Norwegian Pilot 2

A6 Evaluation and final report

NordicWay 2

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Nordic WAY 2

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Content

LIST OF ABBREVIATIONS

NRA – National Road Authorities

OEM – Original Equipment Manufacturer (Car maker)

PMB - Project Management Board

ADAS - Advanced driver-assistance systems

RSRP – Reference Signal Received Power

RSRQ – Reference Signal Received Quality

UE – User Equipment

NKOM - The Norwegian Communications Authority

IMU - Inertial Measurement Unit

CAN – Controller Area Network – one of the vehicle's internal communication networks

1 Introduction

1.1 Readiness for automation – questions to be answered

The NPRA believes that automation will support our main goals:

- Simplify travelling and increased competitiveness for industry
- Better value for money
- Effective use of technology
- Vision zero
- Contribute to fulfill Norway's climate and environment targets

Research projects in the field of automation have been conducted around the world. Many of the projects focus on highway operation of automated systems and are tested on the arterial and trunk road networks. The Nordics have some interesting additional challenges compared to mainland Europe. Weather is a challenge that is mentioned quite a lot, snow and ice creates unique challenges. The Finnish pilot has investigated the winter challenges. But god weather conditions may also prove to be challenging in the Nordics. A common trait of the road network in the arctic region is low traffic volumes and single carriageway roads. Building new high capacity roads is not an option as the cost benefit will be too weak for financing. This in turn means that there is a need to understand the state of the infrastructure today. But which infrastructure?

The NPRA have completed several projects that has focused on ITS technologies and the fundamental needs of these systems (Smartere vegtrafikk med ITS (SmITS) 2012-2017 n.d.). One result of this research program was the identification of services needed in addition to traditional road infrastructure.

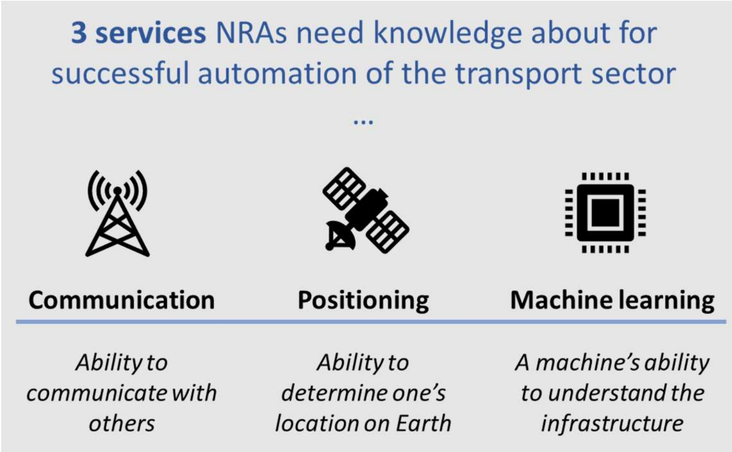

Figure 1 3 services needed for automation

It should be noted that the research effort is conducted to reach the goal the politicians set in the national transport plan. And of the future goals of the national transport plan is the automation of the transport sector.

The three additional services in addition to traditional road technology are:

- **Communication** – having the ability to communicate with other vehicles or infrastructure (two-way). The focus has been on the ability to send and receive messages based on use cases that are relevant for NRAs. This can be anything from transmitting the location of stopped vehicles, slow moving road works or to the state of signalized intersections.
- **Positioning** – having the ability to find one's location on the earth's surface and digital descriptions of infrastructure objects. GNSS has been the most prominent technique for finding the location in the transport sector, due to cost and availability to equipment.
- **Machine learning** – using computer vision or local sensor systems to understand the world around a vehicle. NRAs have little influence over the algorithms, but they may have a responsibility for making sure that roadside objects are readable.

For NRAs to create high quality standards that serve the road users well there is need to understand the current state. The aim of the Norwegian Pilot 2 (A6) is to discover the state of the traditional infrastructure and the "new" services that must be available to achieve automation.

During the project the idea of the NordicTour was born. The original plan was to use the trunk road network in Norway to produce knowledge about the state of the infrastructure. But the topic of border crossing issues and possible roaming issues lingered in the back. The physical lane marking in the Nordics also differ, the difference is hardly noticeable for the human as we quickly adapt to different color schemes on signs and lane marking. But do state of the art ADAS systems understand these differences? Extending the data collection to include Norway, Denmark, Sweden and Finland was not a considerable cost. The largest cost was in the setup of the systems for data logging and processing. Hence in agreement with the project management board the Norwegian data collection was extended to cover the main routes between the capitals of the 4 nations. All costs were covered by the Norwegian Pilot 2.

The method to be applied to study readiness for automation was to map the state of the services. Some of the data is hard to get access to. The only way to get reliable data out of a vehicle is to have a cooperation with the OEM. The OEMs have also begun to think about the three core services for automation, and there was a need to have a research collaboration with the OEM. A joint research contract was awarded to Volvo Cars, both for vehicle data and access to researchers and engineers to conduct the mapping expedition. In addition to data collection, a set of tools was setup to analyze the data - the

Trantek-platform. The code for platform setup is published on GitHub[1], and is free to use as it only uses open-source components.

The results from the mapping expedition, workshops and meetings will form the basis of the recommendations in relation to what NRAs must consider, to capitalize on the benefits of automation.

1.2 Overview of Norwegian Pilot 2

The NordicWay 1 project gave valuable insights into how challenging data collection from vehicles can be. Hence an iterative process started early to identify equipment and relevant parameters. In addition, data must be analyzed after it has been collected. The key challenge is linking the data sources together and to available digital infrastructure descriptions. A data analysis platform had to be created and tested before the data collection.

1.2.1 The Trantek -platform

A large-scale data collection creates a need for automation. It is not practical to work with millions of datapoints using manual methods. The pure computational requirements include the ability to store data, clean data, inspect data, process data, analyze data and present results. For this purpose, a set of open-source tools were put together to produce a platform. The platform was deployed on a server with 1 terabyte of fast storage and 96 Gigabytes of RAM. Milestone 24 documented the platform, in addition to it being published on Github: https://github.com/NPRA/trantek

Equally important to having a platform to receive data was to have contingency plans to minimize data loss. How to join data from several data sources is the critical issue. Best practice is testing of the equipment end to end, do a test drive, collect data and do trial processing of data. Milestone 23 marked the end of this task.

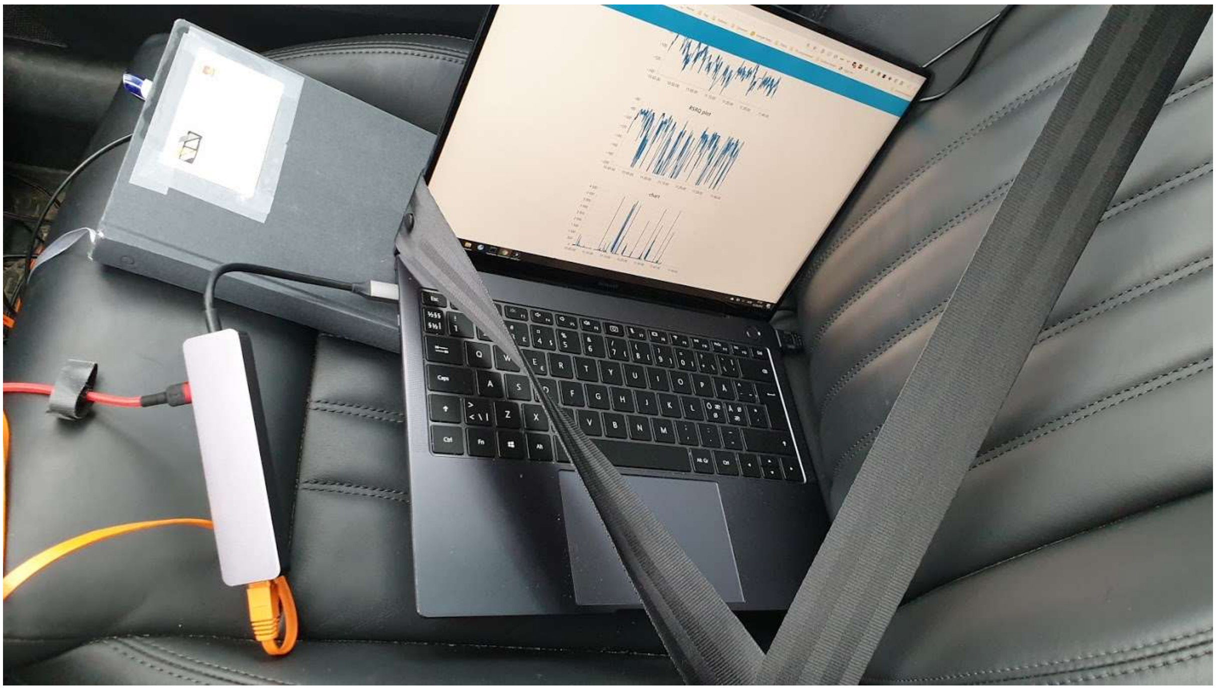

Figure 2 Trial run testing LTE coverage and GNSS quality

Figure 2 is from a trial run logging data on LTE reception and GNSS quality. The test run was set up to include several tunnels and crossing of the Norwegian/Swedish border at Storlien. This test run was very valuable as it showed that the modem used for logging LTE coverage had a bug giving a false very long transition period at the border. The issue was with the roaming configuration in the modem, that gave a 15-minute timeout with no coverage. After updating the modem firmware, the handover from roaming network to home network worked.

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[1] https://github.com/NPRA/trantek

In order to analyze all the mapped data an extra precaution was taken, all datasets needed two keys for joining data. One spatial key (latitude and longitude) and one timestamp. The timestamp was set in UTC to avoid possible hiccups with time zones and daylight savings time.

After several tests and trial data analysis, the plan and techniques were presented for the PMB as milestone 25.

1.2.2 Lessons learned from Road transport automation in snowy and icy conditions

According to the Arctic challenge final report (Ilkka Kotilainen et al. 2019):

The aim of the Arctic Challenge project was to study automated driving in snowy and icy northern conditions. This Finnish public road authorities and EU CEF-funded project included three industry coalitions that were selected in a public procurement process to study four research questions in Arctic conditions related to posts and poles for guidance and positioning, Cooperative Intelligent Transport Systems (C-ITS), communication infrastructure and remote driving, as well as vehicle positioning

The aim of the cooperation with the Finnish team was to avoid duplication of our efforts(Tomas Levin 2019). The Finnish effort focuses on a small area with LTE and 5G communication under extreme conditions. While the testing conducted in A6 would then focus on a large geographic area with a great deal of variance in roads and topography. The data collection was also to be run after the summer maintenance season on the roads.

Even if the final report was not done before the data collection in the Nordics, a close cooperation with the project partners made sure that we had access to enough information for the design of the data collection.

The data collection effort got the name NordicTour and traverses all four capitols using the arterial network which also serve the purpose as main freight route in each respective country.

1.2.3 NordicTour

The NordicTour became the method for data collection. As stated, the Original plan was to use the stretch from the E8 at Kilpisjarvi down to the E6 Swedish border crossing at Svinesund. There was the possibility to include the E136 from Dombås to Åndalsnes. Extending the data collection improved the dataset vastly, first it allows for benchmarking of data between the 4 partner countries. The second benefit of having a Nordic tour compared to a Norwegian tour is that there will be more variability in the dataset, including an extra border crossing (Denmark/Sweden). In addition to the datalogging operation the NordicWay interchange was tested during the tour. A phone in the vehicle was displaying all messages passed to the interchange from Norway, Denmark, Sweden, Finland and the Finnish partners.

Figure 3 Environmental obstruction warning issued by the Finnish TMC over the interchange

Figure 3 documents that we received an environmental obstruction message over the interchange just east of Helsinki. As the picture shows there was flooding in an underpass. This message was sent from the Finnish TMC and received by the interchange node in Norway where it was extracted, put on a map and sent to the vehicle. We saw the message early on and could have made a detour if we wanted to, but we were also curious about what the message meant in real life. Hence the tour also provided a vessel for testing messages passed over the interchange.

1.2.4 Vehicle understanding of infrastructure state

Vehicles have a lot of knowledge about their own state. The NPRA was wondering if this knowledge could be turned into datatypes that NRAs use and understand. For example, can cameras be used to identify road damages for avoidance or be used to monitor damages to the road surface? Likewise, can information on how “rough” the ride is be translated into an estimate of the road condition? From an OEM perspective knowledge on damages and rough roads can be used for avoidance or adaptation of driving behaviour. While road operators could use data derived from the vehicle to monitor the state of the road surface, to target inspections using costly techniques like using measurement vehicles. Here we explored how data could be collected from the vehicle, under controlled experiments investigated if these techniques could be integrated into future vehicles.

1.2.5 Data sharing between OEM’s and NRA

In the NordicWay 2 project Norway had a research cooperation with an OEM to get access to knowledge and data from vehicles. From an NRA perspective it has been quite difficult to get into dialogue with OEM’s for production purposes. Hence securing data for use in real-world full-scale applications has been difficult for the NPRA. The main issue has been the cost associated, both for the data and building of the systems to receive the data. Instead of trying to get access to more data for piloting, the NPRA conducted a study into the OEMs willingness to share data(Einar Michaelsen, Guro Fladvad Størdal, and Tom Einar Nyberg 2020). This study set out to explore 4 basic questions about sharing of data:

- What data is useful for OEMs?
- What data is useful for road operators?
- Which technological solutions for data sharing of vehicle data exists?
- How to share incurred costs for data sharing?

2 Mapping activities of Norwegian Pilot 2

This section goes more into details about the NordicTour, why data was collected, where data was collected, the route followed.

2.1 From a Norwegian perspective to a Nordic perspective

An important question for the NPRA was – how ready is our infrastructure for automated vehicles? As mentioned in the introduction the NPRA expects that automated vehicle will have a dependency on the traditional road infrastructure, but also depend on supporting infrastructure for communication and navigation. Mapping out the Norwegian infrastructure with state-of-the-art production equipment will generate valuable information that can be used in dialogue with the authorities in frequency and mapping domains.

The inclusion of the other countries that are partners in the NordicWay project gave the NPRA a unique chance to create a dataset for direct comparison between the Nordic countries. This is useful for understanding findings in a Nordic perspective – how do we compare to our neighbours. The other aspect that was very beneficial was that we could compare the true interoperability, a Swedish car filled with both Swedish and Norwegian cellular equipment including sim cards. Both corporate sim cards and normal personal sim cards. This gives an insight into if there were differences between OEM solutions and retrofit solutions based on the type of sim cards used.

Including the Nordics increased the variance in infrastructure. Denmark contributed with motorways with higher speeds than in Norway. In addition, Denmark has motorways running through the country and dense traffic in the Copenhagen area. Denmark is a flat country, with no mountains. Hence cellular connectivity and GNSS should not be limited by the topography of the country. Sweden also has motorways through the country, but there are areas with low volume roads. Finland has more variance in road standard the further North you get. But the terrain is not challenging, and roads tend to be straight even if they are normal 2 lane roads. While Norway has roads that are twisting and turning because one must traverse fjords and mountains on your way from the North to the South. Another important property of the Norwegian road network is the number of tunnels. There are 54 tunnels between Kilpisjarvi and Svinesund, ranging from high quality motorway tunnels to narrow and dark tunnels.

In dialogue with the PMB the idea of a NordicTour was launched and in the PMB in Stockholm all countries agreed to explore the possibility of a NordicTour. The benefits of shifting from a Norwegian centric tour to a Nordic tour was believed to be so beneficial due to data variance that it was decided that the tour would take place in September 2019.

2.2 NordicTour route

As the research partner was located in Gothenburg, with the necessary assets, it made most sense to start and end the tour in Gothenburg.

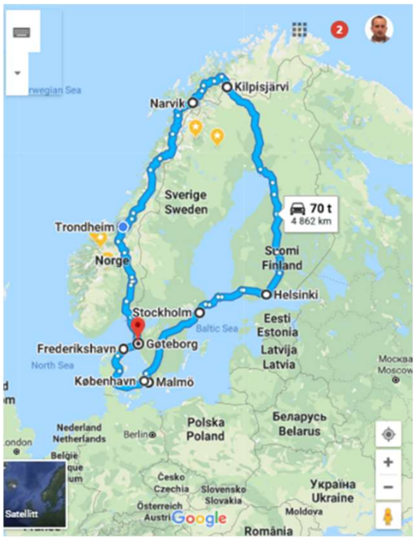

Figure 4 First presentation of the NordicTour route

Figure 4 shows the first route suggested by the NPRA. In the end there was limited deviance from this initially planned route. The only big difference was the extra loop that was added in Finland from Helsinki towards the east. This extra loop made it possible verify that we were receiving messages from the Finnish partners through the interchange.

Getting enough variance in the weather is always challenging, and the choice of September would ensure that the data collected on understanding of road infrastructure would be best case for the Nordics just after the summer road maintenance season with paving and lane marking. As a plan to get more data with greater weather variability an additional extension to the tour was planned for end of winter 2020. A second trip would also improve the comparability between Norway, Sweden and Finland when it comes to mobile networks. This because the second trip would collect data from the south of Sweden to the north.

The tour started in Gothenburg with the outfitting of the vehicle for the tour. All NPRA logging equipment was added. The NPRA drivers got training in the equipment installed in the car by the OEM.

Figure 5 The NPRA and Volvo car team solving equipment issues

Outfitting the car with the NPRA and Volvo equipment to closed to 2 days including limited test drives.

