Finnish Transport Infrastructure Agency

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Annex to the FTIA publication 21/2021

Automated Driving on Motorways (AUTOMOTO)

Compilation of working reports of the subtasks

Co-financed by the Connecting Europe Facility of the European Union

Content

Working reports of the subtasks for the FTIA Publication 21/2021; Automated Driving on Motorways (AUTOMOTO)

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Task 1.4 Weather conditions, 28 pages.

Task 1.5. C-ITS and other mobility services, 38 pages.

Task 1.6 Infrastructure data collection, 31 pages.

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Working report
6/5/2021

Service level framework for automated road transport

Task 1.1 Physical infrastructure, traffic management and traffic conditions

Co-financed by the Connecting Europe Facility of the European Union

Service level framework for automated road transport

Task 1.1 Physical infrastructure, traffic management and traffic conditions Working Report

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Annexes Physical infrastructure attributes on E12 between Helsinki and Tampere

1 Goal of the Task

The overall objectives of the project ”Service level framework for automated road transport” for the Finnish Infrastructure Agency were to

- assess the feasibility of the selected motorway section (Highway E12 between Helsinki and Tampere) for the automated operation of SAE Level 3 and 4 automated vehicles
- propose a way to classify Finnish road network from the automated vehicles operations’ point of view, i.e. propose a framework for service level classification for automated vehicles
- prepare a proposal for further actions in research- and development work, as well as in international cooperation.

This report describes the methods and results of a task of the afore-mentioned project focusing on the physical infrastructure, traffic management and traffic conditions related attributes of the Operational Design Domain ODD of highly automated vehicles. The attributes were selected based on a list provided by the projects EU EIP and MANTRA (Kulmala 2020).

The objective of this task was to detail the available data from the data bases and registers of the Finnish Transport Infrastructure Agency and Fintraffic on:

1 Static data on physical road infrastructure and its equipment
2 Road infrastructure condition data
3 Road and winter maintenance service levels
4 Real-time data on traffic and incidents
5 Historic data on traffic and incidents
6 Traffic management related data

The work was carried out via an inventory of the data bases and then producing an Excel workbook containing the values of the different ODD-related attributes along the E12 from Helsinki to Tampere on carriageway 1, and from Tampere to Helsinki on carriageway 2 of the motorway.

The results are usually provided as the values obtained from the data bases. There are inaccuracies, however, and some of them have already been dealt with in the task. Such actions have been described later in the report. The quality of the results and the actual values of many of the attributes were also checked in another task of the project focusing on field measurements of the physical infrastructure using an instrumented vehicle. The results of this task have been reported by Äijö et al. (2021).

2 Methodology

2.1 Data organisation

The data was compiled into an Excel workbook as stated earlier. The data is organised in homogeneous road sections so that a new section starts always when the value of at least one of the attributes changes. Spot-oriented attributes such as junctions and traffic signs are registered as sections with the length of 0 m. The locations are coded as a road address containing of road number, road section number, distance (m) from the beginning of the road section.

2.2 Physical infrastructure

The analysed road datasets were downloaded from Finnish Transport Infrastructure Agency's open data service: https://julkinen.vayla.fi/oskari/?lang=en. The service also includes a metadata description from all the road data objects.

Loaded dataset included road objects from the Helsinki ring road 3 to south of Tampere's southern causeway (European road E12, road parts 103 – 135). Unnecessary data objects from the perspective of this study was removed from the dataset and road object data was aligned by road address from both driving lanes separately by using QGIS and Excel. Data includes following road objects: speed limit, width of carriageway, verge width, road lighting, fences, road type, type on pavement, winter maintenance class, average bearing capacity, barriers, rest stops and traffic signs.

2.3 Traffic management and information services

Information and data related to traffic management and information services have been gathered by the following methods:

- Variable message sign locations have been determined based on FTIA (Finnish Transport Infrastructure Agency) road register, Fintraffic traffic situation service and traffic management system layouts. The features of VMS have been checked by interviewing Fintraffic experts by phone, e-mail or video call.

- Data on traffic monitoring devices (cameras, road weather stations, induction loop measurement devices) and their features have been gathered based on a device list received from Fintraffic and by interviewing Fintraffic experts. The detailed features of road weather stations were checked from the Fintraffic Extranet.

- Features related to traffic management IT systems, interfaces etc. were gathered by interviewing Fintraffic experts.

2.4 Traffic condition and event information

Traffic volumes and percentage of heavy vehicles determined based on FTIA traffic volume map service. Amounts of accidents leading to personal injuries were gathered from FTIA'S safety impact assessment service TARVA MT.

Traffic conditions were estimated based on the traffic fluency reports based on induction loop based monitoring stations. These reports were printed from FTIA Extranet's ”Tiira” service.

The rates of different kind of events were estimated based on traffic announcement, road work message and contractor measures request data from 2016-2020. The data was received from Fintraffic.

3 Results

3.1 Physical infrastructure

The customized dataset with comments and explanations was exported to Excel workbook. The results of the inventory with regard to different attributes are presented in Annexes 1 - 4.

3.2 Traffic management and information services

3.2.1 Systems and services

The E12 motorway section from Helsinki ring road III to Tampere southern ring road comprises a number of traffic management (TM) systems, devices and services. These are listed below in the order of location starting from the ring road III and ending in Tampere.

Traffic management system Helsinki ring road III –Klaukkala (11.5 km)

The system contains following VMS types:

- variable speed limit
- text and warning sign
- park & ride sign

The system also includes the following traffic monitoring device types:

- pan/tilt/zoom CCTV camera
- road weather station
- induction loop measurement device
- specific purpose induction loop device

The VMS are controlled based on real time traffic and road weather data. The park & ride VMS were not in use in Spring 2021, because the parking lot operator does not distribute data to the traffic management system. The specific purpose induction loop devices are neither so far not integrated with the current traffic management system. The overall system is integrated with and controlled by the centralized traffic management system T-LOIK. All devices are connected to the system logics by fibre optic connection. The system is being extended about 10 km towards north. The extension will be ready at the end of 2021.

Travel time information service (19 km)

The system extends from Helsinki ring road III to Nurmijärvi intersection.

- Travel time information is gathered for operative traffic management use.
- The service is acquired from a private service provider. The travel time information is gathered by Floating Car Data (FCD) technology. No roadside devices.
- The current contract is valid until the end of 2021. No decisions have yet been made about its future.

Traffic management system Hämeenlinna tunnel (2.5 km)

The system includes the following VMS device types:

- variable speed limit
- speed limit and warning sign
- text and warning sign
- full-text VMS
- prism displays for lane guidance

The system contains the following traffic monitoring device types:

- pan/tilt/zoom CCTV camera
- road weather station
- induction loop measurement device
- specific purpose induction loop device

The system also includes remotely controlled traffic signals and traffic barriers. The VMSs are controlled based on real time traffic and road weather data. Slow vehicles are detected by induction loops. In addition, there are control sequences for fire alarm and lighting fault situations. The system is controlled by a separate traffic management system specific user interface. All devices are connected to the system logics by fibre optic connection. The replacement investment evaluation for the current traffic management system will take place in 2021 or 2022.

Traffic management system Lempäälä-Tampere variable speed limits (12 km)

The system includes the following VMS device types:

- variable speed limit

The system also includes the following traffic monitoring device types:

- pan/tilt/zoom CCTV camera
- road weather station
- induction loop measurement device

The VMSs are controlled based on real time traffic and road weather data. The system is integrated with and controlled by the centralized traffic management system T-LOIK. All VMS are connected to the system logics by wireless mobile connection. The replacement investment evaluation for the current traffic management system will probably take place in 2021.

Tampere traffic information system

One text and warning sign VMS on the carriageway towards north. The system includes also other VMS in Tampere region outside the review area of this project.

Monitoring devices

Traffic and weather conditions are monitored also on road sections that are not managed by any traffic management system.

- CCTV cameras are used for traffic and road weather monitoring.
- Road weather stations provide traffic management centres, contractors and road users information about weather conditions on the road. The devices are usually located in places known as either challenging or representative.
- Induction loop measurement devices collect traffic data for statistical purposes. Real time traffic volume and average speed data are also available for traffic management centre and as open data.

3.2.2 Technical features

Variable message signs

The communication between traffic management systems and VMS devices is constantly monitored. The message or display that is currently shown in VMS is updated within 1 to 5 seconds after the control measure has been selected in the traffic management system.

The brightness of the VMS is adjusted by pulse width modulation. Infra-red LEDs are commonly used for VMS heating. This might affect how well the VMS display is machine readable by vehicle cameras. The pulsating rates of the current VMS signs are not known because no requirements have been set to the feature so far and the feature is not mentioned in the VMS technical specifications either. According to the manufacturer, the new VMS signs that will be acquired to the Helsinki ring road III – Klaukkala traffic management system expansion will have pulsating rate of 275 Hz (range 220 Hz – 320 Hz).

VMS signs on the E12 motorway section are presented in Excel workbook and Annex 5.

CCTV cameras

All roadside CCTV cameras are heated and provide pan, tilt and zoom functionality. The cameras are controlled remotely from the traffic management centre (TMC). The TMC has access to the real time video stream from the cameras. The newer cameras have HD resolution, while the older ones have SD resolution. The cameras are listed in the table below.

CCTV cameras on the E12 motorway section are presented in Excel workbook and Annex 6.

Road weather stations

The road weather stations have road surface and optical sensors. Data transmission interval of the weather stations which are part of a traffic management system is 5 minutes. Other stations send data every 5 min or every 10 min depending on the station. Some weather stations have sensors on both carriageways while some only on a single carriageway. The stations are listed in Table 4.

The Road weather stations measure following parameters

- air temperature (°C)
- road surface temperature (°C, separately for each driving lane)
- ground temperature (°C, 6 cm below road surface)
- dew point (°C)
- relative humidity (%)
- rain and its appearance (water, snow, sleet)
- 30 s precipitation (mm)
- visibility (m)
- cloudiness
- friction value
- wind speed 10 min (m/s)
- wind direction 10 min
- maximum wind 10 min (m/s)
- sun risen or not
- ice frequency on road surface
- humidity on road surface (mm)
- salt on road (g/m2)
- salt concentration on road surface (g/l)
- water accumulation on road (mm)
- snow accumulation on road (mm)
- ice accumulation on road (mm)

Road weather stations on the E12 motorway section are presented in Excel workbook and Annex 7.

Induction loop measurement devices (LAM points)

Measurement stations have induction loop sensors on all driving lanes. The devices measure the following parameters from every vehicle:

- date and time
- driving direction
- driving lane
- speed
- length of vehicle
- time gap between successive vehicles
- vehicle type.

The vehicle type is defined based on the following categories:

- motorbike or moped
- passenger car or van
- lorry/truck
- bus
- semitrailer
- road train
- HCT trailer (distinguished only by the newer DSL-6 model devices)

Measurement devices which are part of some traffic management system provide data in 1 s data transmission intervals. Other devices send data to the collection system every 5 minutes. The DSL-4 and DSL-6 device models are otherwise quite similar, but DSL-6 can distinguish also HCT trailers. The loop stations are listed in Table 5.

Induction loops measurement devices on the E12 motorway section are presented in Excel workbook and Annex 8.

Specific purpose induction loop devices (LML)

Specific purpose induction loop devices consist of single or two successive loops on a ramp or driving lanes. They are designed for some specific traffic management purpose, i.e. to detect slow driving vehicles or congestion. These systems are listed in Table 6.

Specific purpose induction loop devices on the E12 motorway section are presented in Excel workbook and Annex 9.

Travel time information service

The FCD based travel time information service has the following quality requirements:

- Allowed measurement error ±20 %, which can be exceeded only in 10 % of the measurements.
- API interface must available 99.5 % of time per month.

Systems and interfaces

VMS are controlled by traffic management systems manually or based on automatic weather and traffic condition analysis performed by the system. The system can make automatic controls or control proposals that have to be confirmed by the TMC operator.

Centralized traffic management system T-LOIK analyses the road condition class based on the information received from road weather stations. The analysis is made every 60 seconds. Based on road condition and real time traffic information received from the loop measurement points, automatic or recommended controls for VMS are set. The traffic management systems Helsinki ring road III – Klaukkala and Lempäälä – Tampere are integrated with T-LOIK.

The traffic management systems that are not integrated with T-LOIK analyse weather condition data every 5 minutes.

Road weather and traffic data as well as CCTV camera still images are published as open data through Fintraffic's Digitraffic interfaces.

3.2.3 Road section features

The features of both carriageways are presented in Excel sheets ”Road objects Hki-Tre” and ”Road objects Tre-Hki” (Annex X). The following columns describe features related to traffic management and information services:

- *Traffic management system*: Describes if the road section is managed by some traffic management system. The traffic management system is considered to reach from the first VMS sign to the end of influence area of the last VMS sign on the particular carriageway.

- *Variable speed limits*: Describes if the road section is inside the influence area of variable speed limits.

- *Slow vehicle detection system:* Describes if the particular road section has slow vehicle identification feature.

- *Travel time information service*: Describes if the particular road section is part of travel time information service coverage area.

3.3 Traffic condition and event information

3.3.1 Traffic volumes

Traffic volumes and percentages of heavy vehicles were gathered from FTIA’s map service. The data for the year 2019 was used as it was considered to be more representative than the data for 2020 because of the corona virus situation. The traffic volumes presented in FTIA map were total traffic volumes including both driving directions. It was assumed that the traffic volumes were evenly distributed between both carriageways.

3.3.2 Personal injury accident data

The estimated annual amounts of personal injury accidents for the road links were gathered from the TARVA MT service. The input data included separate estimates for line links and intersections. It was assumed that accidents located at intersections would divide equally between adjacent links. In addition, it was assumed that the estimated accident numbers divide equally between both carriageways.

Based on the traffic volume data and personal injury accident numbers, the accident rates (accidents / year / 100 million vehicle-km) were calculated.

3.3.3 Traffic condition

For every induction loop measurement device (LAM point) on the road, annual traffic fluency reports were printed from the FTIA Tiira service. The printed reports included percentages for free flow (level of service level A), fluent (B), queued (C), slow (D), stopping (E) and stationary traffic (F) for years 2016–2020 by driving direction for all traffic and separately for heavy and light vehicles.

Percentages for decreased service levels were estimated by counting the sum of annual percentages for light vehicle classes ”slow”, ”stopping” and ”stationary” (D to F) for each year and calculating their average (weighted by annual vehicle kilometrage). This was made for each measurement point and for both directions. It was assumed that the calculated figure represents the road section between two consecutive intersections where the particular measurement point is located. On road sections not containing a measurement point no traffic condition data was considered to be available.

3.3.4 Event information

Rates for different kinds of traffic events and road works were estimated based on actual and registered events occurred between 2016–2020. The data included the following log files:

- traffic announcements made by TMC operators
- requests for maintenance contractor actions, made by TMC operators
- contractor road works notifications to the TMC

On the basis of the log files, information the following rates were estimated and presented in Excel:

- Traffic announcement rate (number/km/a): Average number of traffic announcements (excluding announcements related to animal warnings and road works) on the particular road section between intersections in the selected driving direction.
- Animal warning announcement rate (number/km/a): Average number of traffic announcements related to animal warnings (elks, deers or other animals on road) on the particular road section between intersections.
- Road work rate (number/km/a): Average number of contractor road work notifications and traffic announcements related to road works on the particular road section between intersections and driving direction.
- Obstacle on road rate (number/km/a): Average number of contractor measures requests related to stopped vehicles to be transferred and other obstacles on road on the particular road section between intersections.
- Pavement damage measures request rate (number/km/a): Average number of contractor measures requests related to pavement damages on road on the particular road section between intersections.
- Winter maintenance measures request rate (number/km/a): Average number of contractor requests related to winter maintenance on the particular road section between intersections.

The rate estimations above should be interpreted only as very rough estimates because presumably only a small part of the real events on the road are reported and included in the log files. Traffic announcement and contractor measures request numbers likely are directly proportional to TMC situational awareness. The TMC presumably has better situational awareness on those road parts that include traffic management systems, have traffic monitoring devices and which have large traffic volumes and thereby also more road users who inform the traffic management centres about disorders.

In addition, the log files data had many shortages in meta data for example regarding the exact location of the events and driving direction that they affect. Many assumptions had to be made to be able to process the large data.

4 Conclusions and recommendations

4.1 Recommendations for the service level framework

In general, the setting of service levels physical infrastructure with regard to facilitating use of highly automated vehicles in automate mode throughout the section has three specific aspects. The first one is to provide continuity of the ODDs throughout the motorway connection. The second one is to ensure that ODD discontinuities due to e.g. severe weather problems and other factors beyond physical infrastructure resulting in large numbers of MRMs to be performed along the motorway do not cause severe accident nor congestion problems. The third one is to make sure that all relevant automated driving use cases should be covered.

Concerning the continuity of the ODDs, the current standard design requirements set to the motorways in Finland are likely sufficient. The main issue is likely that the physical infrastructure of the motorways should be maintained so that the quality remains high. The critical attributes in this respect include at least the visibility and condition of the lane markings and traffic signs, quick repair of and pavement damages and excessive ruts as well as elimination of any confusing road markings. The service levels could be built on such attributes.

With regard to the MRMs, the question is how and where to reserve space for carrying out the minimal risk manoeuvres. Normally, the outside shoulder will be wide enough to facilitate stopping the vehicle there. However, crossing lanes to the outside shoulder is not a very safe manoeuvre and thereby the inside shoulder should also be wide enough for stopping the vehicle. For a car this means minimum width of 2 m, and for heavy vehicles 3 m. Normally, the inside shoulders are not fulfilling the requirement. In the future it could be possible to reduce the width of the driving lanes as highly automated vehicles are able to keep to their lanes better than human-operated vehicles. Thereby the inside shoulder width of 2 m could be reached by new lane arrangements by painting without any need to change road structures. Today there is still no need to make any changes into the motorway planning guidelines nor practices in this respect.

In case of lack of shoulders, the MRM can be facilitated by carriageway widenings or even lay-bys offering numerous parking spaces. The width of shoulders and availability of widenings and lay-bys could be used to differentiate between service levels.

The automated driving use cases will set different demands to the physical infrastructure, both in relation to the ODDs and also to the MRM. A very specific use case in this respect is truck platooning. Truck platooning may need specific areas for coupling and uncoupling of platoons unless these can be performed ad hoc while driving on the road section. Furthermore, it is likely that the currently typical bearing capacity of motorway shoulders may not be sufficient for MRMs of truck platoons.

Regarding digital infrastructure and traffic condition and event information the aspects described below can be considered to affect the ODDs for automated driving.

The road sections wit traffic management systems and services are better suited for highly automated driving. Such sections have higher quality of traffic and road weather monitoring and thereby better situation and environmental condition awareness than average sections with no traffic management. In addition, the existing electricity and communication supply for the traffic management devices can be utilized to serve also highly automated driving purposes.

The Hämeenlinna tunnel has some special features that can affect highly automated driving. The tunnel is occasionally closed during the night because of maintenance and testing actions with traffic being directed to detour through the city street network. The tunnel can also be closed due to serious accidents. At the same time, there is a dense network of monitoring and control devices in the tunnel and the traffic management centre has a good situational picture concerning the tunnel.

Traffic flow data is available only from specific measurement points so the data is not comprehensive. The weaving section just north from Helsinki Ring Road 3 and the sections following that seem to be congestion prone so that could affect the ODDs of a number of automated driving use cases such as truck platooning.

In addition, the following aspect should be taken into account:

- It is not relevant to make far-reaching conclusions about traffic announcement rates and contractor action rates. It is possible that more incidents and situations demanding contractor actions occur on the sections with higher rates. However, traffic management centres have better situational awareness concerning road sections equipped with traffic management systems, and such sections also tend to have high traffic volumes and more road users to report about possible problems demanding contractor actions.
- Replacement investment evaluations of the Hämeenlinna tunnel and the Lempäälä–Tampere traffic management systems will be carried out in the near future. It is possible that some of the current devices or services will be dismantled. The future of the travel time information service is also uncertain. Hence, the impact of these uncertain digital infrastructure assets should be kept in mind when assessing the service level of the Helsinki-Tampere motorway connection.
- The current data transmission intervals and latencies etc. of traffic management devices and systems are based on current needs of traffic management centres and road authorities. If highly automated driving sets stricter technical demands the current systems might be modified to meet the new requirements with relatively small changes and investments.
- The estimated traffic condition and event information rates are only rough estimates as described earlier in the document.

4.2 Recommendations for further research and development

The specification of MRMs to be used on public roads including motorways needs to be developed taking on board the safety and efficiency requirements of the road operators so the MRMs will not result in network lockdowns nor major bottlenecks. In addition, the detailed requirements concerning the traffic management, road space and other road operator actions required by MRMs should be clarified for the various automated driving use cases.

Road markings have been identified (Somers 2019) as important for automated vehicles with regard to their positioning and navigation. On motorways, the lane markings may wear in an exceptional manner at ramp exit and entrance spots. On Finnish non-motorway highways, widenings at junctions and especially T-junctions have been implemented to make evasive actions due to left-turning vehicles easier and safer. Such widenings may be problematic locations for automated vehicles as the right-hand edge line is painted according to the widening and the automated vehicles will likely follow that line making abrupt trajectory changes at such junctions, potentially confusing the vehicle occupants. Solutions for these lane and edge marking related problems should be developed.

Further studies are needed to find out the impacts and demands of truck platooning on road structures and pavements including paved road shoulders.

Regarding digital infrastructure and traffic condition and event information the following recommendations were recognised:

- When analysing the contractor notification (contractor → TM centres) and traffic announcements (TM centres → road users as open data) it seemed that traffic announcements had been made only of part of the road works. From the viewpoint of traffic automation needs, all situations that the traffic management centre is aware of and that affect the usability of the road should be informed about to the road users.
- In traffic announcements, some of the information is presented only as freeform text apparently partly because of lack of available meta data fields and partly because of variable reporting practices. All relevant information is recommended to be presented according to harmonised meta data specifications to make it more useful for automated driving purposes. However, in many cases the traffic management centres do not know the exact location of the event and the driving direction affected by the event.

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Annex 1 Physical infrastructure data elaboration

Comments and explanations about data sets:

speed limit: shown as kilometers per hour

width of carriageway: shown in cm's, rounded to nearest ten

shoulder width: width of the paved shoulder, shown in cm's, as closest number dividable by 25 cm

road lighting: part of the road is considered lighted, if it has at least 2 continuous light sources

fences: road parts covered by fences, sorted by fence type

road type: motorway, all the way

type on pavement: roads pavement material

winter maintenance class: Ise (highest class), road is kept clear of snow and ice as much as possible

average bearing capacity: bearing capacity is considered good, if it's >540 MPa

traffic signs: only warning signs, priority and give-way signs and prohibitory and restrictive signs are shown

barriers: type of the barrier and side of the road it is

rest stops: placement of rest stops by road address

Annex 2 Road objects

Direction: Helsinki-Tampere

Road number	Driving lane number	Start Road part	start distance	End Road part	End distance	SPEED LIMIT (km/h)	WIDTH OF CARRIAGEWAY (cm)	SHOULDER WIDTH, side 1 (cm)	SHOULDER WIDTH, side 2 (cm)
3	1	103	0	103	380	80	700	150	50
3	1	103	380	103	555	80	750	350	125
3	1	103	555	103	6454	120	750	350	125
3	1	103	6454	103	6805	120	750	350	125
3	1	103	6805	103	7333	120	750	350	125
3	1	103	7333	104	0	120	750	300	150
3	1	104	0	104	857	120	750	300	150
3	1	104	857	106	10578	120	750	300	150
3	1	106	10578	108	856	120	750	300	150
3	1	108	856	109	4897	120	750	300	150
3	1	109	4897	113	4230	120	750	300	100
3	1	113	4230	113	6022	120	750	300	100
3	1	113	6022	115	6350	120	750	300	100
3	1	115	6350	115	6570	120	750	300	100
3	1	115	6570	117	840	120	750	300	100
3	1	116	320	116	820	100	700	300	100
3	1	116	820	116	4700	100	700	325	75
3	1	116	4700	117	0	100	750	300	125
3	1	117	0	117	450	100	750	300	125

3	1	117	450	117	840	120	750	300	125
3	1	117	840	121	2305	120	750	300	125
3	1	121	2305	123	3022	120	750	325	125
3	1	123	3022	123	4403	120	750	325	125
3	1	123	4403	123	5369	120	1130	150	125
3	1	123	5369	124	290	120	750	325	125
3	1	124	290	126	3439	120	750	325	125
3	1	126	3015	126	3439	120	750	325	125
3	1	126	3439	134	915	100	750	325	125
3	1	134	915	134	1191	100	750	325	125
3	1	134	1191	134	2240	100	700	300	125
3	1	134	2240	134	4477	100	700	300	125
3	1	134	4477	135	1727	100	700	300	125
3	1	135	1727	135	1768	100	700	300	150
3	1	135	1768	135	4155	100	700	300	150
3	1	135	4155	135	4800	100	720	300	150
3	1	135	4800	135	5005	100	720	300	125

ROAD LIGHTNING	FENCES (just on side 1)	ROAD TYPE	TYPE OF PAVE-MENT	WINTER MAINTENANCE CLASS	AVERAGE BEARING CA-PACITY	length of the segment (m)
Yes	no	Motorway	hard asphaltbeton	Ise	Good	380
Yes	no	Motorway	hard asphaltbeton	Ise	Good	175
Yes	no	Motorway	hard asphaltbeton	Ise	Good	5899
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	351

Yes	no	Motorway	hard asphaltbeton	Ise	Good	528
Yes	no	Motorway	hard asphaltbeton	Ise	Good	135
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	857
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	21318
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	2966
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	10351
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	24070
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	1792
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	12680
No	no	Motorway	hard asphaltbeton	Ise	Good	220
Yes	no	Motorway	hard asphaltbeton	Ise	Good	7690
Yes	no	Motorway	hard asphaltbeton	Ise	Good	500
Yes	no	Motorway	hard asphaltbeton	Ise	Good	3880
Yes	no	Motorway	hard asphaltbeton	Ise	Good	1050
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	450
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	390
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	23510
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	14334
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	1381
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	966
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	594
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	16111
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	424
Yes	Animal fence	Motorway	hard asphaltbeton	Ise	Good	1551
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	276
No	Animal fence	Motorway	hard asphaltbeton	Ise	Good	1049
No	no	Motorway	hard asphaltbeton	Ise	Good	2237

Yes	no	Motorway	hard asphaltbeton	Ise	Good	3610
Yes	Protective fence	Motorway	hard asphaltbeton	Ise	Good	41
Yes	no	Motorway	hard asphaltbeton	Ise	Good	2387
Yes	no	Motorway	hard asphaltbeton	Ise	Good	645
Yes	no	Motorway	hard asphaltbeton	Ise	Good	205

