more secure trekking of the vehicles can be made to also secure speed profiles. A more detailed study is advised to pinpoint area of equivalent speed. Speed monitoring on this section could secure better predictions on reduced mobility due to friction loss.

## 5.2 Discussion

Probe vehicle data from C-ITS on-board units show good results, however this data will only gain quality with increased network of vehicles. Before a large fleet of vehicles are installed with these units and proper cellular 4G coverage is built on rural roads, other sensors will need to be used for speed profile analysis.

No concluding results can be given on any of the ITS technologies, but a good indication has been shown on their abilities and further research is recommended. One could then discuss a cost analysis on the whole life cycle of the sensors. Installation, operation and maintenance costs and disposal. Initial costs of the magnetometers might be low, but removing 120 sensors drilled into the asphalt can be costly. Installing these at other sites would also require an analysis of the asphalt layers life span. Not installing sensors where a new resurfacing is due shortly after.

Data collection for the speed profile base line was collected using detailed observations and accurate logging technology from a following vehicle. The measured speed profile will contain some irregularities depending on human driver behaviour. Their knowledge of the area, gear use, rpm and if they notice that a vehicle is monitoring them from behind. Waiting on the side of the road and driving up behind can cause

suspicion and changed driving behaviour. However, this will also have an effect on probed vehicle data. Further influences are power utilisation, engine specifications and ACC accuracy. A larger data collection will minimise these irregularities. A statistical analysis of the data should then also be done. This was not done during this thesis due to the low data samples.

The data collected for preliminary study can also be discussed. Using two different sensor technologies for matching vehicles registered at the two locations. Both sensors report a vehicle length error of  $\pm 0.5$  meters. However, it was noticed that the Kistler vehicle length data was consistently higher with roughly 0.5 meters. This deviation on length also questions the accuracy of speed measured at the two sites. The speed measured was the key parameter for matching heavy vehicles and some miss matches are likely when several trucks arrived at the same time with similar length. Due to the low AADT this is likely a small number, but should be considered in future studies or at other test sites.

Further refinement should also be considered regarding heavy vehicle classifications for speed profile analysis. The WIM sensor at Haslebakken and the inductive loops at Gardeborg both use different classifications making matching difficult. For this thesis and further studies a classification on weight to power ratio could make it easier to define a more narrow focus group and for sensors to use as metadata when registering low speeds.

### **5.3 Recommendations for Further Work**

Further testing of the ITS equipment covered in this thesis is needed to secure a proper understanding of all technologies and their ability to se-

cure a safer transportation network in a cost-effective way. Requiring intensive testing and mapping before full scale implementation is possible.

More data for a speed profile base line should be gathered. Looking at variations on equilibrium speed throughout the year and varying road friction. To minimise manual labour, heavy vehicles from the salmon transport could be probed for GPS data.

A study on the distributed acoustic sensing also installed at the test site, but not used in this thesis, should be checked for its ability to monitor vehicles and their speeds. This technology has shown promising results from tests done in Bergen, Norway.

Future test studies should be made on the in-roadway magnetic detectors with manual counting of traffic to properly detect errors of false and missed registrations. Further testing of these sensors should also look into quality of registrations with increased ice and snow cover.

The LiDAR sensors should be tested during more adverse weather than what was registered during this thesis. Adverse weather situations being most important for correct sensor registrations. Also here a manual count of traffic should be made to detect false, missed or incorrectly assigned object classification. For the LiDAR sensor to monitor a specific region of the hill for equilibrium speed trends could be of interest. Defining this section from a larger base line sample as mentioned above.

Further research on C-ITS should include tests of speed profiles being automatically generated and monitored, sending alerts to other heavy vehicles and dynamic message signs upon reducing trends.

The recommendations may be classified as:

- Short-term: Manual traffic counting to find detection errors. Gather

probe vehicle data from salmon transport. Research study on the DAS installed at the test site.

- Medium-term: Looking at data results from adverse weather and snow cover build up.
- Long-term: Communication and monitoring of data from a fleet of vehicles with C-ITS on-board units.

# Appendix A

## Acronyms

Following acronyms and abbreviations are gathered from ITS Terminology, Terms and Definitions (<http://www.its-terminology.com>).