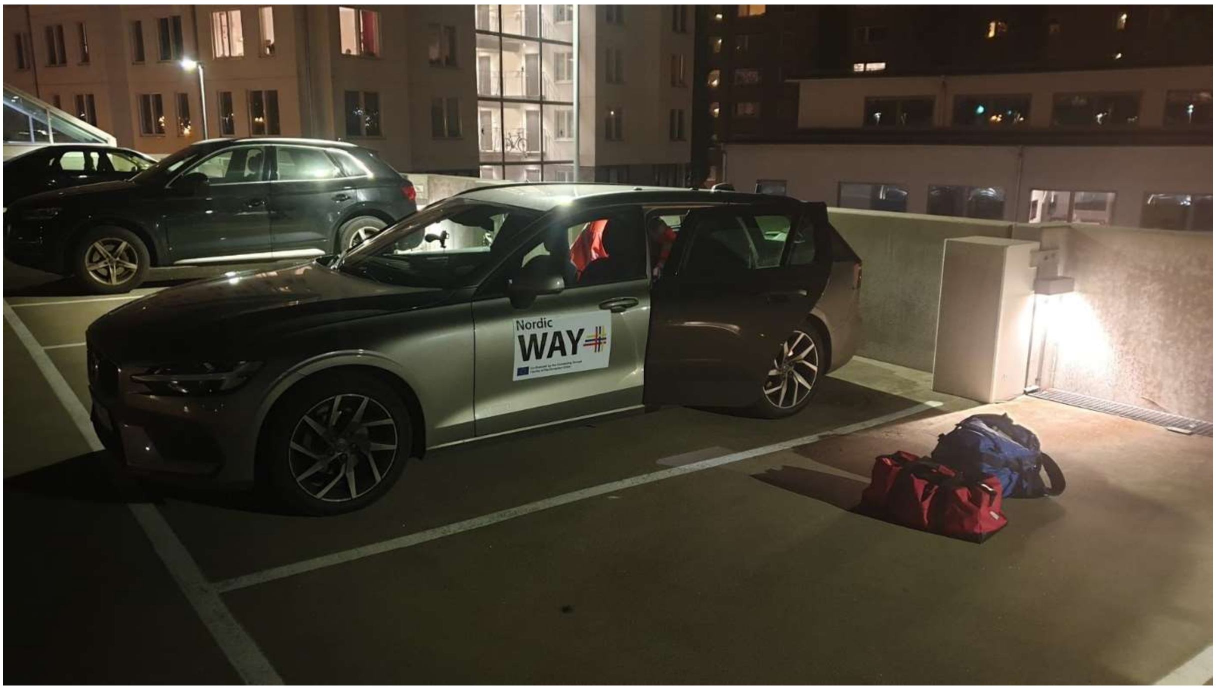

Figure 6 The vehicle was ready for the 5000km long NordicTour

One issue of concern was the all the equipment installed in the vehicle. Hence safe and secure parking became part of the route planning. It was not an option to remove and reinstall the equipment in the car as only the physical process of doing so would take 2 persons more than 4 hours of work. The trip was conducted with two drivers from the NPRA in accordance with an NPRA health, safety and environment (HSE) plan. Each leg of the tour was planned with about 9 hours of driving, with the exception of two long legs in northern Finland and Norway.

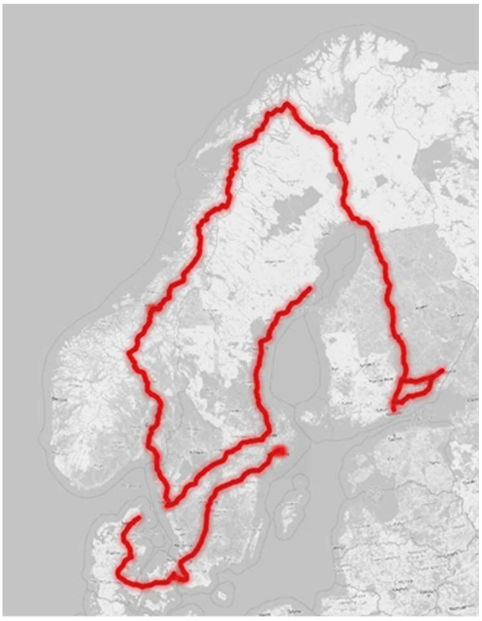

Figure 7 The actual route driven of the NordicTour

Figure 7 shows the actual route driven on the NordicTour. The additional stretch from Gothenburg and up the east coast of Sweden was the second part of the NordicTour. The second part took place mid-March 2020. This was supposed to get extra data on semi winter conditions. The expedition only got halfway up Sweden before the team was called back to Norway since Norway was closing its borders due to Covid-19 pandemic.

The data collection was reduced somewhat in relation to infrastructure understanding under winter conditions. But both GNSS and mobile network connectivity was collected.

2.2.1 The equipment

In total 10 different devices were producing data that that was logged. Figure 8 shows a schematic view of the logging equipment.

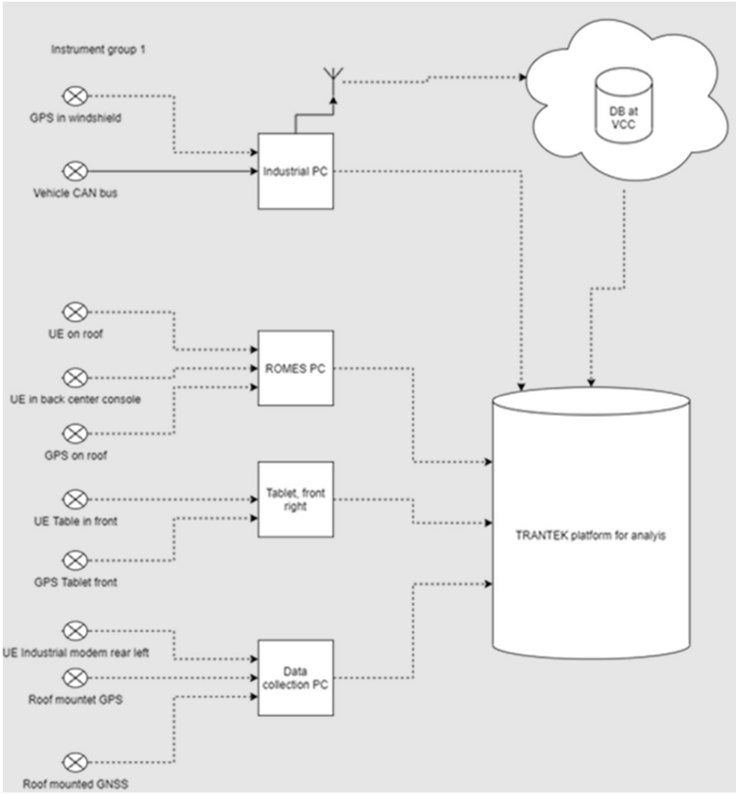

Figure 8 Schematic of logging equipment

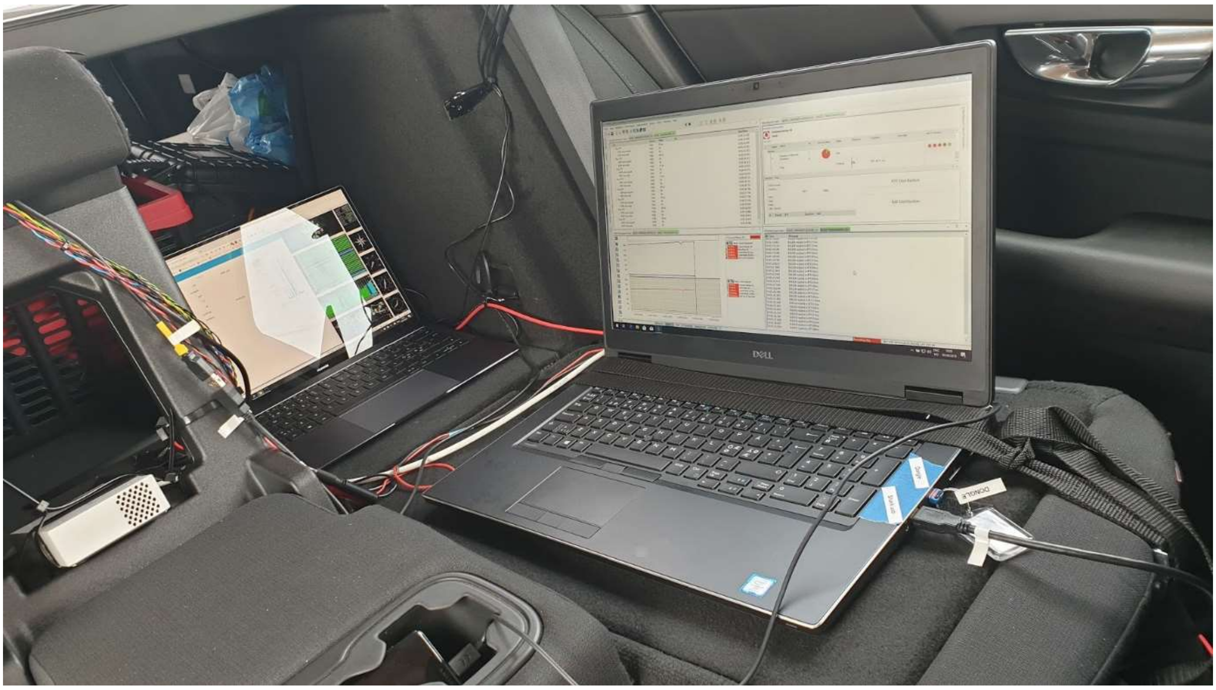

Figure 9 Dataloggers in the back seat

Figure 9 shows the two main logging PCs in the back seat of the vehicle. Each PC linked into sensors connected to the vehicle, on the roof and inside. It was the co-drivers responsibility to monitor the equipment. As this is complex and highly specialized equipment there is always the potential of systems stopping for unknown reasons.

The equipment was set up to record data in three groups.

- Mobile network coverage and quality
- GNSS availability and quality
- The vehicles understanding of the infrastructure

These three groups correspond to the three services that need to be in place for large scale automation to take place. In addition, a forward-facing camera system was mounted to record anonymized video of the complete tour. A 100x speedup of the tour is available on YouTube: https://youtu.be/JLgXyWqkOlk

There were four telemetry units in the car, 2 OEM supplied units including the existing vehicle telemetry unit. In addition, there was a Samsung S3 tablet and an Mikrotik industrial modem. The point of having many telemetry units was to see differences in signal strength and quality due to placement in car, and to see the difference between sim cards that OEMs use and that normal phone owners have. The point with the normal sim cards was to emulate retrofit equipment.

The purpose of the video collection was to be able to go back and study the data and see what was going on in relation to the data logged. The video was also synchronized on time and location.

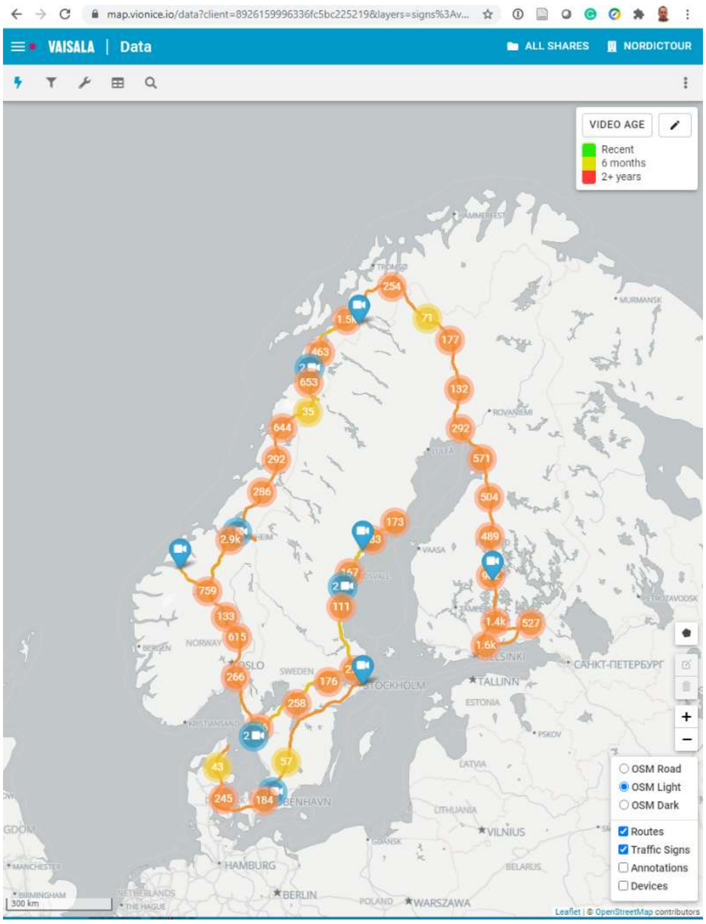

Figure 10 Map of NordicTour with time and location synchronized video

The test was performed by using a 2018-model car with a state of the art ADAS system. The NPRA holds the belief that ADAS systems is the first wave of automation we are seeing. Hence for NRAs it makes sense to try to understand what state of the art ADAS systems understand when it comes to road infrastructure. A key ADAS system is the system that warns drivers if they are outside their lane. Being able to understand the lane markings along the different parts of the route will give valuable insights into challenges. The point is not to comment on the quality of the system reading the infrastructure. But rather for the NPRA to get a better understanding of what areas are challenging to understand, and to what extent these systems understand the NPRAs lane marking today and if there are difference between the Nordic countries.

2.3 Data collected

Close to 150 Gigabytes of sensor data was collected in various binary compressed formats. In addition, close to 1 Terabyte of anonymous video was collected. All data except for the videos were loaded into the Trantek data platform.

From the vehicle the following parameters were collected:

- Accelerations
- Ambient light
- Engine speed
- Front beam
- GNSS
- Lane detection
- Speed limits
- Vehicle speed
- Windshield wiper

From the telematics an extreme amount of data was collected. This included the standard signal strength and quality measurements (RSRP, RSRQ). In addition, many hundreds of datatypes related to the communication interfaces were also collected. The challenge is sorting out the data that was relevant for NRAs. And when it comes to cellular connectivity, we settled on three datatypes for analysis, RSRP, RSRQ and ping time.

Vehicle understanding infrastructure was boiled down to the understanding of lane marking and signs along the road network. The other parameters collected are supporting parameters to understand the limitations and put the observed data into a context.

A Ublox M8 Neo GPS with external antenna was used to collect data on GNSS quality as observed with consumer grade GNSS equipment. Early experiments were conducted with high precision GNSS devices. But this was not chosen for the NordicTour as they are too expensive, about €20 000. The device used for the mapping procedure cost about €20. The is unlikely that OEMs will include GNSS equipment that has a cost equal to the vehicle itself. The price of high precision GNSS equipment is coming down, but it will take many years for them to be affordable enough to be included in vehicles. So the decision was to use consumer grade GNSS equipment. The benefit of using the Ublox receiver is the debug protocol that is built into the device which allows for extraction of a wide set of datatypes.

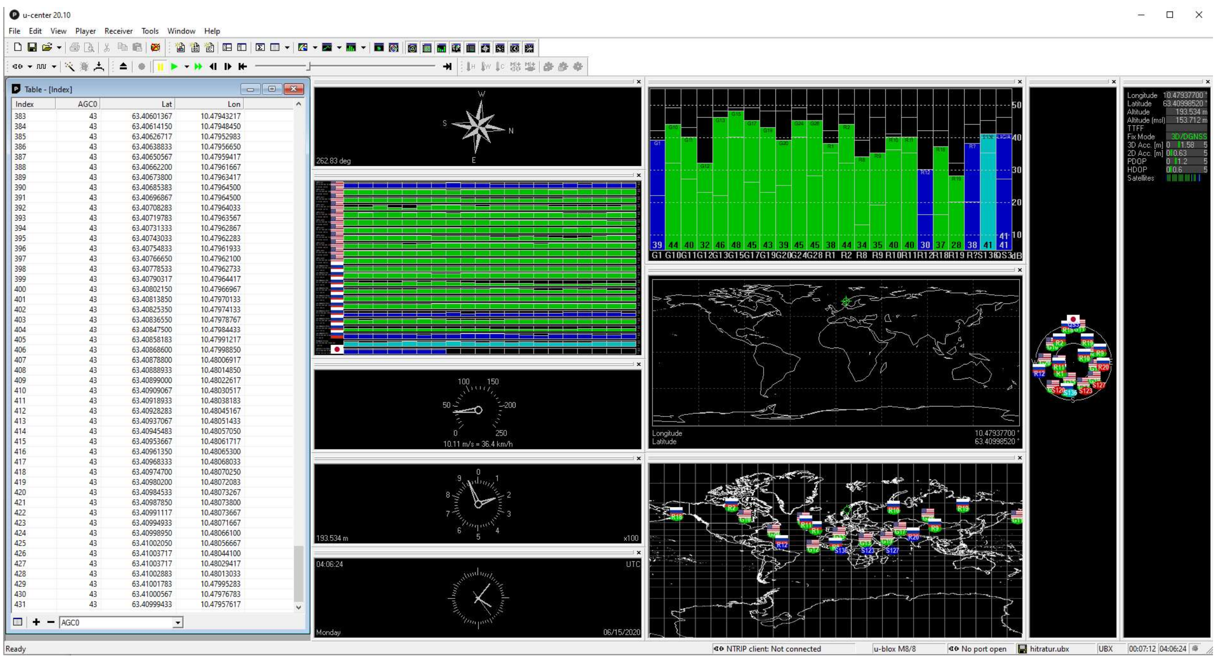

Figure 11 Screenshot from the U-center software for datacollection ana analysis

Figure 11 shows a screen shot from the U-center software that was used for GNSS data collection on the NordicTour. There are more than 100 parameters that can be extracted. From this massive dataset, a subset was chosen that contains the parameters believed to be most important.