Direction: Tampere-Helsinki

Road number	Driving lane number	Start Road part	start distance	End Road part	End distance	SPEED LIMIT (km/h)	WIDTH OF CARRIAGE-WAY	SHOULDER WIDTH, side 1 (cm)	SHOULDER WIDTH, side 2 (cm)
3	2	135	4825	135	5005	100	700	150	650
3	2	135	4155	135	4825	100	700	150	300
3	2	135	1839	135	4155	100	700	125	300
3	2	135	1705	135	1839	100	700	125	300
3	2	134	4648	135	1705	100	700	125	300
3	2	134	4477	134	4648	100	700	125	300
3	2	134	1191	134	4477	100	700	125	300
3	2	134	915	134	1191	100	750	125	325
3	2	126	3500	134	915	100	750	125	325
3	2	126	3015	126	3500	120	750	125	325
3	2	124	290	126	3015	120	750	125	325
3	2	123	5153	124	290	120	750	125	325
3	2	123	3928	123	5153	120	1130	125	150
3	2	123	3022	123	3928	120	750	125	325

3	2	121	2757	123	3022	120	750	125	325
3	2	121	1805	121	2757	120	750	125	325
3	2	117	840	121	1805	120	750	125	300
3	2	117	600	117	840	120	750	125	300
3	2	116	4700	117	600	100	750	125	300
3	2	116	820	116	4700	100	700	75	325
3	2	116	320	116	820	100	700	100	300
3	2	115	6800	116	320	100	750	100	300
3	2	115	6570	115	6800	120	750	100	300
3	2	115	6400	115	6570	120	750	100	300
3	2	113	6022	115	6400	120	750	100	300
3	2	113	4230	113	6022	120	750	100	300
3	2	109	4897	113	4230	120	750	100	300
3	2	108	826	109	4897	120	750	150	300
3	2	106	10578	108	826	120	750	150	300
3	2	104	857	106	10578	120	750	150	300
3	2	104	400	104	857	120	750	150	300
3	2	104	0	104	400	120	750	150	300
3	2	103	7362	104	0	120	750	150	300
3	2	103	6732	103	7362	120	750	130	350
3	2	103	6444	103	6732	120	750	130	350
3	2	103	1723	103	6444	120	750	130	350
3	2	103	380	103	1723	80	750	130	350
3	2	103	135	103	380	80	750	130	150
3	2	103	0	103	135	80	700	50	150

ROAD LIGHT-NING	FENCES (just on side 2)	ROAD TYPE	TYPE OF PAVE-MENT	WINTER MAINTENANCE CLASS	AVERAGE BEAR-ING CAPACITY	Length of the segment (m)
yes	no	Motorway	hard asphaltbeton	Ise	Good	180
yes	no	Motorway	hard asphaltbeton	Ise	Good	670
yes	no	Motorway	hard asphaltbeton	Ise	Good	2316
yes	Protective fence	Motorway	hard asphaltbeton	Ise	Good	134
yes	no	Motorway	hard asphaltbeton	Ise	Good	3417
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	171
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	3286
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	276
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	1490
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	485
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	15687
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	810
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	1225
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	906
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	13882
no	no	Motorway	hard asphaltbeton	Ise	Good	952
no	no	Motorway	hard asphaltbeton	Ise	Good	23010
yes	no	Motorway	hard asphaltbeton	Ise	Good	240
yes	no	Motorway	hard asphaltbeton	Ise	Good	1650
yes	no	Motorway	hard asphaltbeton	Ise	Good	3880
yes	no	Motorway	hard asphaltbeton	Ise	Good	500

yes	no	Motorway	hard asphaltbeton	Ise	Good	1190
yes	no	Motorway	hard asphaltbeton	Ise	Good	230
no	no	Motorway	hard asphaltbeton	Ise	Good	170
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	12730
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	1792
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	24160
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	10381
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	2936
no	Elk fence	Motorway	hard asphaltbeton	Ise	Good	21318
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	457
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	400
yes	no	Motorway	hard asphaltbeton	Ise	Good	106
yes	no	Motorway	hard asphaltbeton	Ise	Good	630
yes	Elk fence	Motorway	hard asphaltbeton	Ise	Good	288
yes	no	Motorway	hard asphaltbeton	Ise	Good	4721
yes	no	Motorway	hard asphaltbeton	Ise	Good	1343
yes	no	Motorway	hard asphaltbeton	Ise	Good	245
yes	no	Motorway	hard asphaltbeton	Ise	Good	135

Annex 3 Traffic signs

Direction: Helsinki-Tampere

Road number	Driving lane	Road part	Distance from road part start	side	Traffic sign code	Codes explanation	Text on the sign
3	1	103	413	1	A20.1	warning: Elks	
3	1	103	414	2	A20.1	warning: Elks	
3	1	103	626	1	B1	Priority road	
3	1	103	855	2	C32	speed limit	100
3	1	103	857	1	C32	speed limit	100
3	1	103	3527	2	C32	speed limit	120
3	1	103	3528	1	C32	speed limit	120
3	1	103	5076	2	C32	speed limit	120
3	1	103	5077	1	C32	speed limit	120
3	1	104	409	1	C32	speed limit	120
3	1	104	409	2	C32	speed limit	120
3	1	106	678	1	C32	speed limit	120
3	1	106	678	2	C32	speed limit	120
3	1	106	6447	1	C32	speed limit	120
3	1	106	6447	2	C32	speed limit	120
3	1	108	424	1	C32	speed limit	120
3	1	108	424	2	C32	speed limit	120
3	1	109	643	1	C32	speed limit	120
3	1	109	643	2	C32	speed limit	120

3	1	109	5388	1	C32	speed limit	120
3	1	109	5388	2	C32	speed limit	120
3	1	109	9317	1	C32	speed limit	120
3	1	109	9317	2	C32	speed limit	120
3	1	111	720	1	C32	speed limit	120
3	1	111	720	2	C32	speed limit	120
3	1	112	794	2	C32	speed limit	120
3	1	112	794	1	C32	speed limit	120
3	1	113	730	2	C32	speed limit	120
3	1	113	730	1	C32	speed limit	120
3	1	113	6016	2	C32	speed limit	120
3	1	113	6016	1	C32	speed limit	120
3	1	115	787	2	C32	speed limit	120
3	1	115	787	1	C32	speed limit	120
3	1	115	2709	1	C32	speed limit	120
3	1	115	2709	2	C32	speed limit	120
3	1	115	6759	2	C32	speed limit	100
3	1	115	6759	2	C32	speed limit	120
3	1	115	6759	1	C32	speed limit	100
3	1	116	874	2	C32	speed limit	100
3	1	116	874	1	C32	speed limit	100
3	1	116	3118	2	A1.2	warning: bend	
3	1	116	3118	1	A1.2	warning: bend	
3	1	116	3964	2	C32	speed limit	100
3	1	116	3964	1	C32	speed limit	100
3	1	117	414	1	C32	speed limit	120
3	1	117	414	2	C32	speed limit	120

3	1	117	5096	2	C32	speed limit	100
3	1	118	607	1	C32	speed limit	100
3	1	118	607	2	C32	speed limit	100
3	1	118	607	1	C32	speed limit	100
3	1	118	5510	1	C32	speed limit	100
3	1	118	5510	2	C32	speed limit	100
3	1	120	830	2	C32	speed limit	100
3	1	120	830	1	C32	speed limit	100
3	1	121	2976	2	C32	speed limit	120
3	1	121	2977	1	C32	speed limit	120
3	1	121	8801	2	C32	speed limit	120
3	1	122	80	2	C32	speed limit	120
3	1	122	82	1	C32	speed limit	120
3	1	122	4565	2	A12	Warning: loose gravel	
3	1	123	775	1	C32	speed limit	120
3	1	123	778	2	C32	speed limit	120
3	1	123	3111	2	C32	speed limit	120
3	1	123	4450	1	C32	speed limit	120
3	1	123	4450	2	C32	speed limit	120
3	1	124	390	1	C32	speed limit	120
3	1	124	390	2	C32	speed limit	120
3	1	124	3555	2	C32	speed limit	120
3	1	124	4153	2	C32	speed limit	120
3	1	124	4155	1	C32	speed limit	120
3	1	124	7969	2	C32	speed limit	120
3	1	125	173	2	C32	speed limit	120

3	1	125	175	1	C32	speed limit	120
3	1	125	4250	2	C32	speed limit	120
3	1	126	809	1	C32	speed limit	100
3	1	126	890	2	C32	speed limit	120
3	1	126	3535	2	C32	speed limit	120
3	1	134	3012	2	C22	Greatest allowed height	4,4m
3	1	134	4553	2	A2.1	Warning: several bends	
3	1	134	4554	1	A2.1	Warning: several bends	
3	1	135	109	2	A2.1	Warning: several bends	
3	1	135	1716	2	C22	Greatest allowed height	4,4 m
3	1	135	2095	1	C8	No vehicles carry-ing dangerous goods	
3	1	135	2402	2	A20.1	warning: Elks	
3	1	135	2404	1	A20.1	warning: Elks	
3	1	135	2863	2	C20	No U-turns	
3	1	135	3095	1	C8	No vehicles carry-ing dangerous goods	
3	1	135	4554	2	C32	speed limit	100 peitetty

3	1	135	4874	2	C8	No vehicles carry-ing dangerous goods	
3	1	135	4874	1	C8	No vehicles carry-ing dangerous goods	

Direction: Tampere-Helsinki

Road number	Driving lane	Road part	Distance from road part start	side	Traffic sign code	Codes explanation	Text on the sign
3	2	135	103	2	A2.1	Warning: several bends	
3	2	135	31	3	C22	Greatest allowed height	4,4 m
3	2	134	3025	3	C22	Greatest allowed height	4,4 m
3	2	126	3529	2	C32	speed limit	120
3	2	125	4243	2	C32	speed limit	120
3	2	124	7962	2	C32	speed limit	120

3	2	124	3552	2	C32	speed limit	120
3	2	123	3125	2	C32	speed limit	120
3	2	122	4564	2	A30	Warning: fallen rocks	
3	2	122	4312	2	C32	speed limit	120
3	2	121	8799	2	C32	speed limit	120
3	2	121	2426	2	C32	speed limit	120
3	2	121	2426	3	C32	speed limit	120
3	2	118	11555	2	C32	speed limit	120
3	2	118	11555	2	C32	speed limit	120
3	2	118	4929	2	C32	speed limit	120
3	2	118	4929	2	C32	speed limit	120
3	2	117	4346	2	C32	speed limit	120
3	2	117	4346	2	C32	speed limit	120
3	2	117	633	2	C32	speed limit	100
3	2	117	633	3	C32	speed limit	100
3	2	116	5277	2	C32	speed limit	100
3	2	116	5277	2	C32	speed limit	100
3	2	116	4354	2	A1.1	Warning: bend	
3	2	116	4354	3	A1.1	Warning: bend	
3	2	116	2893	2	E19	Tunnel	
3	2	116	2893	2	H3	Length of singns ap-plicability	400m
3	2	116	2893	2	E19	Tunnel	
3	2	116	2893	2	H3	Length of singns ap-plicability	400m
3	2	116	2491	2	E20	Tunnel ends	
3	2	116	2491	2	E20	Tunnel ends	

3	2	116	2445	3	C32	speed limit	100
3	2	116	2445	2	C32	speed limit	100
3	2	116	1928	3	C32	speed limit	100
3	2	116	1928	2	C32	speed limit	100
3	2	115	6763	3	C32	speed limit	120
3	2	115	6763	3	C32	speed limit	120
3	2	115	6758	2	C32	speed limit	120
3	2	115	2573	3	C32	speed limit	120
3	2	115	2573	2	C32	speed limit	120
3	2	113	11543	2	C32	speed limit	120
3	2	113	11543	2	C32	speed limit	120
3	2	113	5217	2	C17	No entry	
3	2	113	5217	2	D4	Pedestrian path	
3	2	113	5217	2	C37	No standing or parking	
3	2	113	5217	2	B5	Give way	
3	2	113	4409	2	C32	speed limit	120
3	2	113	4409	3	C32	speed limit	120
3	2	112	8188	2	C32	speed limit	120
3	2	112	8188	3	C32	speed limit	120
3	2	111	2624	2	C32	speed limit	120
3	2	111	2624	3	C32	speed limit	120
3	2	109	11462	2	C32	speed limit	120
3	2	109	11462	3	C32	speed limit	120
3	2	109	7911	2	C32	speed limit	120
3	2	109	7911	3	C32	speed limit	120
3	2	109	4504	3	C32	speed limit	120
3	2	109	4504	2	C32	speed limit	120

3	2	108	6029	3	C32	speed limit	120
3	2	106	11310	3	C32	speed limit	120
3	2	106	11310	2	C32	speed limit	120
3	2	106	6446	2	C32	speed limit	120
3	2	106	6446	3	C32	speed limit	120
3	2	104	10843	3	C32	speed limit	120
3	2	104	10843	2	C32	speed limit	120
3	2	104	2116	2	C32	speed limit	120
3	2	104	2116	3	C32	speed limit	120
3	2	104	1472	2	C32	speed limit	100
3	2	104	1472	3	C32	speed limit	100
3	2	104	961	2	C32	speed limit	100
3	2	104	961	3	C32	speed limit	100
3	2	103	6694	2	H24	Additional panel with text	Hirviaita päättyy
3	2	103	6694	2	A20.1	warning: Elks	
3	2	103	6694	3	A20.1	warning: Elks	
3	2	103	6694	3	H24	Additional panel with text	Hirviaita päättyy
3	2	103	6624	3	C32	speed limit	120
3	2	103	6623	2	C32	speed limit	120
3	2	103	4426	2	C32	speed limit	120
3	2	103	4425	3	C32	speed limit	120
3	2	103	3940	2	H3	Length of singns ap-plicability	3,4km
3	2	103	3940	2	A20.1	warning: Elks	

3	2	103	3938	3	H3	Length of singns ap-plicability	3,4km
3	2	103	3938	3	A20.1	warning: Elks	
3	2	103	1202	2	C32	speed limit	120
3	2	103	1201	3	C32	speed limit	120
3	2	103	562	2	C32	speed limit	80
3	2	103	562	3	C32	speed limit	80

Annex 4, Barriers and rest stops

Direction: Helsinki-Tampere

Road number	Driving lane number	Road part number	Distance from road part start	Side	Type of target
3	1	103	4577	2	Barrier on service access point
3	1	104	751	2	Barrier on service access point
3	1	104	5623	2	Barrier on service access point
3	1	104	10697	2	Barrier on service access point
3	1	106	906	2	Barrier on service access point
3	1	106	6360	2	Barrier on service access point
3	1	106	7682	2	Barrier on service access point
3	1	106	11995	2	Barrier on service access point
3	1	108	761	2	Barrier on service access point

3	1	108	5574	2	Barrier on service access point
3	1	109	785	2	Barrier on service access point
3	1	109	4041	2	Barrier on service access point
3	1	109	5538	2	Barrier on service access point
3	1	109	11406	2	Barrier on service access point
3	1	111	803	2	Barrier on service access point
3	1	111	2514	2	Barrier on service access point
3	1	112	899	2	Barrier on service access point
3	1	112	8120	2	Barrier on service access point
3	1	113	796	2	Barrier on service access point
3	1	113	3052	2	Barrier on service access point
3	1	113	11593	2	Barrier on service access point
3	1	115	735	2	Barrier on service access point
3	1	115	2064	1	Rest area

3	1	115	3958	2	Barrier on service access point
3	1	115	6690	2	Barrier on service access point
3	1	116	866	2	Barrier on service access point
3	1	116	2282	1	Barrier on start of the tunnel
3	1	116	2282	2	Barrier on start of the tunnel
3	1	116	2391	2	Barrier on service access point
3	1	116	3191	2	Barrier on service access point
3	1	116	4944	1	Barrier on service access point
3	1	117	636	2	Barrier on service access point
3	1	117	4367	2	Barrier on service access point
3	1	118	571	2	Barrier on service access point
3	1	118	4172	2	Barrier on service access point
3	1	118	4800	1	Rest area
3	1	118	6243	2	Barrier on service access point

3	1	118	11750	2	Barrier on service access point
3	1	120	788	2	Barrier on service access point
3	1	121	2053	3	Barrier on service access point
3	1	121	3348	3	Barrier on service access point
3	1	121	7725	3	Barrier on service access point
3	1	122	1104	3	Barrier on service access point
3	1	124	2961	3	Barrier on service access point
3	1	124	4512	3	Barrier on service access point
3	1	124	7408	3	Barrier on service access point
3	1	125	634	3	Barrier on service access point
3	1	135	2850	3	Barrier on service access point

Direction: Tampere-Helsinki

Road number	Driving lane number	Road part number	Distance from road part start	Side	Type of target
3	2	126	3273	3	Barrier on service access point
3	2	126	1237	3	Barrier on service access point
3	2	125	3941	3	Barrier on service access point
3	2	118	5600	2	Rest area
3	2	116	3368	1	Barrier on start of the tun-nel
3	2	116	3368	2	Barrier on start of the tun-nel
3	2	115	3265	2	Rest area
3	2	113	6834	3	Barrier on service access point
3	2	113	5217	2	Rest area
3	2	106	7045	2	Rest area
3	2	106	5721	1	Rest area

Annex 5, Variable Message Signs

Main road

Road number	Driving lane number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
3	2	103	2	110	VMS	Park&Ride sign (LP)	Roadside	Kehä III-Klauk-kala	LP010304	VMS technically ready for use but for now parking place data is not received from the P&R operator.
3	1	103	2	855	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010320	
3	1	103	1	857	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010321	
3	2	103	2	1020	VMS	Park&Ride sign (LP)	Roadside	Kehä III-Klauk-kala	LP010303	VMS technically ready for use but for now parking place data is not received from the P&R operator.
3	2	103	1	1202	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010319	
3	2	103	2	1201	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010318	
3	1	103	2	3527	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010311	
3	1	103	1	3528	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010312	

Road number	Driving lane number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
3	2	103	across	4210	VMS	Text and warning sign (VME/TIO)	Above carriageway	Kehä III-Klaukkala	VME/TIO010302	
3	1	103	across	4275	VMS	Text and warning sign (VME/TIO)	Above carriageway	Kehä III-Klaukkala	VME/TIO010303	
3	2	103	2	4425	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010309	
3	2	103	1	4426	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010310	
3	1	103	2	5076	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010307	
3	1	103	1	5077	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010308	
3	2	103	2	6624	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010305	
3	2	103	1	6623	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010306	
3	1	104	2	409	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010322	
3	1	104	1	409	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010323	
3	2	104	2	961	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010301	
3	2	104	1	961	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010302	

Road number	Driving lane number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
3	2	104	2	1472	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010324	
3	2	104	1	1472	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010325	
3	2	104	across	1850	VMS	Text and warn-ing sign (VME/TIO)	Above car-riageway	Kehä III-Klauk-kala	VME/TIO010301	
3	2	104	2	2116	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010326	
3	2	104	1	2116	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010327	
3	1	116	across	1059	VMS	Text and warn-ing sign (VME/TIO)	Above car-riageway	Hämeenlinna tunnel	VME/TIO012301	
3	1	116	1	1261	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012311	
3	1	116	2	1262	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012321	
3	1	116	1	1444	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012311	
3	1	116	2	1445	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012321	

Road number	Driving lane number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
3	1	116	1	1778	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012312	
3	1	116	2	1778	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012322	
3	1	116	1	1901	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012312	
3	1	116	2	1902	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012322	
3	1	116	across	2300	VMS	Fulltext (TIO)	Above car-riageway	Hämeenlinna tunnel	TIO012302	
3	1	116	2	3104	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012511	
3	1	116	1	3104	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012521	
3	2	116	across	3346	VMS	Fulltext (TIO)	Above car-riageway	Hämeenlinna tunnel	TIO012642	
3	2	116	2	3705	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012652	

Road number	Driving lane number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
3	2	116	1	3705	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012662	
3	2	116	2	3998	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012652/-3	
3	2	116	1	3999	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012662/-3	
3	2	116	2	4467	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012651	
3	2	116	1	4468	VMS	Prism display (OPM)	Roadside	Hämeenlinna tunnel	OPM012661	
3	2	116	2	4721	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012651/-2	
3	2	116	1	4721	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012661/-2	
3	2	116	across	4934	VMS	Text and warning sign (VME/TIO)	Above carriageway	Hämeenlinna tunnel	VME/TIO012641	
3	1	126	1	3439	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tampere	KRM040301	

Road number	Driving lane number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
3	1	126	2	3439	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040302	
3	1	134	1	783	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040303	
3	1	134	2	783	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040304	
3	2	134	2	2908	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040323	
3	2	134	1	2908	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040324	
3	1	134	1	4177	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040305	
3	1	134	2	4177	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040306	
3	2	134	2	5767	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040321	
3	2	134	1	5767	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040322	
3	1	135	1	533	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040307	
3	1	135	2	533	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040308	
3	1	135	across	2350	VMS	Fulltext (TIO)	Above car-riageway	Tampere traffic information system		
3	1	135	1	2589	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tam-pere	KRM040309	

Road number	Driving lane number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
3	1	135	2	2589	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tampere	KRM040310	
3	2	135	2	2837	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tampere	KRM040319	
3	2	135	1	2837	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tampere	KRM040320	
3	2	135	2	3601	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tampere	KRM040317	
3	2	135	1	3601	VMS	Variable speed limit (KRM)	Roadside	Lempäälä-Tampere	KRM040318	

Ramps

Road number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
21306	56	1	260	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010316	on ramp towards south
21307	78		1710	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010315	on ramp towards south
21307	12		1830	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010314	on ramp towards north
21307	78		260	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010313	on ramp towards south
21038	89		130	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klaukkala	KRM010303	on ramp towards south

Road number	Road part	Side	Distance	Type	Type (detail)	Position	Traffic control system	ID number	Remarks
21308	45		50	VMS	Variable speed limit (KRM)	Roadside	Kehä III-Klauk-kala	KRM010304	on ramp towards north
20306	56		658	Monitoring device	Specific purpose induction loop device (LML)		Kehä III-Klauk-kala	LML010305	on ramp towards south, not integrated to the TM system at the moment
21307	78		1731	Monitoring device	Specific purpose induction loop device (LML)		Kehä III-Klauk-kala	LML010307	on ramp towards south, not integrated to the TM system at the moment
21307	12		2030	Monitoring device	Specific purpose induction loop device (LML)		Kehä III-Klauk-kala	LML010302	on ramp towards south, not integrated to the TM system at the moment
21308	89		145	Monitoring device	Specific purpose induction loop device (LML)		Kehä III-Klauk-kala	LML010309	on ramp towards south, not integrated to the TM system at the moment
23511	59		180	VMS	Speed limit+Warning sign (VME/KRM)	Roadside	Hämeenlinna tunnel	VME/KRM012431	on ramp towards north
23511	59		40	Monitoring device	Specific purpose induction loop device (LML)		Hämeenlinna tunnel	LML012301	on ramp towards north

Annex 6, CCTV cameras

Road number	Driving lane number	Road part	Side	Distance	Type (detail)	Position	Model	CCTV camera resolu-tion	Traffic control system	ID number	ID name
3	1 and 2	103	2	1890	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Kehä III-Klaukkala	LKA010303	vt3_Vantaa_Ki-vistö_E
3	1 and 2	103	2	2655	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Kehä III-Klaukkala	LKA010302	vt3_Vantaa_Ki-vistö_P
3	1 and 2	103	2	4785	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Kehä III-Klaukkala	LKA010301	vt3_Vantaa_Kei-mola
3	1 and 2	103	2	7456	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Kehä III-Klaukkala	LKA1533	vt3_Vantaa_Klauk-kala
3	1 and 2	108	2	0	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VAPIX	HD			vt3_Hyvin-kää_Noppo
3	1 and 2	112	2	15	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VAPIX	HD			vt3_Riihimäki_Lem-menmäki
3	1 and 2	115	2	0	CCTV camera, pan/tilt/zoom (LKA)	Roadside	HIKVISION	HD			vt3_Janakkala_Tu-renki
3	1 and 2	115	2	7640	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VAPIX	HD			vt3_Hämeen-linna_Hattelmala
3	1 and 2	116	1	2241	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04556	vt3_Hämeen-linna_Etelä
3	1 and 2	116	1	2242	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04558	vt3_Hämeen-linna_Puomi_E

Road number	Driving lane number	Road part	Side	Distance	Type (detail)	Position	Model	CCTV camera resolu-tion	Traffic control system	ID number	ID name
3	1 and 2	116	1	2243	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04557	vt3_Hämeen-linna_Ramppi_E
3	1 and 2	116	1	2550	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04559	vt3_Hämeen-linna_P1
3	1 and 2	116	2	2686	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04561	vt3_Hämeen-linna_E2
3	1 and 2	116	1	2703	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04560	vt3_Hämeen-linna_P2
3	1 and 2	116	2	2818	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04562	vt3_Hämeen-linna_E1
3	1 and 2	116	2	3064	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04563	vt3_Hämeen-linna_Pohjoinen
3	1 and 2	116	2	3335	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04564	vt3_Hämeen-linna_Puomi_P
3	1 and 2	116	1	3736	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VMX_MPH	SD	Hämeen-linna tunnel	LKA04565	vt3_Hämeen-linna_Ojoinen
3	1 and 2	124	1	340	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VAPIX	SD			vt3_Valkea-koski_Konho

Road number	Driving lane number	Road part	Side	Distance	Type (detail)	Position	Model	CCTV camera resolu-tion	Traffic control system	ID number	ID name
3	1 and 2	134	1	1	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VAPIX	HD			vt3_Lem-päälä_Ideapark
3	1 and 2	135	2	8	CCTV camera, pan/tilt/zoom (LKA)	Roadside	VAPIX	HD			vt3_Lem-päälä_Sääksjärvi

Annex 7, Road weather stations

Road number	Driving lane number	Road part	Side	Distance	Type (detail)	Position	Model	Weather station sensors	Data transmission interval	Traffic control system	ID name
3	1 and 2	103	1	4165	Road weather station (TSA)	Roadside	RWS200/ DSC211	Road surface and optical	5 min	Kehä III-Klaukkala	vt3_Vantaa_Keimola_1
3	1 and 2	106	1	4558	Road weather station (TSA)	Roadside	RWS200/ DSC211	Road surface and optical	10 min		vt3_Nurmijärvi_Karhunkorpi_1
3	2	109	2	11127	Road weather station (TSA)	Roadside	RWS200/ DSC211	Road surface and optical	10 min		vt3_Riihimäki_Parmala_1
3	2	115	2	5543	Road weather station (TSA)	Roadside	RWS200/ DSC211	Road surface and optical	5 min		vt3_Hämeenlinna_Miemala_1
3	2	121	2	3192	Road weather station (TSA)	Roadside	RWS200/ DSC211	Road surface and optical	5 min		vt3_Valkeakoski_Jutikkala_1
3	1	124	1	3410	Road weather station (TSA)	Roadside	RWS200/ DSC211	Road surface and optical	5 min		vt3_Lempäälä_Lippo_1
3	1	134	1	5137	Road weather station (TSA)	Roadside	RWS200/ DSC211	Road surface and optical	5 min	Lempäälä-Tampere	vt3_Lempäälä_Kulju_1

Annex 8, Induction loop measurement devices

Road number	Driving lane number	Road part	Side	Distance	Type (detail)	Model	Data transmission interval	Traffic control system	ID number	ID name
3	1 and 2	103		913	Induction loop measurement device (LAM)	DSL-4	1 s	Kehä III-Klaukkala	LAM010301	LAM4, vt3_Kivistö
3	1 and 2	103	1	4180	Induction loop measurement device (LAM)	DSL-6	1 s	Kehä III-Klaukkala	LAM23137	LAM137, vt3_Vantaa_Keimola
3	1 and 2	104	1	0	Induction loop measurement device (LAM)	DSL-4	1 s	Kehä III-Klaukkala	LAM010302	LAM5, vt3_Klaukkalantie
3	1 and 2	106	1	4555	Induction loop measurement device (LAM)	DSL-4	5 min			LAM108, vt3_Karhunkorpi
3	1 and 2	109	2	11127	Induction loop measurement device (LAM)	DSL-4	5 min			LAM429, vt3_Riihimäki_Herajoki
3	1 and 2	113	1	5190	Induction loop measurement device (LAM)	DSL-4	5 min			LAM432, vt3_Janakkala
3	1 and 2	116	2	2329	Induction loop measurement device (LAM)	DSL-4	1 s	Hämeenlinna tunnel	LAM23465	LAM465, vt3_Hämeenlinna_E
3	1 and 2	116	2	3526	Induction loop measurement device (LAM)	DSL-4	1 s	Hämeenlinna tunnel	LAM23466	LAM466, vt3_Hämeenlinna_P

Road number	Driving lane number	Road part	Side	Distance	Type (detail)	Model	Data transmission interval	Traffic control system	ID number	ID name
3	1 and 2	117	1	435	Induction loop measurement device (LAM)	DSL-6	5 min			LAM437, vt3_Hlinna_Mo3
3	1 and 2	124	1	3390	Induction loop measurement device (LAM)	DSL-4	5 min			LAM440, vt3_Lempäälä_Lippo
3	1 and 2	134	1	5138	Induction loop measurement device (LAM)	DSL-4	1 s	Lempäälä-Tampere		LAM401, vt3_Lempäälä_Sääksjärvi
3	1 and 2	135	1	2373	Induction loop measurement device (LAM)	DSL-6	1 s	Tampere traffic information system		LAM471, vt3_Tampere_Multisilta

Annex 9, Specific purpose induction loop measurement devices

Road number	Driving lane number	Road part	Dis-tance	Type (detail)	Traffic control system	ID number
3	2	103	1325	Specific purpose induction loop device (LML)	Kehä III-Klaukkala	LML010304
3	2	103	1730	Specific purpose induction loop device (LML)	Kehä III-Klaukkala	LML010308
3	1	103	3115	Specific purpose induction loop device (LML)	Kehä III-Klaukkala	LML010303
3	2	103	7340	Specific purpose induction loop device (LML)	Kehä III-Klaukkala	LML010310
3	2	116	2600	Specific purpose induction loop device (LML)	Hämeenlinna tunnel	LML012543
3	1	116	2635	Specific purpose induction loop device (LML)	Hämeenlinna tunnel	LML012401
3	2	116	2725	Specific purpose induction loop device (LML)	Hämeenlinna tunnel	LML012542
3	1	116	2775	Specific purpose induction loop device (LML)	Hämeenlinna tunnel	LML012402
3	2	116	2870		Hämeenlinna tunnel	LML012541
3	1	116	2990		Hämeenlinna tunnel	LML012403

Working report
28/06/2021

Service level framework for automated road transport

Task 1.2. Communications

Contents

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Annex 1 Use case tables

Annex 2 Specifics of the field measurement

1 Goal of the Task

The goal of the task 1.2 is to identify and define communication service level requirements (V2N) for the key intelligent transport systems (ITS) use cases.