**AADT-HV** Average Annual Daily Traffic - Heavy Vehicles

**AADT** Average Annual Daily Traffic

**ACC** Adaptive Cruise Control

**C-ITS** Cooperative Intelligent Transport System

**DAS** Distributed Acoustic Sensing

**DMS** Dynamic Message Sign

**GPS** Global Positioning System

**I2C** Infrastructure to Cloud

**I2V** Infrastructure to Vehicle

**ITS** Intelligent Transport System

**NPRA** Norwegian Public Road Administration, aka Statens Vegvesen

**NRDB** Norwegian RoadDataBase

**NTP** Norways national transport plan

**NVDB** Norges VegDataBank

**V2V** Vehicle to Vehicle

**WIM** Weigh in Motion

# **Appendix B**

## **Mean daily value reports**

Following plots are for mean daily weather and speed values, and heavy vehicle traffic volumes at Gardeborgbakken used for analysis in this thesis. One plot for each month, November-April.

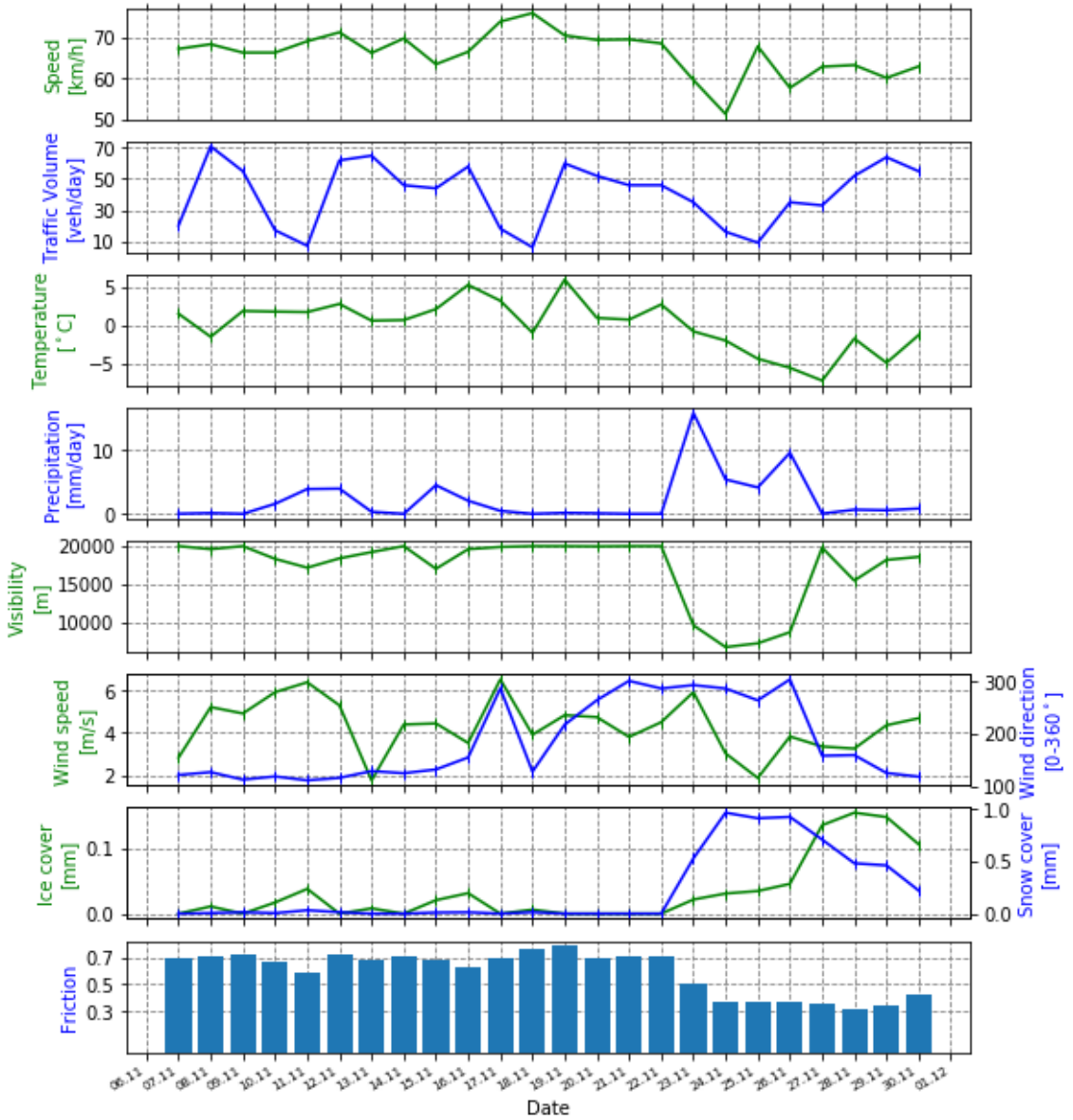


Figure B.1: Mean daily values for Gardeborgbakken, November 2018



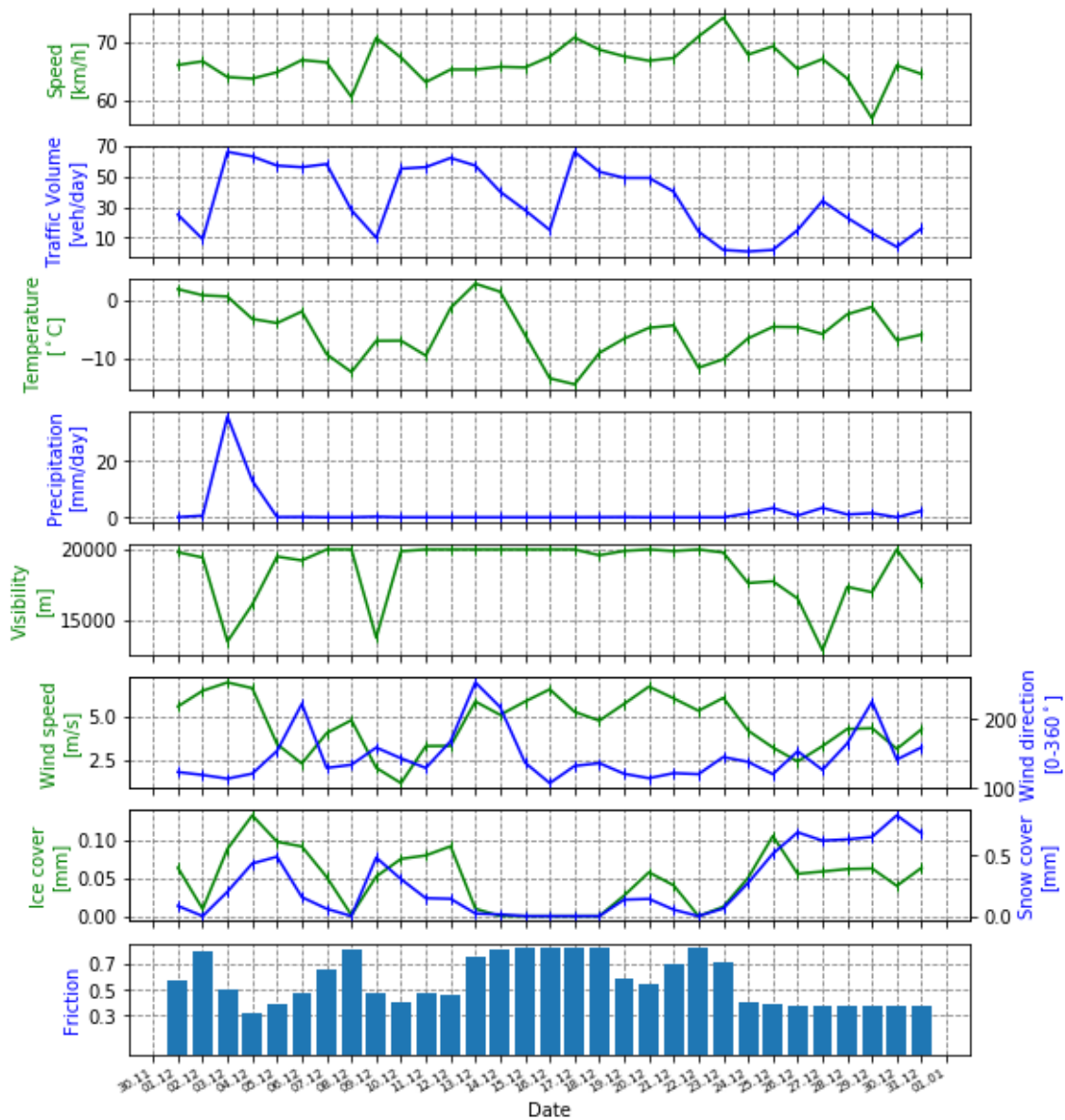


Figure B.2: Mean daily values for Gardeborgbakken, December 2018