- **Timestamp:** UTC GNSS time
- **Latitude**
- **Longitude**
- **Altitude**
- **Jammerindex:** internal variable that indicates if the unit itself is subject to GNSS jamming (tests conducted together with the defense research institute indicates that this only pick up one of three jamming types)
- **Agc0:** Automatic gain control – if this variable suddenly drops, then there is an increase in signal strength – a tell tail sign of jamming
- **Pacc_h:** Positional accuracy horizontal
- **Pacc_3d:** Positional accuracy 3d (Vertical + Horizontal)
- **Pacc_v:** Positional accuracy vertical
- **Hdop:** Horizontal dilution of precision (indication of accuracy in relation the where in the sky the satellites are)
- **Vdop:** Vertical dilution of precision (indication of accuracy in relation the where in the sky the satellites are)
- **Satellites seen:** number of satellites that the receiver can receive signals from, but not used in the location fix
- **Satellites used:** number of satellites that are used in the location fix
- **Speed:** speed over ground for the unit
- **Sats_C_N0:** carrier to noise ratio for all satellites

Agc0, Pacc_v, Vdop, satellites seen and satellites used are the most important parameters. These datatypes will give a good indication of possible GNSS jamming and the accuracy of the GNSS equipment.

2.4 Summary information from the tour

Table 1 shows a summary of the number of datapoints collected for each datatype on the NordicTour.

Table 1Sommary of observations

Datatype	*Datapoints*
GNSS	360 157
Tablet	399 830
Industrial modem	386 147
Vehicle modem	317 044
Modem inside vehicle	309 154
Accelerations	29 933 034
Ambient light	30 524 455
Engine speed	30 273 911
Front beam	953 835
Car GNSS	3 771 645
Speed limits	7 629 509
Vehicle speed	61 062 283
Windshield wiper	7 631 149

Lane detection	15 258 894

In total the drive time with logging was around 110 hours, each equipment is a bit different as all were started in sequence. Datapoint were also mapped to the main roads and areas near the main roads. This meant that small detours to get food, fuel or rest were removed from the dataset as only datapoints located closer than 200 meters to the centreline of the main roads are used for analysis. Table 2 shows the length of the road sections in each country used for analysis, a total of 5715 km was used for data collection and analysis in the NordicTour. 5715 kilometres is twice the distance from Hamburg to Lisbon.

Table 2 Lenght of road network mapped by country

Country	*Distance*	*Unit*
Denmark	500	Km
Finland	1548	Km
Norway	1783	Km
Sweden	1900	Km

There was an issue with data loss. The GNSS receiver equipment failed in Denmark. This issue was not detected until arrival in Malmö. That means that we only managed to collect one hour of GNSS data in Demark. The issue was linked to a defective USB hub that overheated and then dropped the connection to the GNSS equipment. In addition, we had issues with the internal GNSS system of the vehicle as this was integrated into the mobile network antenna. The problem was that the “normal” antenna had been swapped out and replaced with an antenna with debug ports. But since all data sources had two keys for joining this was not a problem. But it meant that data from the vehicle had to be linked to the other datasets using timestamps.

3 Evaluation of NordicTour data

3.1 Communication

The four telemetry units are

Modem: Mikrotik industrial modem, in the boot of the vehicle

Tablet: Samsung S3 tablet, standing by the front passenger seat

Phone: Phone modem inside vehicle – placed in the rear mid console

Roof: standard state of the art vehicle modem integrated into the roof

Table 3 shows the number of observation points per country. The logging frequency was set to approximately 1Hz. The table also clearly shows that the units were started in a specific order each time, the tablet was always started first and stopped last. The Modem and Tablet had normal Telenor business subscriptions and sim cards. The OEM supplied devices had the same subscriptions and sim cards as used for production vehicles.

Table 3 Observation points per country

unit	Modem	Phone	Roof	Tablet
country				
Denmark	21628	21471	21504	25016
Finland	78729	72600	77814	96859
Norway	103483	95545	97616	116748
Sweden	128384	107672	108244	143478

The data collected from the 4 units can be further broken down into technologies in each country. Table 4 shows a breakdown of the technologies seen by the equipment in each country. Here one can see clear differences between the vehicle equipment and the NPRA equipment. In workshops with an OEM and in dialogue with Norwegian telco operators it is quite clear that this can be attributed to the sim card. Telco operators offer different priorities to different sim cards and their related subscriptions. In addition, the user equipment (UE) can be locked into a specific technology or frequency band. This can explain why the vehicle equipment was in 4G in all countries when it had an established connection.

Table 4 Breakdown of observations by country and technology

country			Denmark				Finland				Norway				Sweden
simple_network_tech	2g	3g	4g	unknown	2g	3g	4g	unknown	2g	3g	4g	unknown	2g	3g	4g	unknown
unit																
Modem	242	10,427	8,708	2,251	2,437	60,162	11,438	4,692	4,301	2,485	90,990	5,707	1,312	99,146	23,393	4,533
Phone	nan	nan	21,471	nan	nan	nan	72,597	3	nan	nan	95,540	5	nan	nan	102,394	5,278
Roof	nan	nan	21,504	nan	nan	nan	77,795	19	nan	nan	97,610	6	nan	nan	107,562	682
Tablet	907	2,611	21,498	nan	621	79,763	16,475	nan	3,437	1,530	111,781	nan	211	72,023	71,244	nan

Another interesting perspective is on the Nordic level, which technologies are used by the different user equipment. Table 5 shows a percentage of time the equipment was using the different technologies. Here the difference in connectivity is quite remarkable, both pieces of equipment with private sim cards show a clear tendency to use 3G networks, 52% of the time for the Modem and 41% for the Tablet. While the vehicle equipment was either connected to 4G or not. The antenna location is quite similar for the Phone and the Modem and Tablet – all are inside the vehicle.

Table 5 Nordic technology usage by user equipment

unit	simple_network_tech	Percent of time
Modem	3g	52
	4g	40
	unknown	5
	2g	2
Phone	4g	98
	unknown	2
Roof	4g	100
	unknown	0
Tablet	4g	58
	3g	41
	2g	1

The network technology could be further broken down and spread out over the countries. Table 6 shows this break down. A new dimension to subscription or telco priority is shown in here, possible roaming issues. In Denmark the NPRA equipment (Tablet and Modem) used the 4G network quite a lot, 86 and 40% of the time. While the vehicle equipment used 4G 100% of the time for both units. In Finland the situation is quite different, the Tablet and Modem are on the 4G network only 17 and 15% of the time, most of the time the NPRA equipment is on the 3G equipment. The situation is quite similar in Sweden, but the Tablet spends 50% of the time on 3G and 50% on 4G.

In mobile networks it is the UE that choose between the technologies that the base stations have to offer. So locking the units to selected technologies or frequency bands could explain some of the difference. But locking the UE to a specific technology is a risk as one could get worse connectivity than when freely shifting between best technologies. But to understand this issue a bit more, the focus is shifted to 4G. By choosing 4G as the element for analysis, one can get a picture of the risk one will face if locking down the equipment to a specific network technology.

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Table 6 Technology usage by country and network technology

country	unit	simple_network_tech	Percent of time
Denmark	Modem	3g	48
		4g	40
		unknown	10
		2g	1
	Phone	4g	100
	Roof	4g	100
	Tablet	4g	86
		3g	10
		2g	4
Finland	Modem	3g	76
		4g	15
		unknown	6
		2g	3
	Phone	4g	100
		unknown	0
	Roof	4g	100
		unknown	0
	Tablet	3g	82
		4g	17
		2g	1
Norway	Modem	4g	88
		unknown	6
		2g	4
		3g	2
	Phone	4g	100
		unknown	0
	Roof	4g	100
		unknown	0
	Tablet	4g	96
		2g	3
		3g	1
Sweden	Modem	3g	77
		4g	18
		unknown	4
		2g	1
	Phone	4g	95
		unknown	5
	Roof	4g	99
		unknown	1
	Tablet	3g	50
		4g	50
		2g	0

The mobile network coverage can be measured using the Reference Signal Received Power (RSRP). The RSRP is measured on the UE and is measured in – dBm. A value closer to 0 is better. An interesting observation from Table 7 is that with the same UE there is variance between the countries. The modem is quite stable, while the tablet shows some extreme differences. The tablet signal is 10 times weaker in the other countries compared to the signal in Denmark. The roof top antenna gives a stronger signal for all countries when compared to the other UE. But the difference between the countries is also staggering. The median signal in Denmark is about 10 times stronger than in Sweden.

Table 7 Median values of RSRP in dBm

	median			
unit	Modem	Phone	Roof	Tablet
country				
Denmark	-96	-98	-74	-88
Finland	-96	-109	-84	-97
Norway	-95	-98	-77	-92
Sweden	-96	-97	-86	-98

Table 7 shows the RSRP which gives an indication of the signal strength. It is worth observering that the roof mounted antenna received signal strength is much stronger than for the devices inside det vehicle. Table 8 shows very clearly a difference in reception strength of the built-in antenna and the UE inside the car. The difference may look small but an increase of 3dBm is equivalent to doubling the signal strength. Hence roof antenna has a 16 times more powerful signal than the Tablet inside the vehicle. So even when locking the roof mounted antenna to 4G one will still have an extreme increase in signal reception than a UE inside the vehicle. When comparing the units inside the vehicle, it is quite clear that locking to 4G bands is not smart. Most of the time the locked UE has half or less signal strength than the units that freely shift technologies.

Table 8 Median 4G signal strength dBm

Roof	Tablet	Modem	Phone
-82	-94	-95	-99

It is quite clear from the data that there are signal strength differences between the Nordic countries along their main routes. If ranked based on the roof top antenna, then Denmark provides the strongest 4G signals, Norway comes in second, then Finland and Sweden have the weakest signals. The exact reason for this is not clear. One explanation could be 4G penetration rates but using Open signal data this does not seem to be the case. Norway ranks as number 3, Sweden 9, Finland 17 and Denmark 19. To get a better understanding of why this is, one needs to discuss with telco operators and understand what their deployment strategies are along roads. Do they prioritize main roads with new technology, or do they prioritize urban areas?

The main take away from the logging is that antenna on top of the vehicle provides a much stronger reception than units inside the car. And the difference is quite staggering. Figure 12 shows a cumulative histogram of received signal strength from the device inside the vehicle and the antenna on the roof.

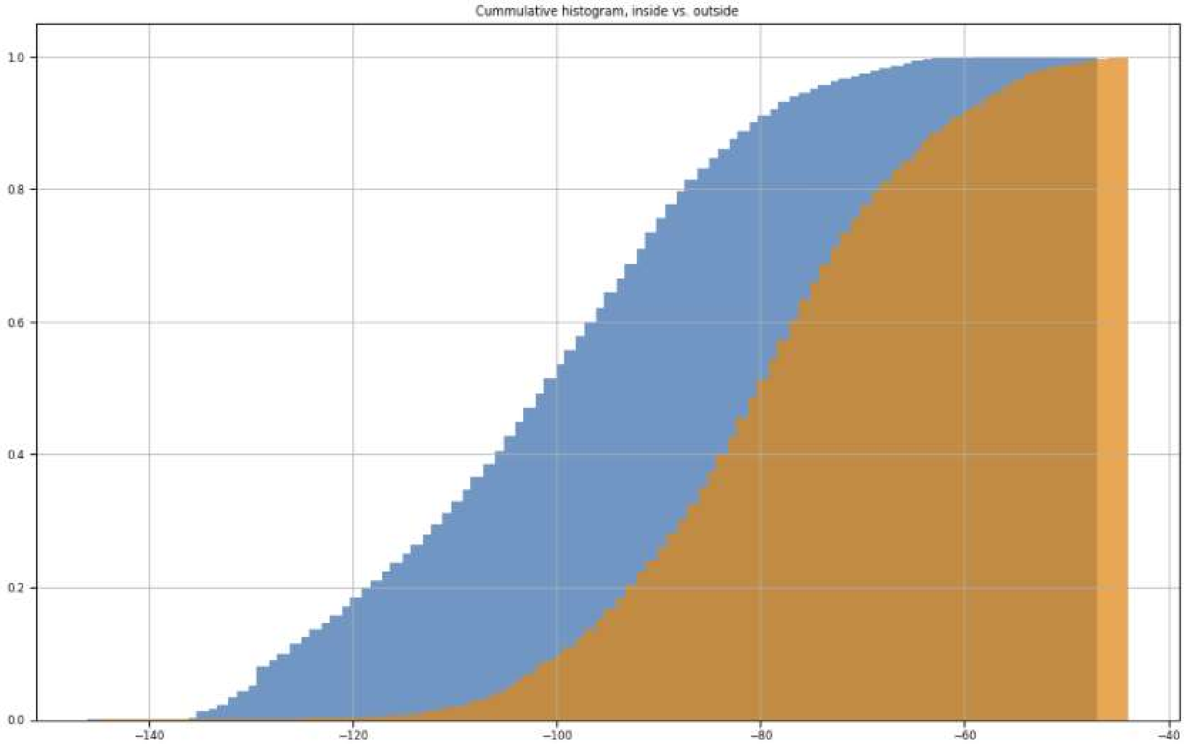


Figure 12 Signal strength inside the vehicle and outside the vehicle on 4G

The Norwegian Communications Authority (Nkom) have agreed on a common scale for RSRP values for LTE. This scale has four levels:

Between -100 and -110 dBm Basic coverage. It is possible to call and surf outside, but if the phone is in a pocket or inside, reception could be reduced.

Between -90 and -100 dBm Good coverage. It is possible to call and surf inside. It should also be possible to call and surf from inside. Indoor coverage will be heavily dependent on building materials and location indoor.

Better than -90 dBm Very good coverage. Here you can most probably call from both outside and inside. Coverage will be dependent on building materials and where you are in the building and phone positioning.

The levels were designed to be used in conjuncture with coverage maps the show the coverage outside in open air. But if you have a signal strength between -100 and -110 inside the vehicle then you are at the limit of establishing a connection.

To investigate throughput, one needs to add one additional parameter, RSRQ Reference Signal Received Quality. The combination of RSRP and RSRQ are among other parameters used by the UE to choose base station or cell. Figure 13 shows a scatter plot of RSRP vs. RSRQ for the Tablet inside the vehicle. The closer to the upper right the better the connection is. When the Tablet had LTE coverage it also had a decent RSRQ, typically better than -10dB.

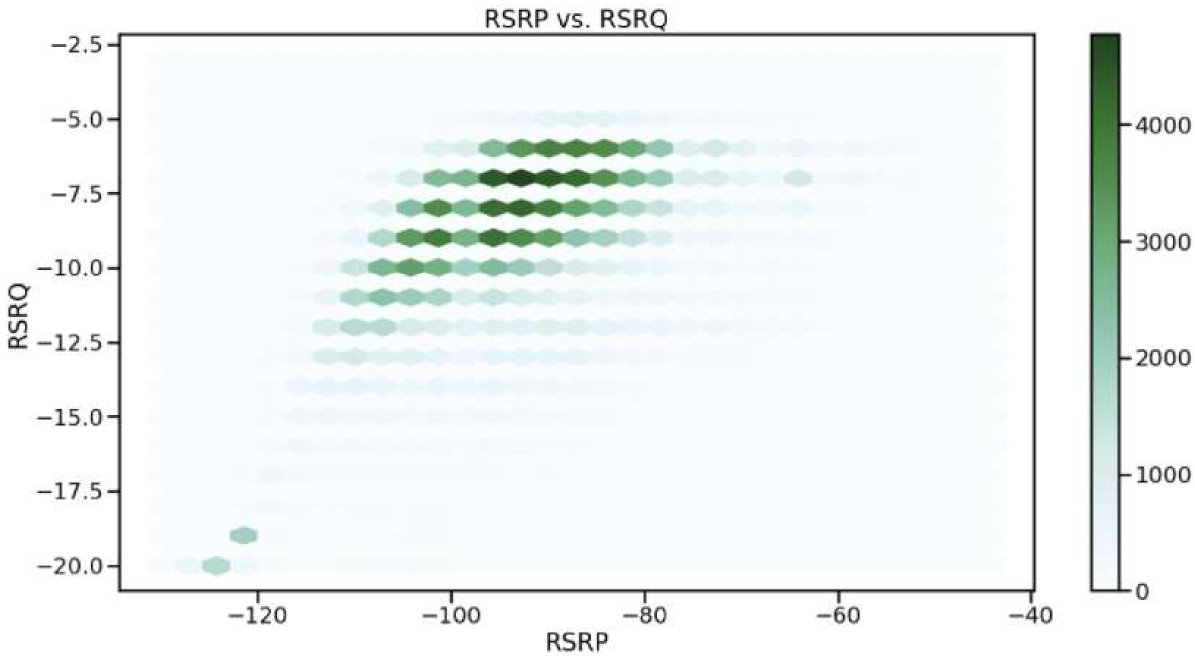


Figure 13 Hexbin plot of RSRP versus RSRQ for Tablet

The data collected was also geo referenced for simpler understanding of where the issues are. Visualizing the vast amounts of observations is challenging as the datapoint will overlap when creating maps. To make sure that one does not lose information due to visualization issues three figures have been created, one for each technology. The dark grey line shows the route driven and the colours shows what technology the tablet had available at any time. Figure 14 shows where the Tablet was using the 4G telco network. The green spots indicate where the vehicle had 4G reception, the map does not say anything about the quality of the reception – only that the Tablet was using 4G. Figure 15 shows where the Tablet was using the 3G network. Here one can see that there are spots in Norway where 3G is used. This was expected as the 3G networks in Norway are being shut down by the two main operators[2,3]. The main reason for shutting down these networks is to "give room" for 5G networks. It is also projected that the 2G network will be shutting down soon, most probably in 2025 I Norway[4]. The status of 3G and 2G in the other Nordic counties was not explored in this study. But from the data one can clearly see that both Sweden and Finland still have large 3G coverage. Hence the fall back from 4G is to 3G rather than 2G as is the case in Norway since the technology is not available to a large extent.