Task included two optional subtasks both of which were executed. In the subtask A the capability of the current 4G and 5G mobile networks along the E12 is measured and results are briefly analysed against the defined mobile communication service level requirements.

In the subtask B, an inventory of mobile base stations and fibre access points within 1 km on both sides of the road. From this inventory list the viability of further mobile network investments is evaluated in an analysis based on the proximity of fibre access points and mobile base station.

2 Methodology

The task was conducted as a literature review.

To identify the key literature and other relevant sources of information the main national professionals of the field were contacted, and publicly available studies of key organizations related to ITS (such as 5GAA, ETSI) were reviewed. However, in several studies the use cases were described in great level of detail, but exact information related to mobile network requirements were only described in a general level (e.g. high/low). For this reason, this literature review is based on following white papers:

- C-V2X Use Cases and Service Level Requirements (Volume I). 2020. 5GAA Automotive Association. Technical Report (version 3.0).
- C-V2X Use Cases and Service Level Requirements (Volume II). 2020. 5GAA Automotive Association. Technical Report (version 1.0).

From these sources the most relevant use cases were collected in a table. Using the table and expertise know-how service level requirements were later defined.

2.1 Current service level of E12

The task was conducted as field measurements of the mobile networks on the E12 between Helsinki and Tampere. Measurements were conducted mainly during week 11 (2021-W11) with one patch run on the week 18 (2021-W18). Measurements were executed by making three measurement drives during different times of the day (a weekday morning, a weekday evening, and a weekday night) to identify possible differences in the performance of the network.

All three nationwide mobile operators (DNA, Elisa, Telia) were included in the measurements. Three key figures which were measured are download speed, upload speed and latency (ping). These figures were measured only from 4G and 5G networks. Mobile phones running special software were used as measuring instrument. 18 terminals were used per measurement drive – 6 terminals per operator. Per each operator 3 terminals were forced to 4G network and 3 were forced in 5G network. Every key figure had dedicated instrument in both 4G and 5G networks.

Alongside mobile phones, a scanner was used on one of the measurement drives to gather information about signal strength of mobile frequencies. All terminals except the scanner were located inside the car during measurements. (More detailed information of the setup, terminals, scripts, and the measurements in general can be found from Annex 2)

Measured data was analysed, and the results are presented in a Web App specifically built for the subtasks A and B. Results were also analysed against the suggested service level framework.

2.2 Inventory of current supportive passive infra

Request for information was sent to mobile networks operators in Finland (DNA, Elisa, Telia). The locations of mobile base stations and fibre access points within 1 km on both sides of the road was requested. All three operators replied and sent some data. Two operators complied to send data as requested, but one operator sent only partial data including only mobile base stations currently servicing E12 between Helsinki – Tampere while refusing to send data about fibre access points.

Received data was further analysed by slicing the inspected road into 100 m slices (both carriageways) and then the proximity of mobile base station and fibre access points was calculated per slice. Slices were categorized based on the proximity of fibre access point.

The goal was to make an inventory of the supportive passive infra. Against this inventory simple estimation was made about how easily the current mobile networks could be updated (proximity of a mobile base station) and how easily a new mobile base station (or other wireless access point) could be erected/deployed (proximity of a fibre access point). Categories were chosen based on the current understanding of the capabilities (coverage of a one cell) of 3,5 GHz and 26 GHz 5G networks. These frequency bands were chosen to this demonstration since they are frequency bands currently in use. Also, they are the only frequencies with wide enough bandwidth capable of providing substantial increase in capacity when deployed.

Mobile cells within the 26 GHz (mm wave) frequency band have an estimated coverage of only few hundred meters even when beams are aligned according to road profile. Because of this a reliable mobile coverage no more than 250 meters distance from the road can be accepted. With 3,5 GHz frequency band the expected coverage for single cell, in motorway environment is between 1 – 2 km, therefore the 3,5 GHz base station can't be deployed more than 1 km away from the road. Based on these assumptions, the categories were assigned as follows:

Proximity of a mobile base station:

A. < 100 m

B. < 250 m

C. < 500 m

D. < 1000 m

Proximity of a fibre access point:

B. < 250 m

C. < 500 m

D. < 1000 m

Results are presented in the same Web App as the results of the subtask A.

3 Results

The key ITS use cases and the V2N service level requirements (SLR) are described in the following tables. The information in the tables are not directly from the original documents. Some level interpretation has been made to make the service level requirements applicable for the purpose of this review. The main interpretation relates to the use cases in which the download and the upload requirements has been indicated as a package size. These use case has been reviewed to make assumptions how frequently information packages will be sent along the highway. Whether the use case bandwidth requirements are a.) nonrecurring b.) ongoing or c.) connected only to certain events or scenario. Use cases are presented in the Annex 1.

The use cases have been classified by 5GAA under following groups:

1. Safety
2. Vehicle Operations Management
3. Convenience
4. Autonomous Driving
5. Platooning
6. Traffic Efficiency and Environmental Friendliness
7. Society and Community

Used abbreviations

- SLR = Service Level Requirement
- HV = Host Vehicle
- RV = Remote Vehicle

The most demanding use cases for communication networks are related to cooperative driving and tele-operated driving. These use cases need high capacity data transfer capability to both directions, the network must be available reliably on demand, and latencies must be very low. In use cases like Coordinated Cooperative Manoeuvring, and Tele-Operated Driving, data service needs might emerge at the same time, and suddenly vehicle needs to send and receive data concurrently from:

- RADAR
- LIDAR
- other sensors
- video in ultra-high resolution(4K/8K)

Depending on the surrounding infra, other vehicles and availability of edge computing, there might be multiple sources of data that needs to be send out, received, or forwarded. Data service requirement for these data streams alone can end up being 100/100 Mbit/s per vehicle or even higher if vehicle needs to relay/forward information from and to infra and to other surrounding vehicles. Requirement for capacity further increases if passenger entertainment is taken into consideration and can set download capacity demand as high as 350 - 500 Mbit/s.

It is crucial to point out that capacity requirement is not continuous. The capacity demand per vehicle varies heavily during the drive and is not depended only on the user and the vehicle, but surrounding traffic and infra as well.

3.1 Results of the field measurements

Performance of the mobile networks was evaluated in the recommended service level framework presented in chapter 4. In general, mobile networks have reasonably good performance along the E12.

4G network coverage is good. 5G network can be found only in the proximity of the cities, though 5G coverage is expected to grow notably after 700 MHz frequency bands are deployed in large scale by all the operators. Since the terminals were forced to operate only in 4G and 5G networks the lack of coverage in this measurement does not mean there is no mobile data service coverage at all. All operators are still using 3G technology and from previous measurements conducted alongside the E12 it can be determined that the mobile data service coverage is 100 %. The mobile data service is expected to further improve after mobile network operators migrate 3G frequency bands to 4G/5G technologies.

Although mobile data service covers the whole E12 from Helsinki to Tampere the data speed rates vary heavily falling sometimes under 1 Mbit/s (download) and exceeding 500 Mbit/s (download) where 3,5 GHz 5G frequency bands had been deployed. On the other hand, latency in the networks is good on the whole length of the E12 seldom exceeding 50 ms.

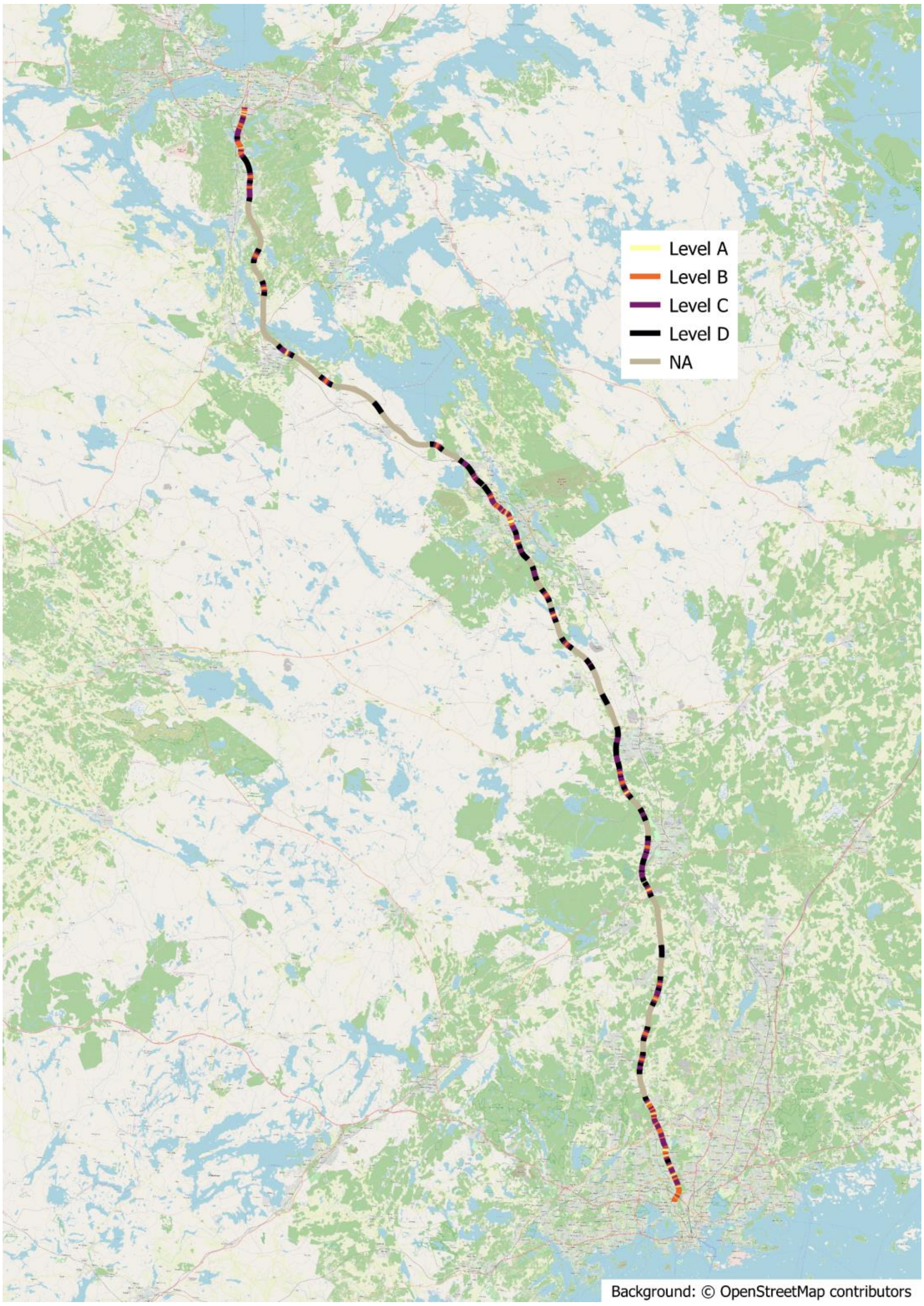
3.2 Results of the inventory of supportive passive infra

Results indicate that density of mobile base stations close to E12 is reasonably good. Especially in proximity of more densely populated areas. Where mobile base station is available at most 1 km away from the road, it is reasonable to assume the updating current base stations with at least 3,5 GHz 5G capable equipment, two thirds of the E12 between Helsinki – Tampere would be covered with high capacity 5G network. Then the network would be capable of providing sufficient mobile networks service level for most use cases, if not all.

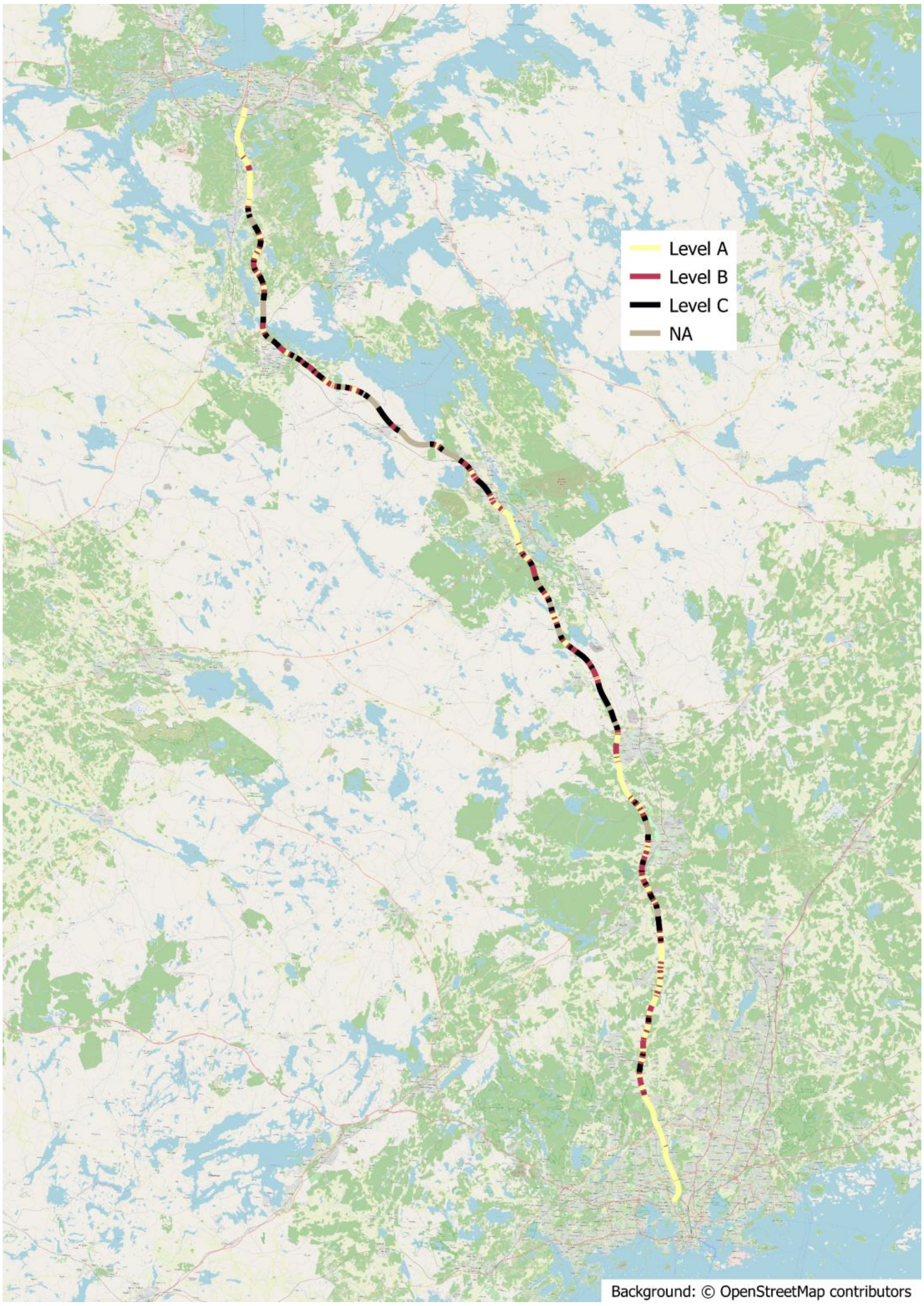
One operator did not send data about fibre access points, but with data from only two operators can be determined that E12 has fibre access points available almost the whole length of the road.

	A	B	C	D	All together
Mobile base stations	3 km	19 km	35 km	43 km	**100 km**
Fibre access points		64 km	43 km	44 km	**151 km**

Table 1: Results of the inventory.



Picture 2: Mobile base station inventory.



Picture 2: Fibre access point inventory.

There are only few areas where fibre access points are not available close to the road along E12. Of these areas which are lacking fibre connection, only few overlaps with areas lacking a base station. This indicates that deploying wireless access points or erecting new mobile base stations alongside the E12 does not require costly fibre construction.

4 Conclusions and recommendations

As autonomous vehicles become more common, the demand for reliable high capacity – low latency networks on the roads will increase. The current mobile networks along most of Finnish roads have been designed to satisfy the needs of a casual entertainment usage of the passengers. Even though the coverage of Finnish mobile networks is great, the capacity, especially on the rural areas, has not been designed for cooperative driving and tele-operated remote driving. These type of data rates can only be achieved in high coverage 5G networks that are operated in 3,5 GHz and 26 GHz frequency bands. The large bandwidths on these frequencies can ensure extremely low latencies, high download and most noteworthy – high upload capacity, which plays a key role in many use cases relying on cellular networks and/or other connectivity solutions.

In theory the listed service level requirements can be achieved with current 4G and 5G technologies although achieving them in practice requires rethinking on how mobile networks and provided mobile services are executed.

Many use cases require 99,99% reliability, which in turn means that vehicles can't rely on cellular networks, if deployed on current standards and design philosophy. Current networks have not been designed for the road user in mind and they are not designed to withstand 99,99 % reliability standards.

Mobile network seems like the best option to provide general connectivity for autonomous vehicles. This is due to its technological potential, flexibility in execution and standardisation of mobile network technology. Autonomous driving sets high connectivity standards and the industry is required to take a holistic view when it comes to V2X connectivity and requires rethinking on how connectivity on roads will be handled in the future. For example, should autonomous vehicles operate in their own network and use commercial networks only when backup is required through prioritised roaming? Can mobile network coverage be complemented with other wireless connectivity solutions to provide access over shorter distances to less critical services?

4.1 Recommendations for the service level framework

Recommendations for the service level framework is based on the use cases presented in this report. Even though the focus of this task has been on mobile communication services, the following recommendations for service level framework are presented for the whole communication system in general.

It is crucial to differentiate the capacity that a single vehicle requires and the capacity of a mobile network cell, here capacity requirement is presented as per vehicle. Download and upload values have been evaluated according to use cases, by assessing on which ISAD framework level use cases are utilized, which of them would be utilized concurrently and finally what would be their total peak capacity requirement together. On top of the peak capacity requirement redundant capacity was calculated (~10-20%).

For example, on service level A both download and upload capacity were estimated to peak around 100 Mbit/s if Coordinated Cooperative Manoeuvring and Tele-Operated

Driving were utilized at the same time. In this scenario vehicle would be sending and receiving RADAR, LIDAR, and censor data along with HD/UHD picture. In turn, on service level B, vehicle would be only receiving this data from its environment.

Capacity requirement recommendation on service level C & D was based on the assessment that most demanding use case on service level C, is to receive video stream from infra and/or other vehicles. On level D data capacity is needed only for smaller messages and possible system updates.

Since requirement for ongoing continuous high capacity data connection is limited to a few use cases, it is challenging to set a value that would satisfy every possible scenario on each service level. Most use cases requiring high capacity can utilize buffering (e.g. HD maps, streaming, system updates etc.), and only a few of the critical (i.e. entertainment excluded) use cases require continues low latency – high capacity network on demand.

Latency is presented as vehicle-service-vehicle latency and not as on-air latency (vehicle-base station). The latency for each service level is recommended according to use case requiring the lowest latency. Estimating the end-to-end latency is challenging since it is heavily dependent on the used technologies and on the topology of the network between communicating systems. For example, the availability of edge computing, the logical and physical distance between systems have a significant effect on latency. In general, end-to-end latency is usually not an issue in 4G and especially in 5G networks. Even on poor quality 3G networks latencies tend to stay under 100 ms.

Reliability of the networks was evaluated on the same method as latency. After assessing ISAD levels for all use case, a use case in with highest reliability requirement in every ISAD category was chosen and its reliability was used for the whole category. In general, reliability is the most challenging attribute to assess and since literature tends to recommend seemingly high reliability figures even for non-critical use cases (e.g. streaming 4K video for entertainment 90 % reliability rate). All wireless communication solutions are always less reliable than fixed network. Currently mobile networks are designed for 90 % reliability, but 5G networks can in theory provide up to 99,999 % reliability.

Other attributes recommended are availability of 4G network, availability of 5G network, availability of 5G mm wave (26 GHz) and number of redundant cellular network providers. 4G network is recommended on the ISAD levels C & D, 5G in turn on levels A & B, 5G mm wave is recommended for high traffic areas for service levels A & B as well. Recommendations are based on capacity available on 4G and 5G networks. In practice 15/15 Mbit/s is hard to achieve already in 4G networks, especially if there are lots of users within the mobile cell service area. 100 Mbit/s for several user concurrently requires 5G network every time, therefore 5G is recommended for the service levels A & B. In high traffic areas, 26 GHz mm wave deployment might be needed to provide extra capacity. 5G can also provide significantly lower latency which is required for most use cases related to cooperative autonomous driving.

	E	D	C	B	A
4G		Available	Available		
5G				Available	Available
5G (mm wave)				Available in high traffic areas	Available in high traffic areas
Number of redundant cellular net-works		At least 2	At least 2	At least 2	At least 2
Download		5 Mbit/s	15 Mbit/s	100 Mbit/s	100 Mbit/s
Upload		5 Mbit/s	15 Mbit/s	25 Mbit/s	100 Mbit/s
Latency		< 100 ms	< 50 ms	< 20 ms	< 10 ms
Reliability		95 %	99 %	99,9 %	99,99 %

Table 2: Mobile service level recommendations for service level framework.

4.2 Summary of the current service level on E12 between Helsinki-Tampere

To get a complete picture of the current service levels on the E12 the field measurement results were analysed in the recommended service level framework. Picture 3 visualises the current service levels and their distribution along the road. Table 3 presents same data in numeral form.

Picture 3: Mobile communication service levels on E12.

E	D	C	B	A
30,5 km / 17,6 %	70,7 km /40,2 %	74,6 km/ 42,2 %	0 km / 0 %	0 km / 0 %

Table 3: Mobile communication service levels on E12.

In this presentation only download, upload, latency, 4G/5G availability and availability of redundant network attributes were used. Reliability and mm wave attributes were ignored.

From the visual presentation, the interpretation is that service levels do not form homogeneous stretches along the E12. Instead service level categories are scattered along the road. Stretches forming somewhat uniform E category areas resemble and are also aligned with the mobile base station inventory presented in picture 1. When data from these areas is compared to scanner data, can be seen that areas in category E are serviced by sub 1 GHz frequencies which reflects very well the mobile base station inventory data.

Individual numbers of the different operators are presented in table 4 (without the requirement for redundant operator).

	E	D	C	B	A
Operator A	21,8 %	37,2 %	41,1 %	0 %	0 %
Operator B	23,2 %	33,9 %	42,3 %	0,5 %	0%
Operator C	21,4 %	30,2 %	46,6 %	1,8 %	0 %

Table 4: Mobile communication service levels on E12 by operator.

As expected, the A & B categories cover 0 % of the road when second redundant network is required, but individually two operators can provide a few kilometres of category B service levels. Same trend continues with the service level C, individually operators provide a better service level when requirement for backup network is ignored. Instead operator networks overlap in a way that areas with category D increase significantly and areas with category E decrease. This indicates that other operators' networks complement each other by overlapping on areas where individual operator's coverage might be poor.

Bibliography

C-V2X Use Cases and Service Level Requirements (Volume I). 2020. 5GAA Automotive Association. Technical Report (version 3.0).

C-V2X Use Cases and Service Level Requirements (Volume II). 2020. 5GAA Automotive Association. Technical Report (version 1.0).