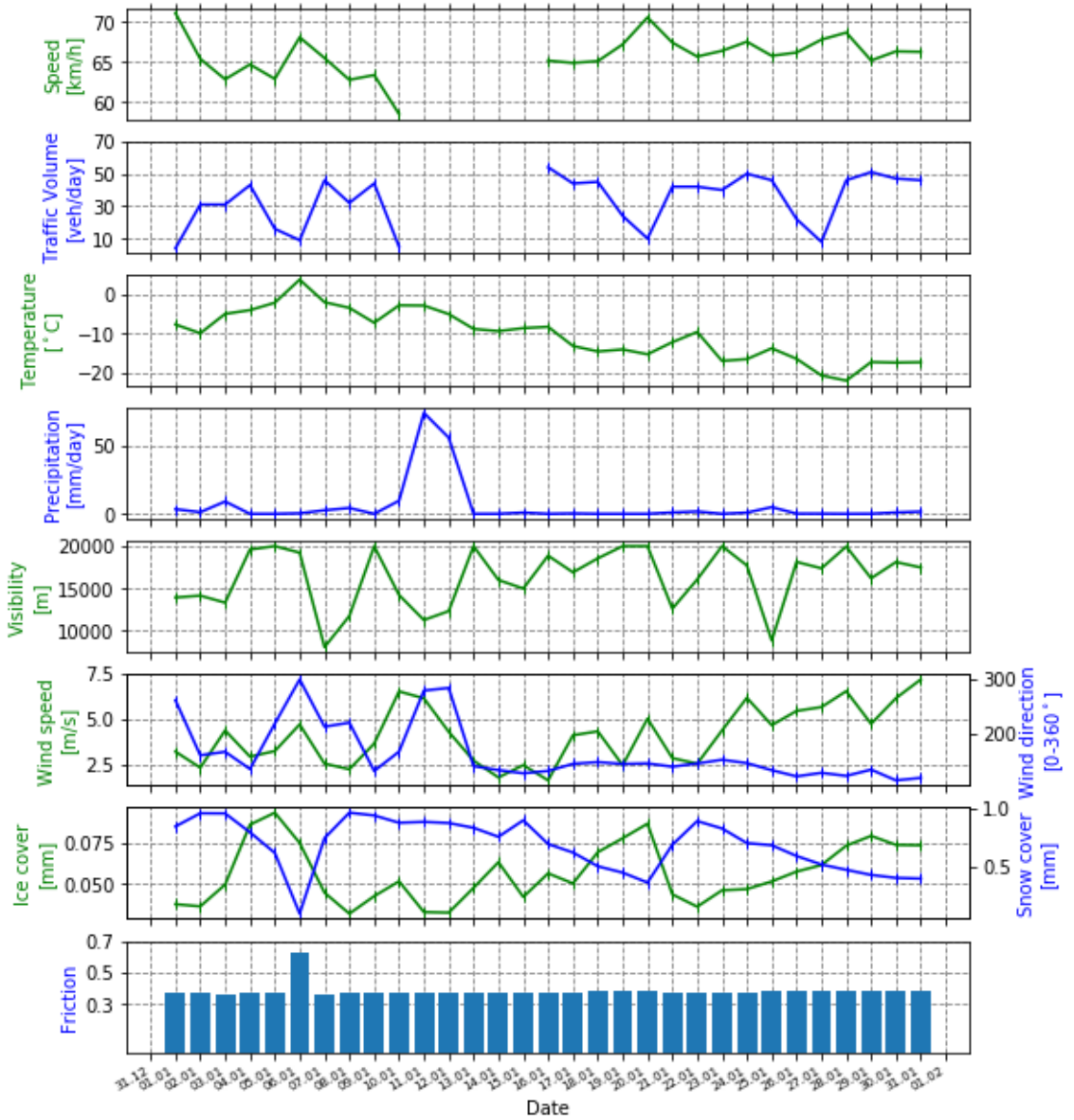


Figure B.3: Mean daily values for Gardeborgbakken, January 2019

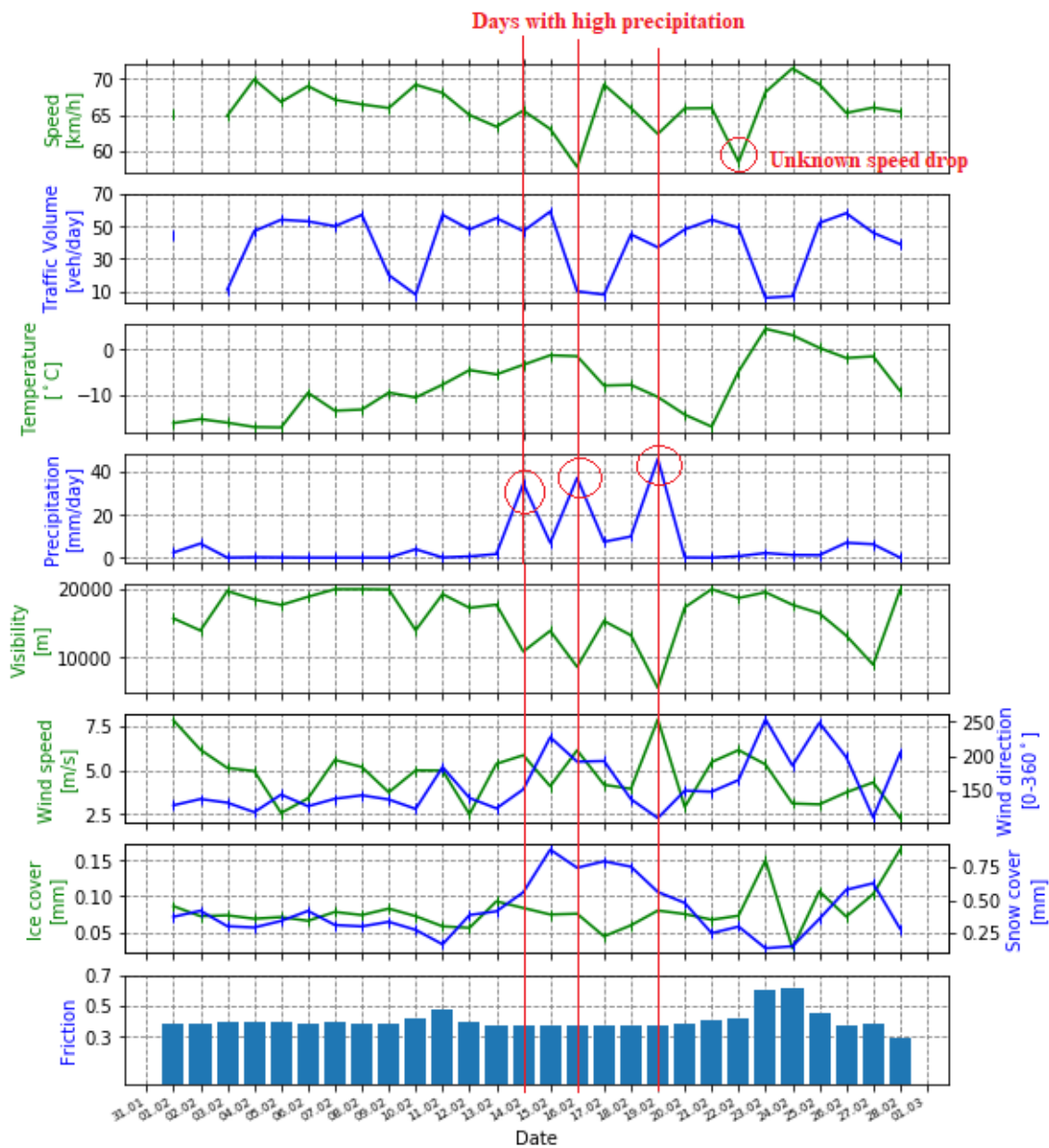


Figure B.4: Mean daily values for Gardeborgbakken, February 2019

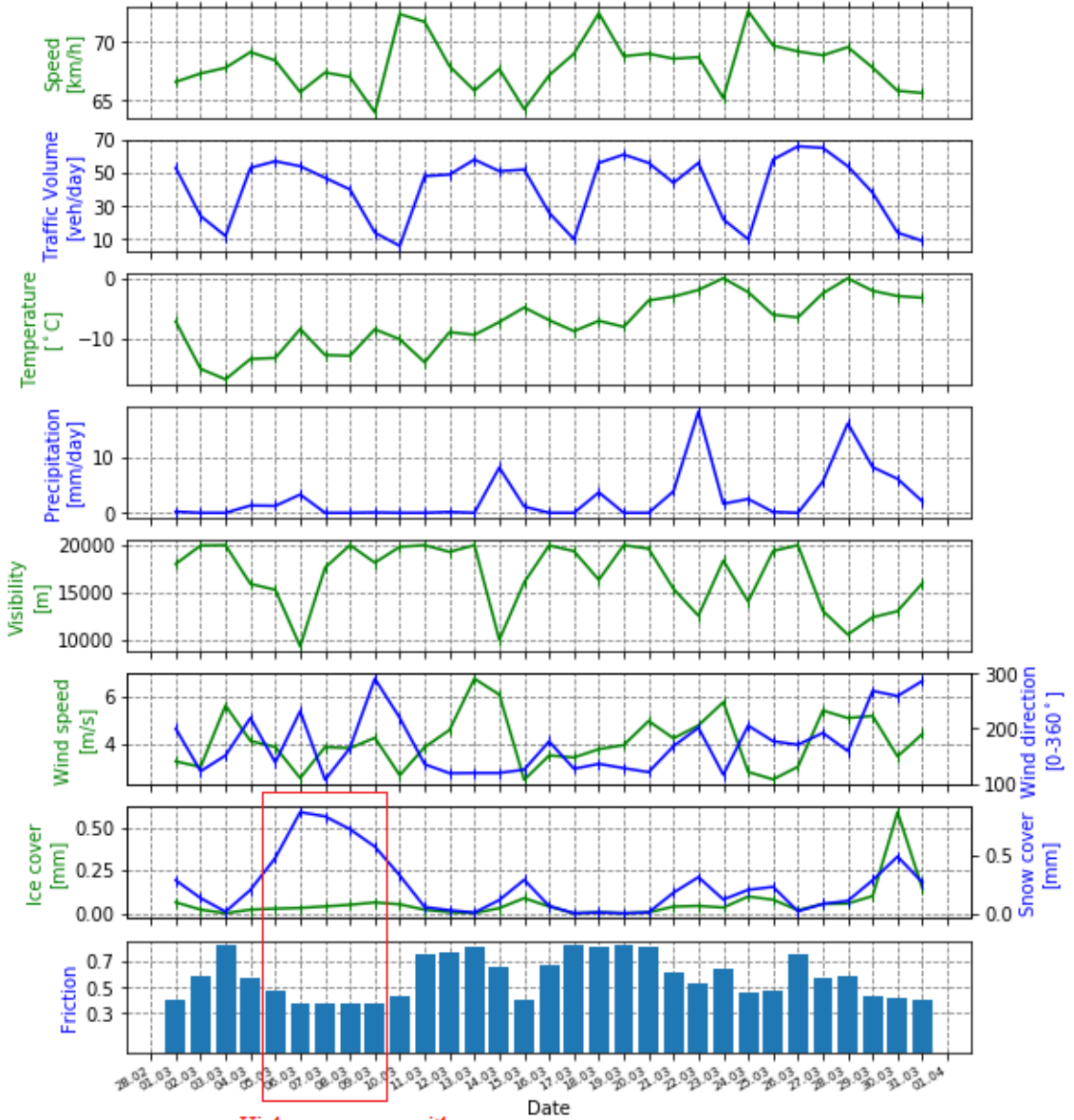


Figure B.5: Mean daily values for Gardeborgbakken, March 2019