Figure 16 shows where the tablet used 2G communication. It is quite clear that 2G is only used when no other technology is available, even if there is coverage of 2G in the whole of Norway[5] as seen on the theoretical coverage maps produced by the telco operators.

[2] https://www.telenor.no/privat/dekning/hvorfor-stenger-vi-3g-nettet/

[3] https://www.telia.no/magasinet/utfasing-av-3g-nettet/

[4] https://www.telenor.no/bedrift/iot/abonnement/oversikt/

[5] https://www.telenor.no/dekning/#dekningskart

Figure 14 4G network connection to Tablet

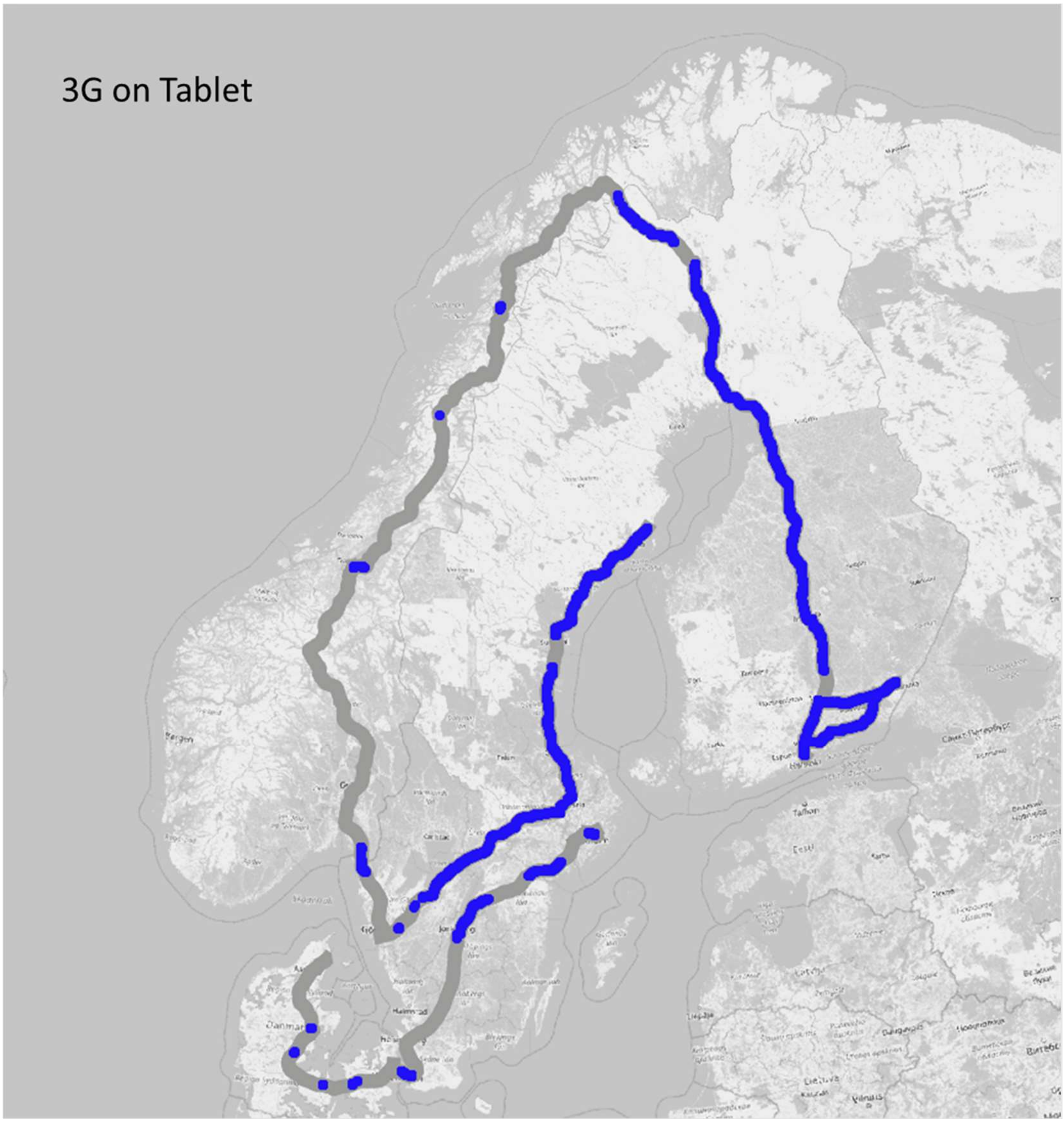


Figure 15 3G Network connection to Tablet

Figure 16 2G Network connection to Tablet

One interesting artefact was found north of Helsinki, a small road segment there was driven 2 times. On the first day the Tablet used 3G on the stretch. On the second day the vehicle used 4G on the stretch. Figure 17 shows this effect, the only difference between those days in the vehicle was that the NPRA crew were joined by a representative from the FTA, there was no difference in placement of the device. The reason for what was observed is hard to understand, every point on the stretch is connected to the same Finnish telco operator Elisa so it is not a difference due to different operators. To the extent 3G is inferior to 4G there could be issues if user devices can freely shift between available technologies. This is probably one reason for OEMs to choose specific radio technologies.

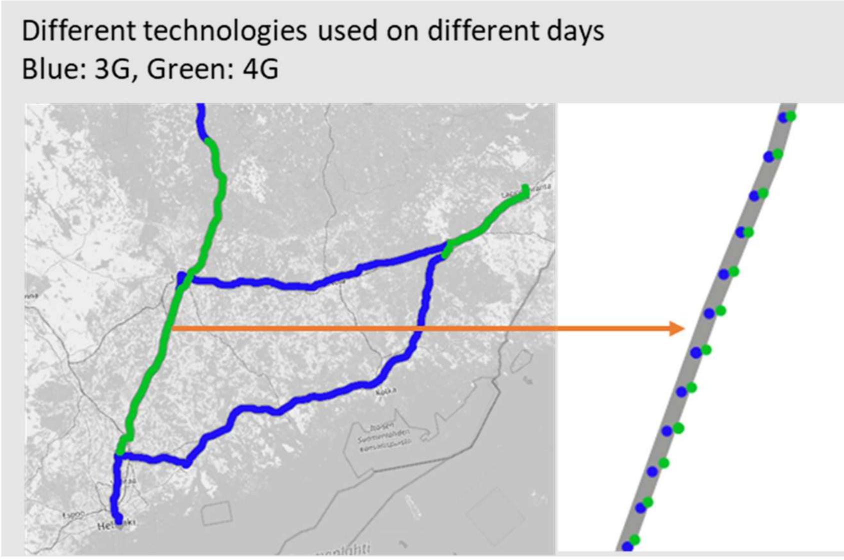


Figure 17 Different technologies used on different days

One challenge for mobile coverage are the tunnels, these are infrastructure objects that lay underground and the radio waves do not penetrate the rock. Hence there is a need for base stations or repeaters if the tunnels are long. Short tunnels can be covered with directional antenna pointing towards the tunnel openings. One challenging area with many tunnels is the Sørfold area in Nordland in Norway. Figure 18 shows the tunnels of Sørfold. The green lines on the figures are the tunnels while the red dots are 2G coverage. Since the location service was based on GNSS, and tunnels have no clear view to the sky all data points for tunnels are recorded at the last known good position, typically just before the start of the tunnel. On the figure one can also see that the GNSS system regained its position while still in 2G coverage area. Hence there are red spots on the entry and exit points of tunnels.

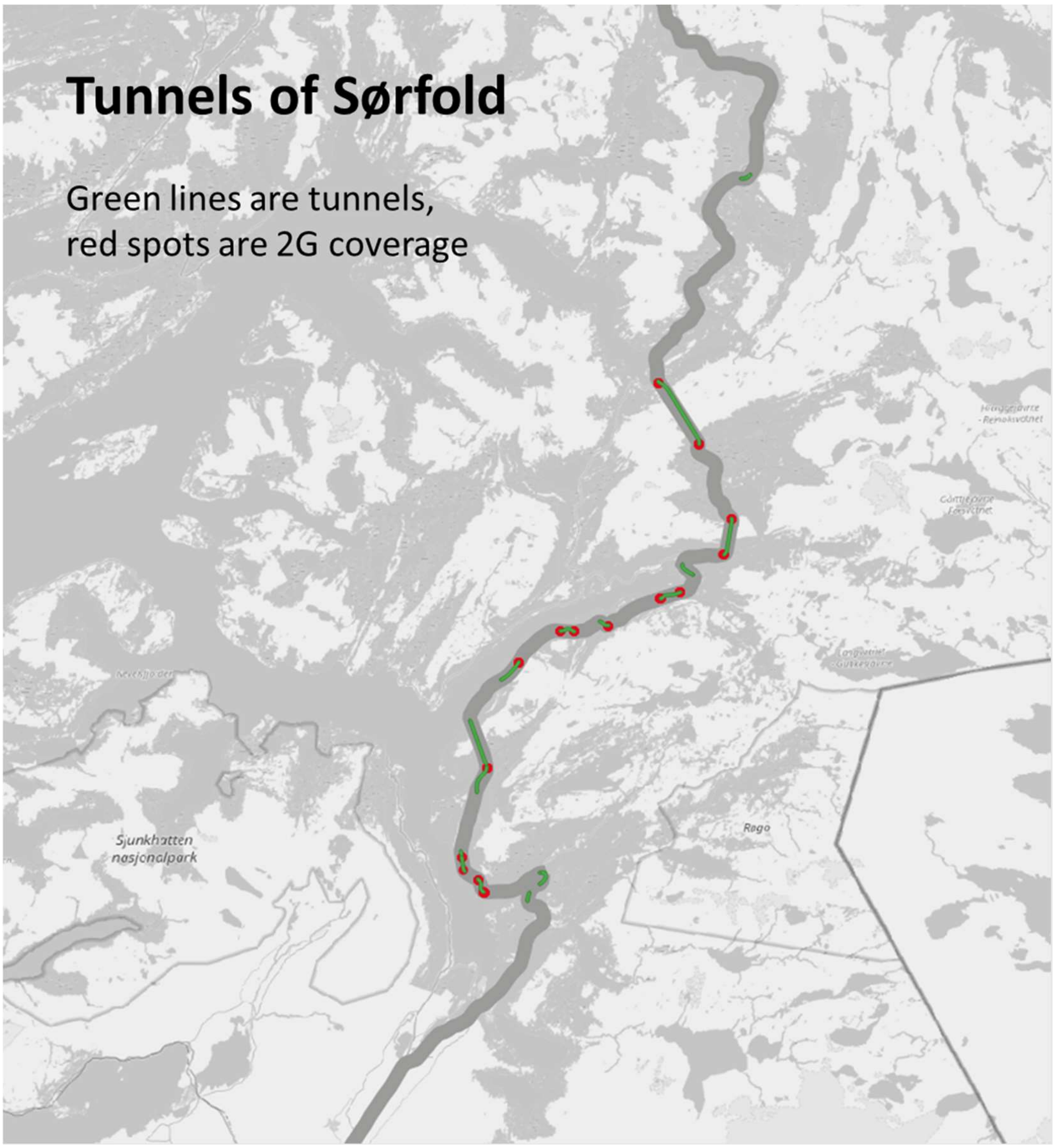


Figure 18 Tunnels of Sørfold

Coverage and signal drop out can be interpreted in many ways. The Norwegian Communications Authority (NKOM) has chosen to look at 400-meter segments without coverage as important gaps to be aware of. The route the NordicTour took was split into 400-meter segments and the number of observations on each segment was calculated. All technologies are used and there were no limits on RSRP. Hence this will be the most optimistic estimate possible of coverage along the NordicTour. In addition, there is the issue of tunnels where some of the logging equipment will not report observations at the correct location. For Norway this is 124 segments where this could be an issue. In total there were 54 tunnels in Norway, but only 32 are longer than 400 meters. The vehicle equipment will report data in tunnels because they do interpolation of the data, hence this problem only affects Modem and Tablet data in Norway.

Table 9 Percent of 400 meter segments with least one observation of signal reception

	Modem	Tablet	Phone	Roof
Denmark	99,4	99,0	100,0	100,0
Finland	100,0	99,9	99,5	99,5
Norway	97,1	96,8	98,0	98,2
Sweden	99,7	99,7	98,3	96,8

Table 9 only shows that some signals from the base stations are received and do not express the ability to communicate, it only gives an insight into how many areas of over 400 meters where there is no mobile phone coverage. As the table indicates, there are not many long stretches of road where mobile phones do not see the mobile networks.

3.2 GNSS

A Ublox M8 receiver was used to test consumer grade equipment. The low cost of the receiver, wide-spread usage and debugging capabilities made this GNSS equipment a good choice. The packaging of the unit was as a USB dongle, with a ceramic antenna on top of the GNSS unit. The unit was placed on the roof over the rear seat on the driver side.

Figure 19 Location of Ublox M8 usb dongle with antenna

All data from the Ublox M8 was logged to a computer in the vehicle running the U-center software. The receiver was configured to send extra debug messages. From these the following subset was extracted:

- Timestamp utc
- Latitude
- Longitude
- pacc_v, internal estimate of accuracy of position given vertical
- pacc_h, internal estimate of accuracy of position given horizontal
- sats_seen, number of satellites see by the receiver at the time a position was given
- sats_used, number of satellites used in calculation of position
- hdop, Horizontal dilution of position
- vdop, Vertical dilution of position

A total of 318972 observations were made. Table 10 shows the distribution of the measurements over the different Nordic countries.

Table 10 GNSS observations by country

country	
Denmark	11758
Finland	78898
Norway	103802
Sweden	124614

The amount of data available in Denmark was low due to data loss. A USB hub overheated and caused the software to stop logging of data. The issue was fixed in Malmö and from there on the GNSS logging worked without any further data loss.

Figure 20 Shows a cumulative distribution of satellites used for calculation of position. 95% of the time the vehicle saw more than 14 satellites. It should be noted that the Ublox M8 is a concurrent GNSS receiver, concurrent GNSS receivers which can receive and track multiple GNSS systems: GPS, Galileo, GLONASS and BeiDou. For the NordicTour GPS + GLONAS was used, but with correctional data from both EGNOS and QZSS.

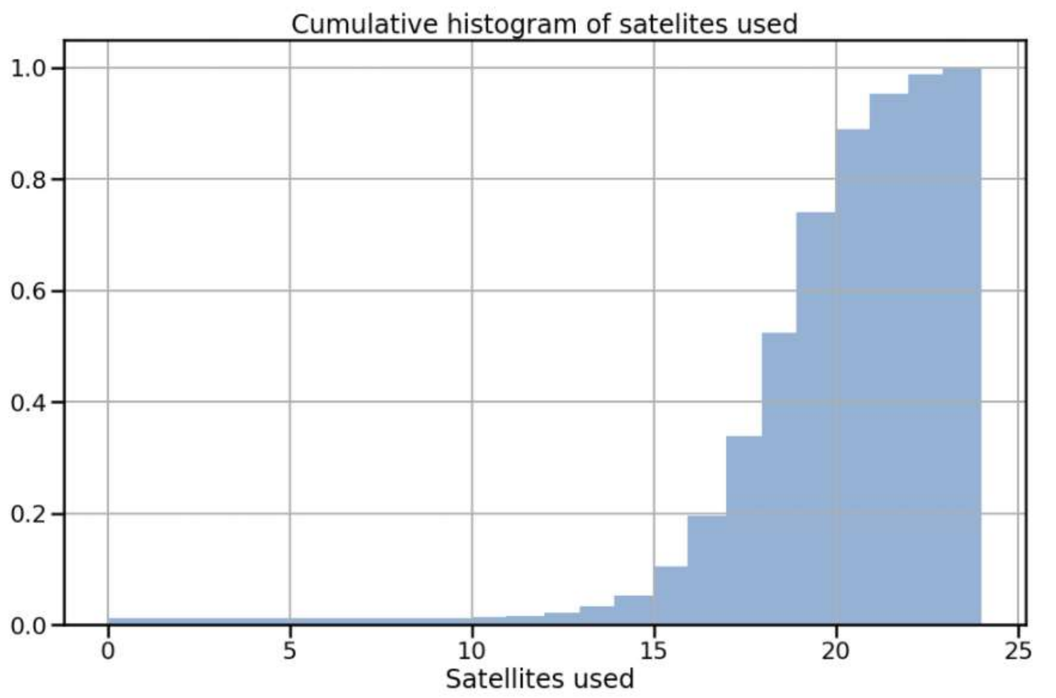


Figure 20 Cumulative histogram over satellites used on the NordicTour

One way to look at the performance of GNSS is to look at the receiver's own estimate of accuracy. The accuracy estimates should not be confused with the actual error in measurement from one spot on the earth's surface, but rather as an expression of uncertainty.

Table 11 Estimate of horizontal uncertainty, meters

country	count	mean	std	min	25%	50%	75%	max
Denmark	11758.00	1.70	8.78	0.80	1.04	1.19	1.38	256.29
Finland	78898.00	1.07	2.00	0.47	0.79	1.01	1.25	403.05
Norway	103802.00	54.27	503.08	0.50	0.78	0.93	1.18	12156.42
Sweden	124612.00	2.45	28.42	0.53	1.09	1.44	1.73	1644.52

Table 11 shows the uncertainty values. Looking at the maximum values, Norway seems to be a more challenging country for GNSS reception. The topography makes this sound reasonable.