Annex 1: Use case tables

			Volume I				
Group	Use Case	Message type	Download	Upload	Reliability	Latency	Use Case Description
1	Cross-Traffic Left-Turn Assist (user story #1)	normal CAM messages	300 B per message	300 B per message	90 %	100 ms	Alerts HV attempting to turn left across traffic of an RV approaching from the opposite direction in the lanes that HV needs to cross.
1	Cross-Traffic Left-Turn Assist (user story #2)	normal CAM messages + projected driving lines	1000 B per message	1000 B per message	99,9 %	10 ms	Alerts HV attempting to turn left across traffic of an RV approaching from the opposite direction in the lanes that HV needs to cross.
1	Intersection Movement Assist	normal CAM or BSM messages	300 B per message	300 B per message	99,99 %	100 ms	Stationary HV proceeds straight from stop at an intersection. HV is alerted if it is unsafe to proceed through the intersection.
1	Emergency Brake Warning (user story #1ja #2)	normal CAM or BSM messages	200-400 B per message	200-400 B per message	99,99 %	120 ms	Alert HV that a lead RV is undergoing an emergency braking event.
1	Traffic Jam Warning (user story #1,#2 ja #3)	BSM or DENM messages	300 B per message	300 B per message	50 %	2000 ms	Alert HV of an approaching traffic jam.
1	Route Information (user story #1,#2 ja #3)	BSM or DENM messages	300 B per message	300 B per message	50 %	minutes	Alert HV of an approaching traffic jam.
1 and 4	Real-Time Situational Awareness and High-Definition Maps: Hazardous Location Warning (HV only supported by RVs)	normal CAM or BSM messages	300 B per message	300 B per message	99 %	100 ms	An autonomous or semi-autonomous vehicle is driving on a road (route), heading towards a road segment, which presents unsafe and unknown conditions ahead. A host vehicle is made aware of situations detected and shared by remote vehicles. Situations may include such things as accidents, weather, traffic, construction.
1 and 4	Real-Time Situational Awareness and High-Definition Maps: Hazardous Location Warning (HV receives information from a backend/cloud)	events or vector data	300-1000 B per message	300-1000 B per message	99% / low	1-2 s / 10-200 s	An autonomous or semi-autonomous vehicle is driving on a road (route), heading towards a road segment, which presents unsafe and unknown conditions ahead. A host vehicle is made aware of situations detected and shared by remote vehicles. Situations may include such things as accidents, weather, traffic, construction.
1	Cooperative Lane Change (CLC) of Automated Vehicles: Lane Change Warning (user story #1,#2 ja #3)	single information and BSM type messages	300 B per message	300 B per message	99,9 %	400 ms	Host vehicle (HV) signals an intention to change lanes.
1	Vulnerable Road User (Awareness of the presence of VRUs near potentially dangerous situations)	raw data and afterwards information	20-40 Mbps (when stabilates then 2 Mbps)	20-40 Mbps (when stabilates then 2 Mbps)	99,9 %	100 ms (prefered 20 ms)	Alert HV of approaching VRU in the road or crossing an intersection and warn of any risk of collision.
1	Vulnerable Road User (Collision risk warning)	raw data and afterwards information	20-40 Mbps (when stabilates then 2 Mbps)	20-40 Mbps (when stabilates then 2 Mbps)	99,9 %	101 ms (prefered 20 ms)	Alert HV of approaching VRU in the road or crossing an intersection and warn of any risk of collision.
2	Software Update (Conventional-Routine)	datatransfer	15 GB within 168 hours	-	99 %	-	Vehicle manufacturer updates electronic control module software for targeted vehicles.
2	Software Update (Conventional-Urgent)	datatransfer	15 GB within 24 hours	-	99 %	1 hour	Vehicle manufacturer updates electronic control module software for targeted vehicles.
2	Software Update (Autonomous-Routine)	datatransfer	3 GB within 24 hours	-	99 %	-	Vehicle manufacturer updates electronic control module software for targeted vehicles.
2	Software Update (Autonomous-Urgent)	datatransfer	3 GB within 2 hours	-	99 %	10 min	Vehicle manufacturer updates electronic control module software for targeted vehicles.
2	Software Update (Without Infrastructure)	datatransfer	15 GB	-	99 %	30 s	Vehicle manufacturer updates electronic control module software for targeted vehicles.
2	Software Update (Vehicle to Workshop)	datatransfer	32 GB	-	99,9 %	15 min	Vehicle manufacturer updates electronic control module software for targeted vehicles.
2	Vehicle Health Monitoring	datatransfer	< 1 KB	< 1 KB	99,99 %	< 30 s	Owners, fleet operators and authorised vehicle service providers monitor the health of HV and are alerted when maintenance or service is required.
3 and 4	High Definition Sensor Sharing (Lane change on automated driving mode)	processed and un-processed data	1000 B per message (processed data). Larger for un-processed data.	1000 B per message (processed data). Larger for un-processed data.	99,9 %	10 ms	The vehicle has automated driving mode and changes lanes. Vehicle uses its own sensors (e.g. HD camera, lidar), and sensor information from other vehicles, to perceive its environment (e.g. come up with 3D model of world around it) and safely performs an automated driving lane change.
3 and 4	See-Through for Passing	videostreaming	15 Mbps	15 Mbps	99 %	50 ms	Driver of host vehicle (HV) that signals an intention to pass a remote vehicle (RV) using the oncoming traffic lane is provided a video stream showing the view in front of the RV.
6	Speed Harmonisation (human driver)	speed and location data	300 B per message	300 B per message	80 %	2500/1800/1400 ms	Notify HV of recommended speed to optimise traffic flow, minimise emissions and to ensure a smooth ride.
6	Speed Harmonisation (HV is highly automated)	speed and location data	300 B per message	300 B per message	80 %	1500/800/400 ms	Notify HV of recommended speed to optimise traffic flow, minimise emissions and to ensure a smooth ride.

			Volume II				
Group	C-V2X Use Cases Volume II: Examples and Service Level Requirements	Messagie type	Download	Upload	Reliability	Latency	Use Case Description
1	Cooperative Traffic Gap	messages and censor data	2 Mbps	2 Mbps	99,9 %	100 ms/ 50 ms	A vehicle intends to pull into a certain lane and needs to cross multiple lanes so it asks vehicles already circulating on the road to cooperate by opening a gap to allow the host vehicle (HV) to enter the traffic and cross (manouvre) safely.
1	Interactive VRU Crossing	"heartbeat" data and location	64 kbps	64 kbps	99,9 %	100 ms	A vulnerable road user (VRU), such as a pedestrian or cyclist, signals his or her intention to cross a road and interacts with vehicles approaching the area in order to improve safety for VRUs and awareness for vehicles.
2	Software Update of Reconfigurable Radio System (Upgrade of Feature-Set)	datatransfer	200 MB per update	-	99 %	-	A Vehicle's reconfigurable radio system has its software or firmware updated (i.e. a feature set, new standard release) to comply with regional requirements, etc.
2	Software Update of Reconfigurable Radio System (Addressing Vulnerabilities)	datatransfer	Few MB up to 100 MB	-	99 %	1 hour to deliver 'critical update required' message	A Vehicle's reconfigurable radio system has its software or firmware updated (i.e. a feature set, new standard release) to comply with regional requirements, etc.
3	Automated Valet Parking - Joint Authentication and Proof of Localisation	location data and simple messaging	-	16 Kbps	99 %	500 ms	Enable access control to a parking facility for autonomous vehicles. Vehicles deposited in a drop-off area are authorised for autonomous navigation within the parking area.
3	Automated Valet Parking (Wake Up)	simple message	3,2 Kbps	-	99 %	500 ms	A parked 'sleeping' vehicle in a parking facility should be autonomously moved for (re)parking pick-up. For this purpose, the vehicle receives a wake-up call.
3	Awareness Confirmation	occational data	40 Kbps (max 50 x in single event)	41Kbps (max 50 x in single event)	99 %/ 99,9 %	20 ms	The host vehicle is sending out messages (e.g. basic safety messages or in the future more advanced 'evolved' message types) indicating whether it would like to receive confirmation. The HV receives confirmation from the remote vehicles and uses this information for various purposes (e.g. adapts its driving style).
3	Cooperative Curbside Management	occational data and steering data	Not known	Not known	99,9 %	100 ms / 5000 ms	A pedestrian and a vehicle are planning a pickup at a crowded curbside to improve the efficiency and safety of this densely populated area.
3	Cooperative Lateral Parking	camera images and sensor data	27 Mbps	27 Mbps	99,9 %	100 ms / 10 ms	A vehicle identifies a free parking space on the side of a road and cooperates with neighbouring vehicles to inform them of the planned parking action and asks them to 'make room' in order to carry out an efficient and fast parking manoeuvre.
3	In-Vehicle Entertainment (IVE) -(High-Definition (HD) Content Delivery, On-line Gaming and Virtual Reality - High-End Service for Cars)	8K and AR videostreaming, VR and gaming	250 Mbps per stream	-	99 %	20 ms	Entertainment content delivery to the passengers of a moving or stationary vehicle (e.g. video, gaming, virtual reality (VR), office work, online education). It is applicable to both automated and non-automated vehicles, where in the latter the driver is restricted in the content he or she is safely allowed to consume.
3	In-Vehicle Entertainment (IVE) (High-Definition (HD) Content Delivery - Low-End Service for Cars)	4K videostreaming	50 Mbps per stream	-	90 %	150 ms	Entertainment content delivery to the passengers of a moving or stationary vehicle (e.g. video, gaming, virtual reality (VR), office work, online education). It is applicable to both automated and non-automated vehicles, where in the latter the driver is restricted in the content he or she is safely allowed to consume.
3	In-Vehicle Entertainment (IVE) (High-Definition (HD) Content Delivery - Bus Passenger Service)	4K videostreaming	50 Mbps per stream	-	90 %	150 ms	Entertainment content delivery to the passengers of a moving or stationary vehicle (e.g. video, gaming, virtual reality (VR), office work, online education). It is applicable to both automated and non-automated vehicles, where in the latter the driver is restricted in the content he or she is safely allowed to consume.
3	Obstructed View Assist (Provision of Video Stream Via CCTV)	videostreaming	5 Mbps	5 Mbps	99 %	50 ms	A HV needs an unobstructed view to proceed safely. This view can be provided by a camera or other vehicles with a better view.
3	Obstructed View Assist (Provision of Video Stream Via RVs)	videostreaming	5 Mbps	5 Mbps	99 %	50 ms	A HV needs an unobstructed view to proceed safely. This view can be provided by a camera or other vehicles with a better view.
3	Vehicle Decision Assist (RV Waiting for a Short Period of Time (RV Broken Down) (Bus Having to Wait)	location data, space data and status data	1000 bytes	1000 bytes	99,9 %	100 ms	This feature helps a vehicle to decide whether it should overtake a stationary vehicle it detects in front.
3	Vehicle Decision Assist (Slow Vehicle en Route)	location data, space data and status data	Few bytes to few MB	Few bytes to few MB	99,9 %	100 ms	This feature helps a vehicle to decide whether it should overtake a stationary vehicle it detects in front.

			Volume II				
Group	C-V2X Use Cases Volume II: Examples and Service Level Requirements	Messagie type	Download	Upload	Reliability	Latency	Use Case Description
4	Automated Intersection crossing	many different kind of short messages	1950 bytes	1950 bytes	99,9999 %	10 ms	An autonomous vehicle goes through an intersection with traffic light. The AV goes through or stops, taking into consideration the timing of the traffic light signal. When stopping at the intersection, the AV can be put into the correct position.
4	Autonomous Vehicle Disengagement Report	sensor data	-	26.7 Mbps	99,99 %	10 min	When a HV's autonomous 'virtual driver' system disengages, it submits a disengagement report containing a time-windowed recording of vehicle systems data, rich sensory information and dynamic environmental conditions to the original equipment maker (OEM) and government data centres.
4	Cooperative Lane Merge	location and route data	300 bytes	300 bytes	99,9 %	20 ms	A host vehicle accommodates a remote vehicle that is merging into the HV's traffic lane.
4	Cooperative Manoeuvres of Autonomous Vehicles for Emergency Situations	many messages from one vehicle to another	48 Kbps	48 Kbps	95 %	10 ms	An Autonomous Vehicle identifies a dangerous situation (e.g. collision with a moving object) and undertakes to coordinate with neighbouring AVs in order to decide and perform their manoeuvres jointly.
4	Coordinated, Cooperative Driving Manoeuvre (Cooperative Lane Change, Pedestrian Crossing and Road Blockage)	many messages from one vehicle to another	24 - 64 Mbps	24 - 64 Mbps	99,9 %	4 x 40 ms	A HV wants to perform a certain action (e.g. lane change) and shares this intention with other traffic participants potentially involved in the manoeuvre. The informed traffic participants confirm or decline the planned manoeuvre with the main traffic participant which then informs a superset of the traffic participants whether it plans to perform the manoeuvre.
4	HD Map Collecting and Sharing	map data	16 Mbps	4-47 Mbps	99 %	100 ms	Vehicles equipped with LIDAR or other HD sensors can collect environment information around them, and share it with a HD map provider (e.g. cloud server). The HD map provider analyses the collected information and merges or combines it in order to build a regional HD map. This allows the construction of HD maps that are dynamically updated with more accurate data.
4	Infrastructure Assisted Environment Perception (Data Distribution about Objects on the Road in Form of Object Lists or Occupancy Grids and Individual Data Transmission in Form of Trajectories or Actuation Commands)	RADAR, LIDAR, camera, messages	Very complex	Very complex	From sensors to edge compute node: 99 Infrastructure to HV: 99,99-99,999 %	100 ms	When an automated vehicle enters a section of the road that is covered by infrastructure sensors it subscribes to receive information from the infrastructure containing environment data from dynamic and static objects on the road. This data is used to increase the trust level of the cars own sensor observations and extends its viewing range.
4	Infrastructure-Based Tele-Operated Driving	RADAR, LIDAR, camera, messages, steering	400 kbps	35 Mbps (LIDAR)	From infrastructure to edge node 99 %. From remote driver to HV 99,999 %	50 ms (RTT 100 ms)	Infrastructure (e.g. sensors, cameras) support the remote driver by providing a real-time picture of the road environment centred around the HV. Based on the perceived situation and the capabilities of the car, the remote driver can provide the appropriate trajectory and manoeuvre instructions to help the autonomous vehicle move to a safer location.
4	Remote Automated Driving Cancellation (RADC)	messaging	300 bytes	300 bytes	99,999 %	100 ms	The High Automated level of an AD vehicle has to be immediately cancelled for safety reasons. This can be triggered for a number of reasons and criteria, including lack of network coverage, insufficient KPI SLA possibilities, unusual and/or unsafe driving conditions, etc.
4	Tele-Operated Driving (ToD)	videostreaming, sensor data, driving commands	400 kbps	32-36 Mbps	From HV to Remote driver: 99 % From Remote driver to HV: 99,999 %	HV to remote: 100 ms. Remote to HV: 20 ms	A remote driver undertakes the control of the vehicle and drives it efficiently and safely from the current location to the destination.
4	Tele-Operated Driving Support (Remote Steering)	videostreaming, sensor data, steering commands	400 kbps	32-36 Mbps	From HV to Remote driver: 99 % From Remote driver to HV: 99,999 %	HV to remote: 100 ms. Remote to HV: 20 ms	An autonomous vehicle asks for the support of a remote driver in order to resolve a situation where uncertainty is high and it cannot make the appropriate decision for a safe and efficient manoeuvre. The vehicle then switches back to the normal autonomous driving mode without the remote driving support.

			Volume II				
Group	C-V2X Use Cases Volume II: Examples and Service Level Requirements	Messagie type	Download	Upload	Reliability	Latency	Use Case Description
4	Tele-Operated Driving Support (Remote Driving Instructions)	videostreaming, sensor data, steering commands	25-400 kbps	32-36 Mbps	From HV to Remote driver: 99 % From Remote driver to HV: 99,999 %	HV to remote: 100 ms. Remote to HV: 200 ms	An autonomous vehicle asks for the support of a remote driver in order to resolve a situation where uncertainty is high and it cannot make the appropriate decision for a safe and efficient manoeuvre. The vehicle then switches back to the normal autonomous driving mode without the remote driving support.
4	Tele-Operated Driving for Automated Parking (Remote Driving Paths)	sensor data and steering commands	25 kbps	4 Mbps	99,999 %	100 ms	When a vehicle arrives at its destination parking area, the driver leaves the vehicle and it is parked by a remote driver located in a tele-operation centre.
4	Tele-Operated Driving for Automated Parking (Remote Steering)	videostreaming, sensor data, steering commands	400 kbps	32-36 Mbps	From HV to Remote driver: 99 % From Remote driver to HV: 99,999 %	HV to remote: 100 ms. Remote to HV: 20 ms	When a vehicle arrives at its destination parking area, the driver leaves the vehicle and it is parked by a remote driver located in a tele-operation centre.
4	Vehicle Collects Hazard and Road Event for AV	single messages HV-RV-AS (application server)	300 B per message	300 B per message	99,9 %	20 ms	Vehicles collect hazard and road event information based on vehicle sensor data for further use by AVs and V2X application servers (V2X AS).
5	Vehicles Platoon in Steady State	Member of a platoon (MV), Head of a platoon (HV), coordination with cloud (CA).	MV - MV: 100 bytes HV - MV: 300 bytes (20 Hz) HV - CA: 1000 bytes (event based)	MV - MV: 100 bytes HV - MV: 300 bytes (20 Hz) HV - CA: 1000 bytes (event based)	MV - MV: 99,9 % HV - MV: 99,9 % HV - CA: 99 %	MV - MV: 50 ms HV - MV: 100 ms HV - CA: >1000 ms	A group of vehicles (e.g. trucks that travel from warehouse facilities to a transportation area) drive closer in a coordinated manner to decrease fuel consumption, increase efficiency and reduce traffic congestion. Member of a platoon (MV), Head of a platoon (HV), coordination with cloud (CA).
6	Bus Lane Sharing request	ID data, authentication, location etc.	500-1000 bytes	500-1000 bytes	99 %	200 ms	Temporary access to bus lanes can be granted to certain vehicles by a road authority/city, in order to improve road usage and traffic efficiency.
6	Bus Lane Sharing Revocation	ID data, authentication, location etc.	500-1000 bytes	500-1000 bytes	99 %	200 ms	Revocation of access to bus lanes granted to certain vehicles if a set of vehicles are likely to disturb/obstruct a bus that is approaching.
6	Continuous Traffic Flow via Green Lights Coordination	messaging	From traffic management server or a roadside infrastructure to HV: 300 bytes	From HV to traffic management server or a roadside infrastructure: 300 bytes (every 50 ms/20 Hz per participating vehicle)	95 %	100 ms	A series of traffic lights (usually three or more) are dynamically coordinated to allow continuous traffic flow over several intersections in one main direction. Any vehicle travelling along with the 'green wave' will see a progressive cascade of green lights, and does not have to stop at the intersections.
6	Group Start	messaging	300 bytes (every 50 ms/20 Hz per participating vehicle)	300 bytes (every 50 ms/20 Hz per participating vehicle)	99,999 %	10 ms	Self-driving or semiautomated vehicles form a group to jointly start at a traffic light.
7	Accident Report	situation data and camera data	-	1,8 Mbps	99,99 %	-	When host vehicles are involved in a traffic incident an accident report containing a time-windowed recording of vehicle systems data, rich sensory information, environmental conditions and any available camera views is sent to government and private data centres.
7	Patient Transport Monitoring	patient status data, videostreaming and voice	1 Mbps (data) + 64 Kbps (voice)	9 Mbps (video + data) + 64 Kbps (voice)	99 % video and voice 99,999 % for data	150 ms	Paramedics, patient-monitoring equipment, trauma centres and doctors share vital patient telemetry data, images, voice and video during patient transport.

Annex 2: Specifics of the field measurements

Test scenario	Terminal	Description
TC1 – Latency 4G	T1-3, Samsun S8	Ping (continues with 0,5 s cycle)
TC2 – Latency 4G	T4-6, Samsun 20+	Ping (continues with 0,5 s cycle)
TC3 – Data download 4G	T7-9, Samsung S9	ftp/http downloading (5 min download – 15 s wait cycle)
TC4 – Data upload 4G	T10-12, Samsung S9	ftp/http downloading (5 min download – 15 s wait cycle)
TC5 – Data download 5G	T13-15, OnePlus8	ftp/http downloading (5 min download – 15 s wait cycle)
TC6 – Data upload 5G	T16-18, OnePlus8	ftp/http downloading (5 min download – 15 s wait cycle)
TC7 – Scanner measurement		RSRP-measurement on 4G and 5G frequency bands

*T1-18 were located inside the car; scanner antenna was located outside.

Run	Date	Time	Start point	End point
Evening	2021-03-17	20:30 – 22:45	Manner-heimintie 7, Hel-sinki	Saapastie 2, Pirk-kala
Morning	2021-03-23	06:55 – 09:15	Saapastie 2, Pirk-kala	Manner-heimintie 7, Hel-sinki
Night	2021-03-17	02:10 – 05:15	Saapastie 2, Pirk-kala	Manner-heimintie 7, Hel-sinki

Finnish Transport Infrastructure Agency

Nordic WAY 3

Co-financed by the Connecting Europe Facility of the European Union

Working report
14/05/2021

Service level framework for automated road transport

Task 1.3. Positioning

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1 Goal of the task

The main objective of the task is to:

- define the applicability of the highway VT3 between Helsinki and Tampere to SAE level 3 or 4 automated vehicles,
- propose ways to classify certain service levels for the Finnish road network for automated driving,
- propose future guidelines for research and development work as well as international cooperation.

This work has been performed by the consulting group comprised of Traficon-Ramboll, VTT and Sitowise based on the framework agreement. For this work, the customer has acquired consultant services under the framework agreement (consultant) between Traficom and the Finnish Transport Infrastructure Agency on international consulting and expert services regarding road transport management, intelligent transport and technologies. The consulting group consisting of Traficom-Ramboll, VTT and Sitowise has submitted to the customer jointly coordinated offers, on the basis of which the customer can acquire expert services for the implementation of the project. The responsibilities of the companies and the experts appointed by them are presented in connection with each sub-task.

This report bases on main two topics:

1) interviews and investigation of the available in E12 motorway (Section 3)
2) experimental results conducted in two trials with tailored positioning devices (Section 4)

This report is assigned to the VTT's documentation registers with ID: VTT-CR-00447-21.

This project is a sub-project under the NordicWay3-project (2019-2023) (www.nordicway.net), which is funded by European Commission Connecting Europe Facility (CEF) programme.

1.1 Positioning and positioning services

Content of the task

Define relevant positioning technologies and define data collected from field measurements. Interview experts from the National Land Survey of Finland (NLS), gathering the information described below.

Minimum information to be gathered:

- technologies available in the target area, their service promise, required communication connections, quality of service including positioning and relevant services future development,
- GNSS (GPS, Galileo, Galileo HAS, Glonass) positioning accuracy (absolute, relative) in lane,

- availability, redundancy the quality of service of the positioning and correction services. Such as FinnRef/FinnPos, GMV/Sapcorda Trimble/Hexagon,
- possible shadow areas of the services,
- connections required, linked to task 1.2.

2 Satellite positioning

The satellite positioning system is divided into three segments (Figure 1). The first segment is the space segment, which includes all the satellites. The second is the control segment, which contains monitoring ground stations and the control centre, and maintains the space segment. The third is the user segment, where the user receivers are located.

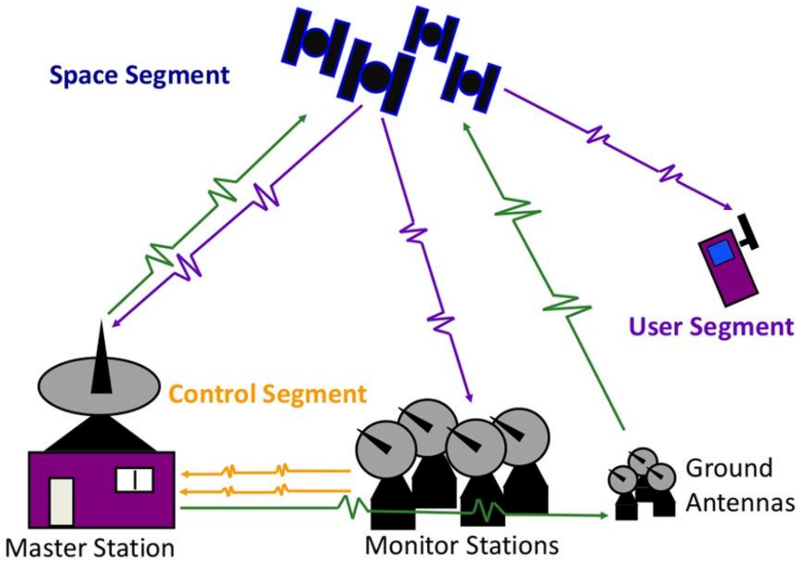


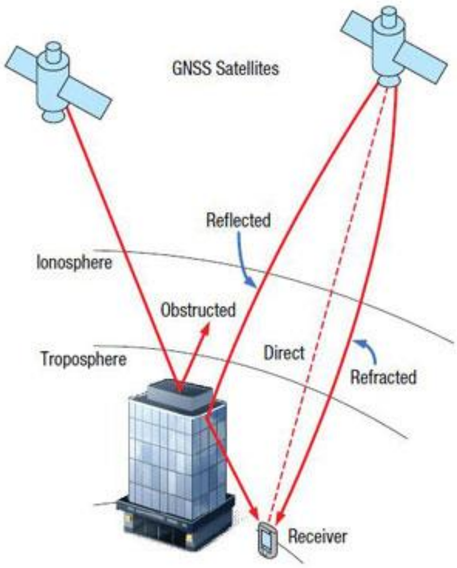
Figure 1. Segments of the satellite positioning system.

This division of responsibilities is generic to all positioning systems. The positioning infrastructure needs to be constructed, maintained, and purchased by some authority. Additionally, the users need to have interoperable receivers. GNSS systems are maintained by governments and the use is royalty free.

The GNSS (Global Navigation Satellite System) system nowadays contains four global constellations, American GPS, European Galileo, Russian Glonass and Chinese Beidou. Beidou is designed to first serve the area of China and Galileo is the only one intended for civil use. India has a local implementation (IRNSS Navic). The GNSS system also contains geostationary satellites (the SBAS, satellite based augmentation system), the European Egnos augmentation system, and the American WAAS and Japanese QZSS augmentation systems. Augmentation systems provide services mainly for aviation applications. Correction data provides DGPS (differential GPS) level accuracy of a few meters. In Finland, the Egnos satellite is at a low elevation and not necessarily available. It is possible to receive satellite data, however, from the Internet.

Every positioning system has an error. Positioning using radio waves is a measurement of time. Because the signal speed travels at the speed of light (299 792 458 m/s), during 1 nanosecond signal travels 30 cm. Thus, the time measurement system needs to very accurate and synchronised. This is achieved in GNSS with satellite atomic clocks, which are adjusted by the control station. Every satellite constellation has its own time frame. The signal timing and resolution need to be extremely accurate to achieve even modest positioning accuracy.

Errors in satellite positioning arise mainly from the atmosphere. Figure 2 presents typical error sources and magnitudes. Basic level GNSS receiver absolute accuracy is approximately 20 metres. Another factor is the geometry of the received satellite positions. If the satellites are located next to each other, the accuracy is poor. If their locations are spread around the sky the accuracy is better. The geometrical error is expressed as a dilution of precision (DOP). In the urban environment, tall buildings obstruct the visibility of satellite signals and receivers can obtain satellite signals only from narrow strips of the sky. The signals are also prone to multipath issues. This means that even if the positioning result is achieved, it is not accurate.