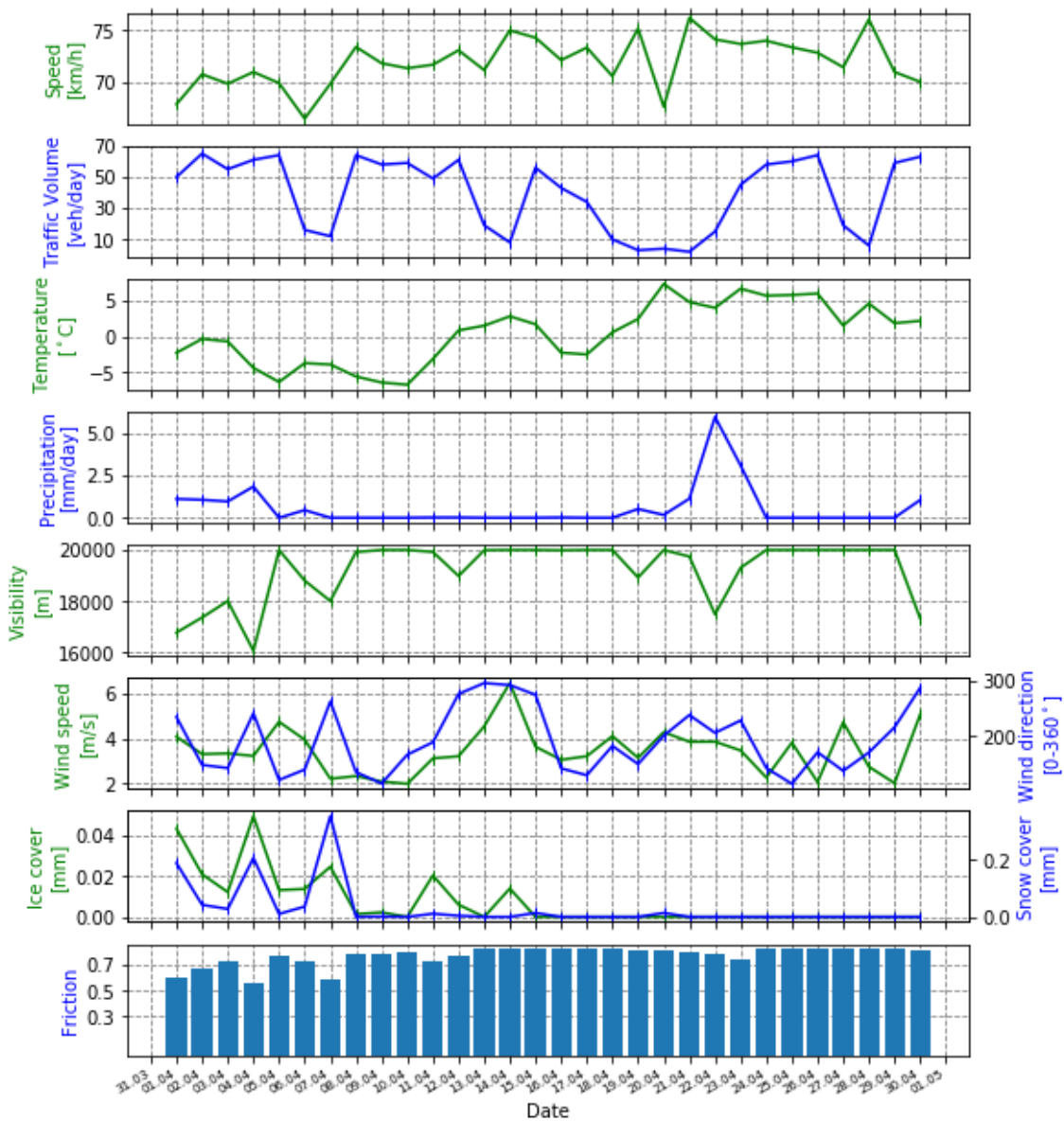


Figure B.6: Mean daily values for Gardeborgbakken, April 2019



# **Appendix C**

## **Curvature at Gardeborgbakken**

Following figures are of the horisontal and vertical curvature at Gardeborgbakken.