Example from south of Fauske, cause unknown

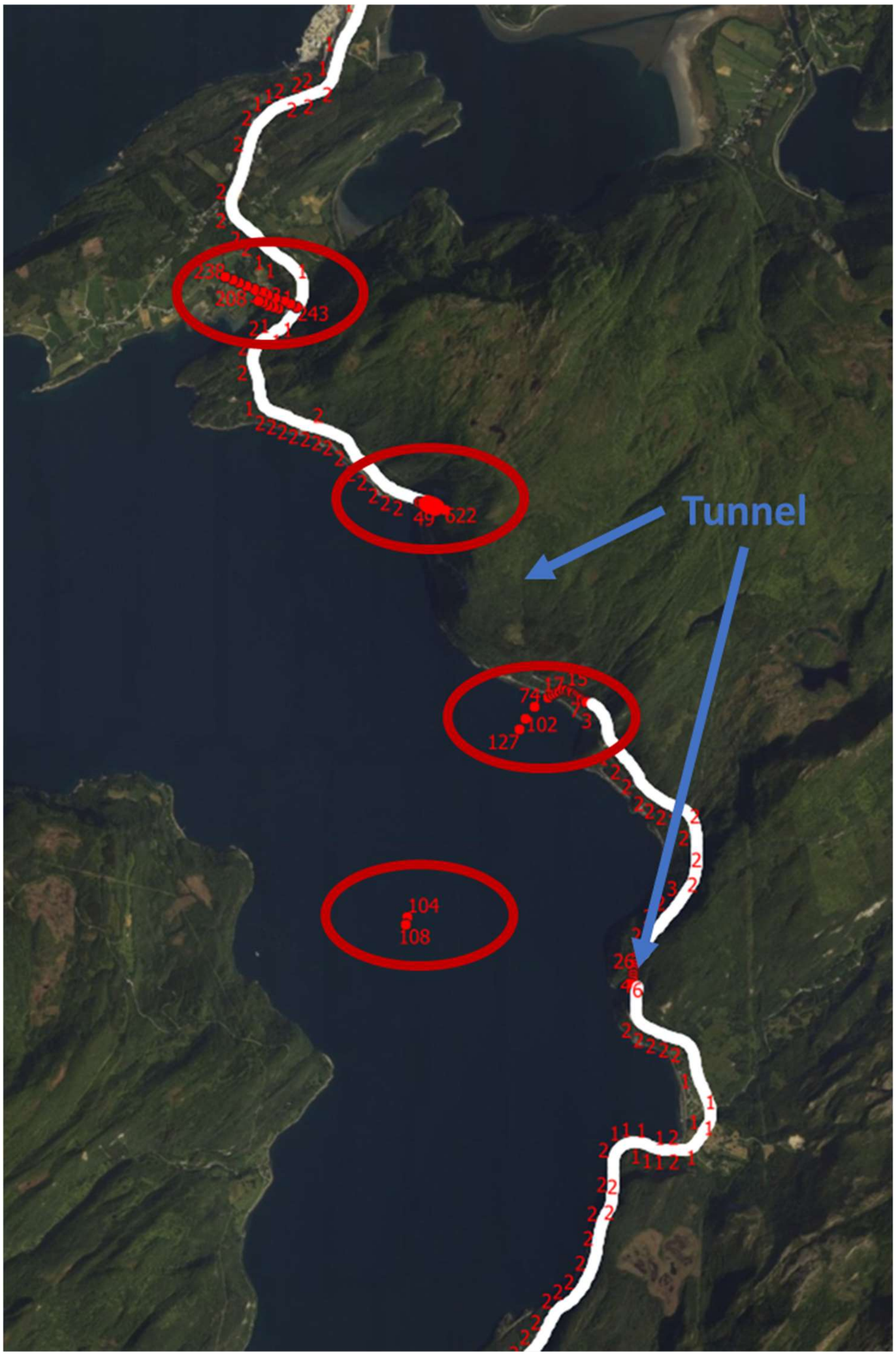


Figure 21 Position errors due to tunnels

Figure 21 shows the effect tunnels have on GNSS measurements. The example data is taken from the south of Fauske in the Northern Norway. The row of points is supposed to be in the tunnel according to the timestamps, this means that the unit has placed then about 2.5 kilometers off the true position. Another worrying issue with this is that the observations could be placed on totally different roads. Hence what happens when vehicles enter and exit tunnels is of great importance. To only have GNSS could create issues when entering or exiting tunnels. The use of GNSS with assisted by Inertial Measurement Unit (IMU) could be one way to avoid these errors. All errors where the GNSS believed itself to be off by more than 5 meters was in the vicinity of tunnels, this was true for all countries.

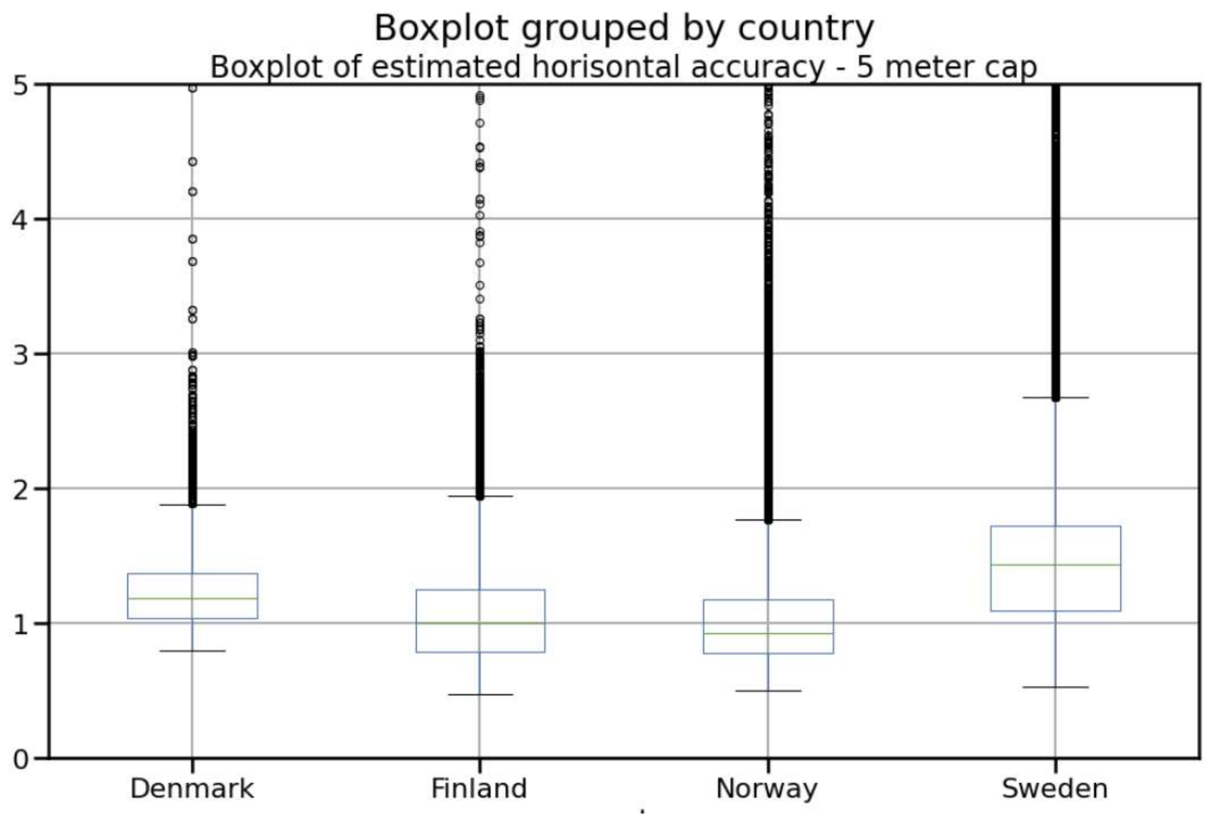


Figure 22 GNSS self-reported accuracy

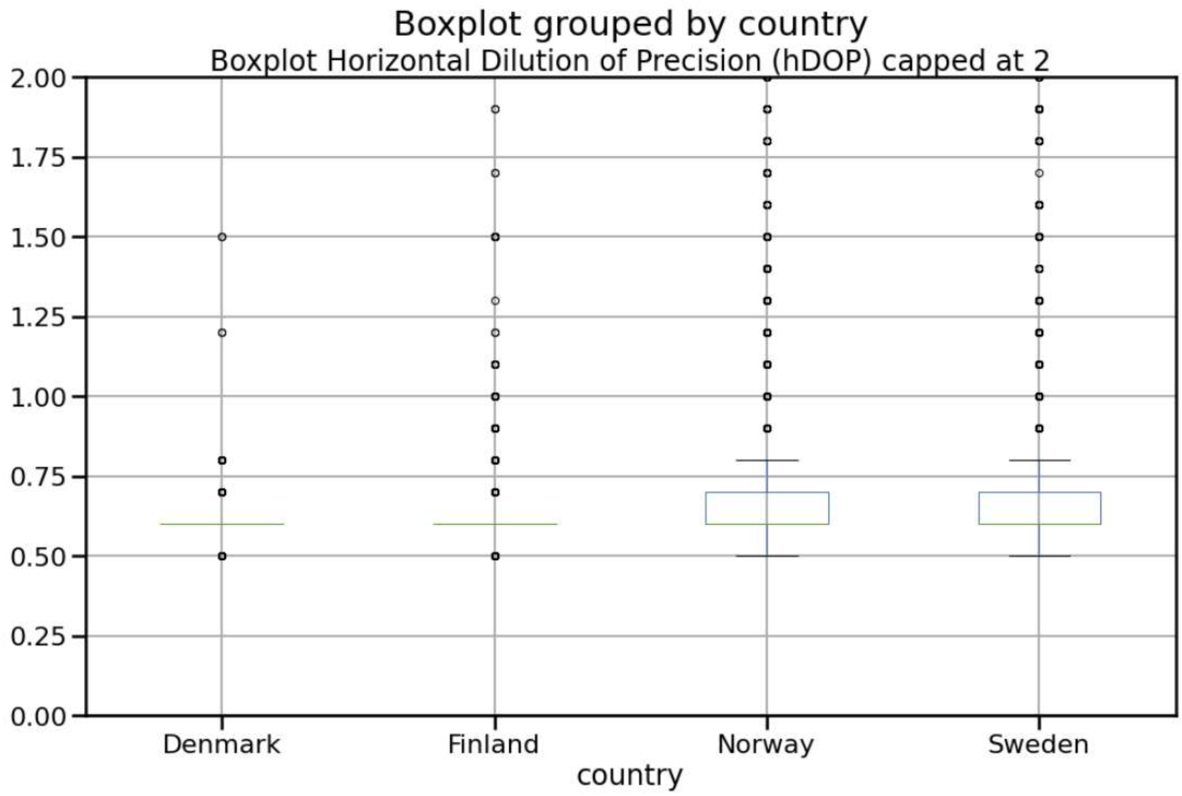
Figure 22 shows a boxplot of the GNSS receivers self-reported accuracy. It is rather interesting to note that accuracy in Norway has a smaller spread than in Sweden. This is very interesting since the topography should be more challenging. It is also surprising to note that Demark har a narrow spread of observations but a higher uncertainty. One plausible reason for this in the difference in speed observed on the main roads in the different countries.

Table 12 Median driving speed in the Nordic countries on the main roads

COUNTRY	MEDIAN SPEED
DENMARK	111.56
FINLAND	81.86
NORWAY	72.94
SWEDEN	98.75

Table 12 gives an indication that the self-reported error in the consumer grade GNSS is dependent on vehicle speed. Denmark has fewer datapoints (only one hour due to overheating USB hub). Sweden has the highest inaccuracy according to the GNSS. While Norway has the lowest in accuracy and the lowest speed on the main roads.

To confirm this, one can look at the Dilution of Precision (DOP). The median dilution of precision is 0.6 for all countries. But a box plot shows that there is a somewhat increase in hDOP for Norway and Sweden. The distribution in Norway and Sweden looks quite similar, but they show a clear difference in accuracy as reporter by the GNSS receiver.



When there was only GPS available one expected the quality of GPS to be reduced the farther north one got. This due to the fact that GPS satellites have orbital paths farther south on the planet. The GNSS receiver used use 2 systems, Glonas (Russian) and GPS (American). Our question was if this theory that precision will drop off the farther north one gets?

Table 13 Satellites seen and used by country

COUNTRY	SATELLITES SEEN	SATELLITES USED
DENMARK	25	19
FINLAND	23	19
NORWAY	21	18
SWEDEN	22	18

Table 13 shows that there is not a great deal of difference between the countries. 4 satellites are needed for a position fix. Just looking at the median is dangerous. A boxplot gives a bit more insight.

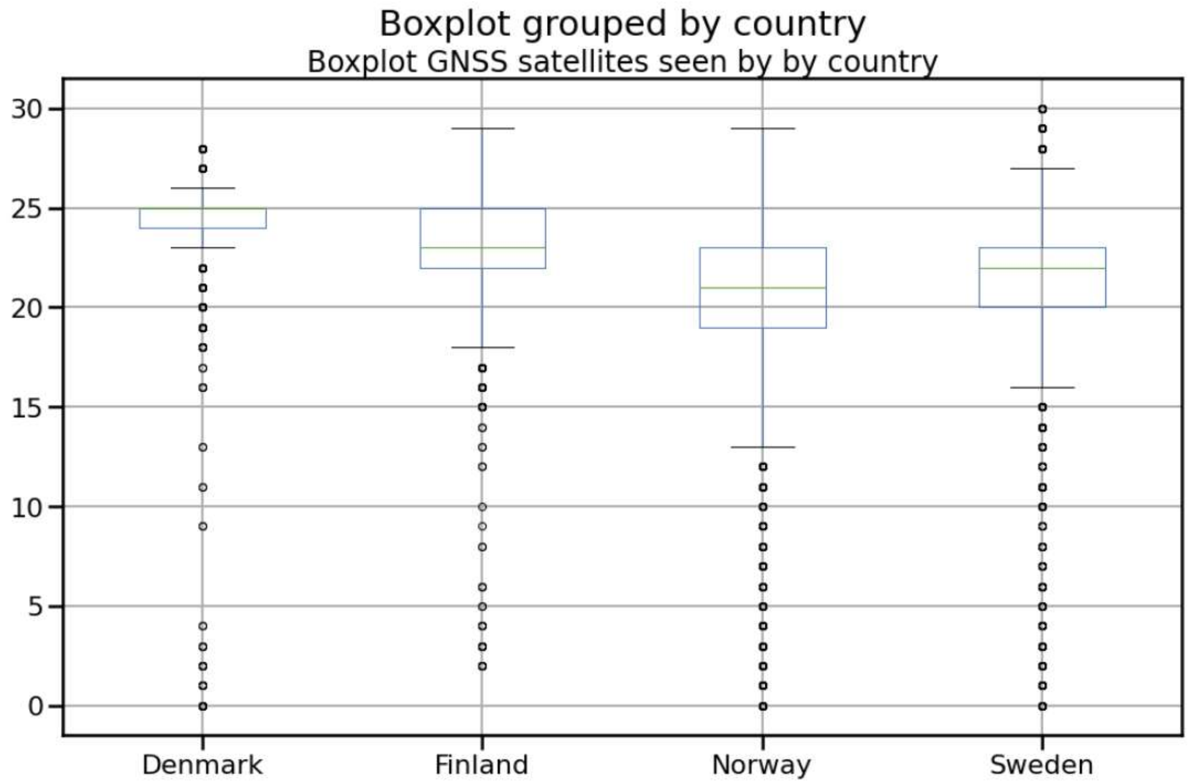


Figure 23 Boxplot satellites seen by country

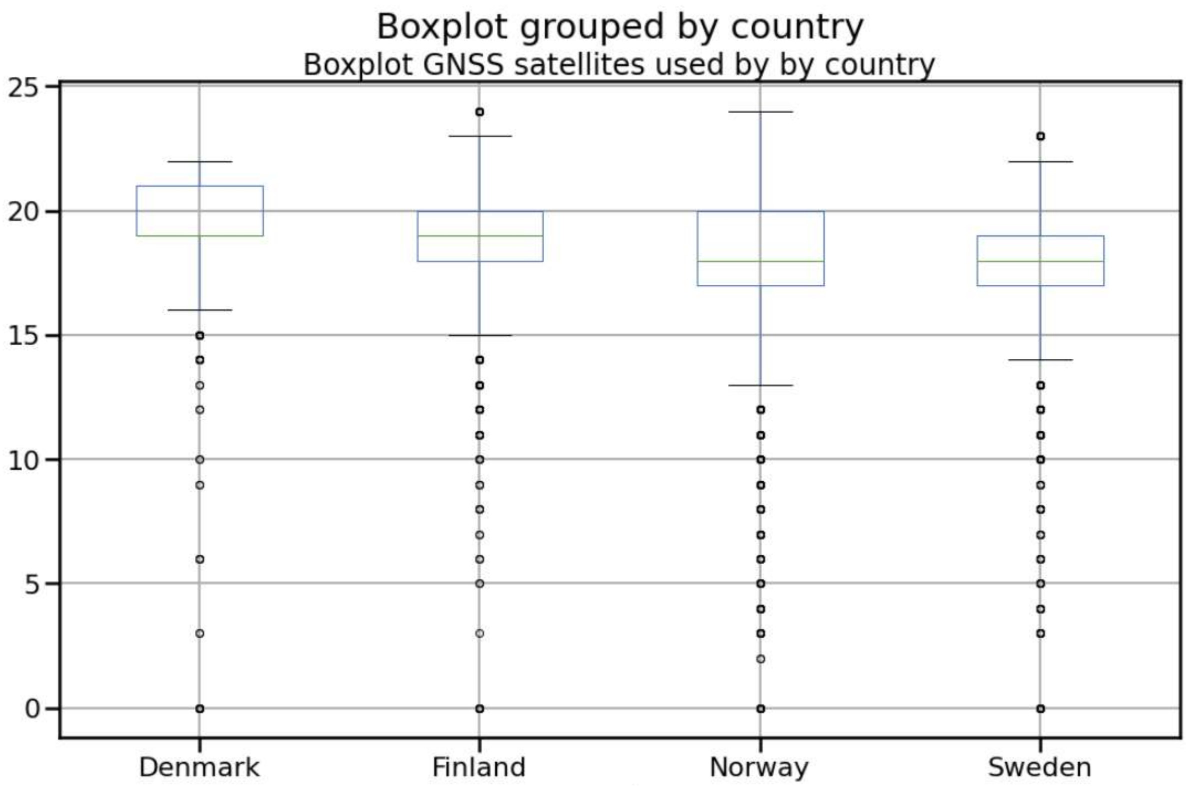


Figure 24 Boxplot satellites used by country

Figure 23 and Figure 24 do not indicate a great difference in the ability to see nor use satellites for finding one's location. There is more variability in Norway, but this is believed to be linked to the number of tunnels on the Norwegian network that is more than 10 times then in the other Nordic countries.