Contributing source	Error range
Satellite clocks	$\pm 2\,m$
Orbit errors	$\pm 2{,}5\,m$
Ionospheric delays	$\pm 5\,m$
Tropospheric delays	$\pm 0{,}5\,m$
Receiver noise	$\pm 0{,}3\,m$
Multipath	$\pm 1\,m$

Figure 2. GNSS error sources. /2/

2.1 Methods to improve accuracy

2.1.1 Dual frequency receivers

The positioning accuracy can be improved using more than one frequency from a satellite. Traditionally, military GPS receivers have used two signals (L1 and L2), while civil receivers have been able to use only one (L1). When two signals with different frequencies are sent at the same time, one can measure the delay caused by the ionosphere from the phase difference. GNSS systems today offer several civil signals. GPS nowadays has signals L1C, L2C and L5. This improves the accuracy by a tenth, but this still represents a number of metres. The Galileo system sends L1, E5a and E5b signals and Glonass L1, L2 and L3.

2.1.2 Correction services

Much better positioning accuracy can be achieved by using base stations, with accurately known coordinates. It can send its measurements to a rover unit, which can calculate its relative position to the base station. The measurements are sent using RTCM (Radio Technical Commission for Maritime Services) messages. The newest version of the protocol is RTCM 3.2. The problem in the past has been the wireless communication between the base station and rover. The first versions used the ULA radio channel from the Finnish Public Service Media Company and the user needed to have a proper receiver. An alternative choice was to use short range radio.

Today correction data is sent via the Internet and mobile data network using NTRIP (Networked Transport of RTCM via the Internet) protocol. The NTRIP network contain several GNSS base stations (NTRIP server) and one server (NTRIP Caster).

The user connects to NTRIP Caster using an NTRIP client application (NTRIP client) with a username/password and selects the desired mountpoint. The mountpoint defines the correction data stream. One base station can serve an area which is about 10-20 km in radius. If one chooses the closest base station, then there is no need to reveal your own location, otherwise location data is needed (NMEA GGA message) in order that the service can choose the closest base station.

The correction service can also calculate a virtual base station. It uses the whole base station network and calculates a virtual base station very close to the user based on error models. RTCM-correction accuracy depends on the distance to the base station. Therefore a virtual base station is a good choice for a large operation area. One drawback is that one needs to send accurate location data to the service. This creates a privacy issue, because the user location can be tracked.

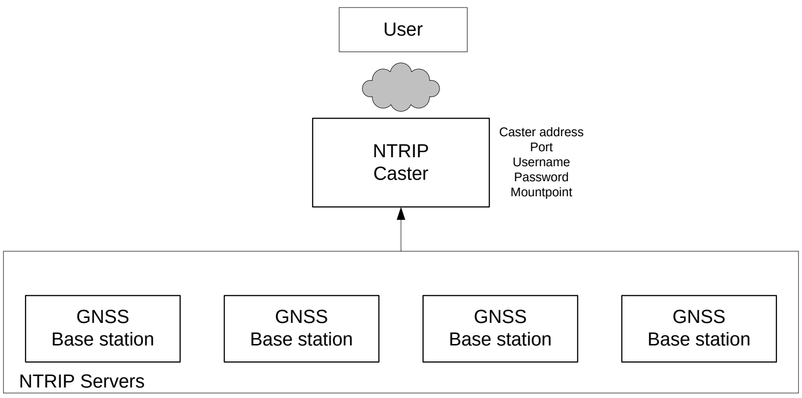


Figure 3. The principle of the NTRIP network.

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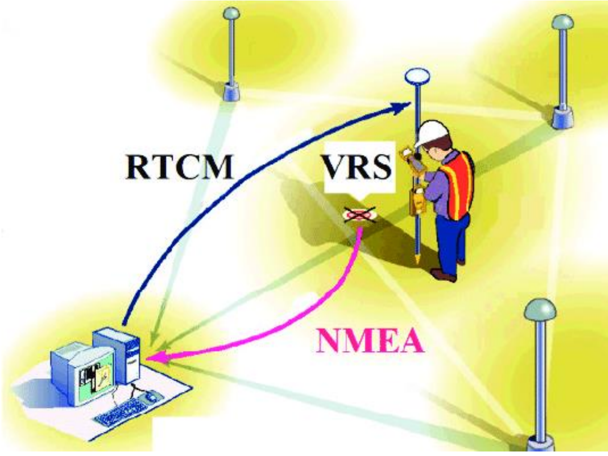

Figure 4. The principle of the virtual base station (Tuşat, Ekrem. 2018).

In Finland one can get commercial services from Trimble and Hexagon. Their base station network contains approximately 100 base stations. The National Land Survey of Finland (NLS) has 50 base stations. A reference network requires maintenance and quality control.

The size of the correction data packet is not large and it is sent once in a second. The client's location is sent every ten seconds. Using a virtual base station each client receives a customised data stream, which increases the load of the server. According to NLS the calculation process is lightweight.

Position accuracy depends on the conditions. A rover unit must be able to receive signals from the same satellites as the base station with a reasonable signal strength. With correction one can achieve different levels. Differential correction has the worst accuracy, of about 2 metres, the next level is RTK (real time kinematic) in float mode, with an accuracy of about a few decimetres. The most accurate is RTK in fixed mode, with an accuracy of a few centimetres. The difference between float and fixed mode is that in fixed mode the receiver can solve the integer number of the wavelengths between the rover and the base station. At the same time some hardware-related delays and clock errors may occur. In practice RTK positioning requires 5-6 satellites with over 40 dB signal strength. Also a good quality antenna, antenna cables and connectors are required.

2.1.3 Precise Point Positioning

The second option for accurate positioning is to use the PPP (Precise Point Positioning) method. This differs from the base station approach in that it requires multiple frequency receivers to remove troposphere and ionosphere errors. Correction data includes the satellite orbit and clock errors (see Figure 2). This data packet can be sent either from the satellite or using the cellular network. Therefore PPP does not require a local base station nearby. Convergence with the accurate solution is slower than RTK, and typically takes 10-15 minutes. The method is suited for remote areas, where base stations do not exist.

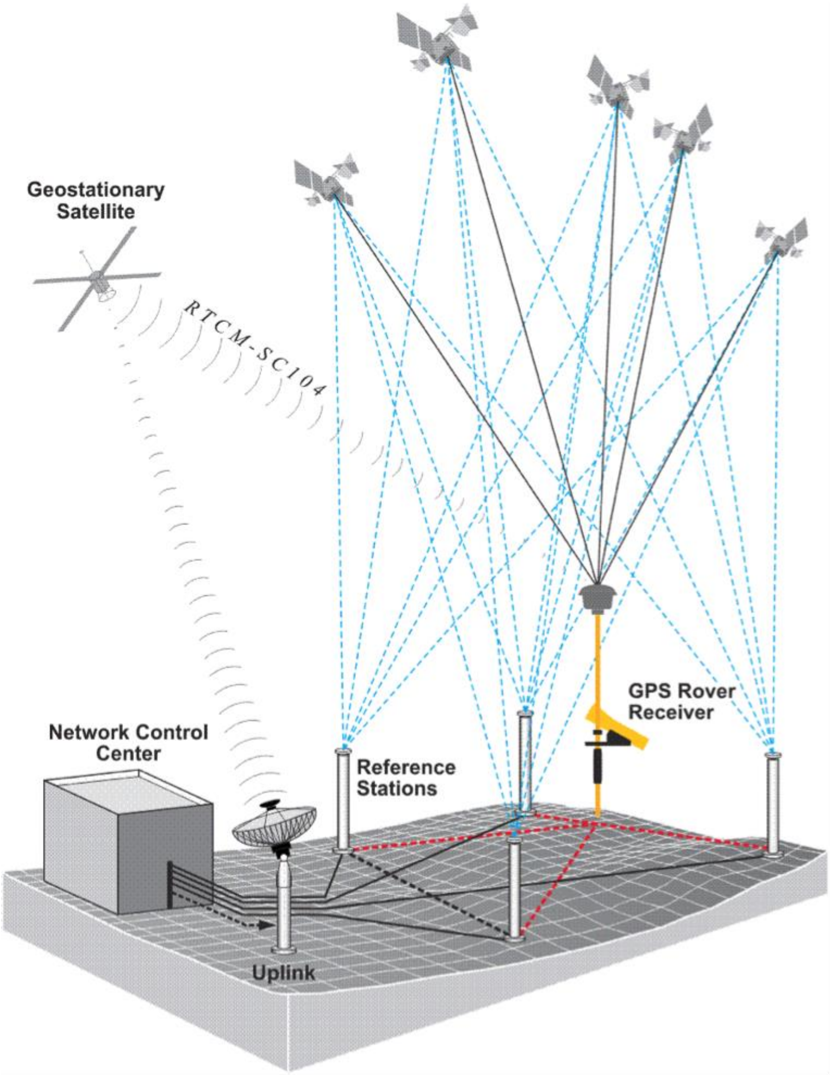

Figure 5. PPP method orbit and clock errors are measured in reference stations and delivered to the rover either from the satellite or cellular network. [source: GPS for Land Surveyors]

PPP is more accurate than RTK, but slower to get an accurate position. It is more sensitive to environmental conditions. If correction data is sent via satellite, the rover naturally must receive that satellite data. The bandwidth of the satellite broadcast is low, therefore downloading data from the satellite is slow. The PPP algorithm has two variants, post-processed PPP and real-time PPP. The latter has become available recently. PPP does not require the client location, therefore its privacy is better than RTK.

2.2 Coordinate frames

GNSS systems work with certain coordinate frames. GPS uses WGS84, which is based on the ITRF (International Terrestrial Reference Frame). The ITRF is updated every 6 years. Changes in the reference frame come from the Earth's deformation over time. Differences between frames (ITRF2008, ITRF2014, ITRF2020?) in this context are negligible, amounting less than 1 cm. The WGS84 relies today on the ITRF2014 frame.

Galileo uses GTRF (the Galileo Terrestrial Reference Frame), which is an independent realization of the International Terrestrial Reference System (ITRS) based on the estimated coordinates for each one of the Galileo Sensor Station (GSS) sites. According to Galileo requirements, the three-dimensional differences of the position compared to the most recent ITRF frame should not exceed 3 cm (2-sigma) (Navipedia).

The GLONASS broadcast ephemeris is given in the Parametry Zemli 1990 (Parameters of the Earth 1990) (PZ-90) reference frame. According to the GLONASS modernisation plan, the ephemeris information implementing the PZ-90.11 reference system was updated on all operational GLONASS satellites starting from 3:00 pm on December 31, 2013. From this time on, the satellites have been broadcasting using PZ-90.11. This ECEF reference frame is an updated version of PZ-90 and is closest to the ITRF2000. The difference is 2-3 mm.

The Finnish coordinate system EUREF-FIN is a 3D realisation of the European terrestrial ETRS89 reference system. The ETRS89 is fixed to the Eurasian tectonic plate. The ETRS89 was aligned with the ITRS (International terrestrial reference system) in 1989. Since then, the Eurasian tectonic plate has moved (translated and rotated) about 2–2,5 cm per year. Thus, nowadays the difference is about 0,70 m to the west and 0,45 m to the south. The corresponding frame in ETRS89 is the ETRF89.

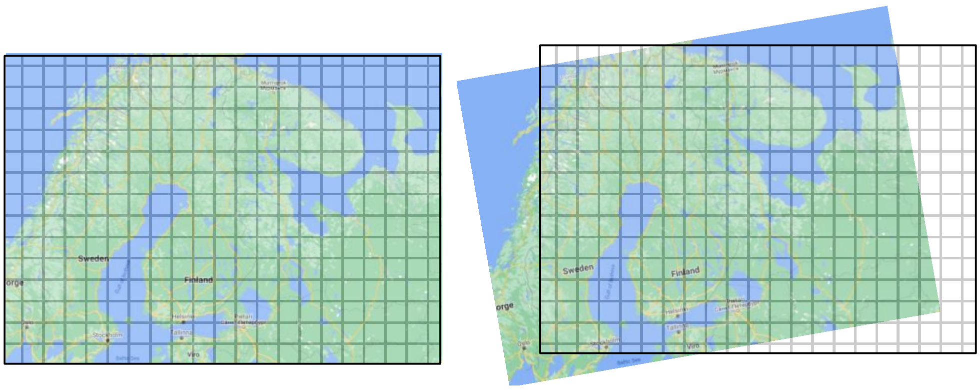

Figure 6. The ITRF (WGS84) and ETRF (ETRS89) were aligned in 1989 (left). The situation in 2020. ETRS89 has moved with the tectonic plate while the ITRF frame has not.

In practice, this mean that GNSS coordinates given by the receiver are 0,8 m off compared to the map coordinates. This misalignment has been insignificant, because the receiver error has been tens of meters. However, when attempting to achieve centimetre-level accuracy, this drift must be taken into account. We have two different use case:

1. When using an RTK correction service, the receiver measures its relative position to the base station. The base station coordinates are given as EUREF-FIN (ETRS89) coordinates, therefore also the measured coordinates are EUREF-FIN coordinates and this matches with map coordinates.

2. When using a satellite-based correction service (PPP, Egnos, Galileo HAS) the coordinates are given for the ITRF frame and thus are 0,8 m off compared to map coordinates.

There is no sense in using WGS84 coordinates with a map data. For this reason the EUREF-FIN and ETRS89 coordinate system was developed at the first place. The movement of the tectonic plate is quite fast and after two years the map error would be 5 cm compared to reality. It is better to use a conversion the ITRF to EUREF-FIN coordinates. It is important to know when to use conversion and when not. What is missing are specific EPSG[1] codes for the conversions. NLS has asked for the code. Additionally, it is essential know which ETRF frame to convert to. Obviously the frame is the same for all the map data used in automated driving.

[1] EPSG (European Petroleum Survey Group) Geodetic Parameter Dataset (also EPSG registry) is a public registry of geodetic datums, spatial reference systems, Earth ellipsoids, coordinate transformations and related units of measurement.

3 Interviews

3.1 NLS, 18 Jan 2021

The first interview for National Land Survey of Finland was conducted by phone on 18th of Jan 2021. The following people were joined to the interview session taking 1,5 hours.

- Jarkko Koskinen (NLS)
- Sanna Kaasalainen (NLS)
- Hannu Koivula (NLS)

Current situation

- The quality of the data connection is unknown over the E12 main road . No detailed knowledge if there are breaks in the availability of the repair signal.
- Trimble / Hexagon and NLS are the only national service providers. Two of the aforementioned have approx. 100 base stations, and NLS has 50.
- Virtual base stations' sensitivity to weather conditions: if a base station falls out of the calculations, then the positioning on the terminal unit moves.
- The quality control of NLS FinnPos virtual repair data: A network that monitors quality independently of the network that calculates repair data.
- Galileo sends repair activities. Some satellites carry out repairs remotely, but not necessarily all of them. This is however expected to be available 2021. Galileo will introduce a new positioning system that will achieve an accuracy of under 10 cm for the coordinate system.
- Euref repairs are marketed because all customer use is included in the national coordinate system.
- Digiroad is not sufficient enough for automated driving purposes. The accuracy is around one metre.
- The difference between the local, national Euref-FIN system and WGS84 can be ~0.5 m, although the indicated accuracy is around one centimetre. Specific knowledge on moving from one system to another is required.
- WGS84 is a dynamic system where, in addition to the coordinates, you also need to know the time to which they refer. It does not acknowledge, for example, land uplift. Changes are needed in the EUREF system because EUREF is static, and the movements of continental plates are tied to a specific time.
- It is not recommended to use national systems if the limits are exceeded. Moving towards the EUREF systems => specifications is estimated by 2030. Finland will probably not be able to make an independent decision.

Recommendations for measurements

- Measurements carried out on the Aurora road provide a good reference point (Arctic-PNT on 2019). A test has been carried out on the Aurora road (Muonio) with an accuracy of up to 2.5 cm. The GNSS/IMU system maintained the accuracy, the base station network served as reference.

The location has been calculated using several frequencies and devices. The reference stations were used to post-calculate the route, and the results were compared to it. The Aurora position measurements and point cloud are extremely accurate. The measurements were made with VTT's automated vehicle 'Martti'. /1/
- For measurement campaign should use one antenna divided between several receivers to get satellite connection same time and same orbital locations. Should also have some accurate reference system available.

Future

- The European system of coordinates will become integrated in the long term.
- Ministry of Transport and Communications' preparatory specs bases on The European GNSS Agency (GSA).
- GALILEO high-accuracy with give sub-metreaccuracy reparations from satellite in 2022. GALILEO high-accuracy chips are on sale.
- Sapcorda (Sapcorda Services GmbH) augmentation service; parts of the NLS repair network can be used in their service and others are/will be available.
- SSR (State Space Representation) – a nation-wide error model could be sent over the Internet. Ionosphere, specifications of track errors etc.
- Repairs, virtual base stations along the entire main road 3 at 1 km intervals. 5G access points could serve as virtual base stations, with 5G network positioning as an additional feature.
- Three independent positionings are needed for safe automated driving since positioning is safety critical system.
- Quality indicator for the main road network needs to specified
- An interference signal does not reach the vehicle, as it typically comes from a ground station in Siberia behind the horizon.
- Local problems (e.g. tunnels) could be solved with GPS/GALILEO jammers.

3.2 NLS, 12 Feb 2021

The second interview was focused on the one developing the FINPOS service in E12, Mr. Ari Hujanen. The interview was conducted virtually on 12th of Feb 2021

- FINPOS have about 500 users at the moment and dedicated for R&D work. There are no service fees.
- The service is provided by NLS / Finnish Geospatial Research Institute (FGI)
- Considered to make the service available also for Trimble, Leica, Sapcorda, etc. which are no basically all RTK based. Be part of other NLS services is one opportunity
- Have done own trials with 5 different devices in past with having hardware level error correction
- No decision is the service will continue like it is when Galileo error correction comes to the markets (beyond 2023). Competiting with public service against the commercial companies require political decision and is difficult question. Basically, the publicly produced data should be shared free.

- North part of Finland is not so well covered
- New base station will be implemented to Hyvinkää and is available for the VTT’s trials
- Cyber-security thread: Interference might be the problem. Software receiver helps typically.

4 Measurement arrangements

Based on the discussions, the following measurement arrangements can be established. In principle, the measurement should be done while driving along rails the location of which is known in high detail, and the longitudinal accuracy should be measured with a photoelectric sensor. A high-end positioning system can only be used for reference. There is no way of determining absolute accuracy.

- Connect four GNSS receivers with an antenna splitter to one high-quality GNSS antenna.
- Configure the receivers for different constellations (GPS, GLONASS, Galileo).
- Get user IDs for the correction services of Trimble (Geotrim), Hexagon (Leica) and NLS.
- It would also be good to include a PPP receiver in the comparison. Galileo HAS is not available, but hardware (www.ardusimple.com) is available for assessing the Sapcorda Augmentation Service; the price is around EUR 1,000, the delivery time is unknown.

First, drive in both directions in the morning and repeat the drive in the evening. The following data is stored for each GNSS receiver using a single repair service.

- Location (position, speed, direction)
- Error estimates from receiver
- Positioning mode (none, 3D, DGNSS, FIXED, FLOAT)
- Spotted satellites, azimuth, elevation, signal strength
- Recording frequency 1 Hz
- Mobile network signal strength, GNSS timestamp and position
- Other repair signals are saved in the file.

Data analysis

- The positioning difference between different constellations. If a reference is used, then the differences in relation to it.
- Blind spots
- Recovery time after an interruption

Option

- Repeat the measurement on three days using a different repair service provider.
- Alternatively, configure the receivers similarly and use different service providers. Drive the route in one day.

4.1 Static measurements

In order to test the measurement system, a simple static test was done. The test was performed by at first connecting the receiver to the computer, starting measurement software and logging. Correction service client was started next. It waited the first positioning result and sent it to the server. After receiving receiver location correction data stream was started. Logging was interrupted after receiver achieve the most accurate result. Ntrip-client is configured to send the NMEA GGA-message at 10 second interval. Therefore there is a delay between 0-10 second, depending on which time of the cycle the first positioning result was received by the client. More accurate results should be achieved by forcing the receiver to make cold start before measurement. Correction service used in the test was the Provider 2.

The GNSS unit can boot up in one of three modes: Cold, Warm or Hot. The Time-To-First-Fix (TTFF) depends on the start up mode, which depends on whether or not the GNSS device has valid almanac and ephemeris data, the unit is within 100 km of the last known location and how much time has passed from the last fix.

The almanac contains Satellite Vehicle (SV) orbit information and allows the GNSS receiver to predict which satellites are overhead, shortening the acquisition time. Ephemeris data contains precision corrections to the almanac data and is required for accurate positioning. The data is continuously updated and so the Ephemeris data within a deactivated GNSS receiver will become stale after 3-6 hours.

Table 1 presents the TTFF time correlation with the previous data available.

Table 1. GNSS boot-up modes vs. Time-To-First-Fix.

Data type	Cold	Warm	Hot
Previous position	N/A	available	available
Time	N/A	available	available
Almanac	N/A	available	available
Ephemeris	N/A	N/A	available
TTFF	up to 12 min	30 - 40 s	< 1 s

One can assume that in self-driving vehicle GNSS unit is always on at least in low power mode. Therefore it barely have to start in cold start. Almanac and ephemeris data can also be loaded form Internet, also the current location and time is known. In practise GNSS unit always perform at least a warm start.

The main interest is the difference between Precise point positioning (PPP) and RTK-GPS startup time.

4.1.1 ArduSimple PPP Sapcorda

ArduSimple PPP Sapcorda (reference) use all constellations. Tracking of the GPS and Glonass satellistes was very fast,as seen in the Figure 7. GPS has seven and Glonass four. Galileo instead has no satellites at startup and it took almost a minute to track seven satellites. GPS achieve max 10 satellites after 30 seconds and Glonass max eigth satellites in 40 seconds.

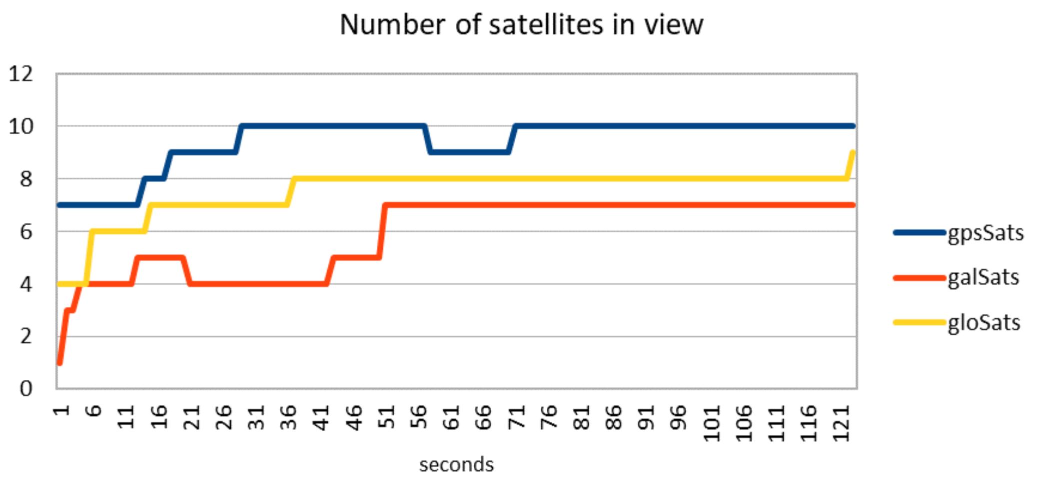

Figure 7. ArduSimple PPP Sapcorda satellites in view after startup. Galileo is much slower than GPS and Glonass.

Positioning quality is shown in Figure 8. First positioning result was achieved after 13 seconds and the most accurate mode (4, fixed mode) was achieved after 100 seconds.

Figure 8. ArduSimple PPP Sapcorda positioning quality after startup. The first fix is achieved after 13 seconds and the best quality (mode 4) after 100 seconds.

4.1.2 GPS and Glonass

uBlox ZED-F9P was configured to track GPS satellites only. The first positioning result was achieved after 18 seconds and the most accurate result (4 fixed) after 38 seconds. Glonass results were equal to GPS.

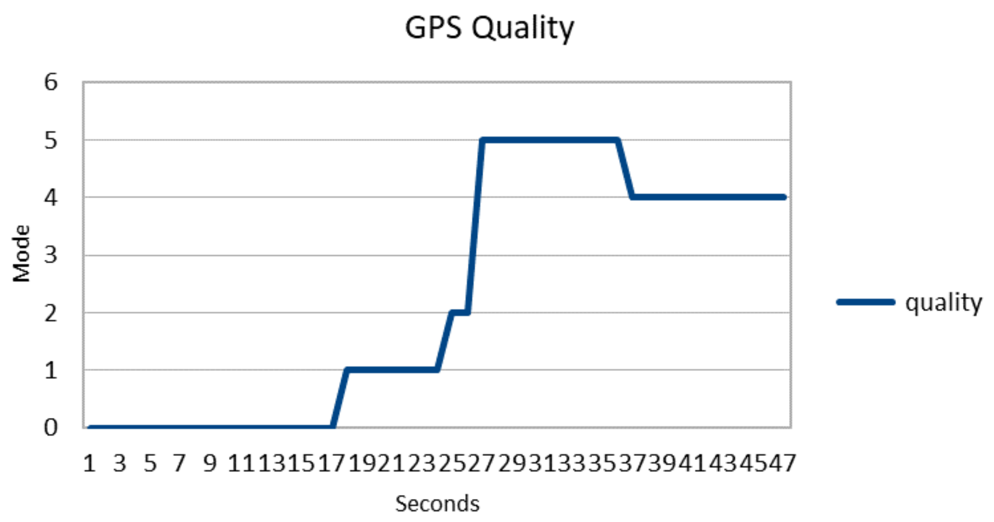

Figure 9. RTK_GPS startup. The first fix was achieved after 18 seconds and the best quality (mode 4) after 38 seconds.

4.1.3 GALILEO

Receiver uBlox ZED-F9P was configured to track Galileo satellites only. The same performance was seen as Sapcorda results (Figure 10). The maximum 7 satellites was tracked after 100 seconds. The performance difference compared to GPS and Glonass is clear. Because in this measurement only Galileo satellites were tracked, sluggishness cannot be explained by tracking order of the constellations, it is characteristic to Galileo. The first positioning result was achieved after a minute and the best accuracy after two minutes as seen in Figure 11.