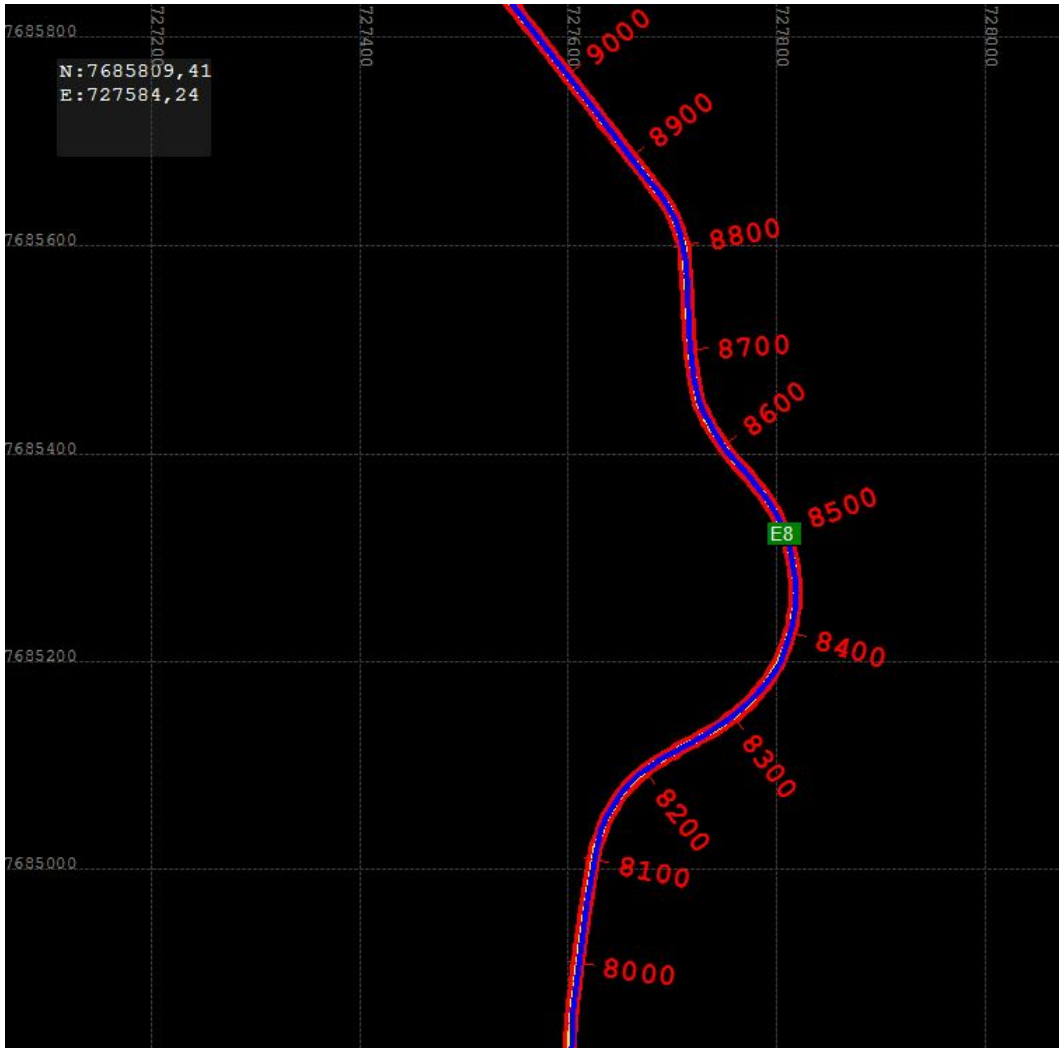


Figure C.1: Horizontal curvature at Gardeborgbakken



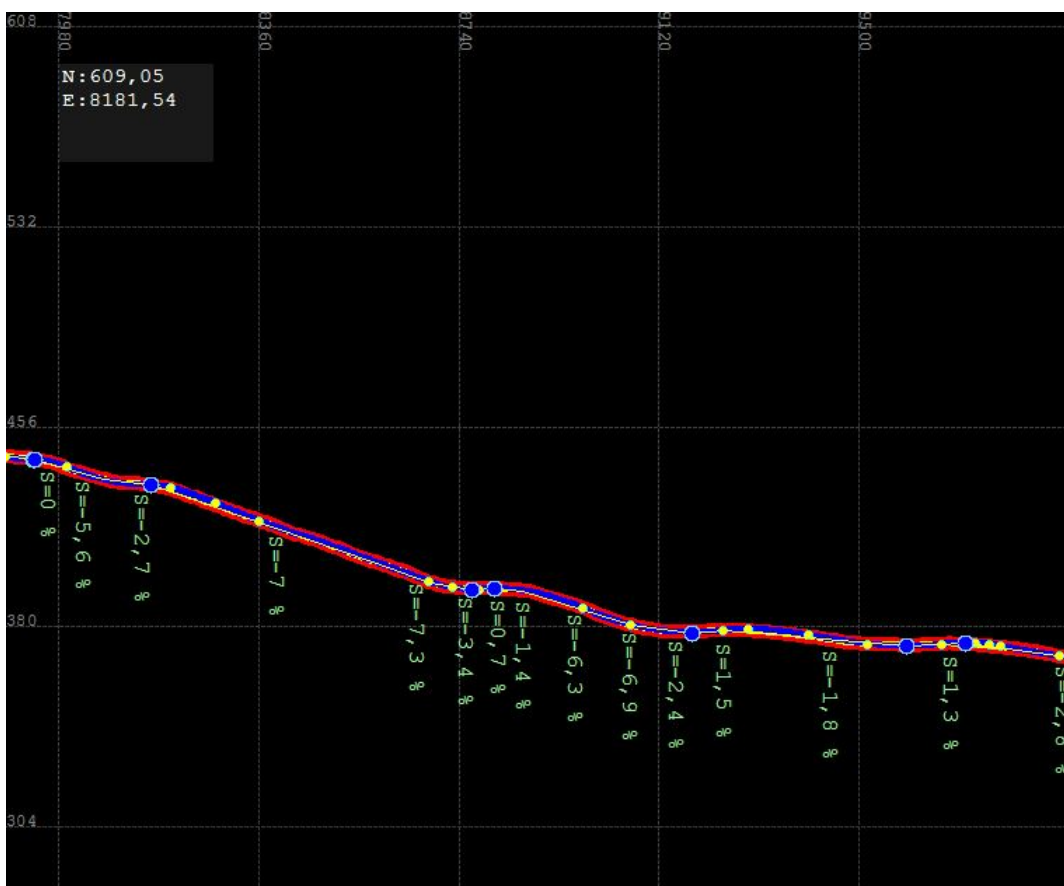


Figure C.2: Vertical curvature at Gardeborgbakken



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