A last interesting perspective is to see if there is a relation between the latitude and number of satellites used.

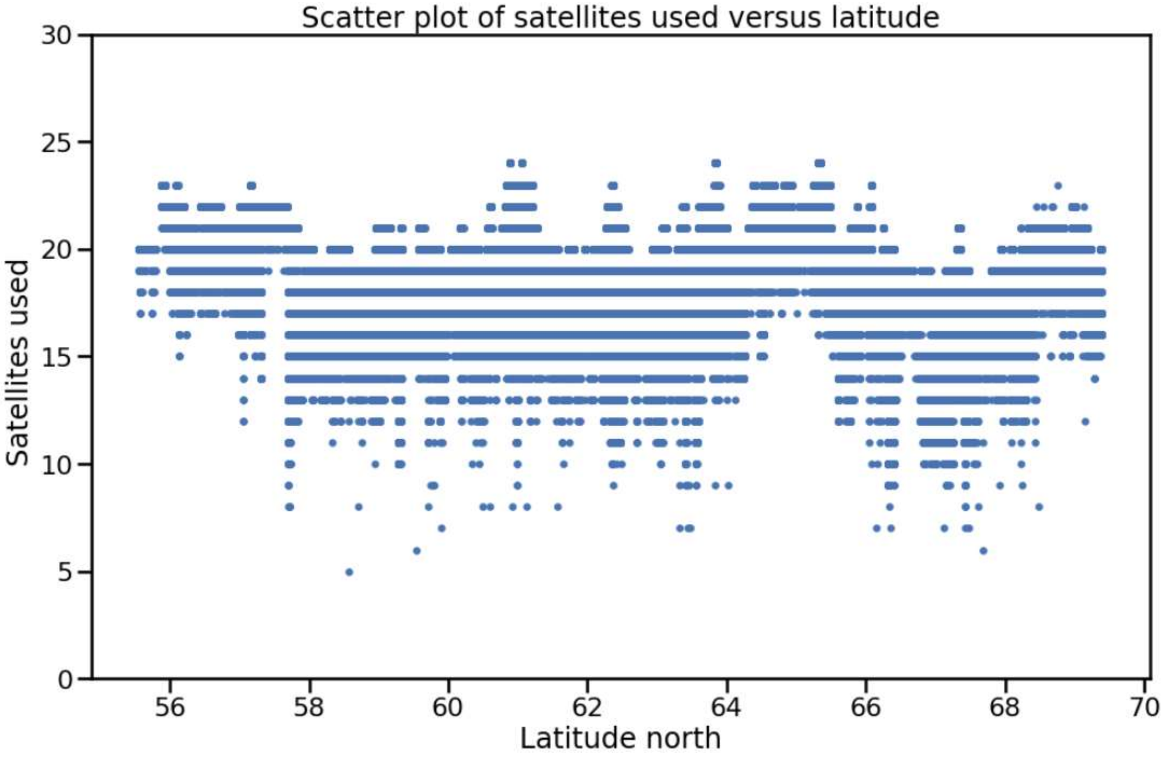


Figure 25 Scatterplot of satellites used versus latitude

Figure 25 shows that there is little or no correlation between the number of satellites used in calculating the position. The correlation between latitude and satellites used is -0.017. Hence for the NordicTour we cannot say that the inaccuracy increased in the north due to the visibility of satellites in the North. In the analysis, data effected by the tunnels were removed. If they were included the correlation would become somewhat stronger -0.04. But this also shows that there are more tunnels in the north of Norway than in the south.

3.2.1 GNSS signal interference

The GNSS receiver was set up to log the automatic gain control of the GNSS receiver. This is an indication of the strength of the GPS signal. This value should be rather stable and have slow changes. From past experiments and cooperation with the Norwegian Communication Authority (Nkom) we did not expect to see traces of jamming on the NordicTour. But looking at the data we were surprised to find 4 indications and one definite interference. The first observation was in Gothenburg on the roof of a parking garage. The video gives no clue to from where the interference came. The second observation was in Kilpisjärvi in the North of Finland, again the video gives no clue to the source, but the road at the point passes very close to the parking lot of the local store. The next observation was in Mo i Rana in Norway. This was an interesting one, we passed the same spot on two days and the same issue occurred on both days. This was in a roundabout on the E6 close to the parking lot of a shopping area in Mo I Rana. The final observation was on the E6 after Hamar in Norway. This time the video gives a good clue to what is happening.

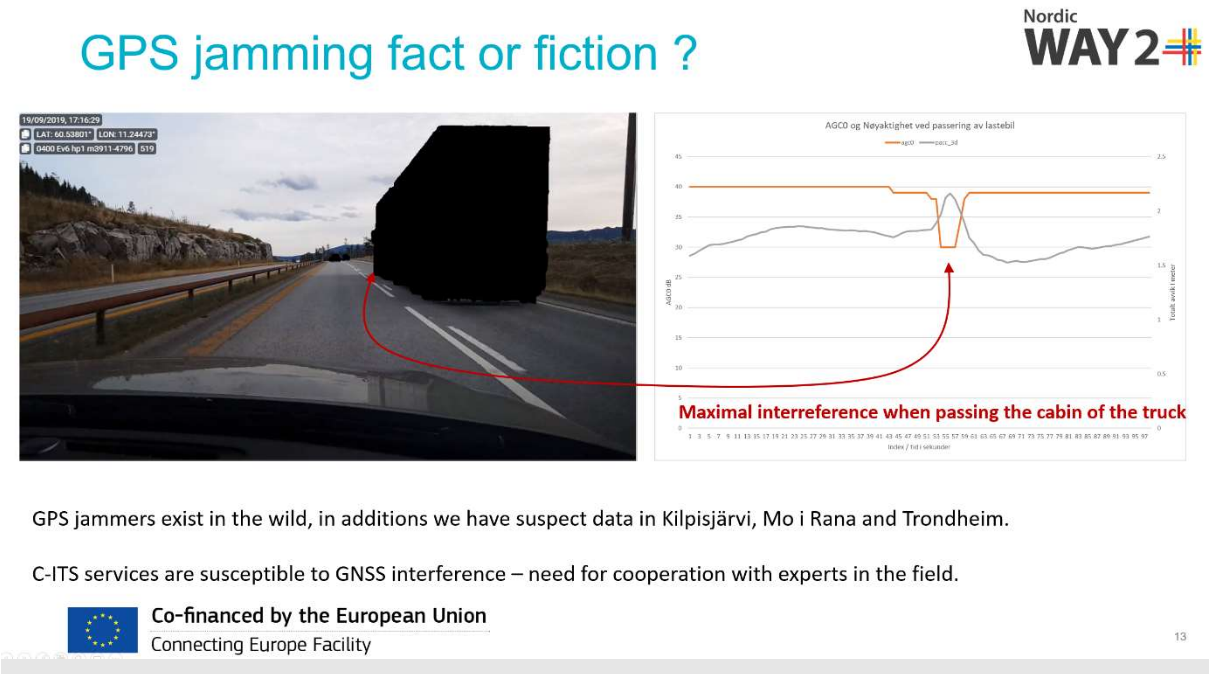


Figure 26 Slide from NordicWay 2 presentation given to the PMB

Figure 26 shows a frame from the video and a plot of amplification and the resulting gain in uncertainty inside the GNSS unit. The maximum level shown in the graph occurs when the test vehicle was just besides the cabin of the truck. It is hard to tell if the interference was intentional or unintentional. But at least it did not cause a loss of GNSS signal, just a degradation in position accuracy. But the data from the NordicTour gives indications that road authorities need to be aware of GNSS jamming and the challenges that come with GNSS jamming.

3.3 Human machine-readable infrastructure

A key trait of automated vehicles is that they need to be able to understand their environment. There are two ways of getting hold of the information they need, either via external sources or through local sensors. Some automakers create systems that are close to truly autonomous, where decisions during driving is made based on data collected by the vehicle. While other vehicle producers expect to use both external data and in vehicle sensors to navigate. The NPRA has tried to ask the OEM's which datatypes they need. But the willingness to share information on this from the OEMs seem to be too close to core business and hence the NPRA has not gotten a lot of feedback. But what is clear from several other EU project, for example Mantra[6], is that road markings play a significant role. To understand the issue, the NRPA conducted research together with Volvo Cars in relation to state-of-the-art ADAS equipment's ability to understand the road. These systems try to interpret the road and the edges of the road. Where it is believed that lane marking plays a major role. Another important aspect is to interpret speed limits, this is typically done reading speed signs. But in relation to speed signs the NPRA also has a database of the speed limits on the main roads in Norway. This database could be used by the vehicles to determine the speed limit.

3.3.1 Vehicle reading of lane marking – edges of the road

The vehicle was outfitted with a specific logging device to extract the data from the CAN bus. The data was then decoded by the OEM to get a human readable description of the signal received from the vehicle. This data was then merged with the other data sources that were collected by the vehicle and the sensors inside the vehicle. The video that sensors in the vehicle see are not available externally over the CAN bus. A better alternative to collecting the data from the in-vehicle camera was to use an external camera that was synced on time and location. Another benefit of using an external system is that the software for analysis and presentation are available with little effort.

[6] https://www.mantra-research.eu/

The data on the CAN bus has a higher frequency than the other data sources. A total of 15 258 894 observations were made. 13 235 435 of the observations were on the main roads in the Nordic countries.

Table 14 shows the total number of detections per country, there is a strong link between number of detection and the distance driven in each country. Table 15 show a more readable format. It shows that most of the time the vehicle can understand both the left and right limits of the road. More seldom can it only understand either the left or right. The results could be interpreted as: The vehicle is capable om understanding the roadway limits from 53 to 76 percent of the time. This is rather interesting, because it shows that the state of the art in production vehicles is quite good, better than expected. This could be partly because the NordicTour part 1 was under best case conditions with fresh markings after the summer remarking season.

Table 14 Absolute number of detections and type of detection by country

detection	0 - No detection	1 - Left	2 - Right	3 - Both
country				
Denmark	202429	25559	15990	755294
Finland	1053941	106704	268259	2468517
Norway	2084605	161175	350798	2885505
Sweden	868814	118935	224875	1644035

Table 15 Percent of detection type per country

detection	0 - No detection	1 - Left	2 - Right	3 - Both
country				
Denmark	0.20	0.03	0.02	0.76
Finland	0.27	0.03	0.07	0.63
Norway	0.38	0.03	0.06	0.53
Sweden	0.30	0.04	0.08	0.58

Another interesting observation is the great difference between the countries. In Denmark the vehicle was capable to understand the road 80% of the time/distance driven. In Finland the vehicle understood the road infrastructure 77% of the time and 70 percent of the time in Sweden. While Norway is in last place where the vehicle understood the road infrastructure 62% of the time. This was expected as the road infrastructure is quite different, with more narrow and twisting roads in Norway. This can be clearly seen in the 100x speed up video of the complete NordicTour (https://www.youtube.com/watch?v=JLgXyWqkOlk&feature=youtu.be).

A challenge when trying to compare between countries is to understand what one is comparing. There is a design limit of the system for detection of lane marking. The system does not output lane marking status when the speed limit is below 60 kilometres per hour. This is not surprising as such automated systems are mainly designed for highway and motorway use. But why does the system seem to work better in Finland than in Norway – Norway and Finland have close to the same population and land area. Part of the explanation lies in how the different Nordic countries build roads. Not the structure of the road but the routing of roads in relation to the country's topography.

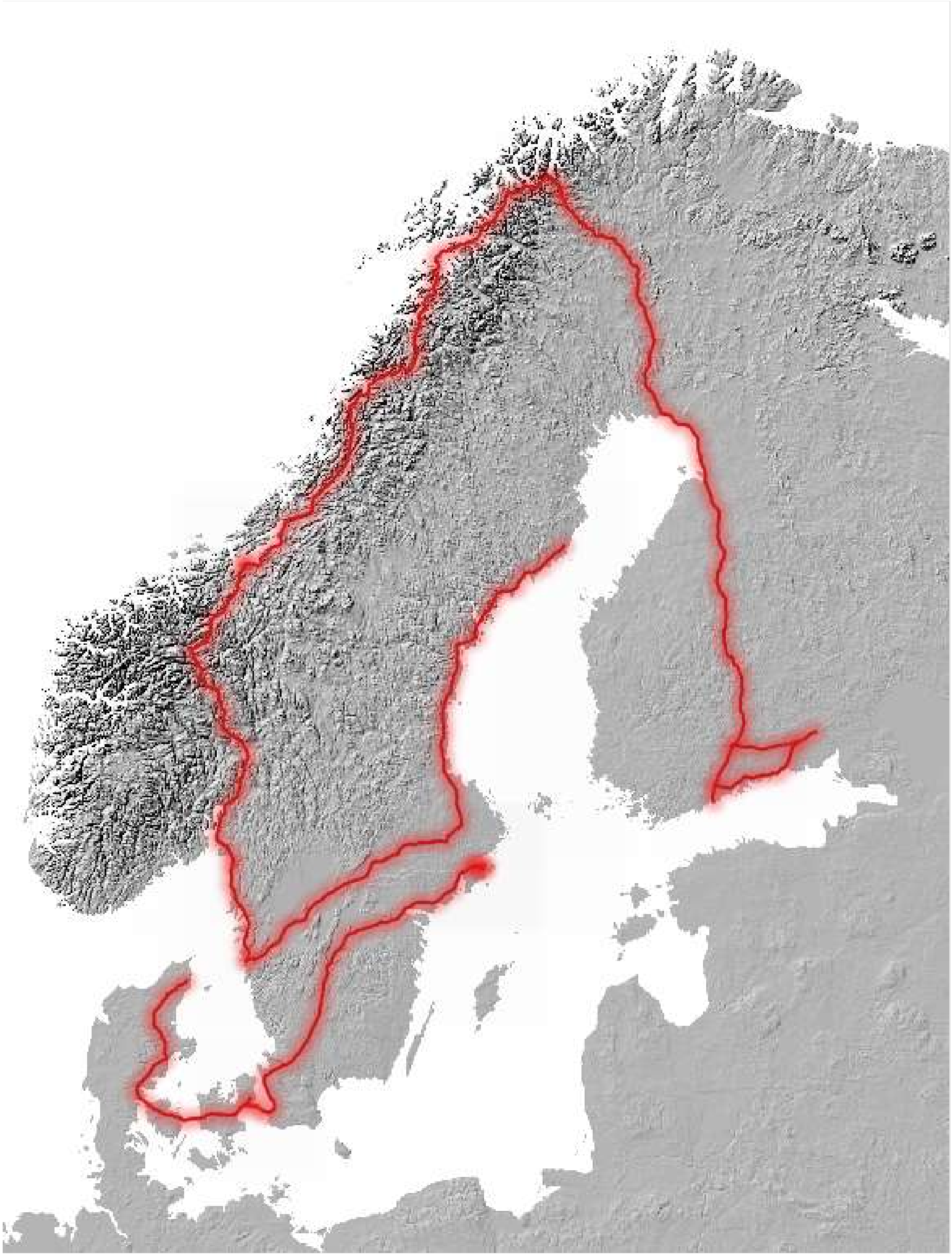


Figure 27 EEA Digital Elevation model with NordicTour superimposed

Figure 27 shows the NordicTour superimposed on a digital elevation model of Europe produced by the EEA. Each cell in this evaluation model is 1km x 1km. Hillshading of the digital elevation models gives a good impression of the terrain in the different countries. The routes in Denmark, Sweden, and Finland are on relatively flat terrain. Building roads in hilly terrain is challenging, it is a necessity to route roads to minimize the need to move earth and rock.