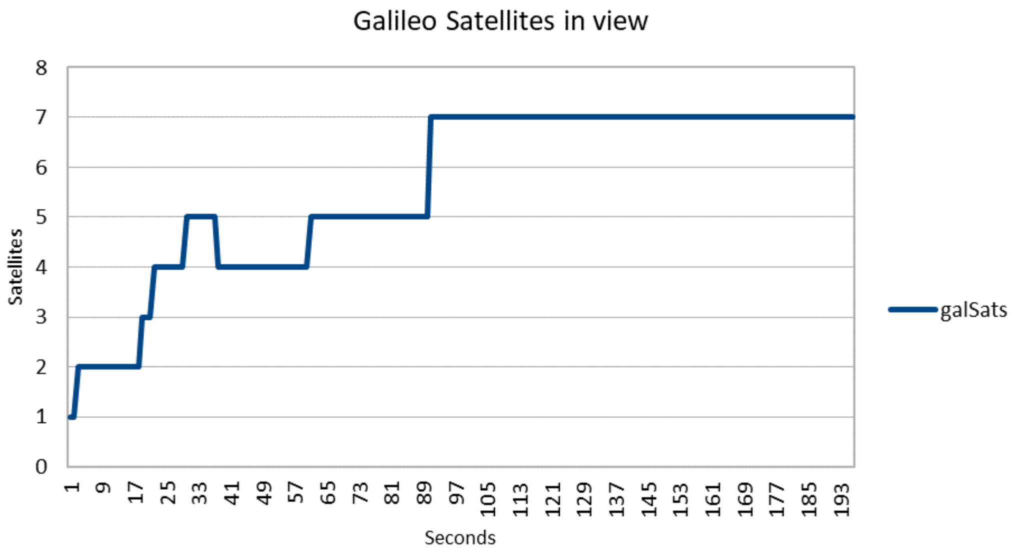

Figure 10. Galileo satellites in view after startup.

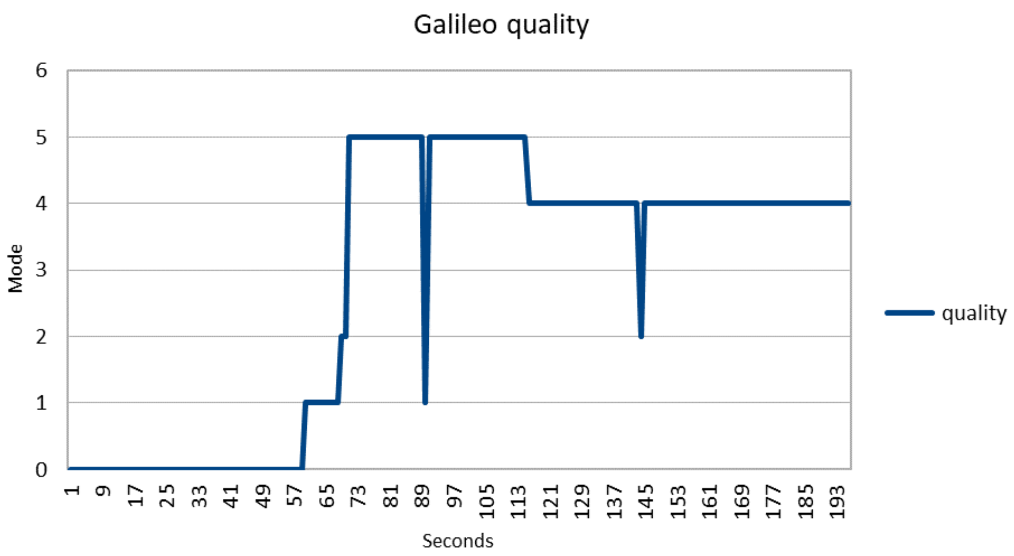

Figure 11. Galileo quality after startup. The first fix is achieved after 58 seconds and the most accurate result after 120 seconds.

4.1.4 Conclusions

- PPP is slower than RTK to achieve the most accurate position fix. Result is in line to the chapter 1.2
- Galileo is much slower in startup than other constellations. The reason is unknown.
- Achieved results are interesting but irrelevant for automated vehicles. There is no need to shutdown GNSS receiver, because its power consumption is negligible in vehicle environment.

4.2 Constellation comparison VT3

Receivers were connected to one high performance antenna (Leica AS-10) through a professional-grade antenna splitter, Tallysman TW164. The measurement setup is shown in *Figure 12*. Reference receiver used all four available constellation and received correction packages using build-in LTE connection the other receivers were configured to utilise one constellation each. The used receiver was uBlox C099-ZED-F9P. Reference receiver was ArduSimple, which is using the same GNSS receiver module, ZED-F9P. The PPP correction service is provided by sSapcorda. Used receivers are in a same quality level, which can assumed to be used in automated vehicles.

LTE-communication signal strength and position were read from the LTE modem (SierraWireless MP70) and synchronisation to position measurement was done using timestamp. Therefore, the built-in GNSS receiver was adequate for this purpose.

Measurement frequency was 1 Hz. Measurement route is shown in Figure 13. Route length is 165 km and used speed was 120 km/h, which ends up about 5000 measurement points to each direction. The route was driven from Tampere to Helsinki at morning and from Helsinki to Tampere at afternoon.

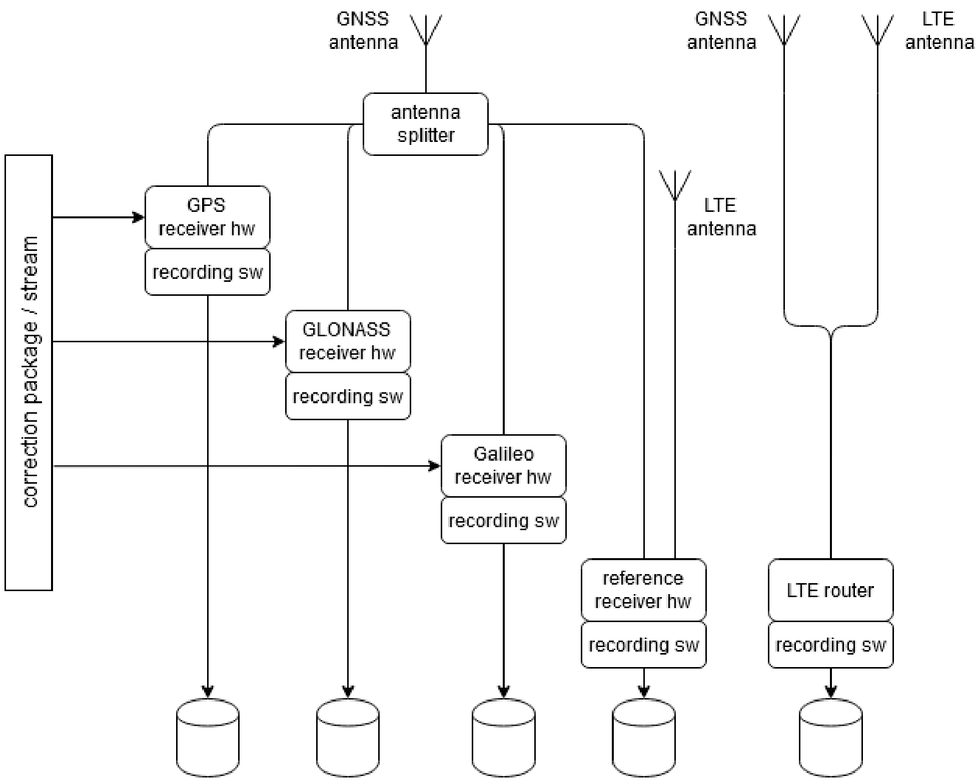

Figure 12. Test setup for comparison of the satellite constellations.

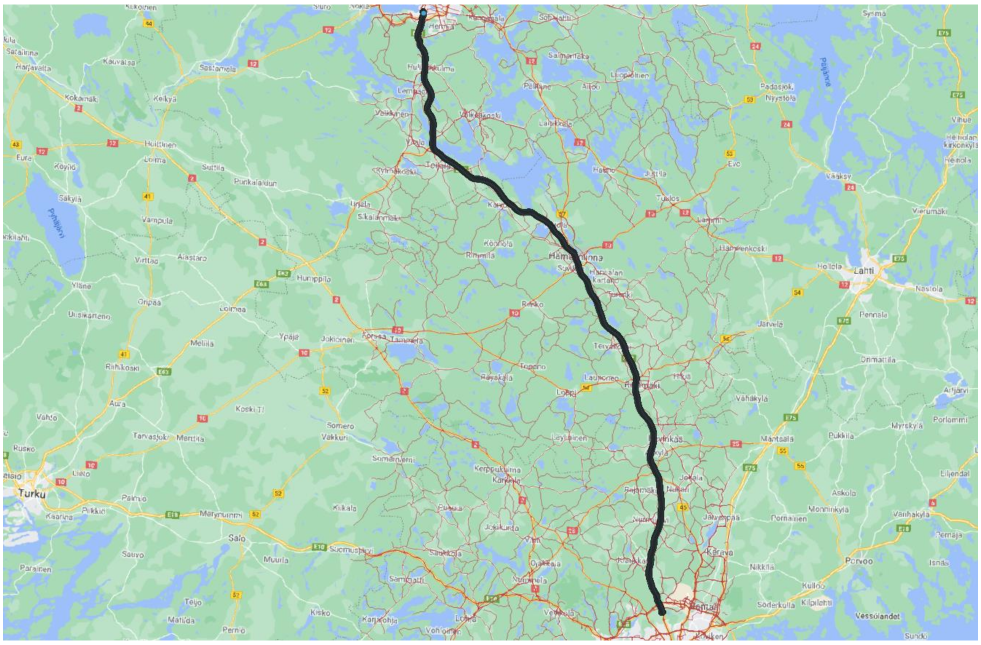

Figure 13. The test route, VT3 between Tampere - Helsinki.

4.2.1 Overall performance

In Table 2 is presented percentages of the availability of the different positioning modes achieved by each constellation. As expected the reference receiver, which used all the constellations, has the best availability compared to individual constellations. It offers the best quality 83,4 % of the time and 96 % at least decimetre accuracy. From the individual constellations Galileo was best (64,7%), GPS the second (54,6%) and Glonass was the third (38,8 %). But if one take the decimetre accuracy, GPS offer 88,8 % availability, Galileo 84,7% and Glonass 80,8%. The Figure 14 and Figure 15 visualises the results.

Table 2. Availability percentages of the different modes.

Mode		GPS	Galileo	Glonass	GNSS PPP
0	No fix	0,1	0,1	0,2	0,1
1	3D	7,3	11,4	11,5	0,0
2	DGNSS	3,8	3,9	10,0	4,1
4	Fixed	54,6	64,7	38,8	83,4
5	Float	34,2	20,0	42,0	12,6

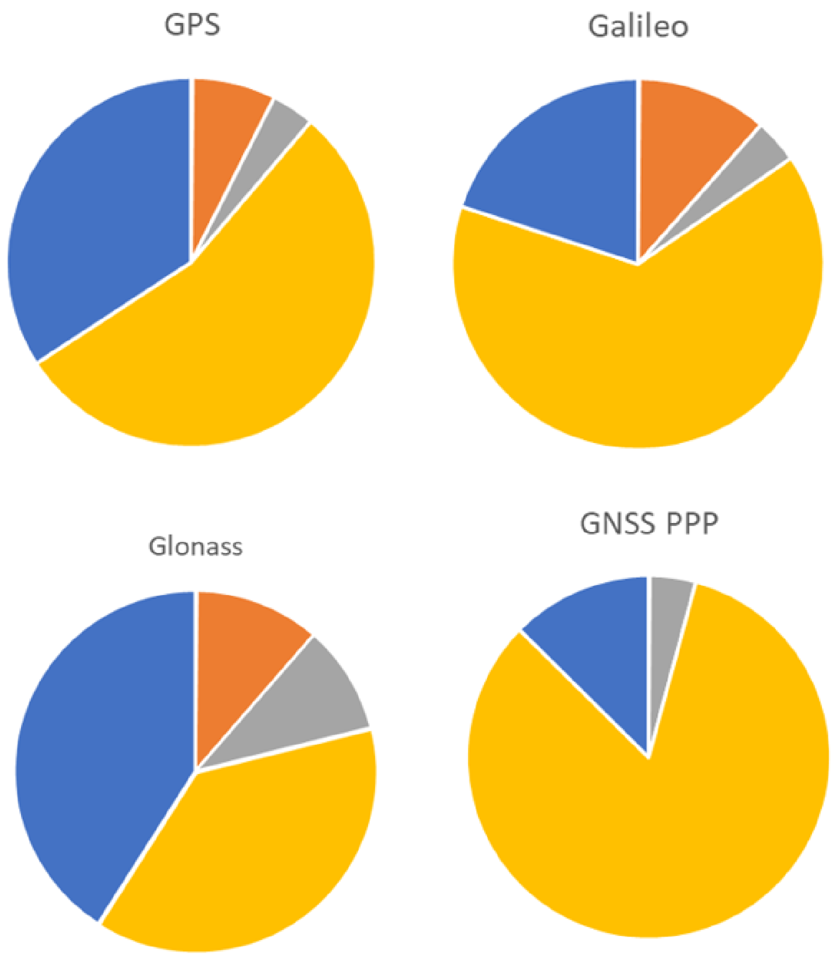

Figure 14. Availability of the positioning modes. Yellow is the best (mode 4) and blue the second best (mode 5) accuracy.

If the positioning result is compared, in practice there is no difference between constellations. In Figure 15 it shows the difference between positioning result, when all were in the RTK fixed mode. Galileo and GPS difference was one centimeter and the Glonass was two centimeter away from the others. Measurement resolution is one centimeter in latitude direction and 0,5 cm in longitude direction.

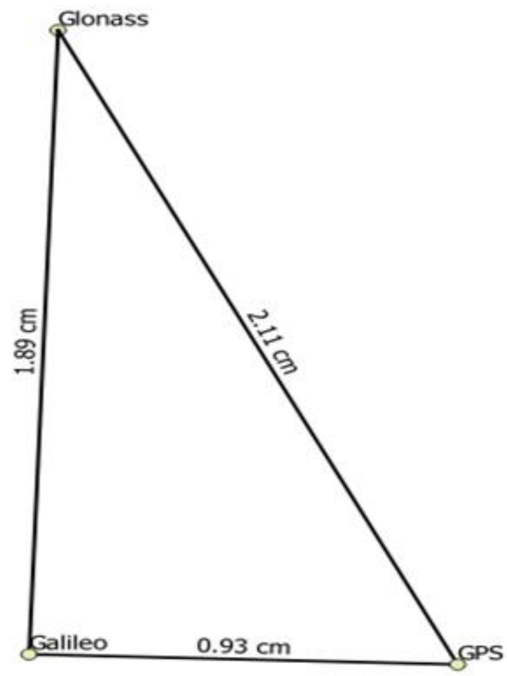

Figure 15. Differences between constellations when all were in RTK-fixed mode.

The criteria for the RTK-fixed mode is said to be at least five satellites and Signal-to-Noise-Ratio (SNR) over 40 dB. Figure 16 presents the GPS measurements as achieved mode versus signal strength. As it can be seen, the fixed mode was achieved only, when SNR was over 40 dB (the red oval). Therefore this criteria is valid and it can be used to classify road sections.

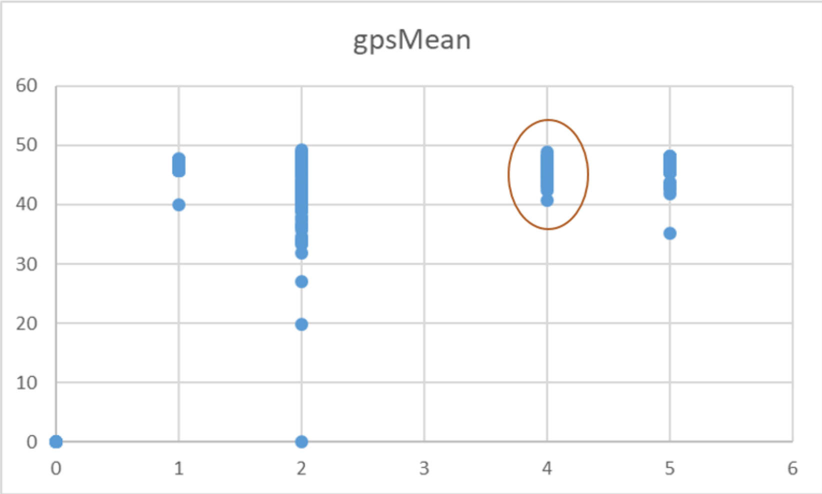

Figure 16. Signal-to-Noise-Ratio (SNR) mean level versus achieved positioning mode. One can see that mode 4 (fixed) has required SNR level over 40 dB as expected.

Overall signal strength for each constellation show that Glonass has slightly higher signal strength. In *Figure 17* is plotted achieved signal strength between Tampere - Helsinki. Gray line is the Glonass, orange Galileo and red is the GPS. It can be seen that most of the time SNR values are over 30 dB and there is only one place where SNR value drops to zero. This place is the tunnel at the Hämeenlinna. *Figure 17* shows that there are no other remarkable shadow areas on route. Short drops are due to overpass. The amount of satellites in view is compared in *Table 3*, where it can be seen that GPS satellites in view mean value is 11,6, Glonass has 9,7 and Galileo has 8,5. GPS and Galileo has equal SNR value and Glonass has 2 dB higher value than others.

Table 3. Mean values of the satellites in view and SNR

	GPS	Galileo	Glonass
mean satellites	11,6	8,5	9,7
mean SNR	46,8	46,4	48,4

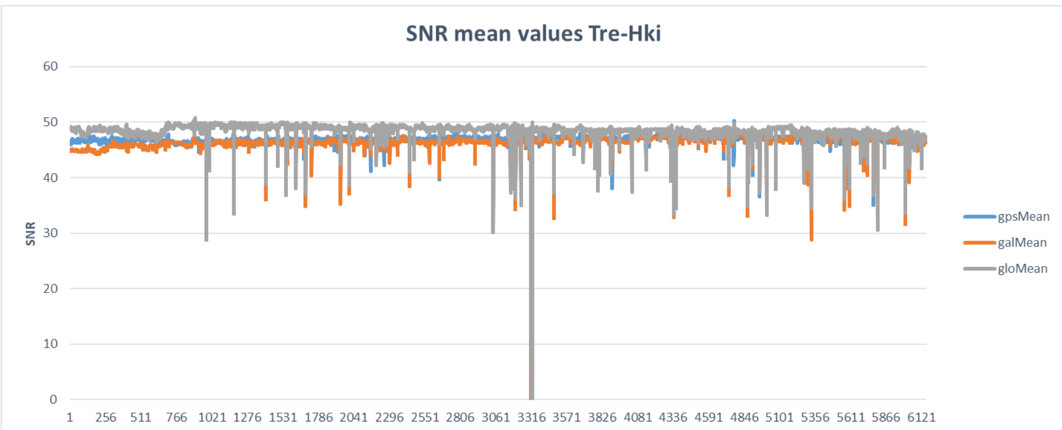

Figure 17. GPS SNR mean level between Tampere and Helsinki. Zero value is the Hämeenlinna tunnel.

Figure 18. Spots where SNR<=40dB, Tre-Hml (left), Hml-Hki (right).

Figure 18 depicts the spots where SNR was below 40dB. Those spots were regurarly within an overpass, continuing several seconds only.

During measurements, Galileo lost correction for longer time as shown in Figure 19. This event might be due the correction service. Server connection was not lost because other constellations worked normally. Also it seemed that messages arrived, but were maybe corrupted.

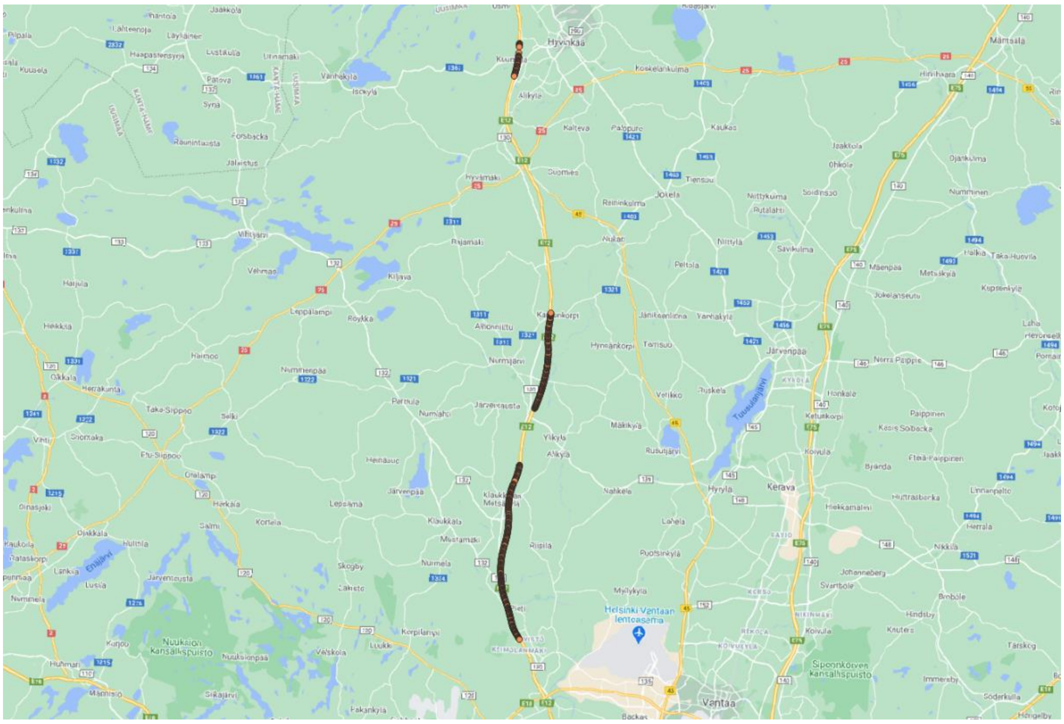

Figure 19. Sectors where Galileo drop correction data. Position is still inside the correct lane. Uppermost and lowest track direction was from Tre-Hki. Hki-Tre is in the middle.

4.2.2 Case Hangonväylä

The following presents typical behavoiur of the signal quality when driving under a bridge. *Figure 20* - *Figure 23* presents several bridge underpass. Signal quality level drops to a lower level for some seconds.

Figure 20. GPS signal quality on several bridge underpass (driving from right to left: Ilomäentie, Hämeentie 45, Hangonväylä 25, Tuusulantie) light green = fix (best), green = float.

Figure 21. Galileo signal quality on several bridge underpass (driving from right to left: Ilomäentie, Hämeentie 45, Hangonväylä 25, Tuusulantie) light green = fix (best), green = float.

Figure 22. Glonass signal quality on several bridge underpass (driving from right to left: Ilomäentie, Hämeentie 45, Hangonväylä 25, Tuusulantie) light green = fix (best), green = float.

Figure 23. GNSS signal quality on several bridge underpass (driving from right to left: Ilomäentie, Hämeentie 45, Hangonväylä 25, Tuusulantie) light green = fix (best), green = float.

4.2.3 Case Toijala, Nahkialanvuori

The following figures present the satellite signal strength when bypassing Nahkialanvuori, Toijala. On the West side there is a motorway cutting. It causes noticeable decline on the satellite signal strength on all constellations. This effect was most noticeable for the Galileo (Figure 26) and Glonass (*Figure 27*). Simultanaously the signal quality drops from fix (4) to float (5). *Figure 24* presents the video snapshot on the road.

Figure 24. Video snapshot, VT3 Nahkialanvuori, Toijala.

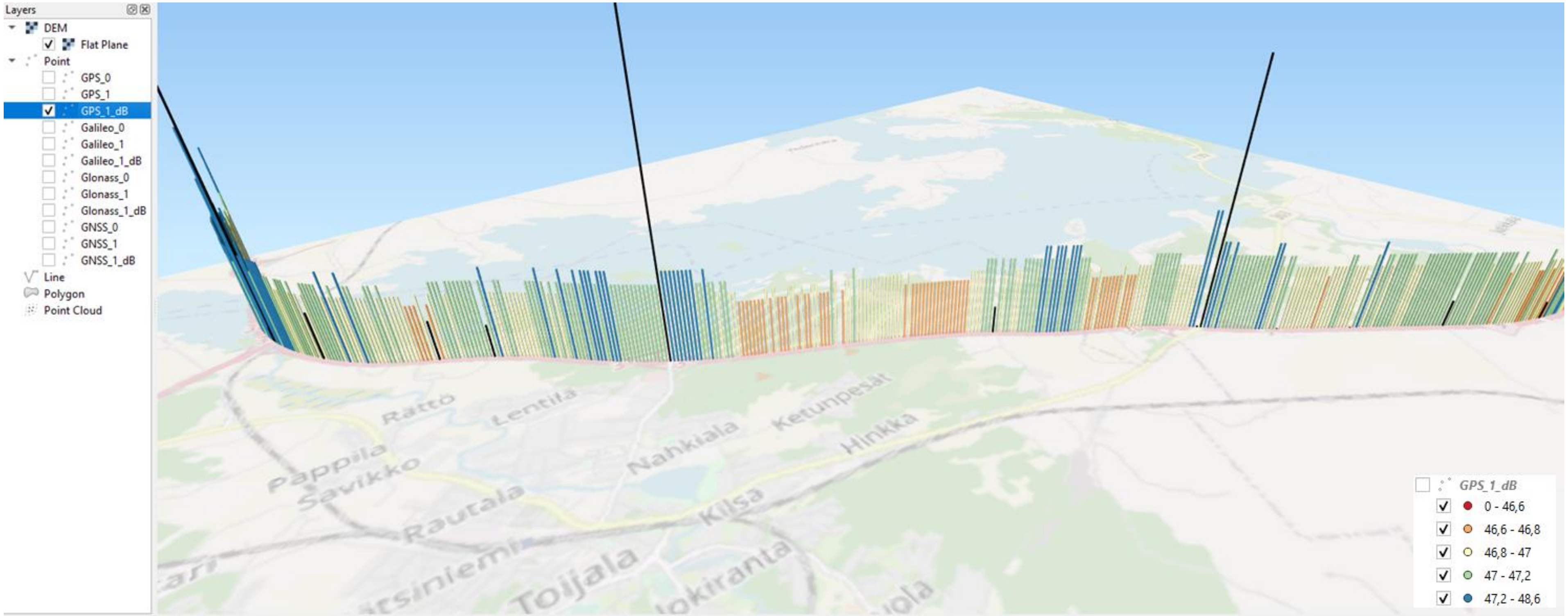

Figure 25. GPS signal strength in Nahkialanvuori, Toijala (dB).

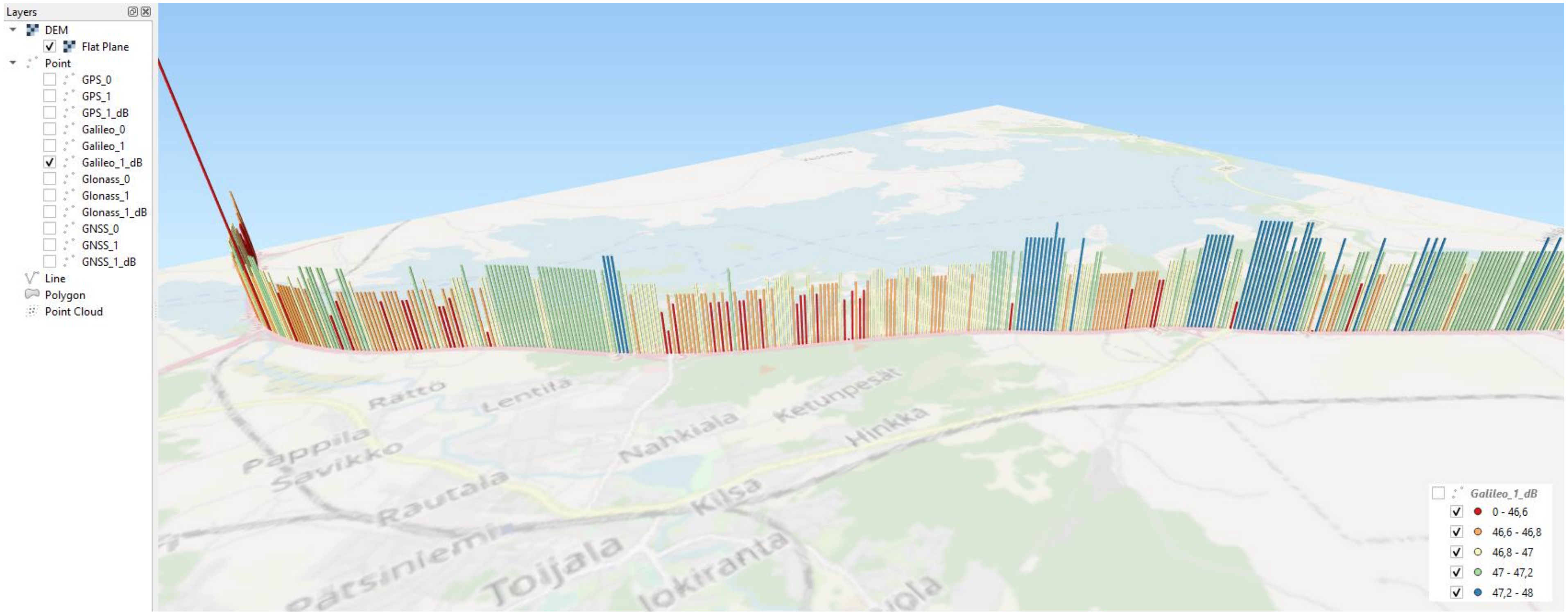

Figure 26. Galileo signal strength in Nahkialanvuori, Toijala (dB).

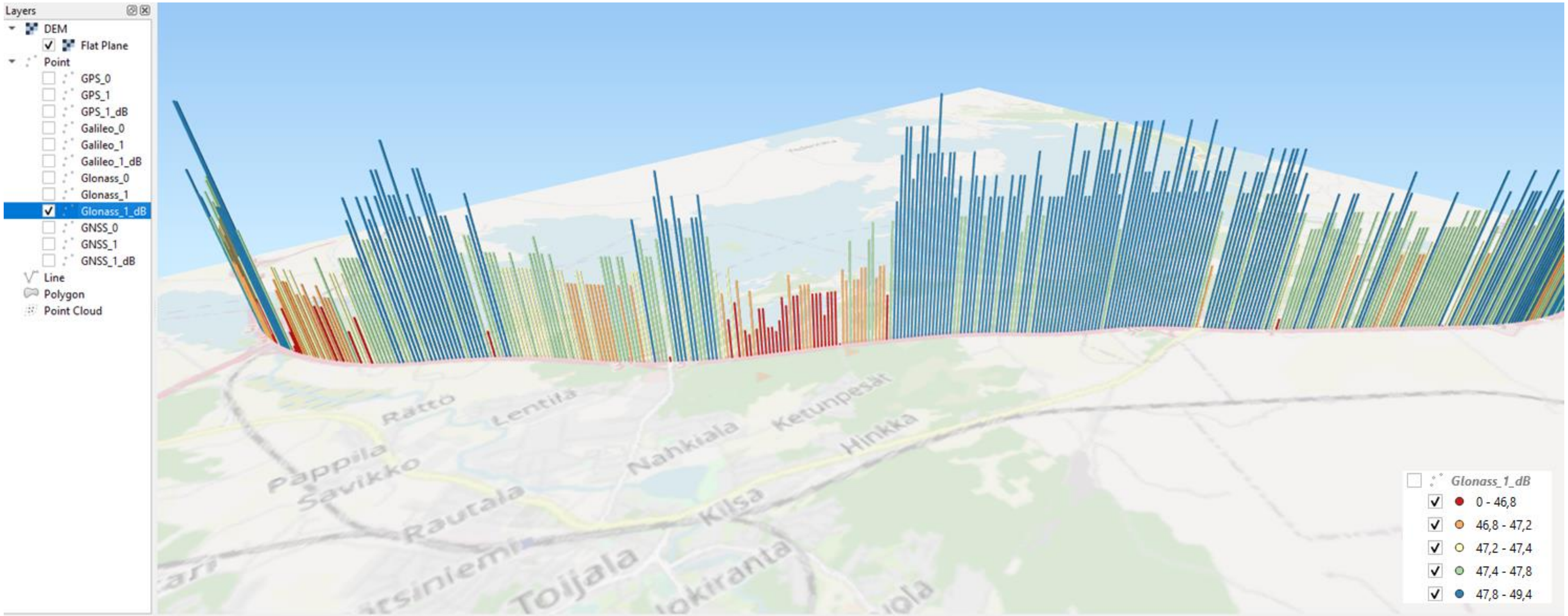

Figure 27. Glonass signal strength in Nahkialanvuori, Toijala (dB).

4.2.4 Case Hämeenlinna tunnel

Special attention paid to the Hämeenlinna tunnel. Figure 28 - Figure 31 presents the signal quality when driving through. GPS and Galileo seemed to maintain equal quality, whereas Glonass was clearly at lower quality level both before and after the tunnel. GNSS used all the available constellations.

Figure 28. GPS signal quality on Hameenlinna tunnel (light green = fix (best), green = float). Driving direction from right to left.

Figure 29. Galileo signal quality on Hämeenlinna tunnel (light green = fix (best), green = float). Driving direction from right to left.

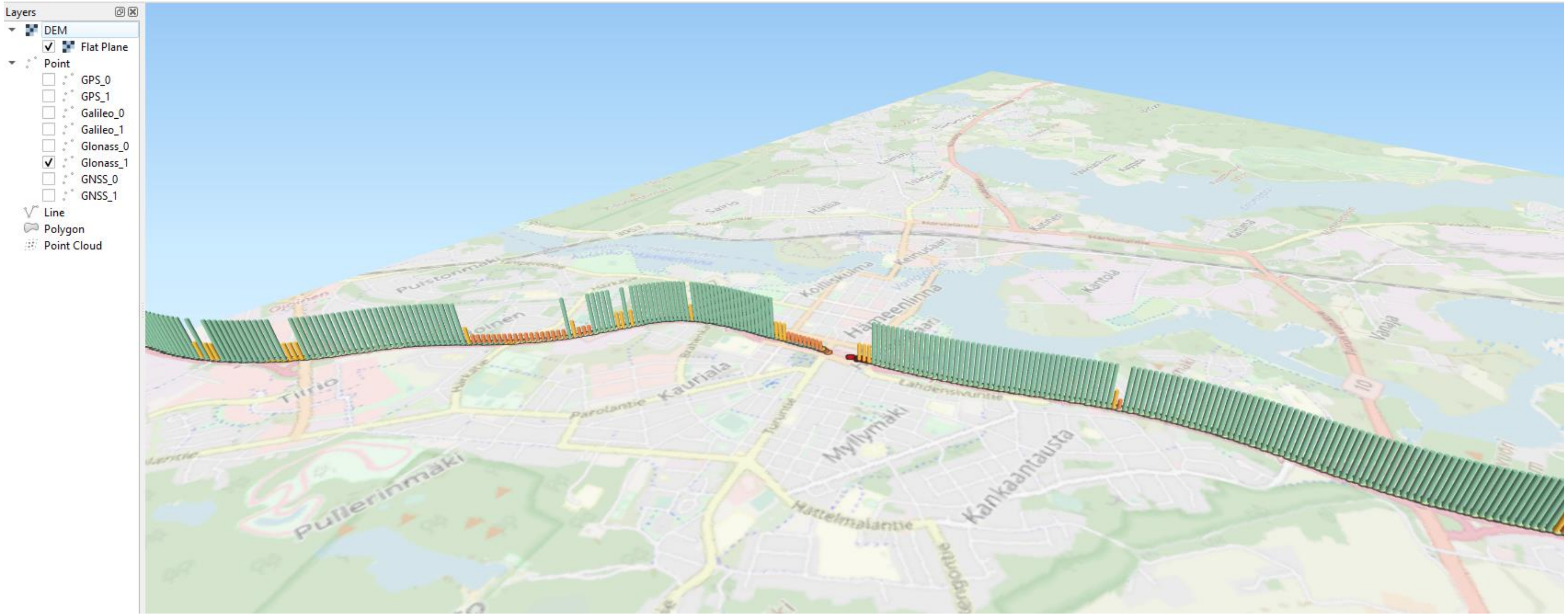

Figure 30. Glonass signal quality on Hämeenlinna tunnel (light green = fix (best), green = float). Driving direction from right to left.

Figure 31. GNSS signal quality on Hämeenlinna tunnel (light green = fix (best), green = float). Driving direction from left right to left.

When examining more carefully the position fixes when entering the tunnel it can be seen that GPS and Galileo maintained the straight trajectory better than the Glonass and GNSS counterparts. GNSS was more likely utilising Glonass constellation and therefore the same phenomen was visible here.

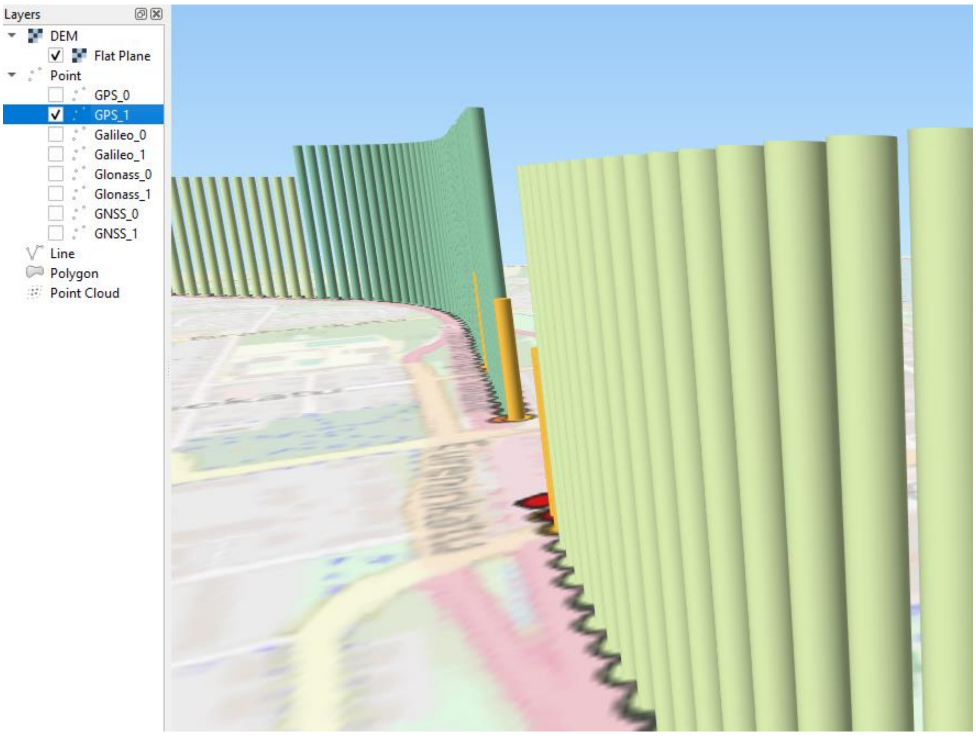

Figure 32. GPS positioning on Hameenlinna tunnel.

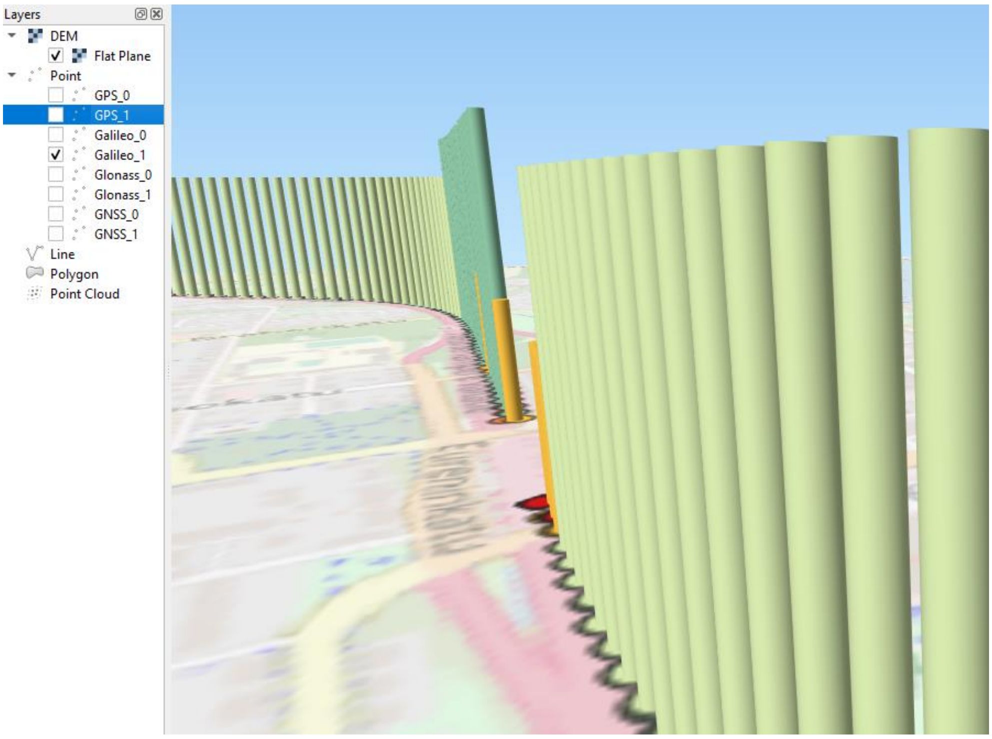

Figure 33. Galileo positioning on Hameenlinna tunnel.

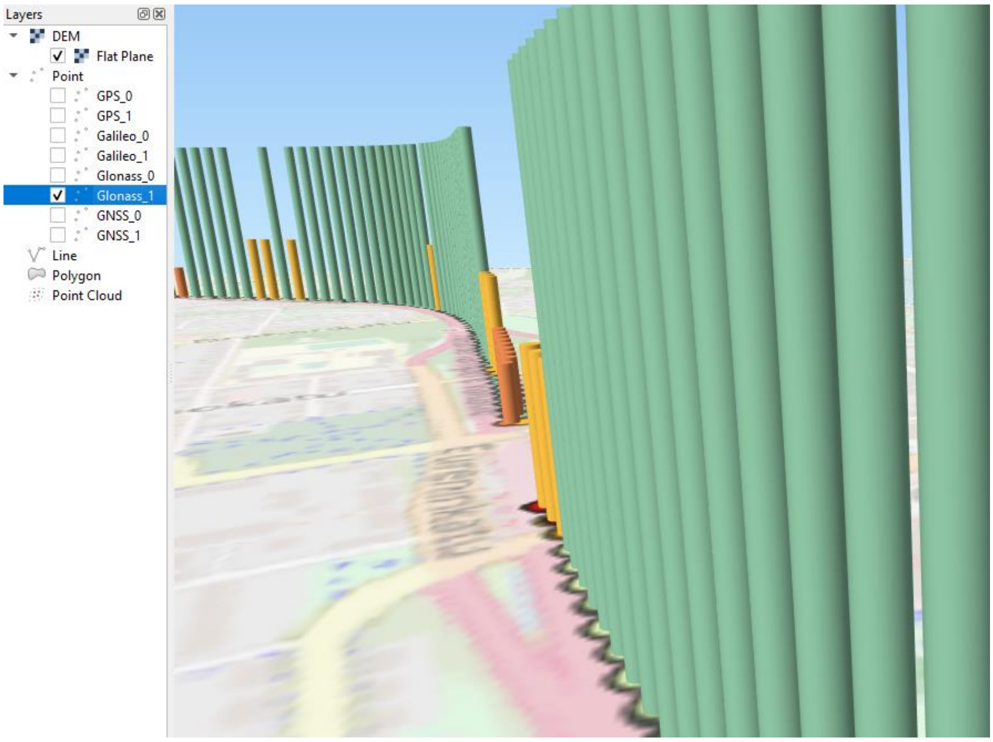

Figure 34. Glonass positioning on Hameenlinna tunnel. The lowest orange bars are slightly off the straight line.

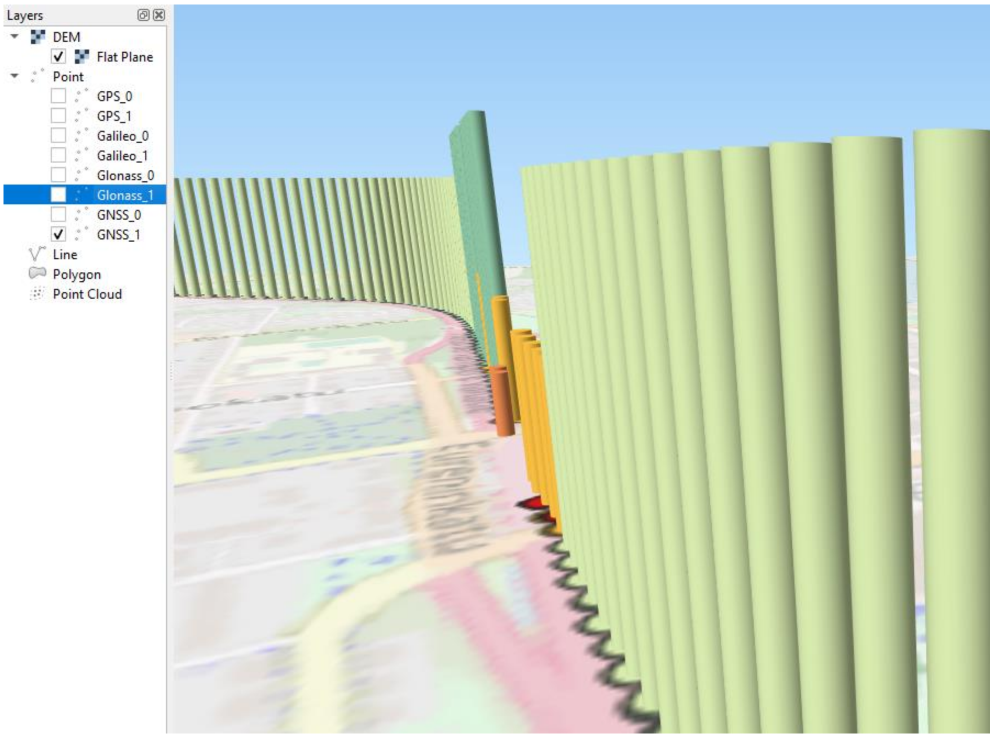

Figure 35. GNSS positioning on Hameenlinna tunnel. The lowest orange bars are slightly off the straight line.

4.3 Correction service comparison VT3

Comparison of the correction services were done with the same hardware, but different configuration. All the receivers were configured to use GPS, Galileo and Glonass contellations, but different correction service. Reference receiver was the same as constellation comparison. Used test route, measurement frequency and vehicle speed were the same as used in the constellation measurement.

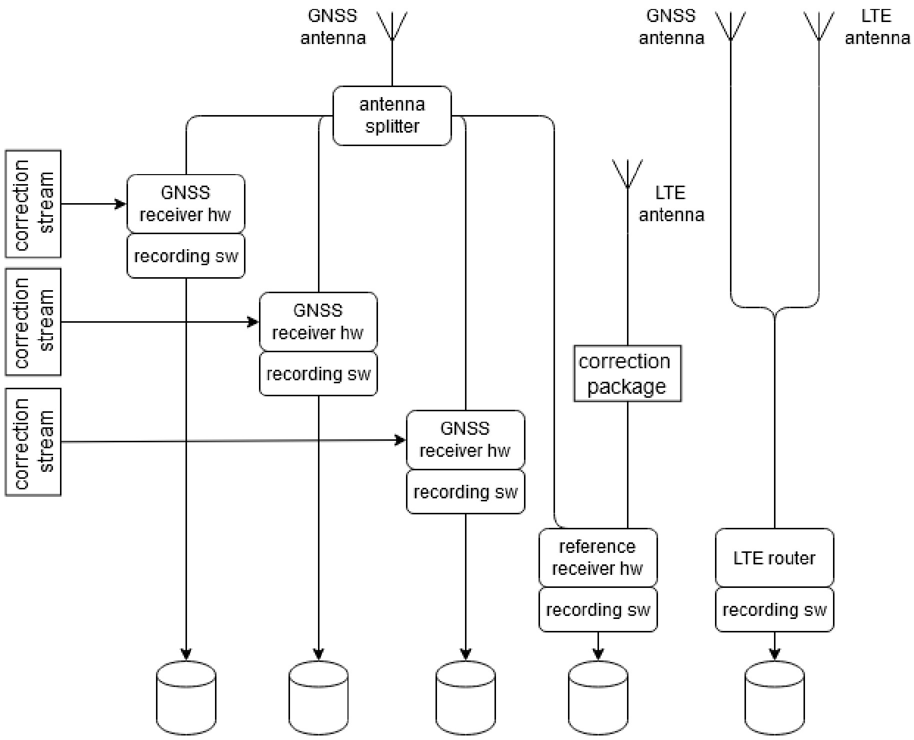

Figure 36. Test setup for the correction services comparison.

4.3.1 Availability results

Results are shown in *Table 4*. The best availability was achieved by Provider 2 where the best mode was available 93,6 % of the samples during the route. The second was the Provider 1 and third was the PPP correction. Provider 3 had only 79,1 % availability. The cause was that service freeze twice during the test. Server connection was not lost, but it didn't send any data. Connection was recovered by itself. Break was from Iittala to Toijala and the shorter one just before Hyvinkää.

Table 4. Availability percentages of different modes achieved using different service providers

Mode	Provider 1	Provider 2	Provider 3	PPP
0	0,1	0,1	0,1	0,1
1	0,0	0,0	0,0	0,0
2	2,9	3,5	11,6	4,4
4	87,7	93,6	79,1	80,8
5	9,3	2,8	9,1	14,6

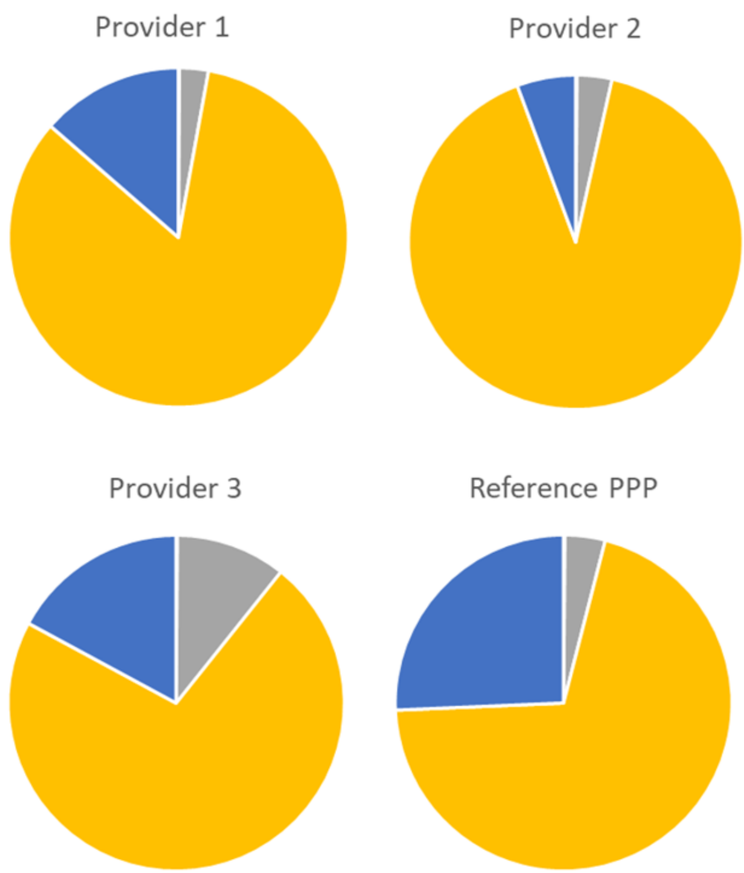

Figure 37. Availability of the positioning modes between different service providers. The yellow is the best mode (4, fixed).

There was no differences between service providers achieved relative accuracy as shown in *Figure 38*. Pattern is the same as comparison of the constellations. Positioning results are within 2 cm.

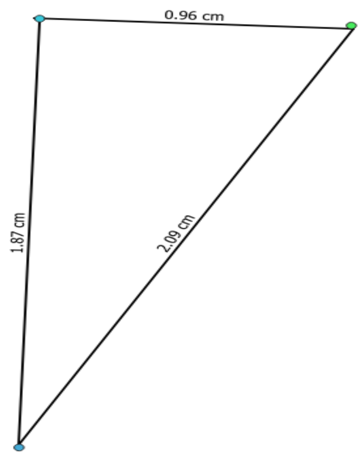

Figure 38. Location differences between service providers in fixed mode.

4.4 Mobile phone network measurements VT3

The mobile phone network performance was measured along the whole VT3 route. Device used was the Sierra AirLink MP70 4G LTE modem equipped with Elisa operator SIM card. *Figure 39* presents the Reference Signal Received Power (RSRP) values below -90dBm i.e. slightly better received power levels on the southern part of the route (Hml-Hki).

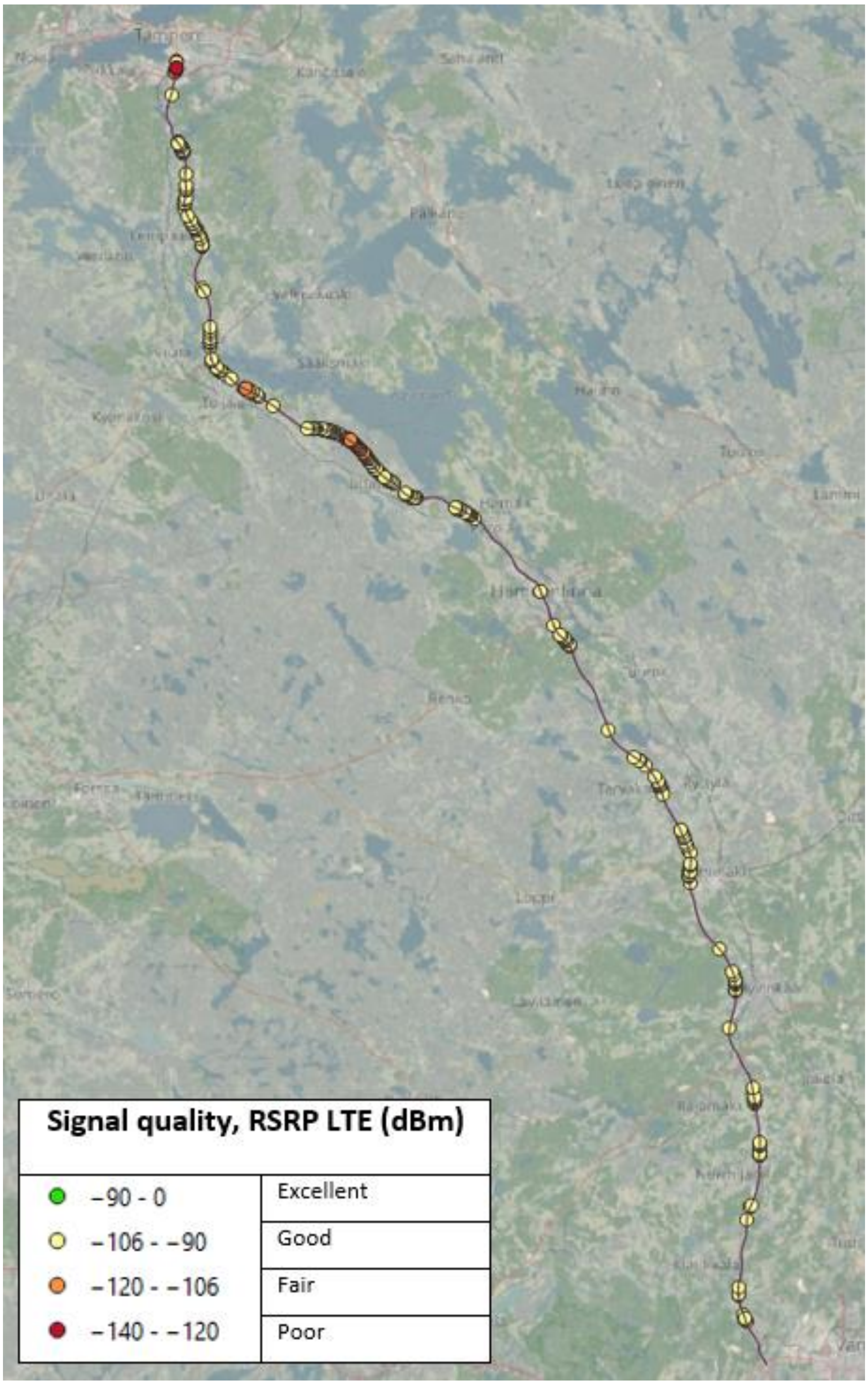

Figure 39. Tre-Hki, mobile network LTE measurements, RSRP < -90dBm.