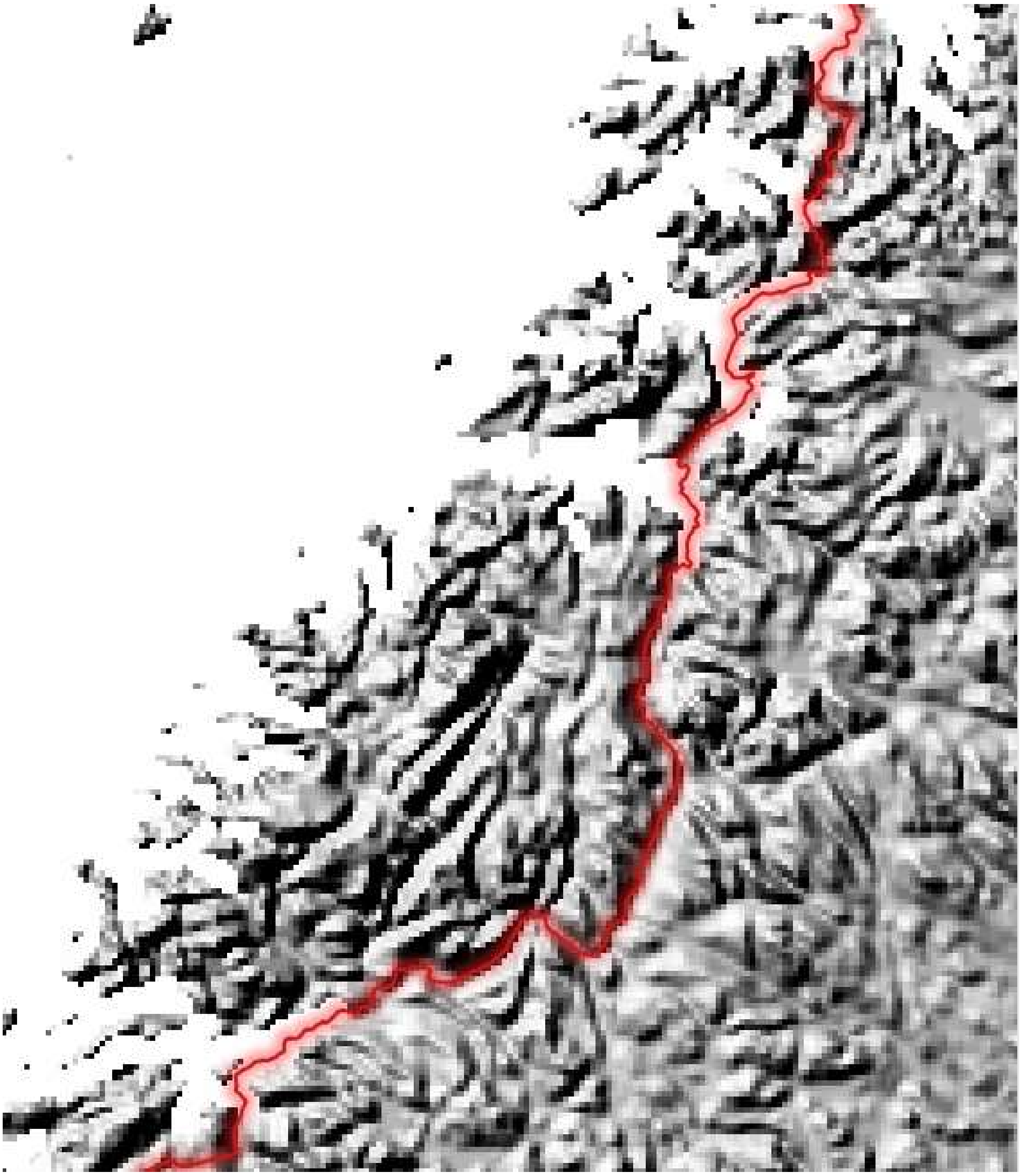


Figure 28 Zoomed in on route over Saltfjellet

Figure 28 shows how roads on a macro level follow the terrain, the area shown is Saltfjellet (A mountain pass) where one can see that the road follows a wide wally between to mountains in the pass and in the south the road follows the fjord. In addition, the main roads in rural Norway tend to go through the city centres, hence the speed on the main road drops to city speed regulation – 50 or 30 km/h. Table 16 shows that Norway has more 50 km/h areas than the other countries on the main roads, as seen in Table 16. Speed limit of 0 in the table is an indication that new speed signs have not been observed for a specific time. In the case of Norway when outside of a city the general speed limit is 80, but there is no sign to indicate that his is the case. Speed signs are for humans, you need additional knowledge to know what the speed limit is at certain parts of the road network. Hence a system only utilizing a camera will have a hard time – since in Norway it has to figure out if the scene captured is in a city or outside a city.

Table 16 Speed limits observed on the main roads driven

country	0	10	15	30	40	50	60	70	80	90	100	110	120
Denmark	54%	0%	0%	0%	0%	0%	2%	2%	4%	3%	0%	33%	2%
Finland	23%	0%	0%	1%	2%	4%	9%	1%	21%	0%	30%	0%	9%
Norway	46%	0%	0%	2%	3%	10%	7%	15%	6%	8%	1%	3%	0%
Sweden	26%	0%	0%	3%	8%	2%	2%	5%	10%	4%	15%	22%	2%

To understand these issues there is a need to go into the details and study specific areas where lane detection system does not understand the road infrastructure. Figure 29 shows a classic example with fresh paved road and no markings. It is quite normal that resurfacing takes place first and then the lane marking will get repainted later. Under real world scenario one has to take this into account, alternatively look into the standards and contracts to ensure the remarking is done immediately after repaving.

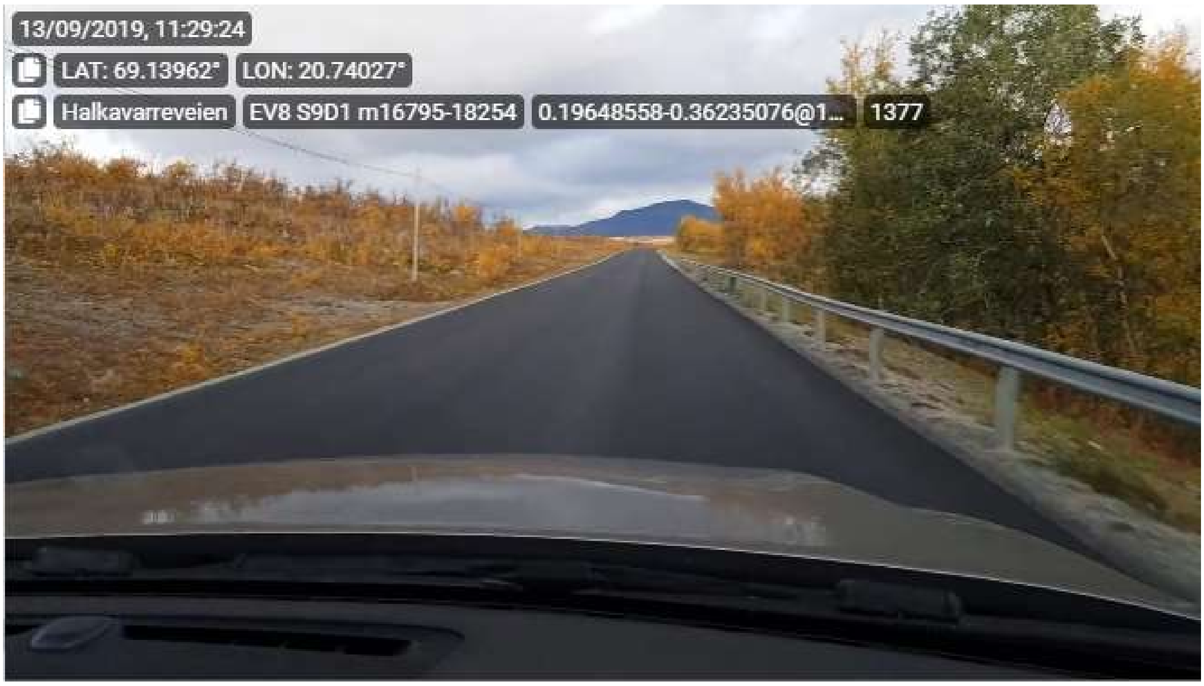


Figure 29 Fresh asphalt and no road marking

Figure 30 Hard left turn

Figure 30 shows another example where the vehicle no longer understands the markings. In the picture on can clearly see the markings, but the turn to the left is hard. This is also the reason for the chevron sign in the back. It will be very challenging or dangerous to try to take this turn with a speed close to the speed limit. These kinds of turns may not be within the operating limits of the system. There is a need for a dialogue between the OEMs and the NRAs to identify these issues. The issue of sharp turns also raises the question of whom is expected to set the safe speed in turns like the one above. The speed limits in Norway are not a recommended speed, but a maximum speed allowed. For summer conditions with ample friction, it is possible to calculate safe speed in advance, but how shall this be done in the future when algorithms take over the driving. Maintaining a specific friction level on the road network all the time will be very costly and hard to do.

Figure 31 Blurred area after asphalt works

Figure 31 shows another situation where the system has a challenge reading the markings. This is just before entering an area that has been repaved. Here one can see vehicles smudge bitumen from the fresh asphalt over the old asphalt including the lane markings. This happened several places where there was a transition. It should also be noted that there are no lane markings on the fresh asphalt. This raises the questions about how road operators conduct maintenance work. There will always be a need for road works in a road network. The NRAs have standards for how this should be done, the standards are designed with the human driver in mind. There seems to be a need to rethink these standards in relation to automated vehicles. What kind of marking is needed for automated vehicles in roadwork zones?

Figure 32 NPRA measurement vehicle with flashing yellow blinker on top

Figure 32 is rather interesting, the lane marking is quite visible, but the vehicle in front seems to confuse the system. The vehicle drives very close to the right edge marking. Another thing that is hard to see in the anonymized image is the yellow blinker of the vehicle. It is hard to say why the system does not detect the line marking, but it is probably linked to the vehicle in front. As soon as we pass the vehicle the system starts and finds the lane markings.

Figure 33 Pre-marking for lane marking

Figure 33 shows a stretch where the system is not able to detect the lane marking. The exact cause is hard to identify but compared to the stretch before and after, this stretch has pre-marking for lane marking. The pre-markings are the white spray-painted lines in the middle of the road in addition to yellow lines. Another cause could be the long vertical curve of the road that makes it hard to see the markings in the distance.

Figure 34 Lane merger with barrier in the middle

Figure 34 is rather confusing and shows the challenge of teaching these systems to understand the infrastructure. There is a single lane merging into the oncoming lane and due to the sharp curvature, there is a crash barrier in the middle separating lanes in the same direction.

Figure 35 Overtaking of maintenance vehicle and lane split in opposite direction

Figure 35 shows a maintenance truck on the right shoulder that masks out the right lane, the centre line disappears under the horizon and a there is a start of an extra lane in the oncoming direction. This is again a situation that occurs in real life which will make it hard for automated vehicles to interpret the surrounding. Norwegian road standards have sight and stopping distance requirements, but if these are obscured temporarily or the road is not built to standard then these issues will give problems.

Figure 36 Transition in centre marking, dual yellow to single yellow

Figure 36 shows another edge case that we have seen a few of in the data set. Here the dual yellow lines change to single yellow lines in the centre, but in addition there is pre-marking, wet roads and flat light. A human driver will probably be able to filter out the pre-marking, but the wet and flat road makes it hard to know what the marking is. A human driver will probably assume a kind of lane marking.

Figure 37 Short period of outage, probably reflections from sun on wet asphalt about 2 seconds

Figure 37 shows another type of pre-marking and freshly painted markings, fresh asphalt, wet conditions and plenty of lines in the picture. This is truly a hard scenario to identify lane markings. The period when the system does not detect the lane markings is short, about 2 seconds. Which is impressive when watching the video as it is hard to see the lane markings. The camera used for this video also has a polarizing filter to remove quite a lot of glare from the road surface.

Figure 38 Complex intersection with filter lane and separation between directions

Figure 38 shows another interesting intersection, here the oncoming lane is separated by and small area with grass, on the right there is a filter lane. The system is confused coming into this intersection, but as soon as the vehicle passes the intersection lane marking is detected again. This example shows that intersections can be built in many ways and that this makes it hard for automated systems to understand the areas in and around the intersections.

Figure 39 Wet fresh asphalt and water vapor from vehicles in front

Figure 39 shows a stretch with extreme sun glare and spray from the vehicle in front. Again, the system is not able to detect the lane marking for a short period (2 seconds).

Figure 40 Low light, wet asphalt and dry tracks (lines)

Figure 40 shows how the road dries, first the wheel track then the rest of the road. This causes plenty of lines in the picture, that can confuse the system. The duration of the system not being able to detect the lane markings was a few seconds.

Figure 41 Sharp left turn

Figure 41 shows a sharp left turn where the system did not understand the markings. There is a road going off to the right also. The number of chevron signs are a clear indication that this turn is sharp. This was the longest outage seen due to the infrastructure, 23 seconds in total. A map of the curve can be seen in Figure 42. The three red dots just before the turn onto the bridge was due to a small stop on the right-hand side of the road with missing marking.

Figure 42 Map of sharp left turn

Figure 43 Hairpin turn in 80km/h

Figure 43 is a curiosity of the Norwegian road network. On the E6 (main freight route from North to South in Norway) there is a hairpin turn where the speed limit is 80 km/h. In addition to reducing the speed enough to complete the curve the driver needs to turn his/her head 90 degrees to see if there is oncoming traffic into the curve. This example shows that even though NRAs have standards for building roads there are parts of the road network that will be outside the standard.

Figure 44 Road disappears due to vertical topography

Figure 44 shows a specific stretch of road with “rolling hills”, the vertical profile is such that the road disappears for a while. Whole vehicles will disappear from view as well as the road. Hence the traffic signs on this stretch says no overtaking. While the road marking says that one should take extra care when overtaking. Along this stretch of road there are 5 spots where the road disappears under the horizon so it's not possible to see the road markings.

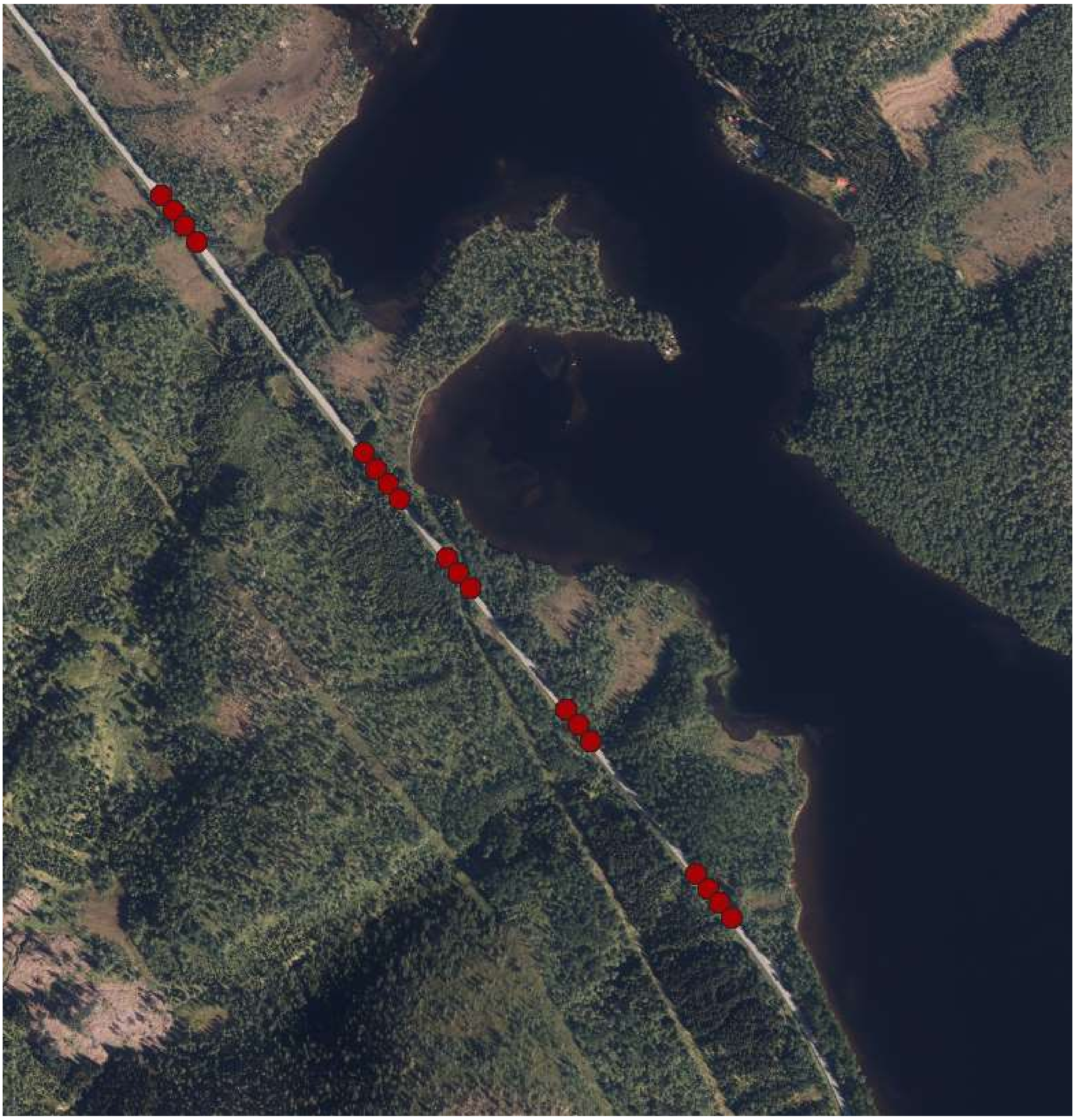


Figure 45 Section with overtaking prohibited due to lack of sight, last picture is from second zone from the North

Figure 46 Strange markings in Finland

Figure 46 shows an interesting view form Finland. There is a mix of yellow and white markings in centre. This is unusual for Norwegian human drivers. It is unclear if this is normal or not in Finland. In other parts of Finland, on comparable roads, the middle marking was white. This picture shows that NRAs have quite different lane markings and that this could potentially be challenging for automated systems. This again raises questions about standardization and the cost benefit of such standardization form NRAs.

Figure 47 Slush coverings up the right line and expansion to 2 lanes in same direction

Figure 47 is taken from the second part of the NordicTour. This is North of Umeå where there still was snow. Here the combination of going from one lane to two lanes in the same direction and snow makes it quite hard for the system to understand. Contrast under such weather conditions is also challenging and one can see that the snow on the right-hand side covers the right lane marking. There are quite a few examples like this on the second part of the NordicTour. A common feature for all areas where the system does not understand the lane markings is that the length of such an area is short. Typically, we see parts that are 1-2 seconds long where the system is not able to detect lane marking, but there are quite a few of them.

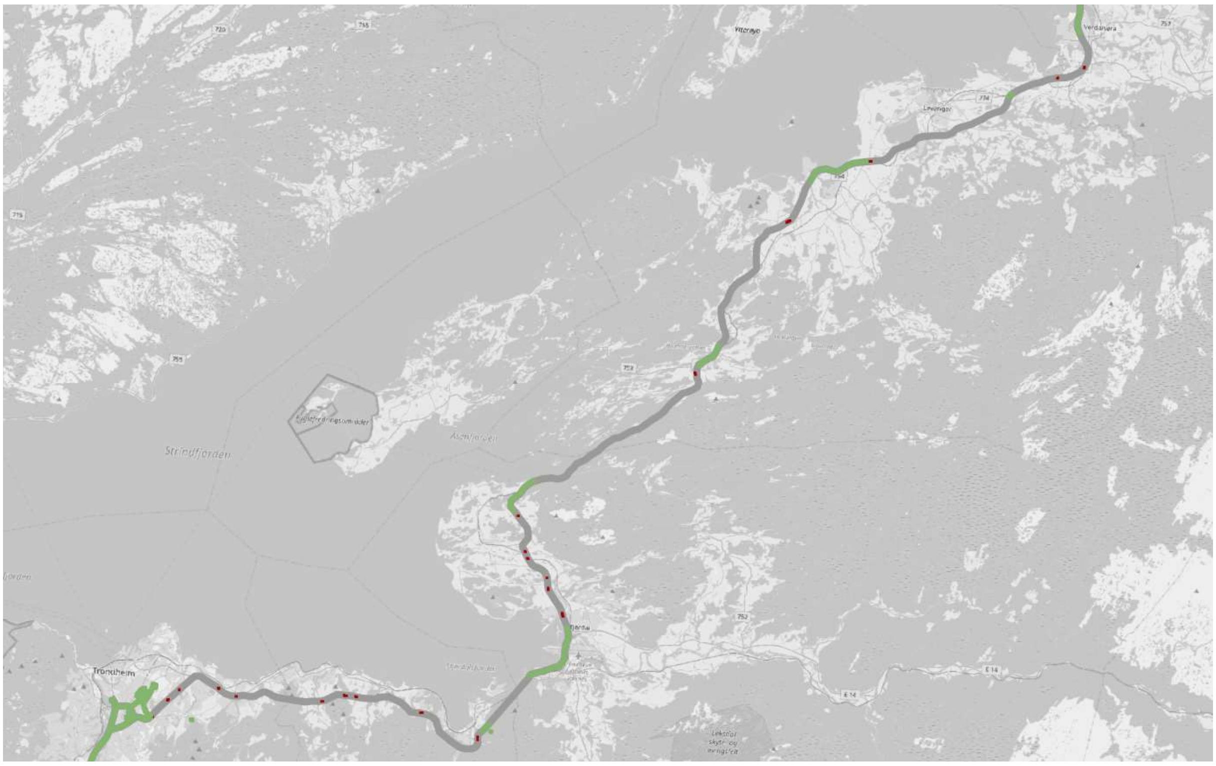


Figure 48 Spots with one hour of driving

Figure 48 shows one hour of driving from Levanger to Trondheim. The green areas are areas with speed limit 60 km/h or less. The data collected shows that lane markings are not detected when the speed limit is 60 km/h, or lower. While the red spots show where the system does not understand the lane markings. Here it is possible to see that the parts with red dots are small and of limited duration. In this picture there are 21 segments where the system is not able to understand the lane marking. On this map the typical incidents of where the system does not understand the lane marking is where there is no lane marking (the longest stretch is on a bridge with no marking, 8 seconds).

Another very specific issues in relation to lane markings is national differences. A specific case that we saw in the dataset was show merging lanes on motorways end. Form the video one can see that Finland and Sweden have the same system, where the white stapled line continues all the way across the merging lane at the end. While in Norway and Denmark, the stapled line stops when there is not enough room for a vehicle. In addition, Norwegian marking has double lines to the right, to tell driver do not change lane into the right lane when there is an entering merging lane on the right lane. These differences make it hard for the system to understand. Figure 49 Shows the end of a Norwegian merging lane south of Oslo while Figure 50 shows the end of merging lane in Sweden, just south of the border.

Figure 49 Norwegian end of merger lane

Figure 50 End of Swedish merger lane

Infrastructure interoperability and readability is challenging. The lack of common standards when it comes to infrastructure design is a big issue. It will not be easy nor without cost for NRAs to harmonize their infrastructure. But in I future where machine readability is becoming more and more important one must think of how to solve these issues. This is not a problem that NRAs or OMEs can solve on their own, it will require cooperation and sharing of knowledge about the capabilities of these systems. Without having access to research staff and equipment at Volvo Cars the NPRA would not have been able to build the needed know-how and knowledge. The challenge moving forward will be to ty to figure out whom can solve the issues identified in the most cost effective and future proof way.

3.4 Additional discoveries

On the NordicTour, other issues were also identified. One of them was signs that do not make sense or are complicated to understand. Figure 50 and Figure 51 show signs observed that make little sense. The first one tries to explain that there are different speed limits depending on time of day and the day of week. The second picture is a probably an issue with maintenance where two different signs are used.

Figure 51 Speed signs with time limitation

Figure 52 Different speed signs on either side of the road

The point of these two photos is to exemplify that there are small issues that can become big issues for automation. One thing is to have paper standards for how things should be done, but another is to deviate from the standards. In a machine-readable future, it will become increasingly important to adhere to the standards to ensure optimal usage of automation in the transport sector.

From an NRAs perspective this could potentially mean that there is a greater need to follow up the physical infrastructure to make sure it is up to standards. From a cost perspective it is not possible for NRAs to go out and monitor the whole network, at all times. Hence there is a need for a flow of data from the vehicles on the road to the NRAs or road operators. This can help in identifying issues that have to be fixed by maintenance crews.

4 Infrastructure state discovery

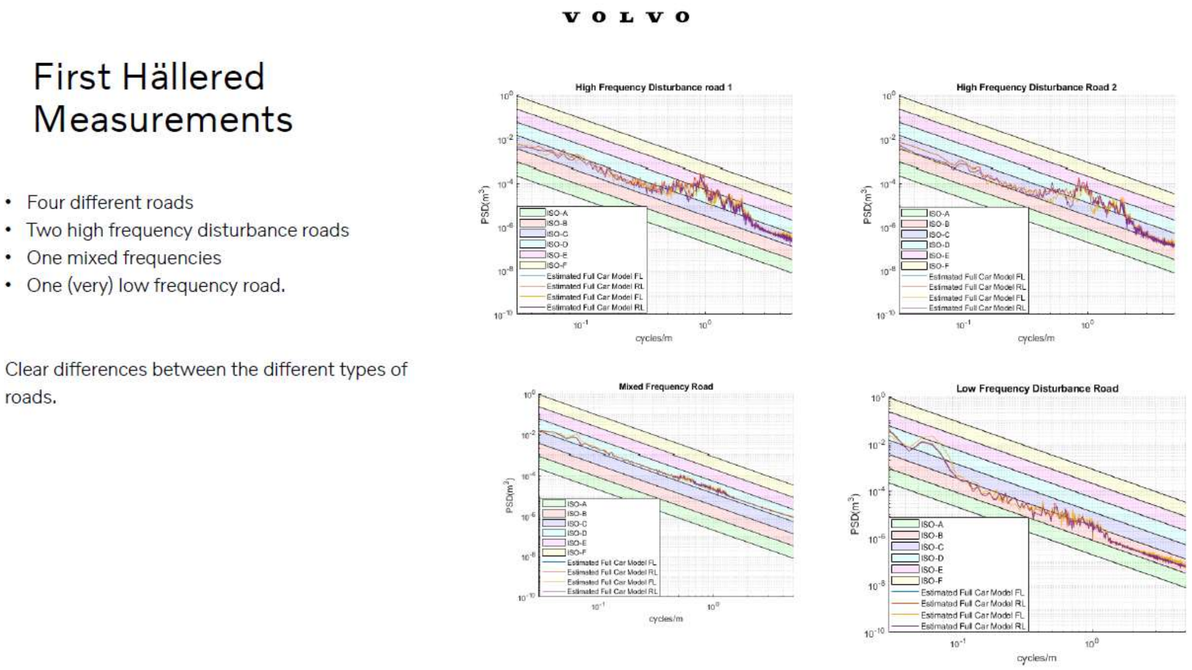
The vehicles that travel the roads everyday have a lot of knowledge about how the vehicles interact with the roads. In the NordicWay 1 project the NPRA explored how vehicles could inform about road friction. And in that project, one learned a lot about the capabilities of the vehicle to understand road friction. In readiness for automation a different challenge was endeavoured. This was detection of damages to the road and road surface. NRA's have big catalogues of road damages that are important for road operators. Automakers har issues with their vehicles being subject to road damages. Sometimes the road damages are so big that they can cause damage to the vehicle, on other occasions OEMs want the vehicles to have a smooth ride. The challenge with automated systems is the ability to detect the damages and avoid them. Or at least limit the number of vehicles that are subject to the same road damage.

Both road operators and OEM's are trying to do the same, detect damages and fix then, drive around for OEMs and fix the damages for the road operator. As both road operators and NRAs have a shared interest in the detection of damages, there should be grounds for cooperation. But cooperation and willingness to share data is not enough. There is a need to understand which kinds of damages can be found and which technology is best for detecting the damages. When damages are detected the NordicWay interchange is a suitable platform for exchanging information between the OEMs and NRAs. The technical maturity of the interchange has been proven; thus, the focus was on the data generation.

There are several ways of identifying damages, one is from cameras looking forward and the use of advance image processing. The other is to "listen" to the vehicle suspension. Fast deflections observed by the shock absorbers can give indications of damages that are there, but the vehicle is capable of handling them. While larger damages will cause the whole vehicle frame to shift.

Both systems were explored and shown to work. The experiments conducted by Volvo Cars showed that damages in the road could be detected by the system. In the experiment it was also showed that this will be possible with the computing power that will be available in automated vehicles. Hence the trained models for detecting damages to the roads will be able to run in normal production cars with automated driving functionalities. The biggest benefit of this is that the vehicles can generate events in relation to road damages. This reduces the amount of data that needs to be sent from the vehicle, and road operators will only receive data that is of importance. The original plan was to conduct and common data collection in Norway with following workshops. Covid-19 made this impossible, so another solution was found where the experiments were conducted at a test track with ground truth data and on open roads with challenging conditions. Then the results were discussed in online workshops.

The other way of detecting damages is looking at the shock absorbers and deflection of the vehicle body. Using the shock absorbers is comparable to the traditional way NRAs monitor road surface deterioration using the International Roughness Index (IRI). The IRI is calculated using a quarter car model, this was explored in addition to the creation of a full car model. The continuous road profile estimator was further developed, extended from ¼-Car model to full car model.



The results are promising and showing that the vehicle can produce a continuous profile that can be classified into the ISO 8608. The ISO 8608 specifies a uniform method of reporting measured vertical road profile data for either one-track or multiple-track measurements. A full car model will provide for multi tracks.

The piloting of detection damages to the road works, and results indicate that there could be a possibility for road operators to source data on road damages from vehicles. Both damages stemming from the vehicle platform and vision data could be collected and shared in future vehicles. For these methods to work with production cars there is a need for more computing power than what is already in the vehicles today. The advent of automated driving vehicles could solve this issue as AD requires a lot of computational power.

5 OEM data exchange

On behalf of Statens vegvesen, co-financed by the CEF of the European Union, KPMG has conducted a research on data sharing in the automotive industry. This study seeks to discover how ready the automotive industry is to share data with road authorities, which can be broken down into 4 groups of questions:

- What data is useful for OEMs?
- What data is useful for road operators?
- Which technological solutions for data sharing of vehicle data exists?
- How to share incurred costs for data sharing?

The key findings from the report are as follows.

1. The value of data increases exponentially

The value of data is expected to reach USD 450 to 750 billion by 2030. This is driven by the use and can provide new opportunities in several different industries.

2. Car manufacturers are increasingly positive about sharing data

In 2019/2020, there was a change in their attitudes and several car manufacturers began to enter into agreements with third parties. Nevertheless, they have yet to experience successful uses for new revenue streams.

3. The authorities take an active role in enabling data sharing

In several European countries, authorities are taking a role in enabling data sharing, with the aim of improving traffic safety, traffic flow and sustainability. For example DGT 3.0, which is a connected vehicle platform in Spain, will support their zero vision: zero fatal accidents, zero injuries and zero emissions by 2050 - in line with the EU's Vision Zero.

4. Consortiums work with data sharing in the automotive industry

Several different consortia work with data sharing across different stakeholders, car manufacturers, authorities and technology companies. One of these is the Data Task Force, which since 2017 has worked to enable data sharing associated with Safety Related Traffic Information. Now they want to move on to also look at commercializing other data sharing.

5. Technology companies are taking a stronger position

Both start-ups and companies with a long tradition in the industry are taking an increasingly strong position in the automotive industry. These help enable data collection, data aggregation and data sharing in the industry, with several different approaches. Big Techs has also worked for a long time for entry into the industry, and is now starting to gain a foothold.

The full report is available at: https://home.kpmg/no/nb/home/nyheter-og-innsikt/2020/11/automotive-data-sharing.html

6 Key findings

To prepare for automation the NPRA has focused its efforts in relation to three services:

- Communication
- Positioning
- Human / machine-readable infrastructure

These areas are seen as the ones where NRAs have to take an active role to ensure the performance of these systems. In Norway the Norwegian Mapping authority is the authority in relation to navigation and positioning service. When it comes to communication it is the Norwegian Communication authority that has the regulatory powers. The NPRA has taken the role of building a common understanding of the challenges facing all three authorities in relation to automation of the transport sector. Long mapping activities with industry involvement is key to getting trustworthy and accurate data on the different services.

When it comes to communication the Nordic countries have a god coverage as the table below shows.

Here we have divided the road network into 400-meter segments and calculated the number of segments having at least on observation on them. That does not mean that you are able to communicate on the 400-meter segment, but that there is a change at atleast one spot on the 400 meters where one can make a call.

	Modem	Tablet	Phone	Roof
Denmark	99,4	99,0	100,0	100,0
Finland	100,0	99,9	99,5	99,5
Norway	97,1	96,8	98,0	98,2
Sweden	99,7	99,7	98,3	96,8

All figures are consistently in the high 90's. Since there is no weighting of the strength of the signal it is not possible to see the difference between equipment with antenna on the inside and outside. For 4G this was tested and there is a significant difference in the placement of antenna. It's quite clear that retrofit equipment need to think about antenna placement.

When it comes to GNSS the outlook is quite positive. The problem with a lack of available satellites up north is gone. There was no significant difference in available satellites for positioning in latitudes ranging from Copenhagen in the South to Tromsø in the North. The most worrying aspect when it comes to GNSS is the challenge with infrastructure, for example tunnels. Entering or exiting tunnels is the prime cause of GNSS errors. This could be solved with inertial navigation units connected to the GNSS receivers. This will be a must for ITS G5 applications to work in tunnels or in the vicinity of tunnels. GNSS is also susceptible to interference. NRAs should monitor GNSS disturbances as most C-ITS services are dependent on GNSS. Without GNSS C-ITS services quickly lose their value to the traveller. As most of the GNSS issues where related to tunnels there is a need for support to the GNSS systems. Dead Reckoning should be tested out to see if this helps with the issues with tunnels. There are GNSS modules that include this to make more robust GNSS location estimates.

Interoperating the infrastructure is a challenge, the success depends on two factors, the quality of the algorithms and equipment used by OEMs and the multitude of road operators' solutions. One way to move forward is to enhance the cooperation between the road operators and manufacturers of automotive equipment or vehicle. Both actors have a common interest, even if it is expressed differently. Mainly that both actors want the travellers to reach their destination safe and sound. Traffic safety is a common goal, but OEM's may also worry about driver comfort and good experience with the systems they provide in the vehicles. While NRA and road operators have a focus on reducing traffic accidents. Automation has the potential to serve both NRAs and OEMs hence closer cooperation is needed. The challenge is that one needs to work with the complete set of OEMs at level that lowers the efforts and cost of all parties to increase traffic safety. Sharing of data and building common datasets can be one way to move forward. This allows for sharing of information about what different systems find hard to understand regarding the infrastructure. But it also opens the possibility for NRAs to build datasets than can help all OEMs to build systems that cater for more of the differences observed in relation to road infrastructure. The NRAs also have a need to focus on their internal processes to generate high quality data to the vehicles. As seen on the NordicTour there were issues with the quality of roadworks data and sign data. Here the internal processes at the NRA level should be reviewed based on that the first indication tells us that automation will function better if data quality is better.

As pointed out in the last paragraph, data sharing between OEMs and NRAs will be of increasing importance. This is the only way to see both sides of the problem. But OEMs also have the possibility to help share data in topics outside of their primary domain. In this project we tested with sharing of data in relation to road quality and damages. For automation to be successful there is a need for the vehicle to know in advance if it is likely that the vehicle can finish the trip. For example, sending your kids with no driver license to visit their grandparents. This requires quite a lot of information on the state of the road. In Nordicway 1, Norway focused on friction. In Nordicway 2 the focus has shifted to damages in the road surface. This problem is one that can be seen by the vehicle or felt by the vehicle. NRAs typically use expensive data acquisition trucks to collect this type of data. To some extent additional sensors like lidar is used to generate data that can be used to simulate what a vehicle feels (IRI modelling). An alternative is to ask the vehicles what they actually see and feel, and to process the data in the vehicles so that only events are sent to road operators. This was explored and both seen and felt data can be observed by the vehicles. But there is a need to increase the computational capacity of the vehicles to generate the events. The advances in automated driving are likely to produce generic hardware that can increase the computational capability as well as process data for road operators.

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