Also the measured quality; Reference Signal Received Quality (RSRQ) reveals similar results. *Figure 40* presents the poor RSRQ values, slightly weak network quality is along the northern part of the route (Tampere - Hämeenlinna). Additionally, it was observed that the mobile data connection was not interrupted.

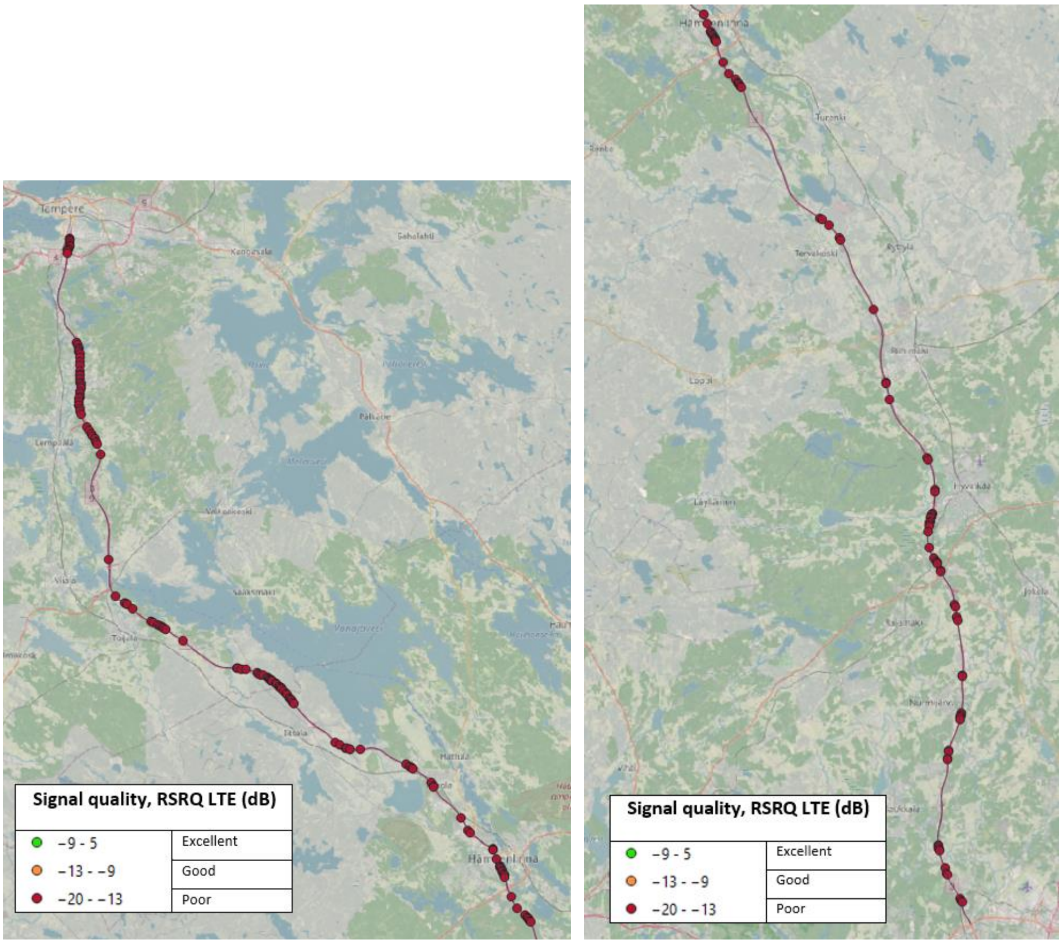

Figure 40.Mobile network LTE measurements, RSRQ < -13 dB (Tre-Hml left, Hml-Hki right)

4.4.1 Video logging VT3

For the backup data the whole VT3 route was video recorded on both directions. This enables to check the events happened on the road§ afterwards. Situations where the measurement vehicle was surrounded with trucks was carefully examined to inspect whether it had effect on the GPS coverage. The result was that no effect was not found. Figure 41 depicts a snapshot of the recorded video.

Figure 41. Video snapshot overlayed with speed, coordinates, timestamp and date.

The system used was the Video VBOX by Racelogic (*Figure 42*), an in-car video system with the following features: accurate GPS logging at 10 Hz, 2 video camera inputs, SD card logging, rugged enclosure and customisable UI graphics.

Figure 42. Video VBOX recording system.

5 Conclusions and recommendations

- There are some differences on the availability between service providers.
- The use of all constellations give better results in availability than using only one constellation.
- There is no difference in accuracy between constellations.
- There is no difference in accuracy between service providers.
- Coordinate frames are very important and content providers should be aware of used frame and provide metadata where used frame is clearly announced.
- Individual EPSG code for Finnish grid is essential to provide coordinate transformation between ITRF20XX frame and ETRS89 frame.
- Current modern receivers have a some sort of jamming detection mechanism.
- Current modern receivers have a some sort of dead reckoning data processing.Satellite positioning will shift from large-scale ground-based national augmentations to large-scale satellite-based augmentations.
- Similar services provided by Sapcorda will be available in future. Keep track of the Galileo HAS service product launch and Sapcorda PPP rivals and arrange road measurements.
- It is worth of considering to renew road markings every Spring 2km before and after the Hämeenlinna tunnel, because that seemed to be a road segment with varying GNSS signal level. Together with good visibility road markings the supporting machine vision system will work better.Galileo HAS might be available in 2022, but it will provide access to sub-metre accuracy, only.
- Three independent positioning service technologies are needed for safe automated driving.
- Service level indicator for road sections could be the measured signal strength (SNR) over 40 dB using five strongest satellites from each constellation. This can be measured using dual fequency receiver equipped with a high quality antenna configured to use all available constellations. Signal-to-Noise-Ratio below 40 dB indicates a shadowed region and probability for the most accurate positioning result is low.

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/2/	SOURCES OF ERROR IN GNSS. available in [http://www.blackroc.com/284-2/?doing_wp_cron=1620985828.8577859401702880859375]. cited on 14 May 2021

Finnish Transport Infrastructure Agency

Nordic WAY 3

Co-financed by the Connecting Europe Facility of the European Union

Working report
24/06/2021

Service level framework for automated road transport

Task 1.4. Weather conditions

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1 Goal of the Task

This study estimates, what kind of automotive sensing performance is to be expected in the near future, and in what kind of environmental conditions automated vehicles (AVs) would be able to drive Finnish motorways using such sensors. The motorway between Tampere and Helsinki is the case studied in more detail.

The perception sensors considered are automotive radar, automotive lidar (Light Detection And Ranging), and automotive vision system consisting of illumination, camera, and image processing algorithms.

The driving conditions include various weather found in Finland during the four seasons. The stored data from the selected roadside weather stations are utilised for detailed weather statistics.

To achieve a more analytical results, the driving environment and situations studied are simplified somewhat, see chapter 2.1.

2 Sensor detection range and the effects of friction

First, the likely detection range of the three different sensor subsystems to the listed objects (see Chapter 2.1) is estimated. Especially with optical subsystems, the weather plays an important role, which is culminated to the measure of visibility.

Secondly, the stopping distance of the subject vehicle as a function of its current velocity and tyre-road friction is analysed, using the assumptions below.

Finally, the analysis above are combined, and by focusing on the most difficult object to detect, the results are drawn as subdomains consisting of initial velocity - friction - visibility, where stopping is possible within the detection range.

2.1 Assumptions

The driving environment is a Finnish highway, where it is assumed for simplicity that

- The assumed detectable objects (~obstacles) on the road are
  - stationary truck facing towards driving direction,
  - stationary car facing towards driving direction,
  - stationary motorcycle facing towards driving direction,
  - elk standing or running sideways to the subject vehicle,
  - standing human facing towards the subject vehicle.
    (as a result of car malfunction, or traffic accident)
- Road curvature, inclination and slopes are so modest that they do not affect the braking distance.
- Road curvature, hills, and roadside features do not obscure the field of view of the vehicle sensors.
- The perception sensors have nominal perception capability (their surfaces are clean enough).
- The obstacles above are not covered in so thick snow, that general assumptions of radar cross section or light reflectivity would be worsened.
- The tyre-road friction coefficient may vary over time due to environmental conditions, but the coefficient is constant during each stopping or avoidance manoeuvre.
- The wind or the subject vehicle’s air resistance does not affect its braking distance.
- All vehicles are driving towards the same direction obeying the current speed limit, or an individual vehicle has stopped on the road due to an accident or vehicle failure.
- Lane change situations (cutting in or out) are not studied.

The sensor systems considered

- Includes at least a radar subsystem, and an optical subsystem, all working in parallel. The optical subsystem may consist of automotive camera subsystem alone, automotive lidar subsystem alone, or both.
- Is analysed by studying each sensor subsystem separately, to utilise more accurately the knowledge of their capabilities in different weather conditions, and with the assumed obstacles listed above.

- Have been analysed focusing on their detection range. “Detection” means that the subject vehicle becomes certain of an obstacle on the route, but cannot yet know what kind of obstacle category it belongs to. (Which would be called “Recognition”, and becomes possible when the subject vehicle gets closer. Recognition often allows more sophisticated avoidance decisions.)
- Is assumed to immediately lead to an emergency braking manoeuvre, when even one of the sensing subsystem (radar, lidar, or camera) gets a reliable detection of an obstacle on the route of the subject vehicle.

2.2 Environmental conditions and perception sensors

The attenuation of optical light and radiofrequency signals have already been studied a long time due to military, marine and aviation needs. The summarising Figure 1 can be found from some European automotive sensor studies. As can be seen, the optical signal (e.g. the 850nm wavelength) is more prone to rain and fog than the frequency of typical automotive radar (77 GHz). Excessive Rain (150mm/h) is practically unknown to Finland, Heavy Rain (25mm/h) may take place every now and then. The figure does not cover snowing conditions.

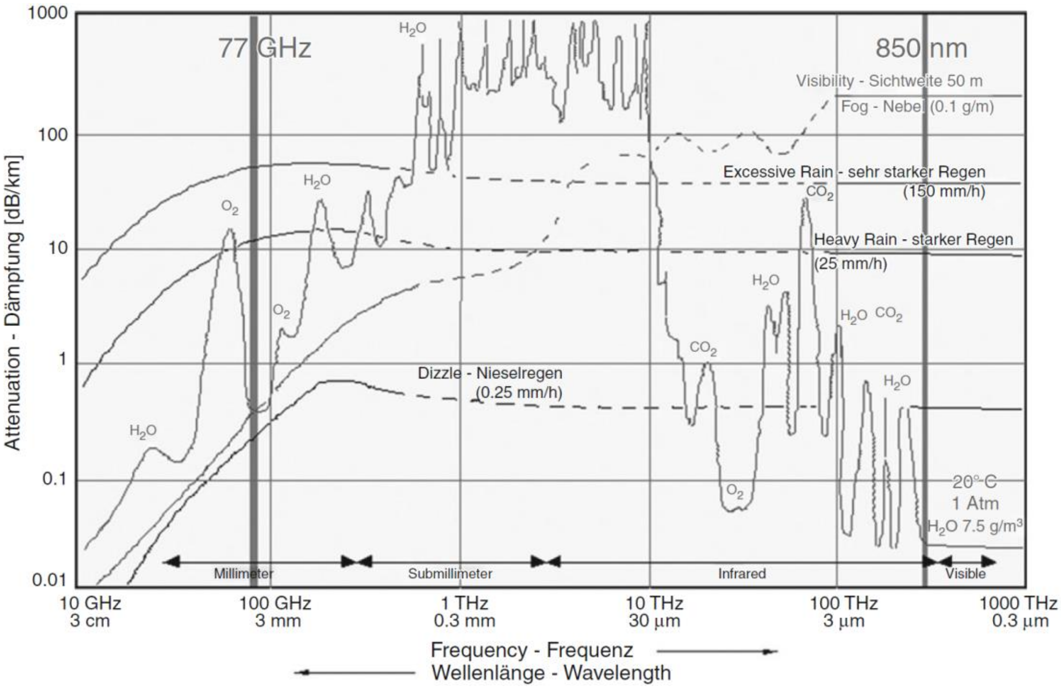

Figure 1 Sensor signal attenuation caused by atmosphere, together with attenuation caused by rain, drizzle and fog. 77 GHz is the frequency used by novel automotive radars, 850nm … 905 nm are the wavelengths used by typical automotive lidars. /1/

2.3 Radar detection range

Radar is sensitive to weather conditions in three ways:

- The first condition is the sensor or its shielding being so covered with water/slush/snow that it cannot send and receive its signal, thus becoming blind. In this study, this alternative is not analysed. Partly because majority of the material accumulation may have taken place before entering the motorway, and partly because automotive radars can detect this condition. This allows the higher level system to take safety measures - e.g. prevent automated driving until the sensor is cleared.
- The second condition is the focus of this study; how does airborne fog, mist, rain and snowfall reduce the perception capability of the vehicle sensors.
- The third condition is the detectable object being so covered with slush/snow that the object becomes impossible to identify or detect. In this study this alternative is not analysed, because the motorway is so well maintained that not the road nor the vehicles have time to become seriously hidden.

The average detection range of automotive radar under the second condition is estimated using radar range equation, and by estimating a reduced detection range due to Heavy Rain together with water and dirt on the radar cover.

Since a radar sends itself the necessary radio frequency excitation signal, it does not need any additional systems for e.g. night operation.

The radar range equation /1/ /2/ contains several parameters, but when one radar is used to detect two different objects at the same direction, only the radar cross section value changes, resulting to a simpler equation below.

$$\frac{R_1}{R_2} = \sqrt[4]{\frac{RCS_1}{RCS_2}} \qquad (1)$$

where R_1 is the radar detection range of object 1
R_2 is the radar detection range of object 2
RCS_1 is the radar cross section of object 1
RCS_2 is the radar cross section of object 2

The first assumption made is that the radar cross sections of a human, motorbike, car, and truck (or bus) have 1/10 ratio. /1/ /2/

The second assumption is that radars used in coming automated vehicles can detect a car in front of them at least at 200 m distance. The detection distances to other objects in are calculated with equation (1). Alternatively, a car detection range of 160 m is also included to the table below to indicate reduced signal strength due to Heavy Rain (~25mm/h) and some dirt and water on the radar surface. /2/

There is preliminary information that the next generation automotive radars would have longer detection range and would be capable of higher accuracy and detailedness. Since there is not much concrete information available of this new performance level, this study relies on known detection ranges.

Table 1 Radar cross sections of traffic objects, and corresponding detection ranges of typical automotive radar.

Object	Typical Radar Cross Section [m^2]	Detection ranges assuming that the radar in the automated vehicle can detect a car from	
		160 m distance [m]	200 m distance [m]
Truck/bus	1000	285	350
Car	100	160	200
Motorbike	10	90	112
Elk	3[§]	67	83
Human	1	51	63

§ RCS of elk is approximated based on the area ratio between the human silhouette, and the silhouette of an elk running sideways to the radar. Estimation is based only to area ratio, because both objects are similar kind of material.

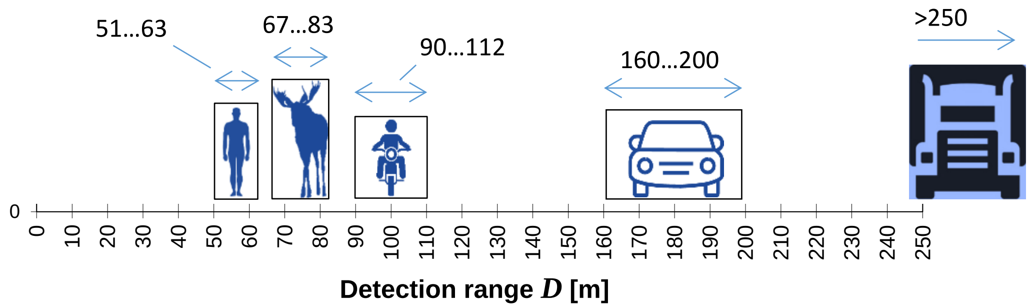

Figure 2 Radar detection ranges of Table 1 visualised: How far a typical automotive radar can detect an average human, elk, motorbike, car, and truck/bus. Since the maximum range of many radars is about 250 m - below the calculated detection range of trucks and buses - truck/bus is simply marked at 250 m distance.

2.4 Lidar detection range

Main focus in this study is on lidars using wavelengths 850 … 905 nm, e.g. very near to the wavelengths visible to human eye. These lidars are cost efficient, and majority of automotive lidars use these wavelengths. Their detection range is limited by two factors:

a) the maximum optical power of the laser pulses they send, and

b) the point cloud density at the target.

Regarding case a) the optical power is limited for eye safety reasons set by safety authorities. Therefore, when the lidar is sending a light pulse to a distant target having low reflectivity (the target is e.g. black garment), it is obvious that the amount of light reflected back to the optical receiver of the lidar is very limited. In fact, instead of 'amount of light', it is better to talk about the number of photons received[1].

Case b) is best explained with the Figure 3 below: When the distance to the object increases, less and less lidar points hit the target. In order to be certain that there really is an object, one may want to have a minimum number of detected points at every sample time.

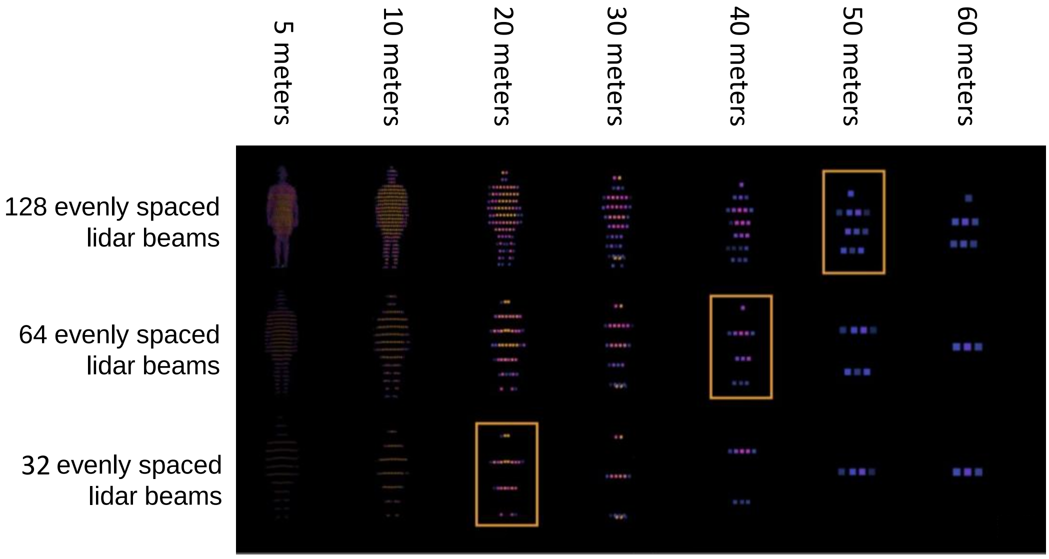

Figure 3 When distance to an object grows, less and less laser points hit the target. Finally only one point, or none at all are detected. In that case: is there an object or not? /5/

Lidar is sensitive to weather conditions in three ways:

- The first condition is the sensor or its shielding being so covered with water/slush/snow that it cannot send and receive its signal, thus becoming blind. In this study, this alternative is not analysed: partly because majority of the material accumulation may have taken place before entering the motorway, and partly because future automotive lidars will probably be located behind windshield, or integrated in headlamps with some kind of cleaning system.
- The second condition is the focus of this study; how does airborne fog, mist, rain and snowfall reduce the perception capability of the vehicle sensors.

[1] There are some lidars using 1550 nm wavelength. They have longer detection range than 850 ... 905 nm lidars, because they can use stronger laser pulses without risking eye safety; 1550 nm wavelength is further away from visible wavelengths, meaning that human eye is less sensitive to be damaged by it. However, 1550 nm lidars are more expensive technology, and therefore it is likely that they will be mainly used on more expensive vehicles.

- The third condition is the detectable object being so covered with slush/snow that the object becomes impossible to identify or detect. In this study, this alternative is not analysed, because the motorway is so well maintained that neither the road nor the vehicles have time to become seriously hidden.

Since a lidar sends itself the necessary laser pulses for sensing, it does not need any additional illumination systems for e.g. night operation.

The average detection range of automotive lidar under the second condition above is estimated by assuming that lidars designed for highway speeds and detection ranges have features similar to /6/ in the relevant field of view around the driving direction:

a) Can detect objects having 10% reflectance (e.g. black clothes) from 140 m distance.
b) Has so dense forward aimed point cloud, that a 150 cm tall human gets necessary amount of detected points for a reliable detection at 135 m distance. (vertical and horizontal resolution is less than 0.1°)

The assumption of low reflectivity of vehicles is justified in Finland, where the rear of the vehicle is often covered by dirt, including highly reflective parts like license plate and rear lights. Table 2 below contains assumptions of the reflectivity of various road objects, their approximate size, and the corresponding detection distances. Each detection distance is based on either:

a) It is the maximum distance from which the assumed lidar can detect a surface having the minimum reflectivity, or
b) It is the maximum distance, in which the object is hit by at least certain number of lidar points. This number depends on required detection certainty, but could be assumed to be close to 10, when it is important to get an early detection

So, the applicable lidar detection range D is mathematically

$$D = min\ (a, b) \quad (2)$$

However, when the lidar is facing strong light - e.g. the low hanging sun - the background noise in lidar's light receiver increases, which may reduce its ability to detect an object reflecting a barely detectable amount of laser pulse back to the lidar. This condition is more likely in Nordic areas, where the sun lies more often close to horizon than e.g. in mid-Europe. A possible estimate of the average reduced detection range of various lidars in oncoming sunlight could be about 80%. This kind of sensitivity reduction covers also situations, where the sensor surface has become dirty. Mathematically this can be formulated as

$$D \sim min\ (0.8a, b) \quad (3)$$

Table 2 Assumed reflectivity of objects, and corresponding detection ranges. Possible range reduction caused by oncoming sunlight is also estimated.

Object	Assumed dimensions width x height [m]	Assumed reflectivity [%]	Assumed detection ranges of a lidar designed for highway operation			
			a) Reflectivity limited [m]	b) Number of points limited [m]	Detection range reduced by oncoming sunlight ~min(0.8*a,b) [m]	Detection range in normal conditions ~min(a,b) [m]
Truck/bus	2.5 x 3.0	20	180	>250	**145**	**180**
Car	1.7 x 1.3	20	180	~200	**145**	**180**
Motorbike	0.6 x 1.2	20	180	~150	**145**	**150**
Elk	1.2 x 1.0#	10	140	~165	**112**	**140**
Small human	0.4 x 1.5	10 >90§	140 >240§	~135 ~135	**112** **135**	**135** **135**

Side profile, and excluding thin parts like legs and horns.

§ If human is wearing reflecting clothing similar to traffic guidance personnel, or road construction workers.

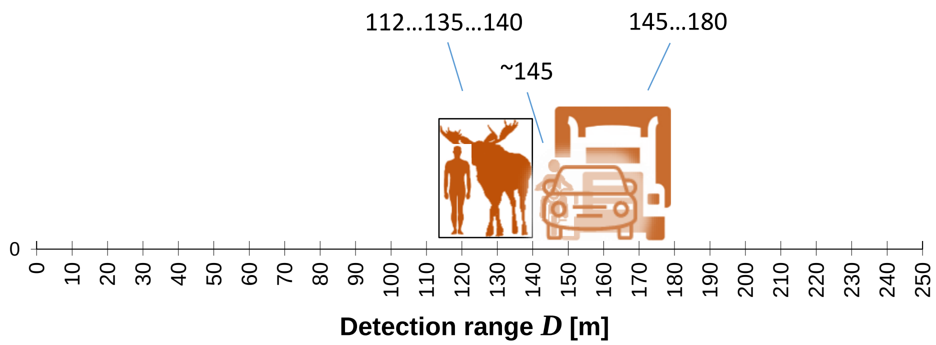

Figure 4 Lidar detection ranges visualised: At what distance could an automotive lidar, which is designed for motorway operation, detect small human, elk, motorbike, car, or truck/bus. For safety, the reflectivity of the analysed objects is assumed to be lower than usually.

Since an automotive lidar is an optical sensing device operating typically close to wavelengths of human eye, its detection range is affected by the visibility of the environmental conditions. In previous projects to which VTT has participated, reliable lidar detection range of well reflecting targets in fog has been more than half the visibility, although the distances studied have been shorter than motorway-relevant lidar ranges. Articles have shown that for objects having about 10% reflectivity, the lidar detection range in fog is about 0,22 … 0,28 times the visibility /7/ /8/. Since the human object (see Table 2) is dressed in dark clothes (10% reflectivity), this study assumes that the object detection using lidars is reliable, as long as *the visibility is four times the lidar detection range* $\boldsymbol{D}$.

When comparing the radar range (and Figure 2) with lidar range (Table 2 and Figure 4), it is clear that humans and elks are challenging for radar, whereas larger and more metallic objects are quite safely detected - even in poor environmental conditions. Complementing the radar, a lidar designed for motorway driving can detect humans and elks at distances, which enables automated driving at motorway speeds - as long as the visibility allows this. It would therefore be beneficial that a lidar system contains means to detect low visibility conditions, and the subject vehicle has functionality to adjust its speed accordingly. Lidar will also reinforce the radar detections of cars and trucks/buses, which are the most common moving objects at motorway.

2.5 Camera detection range

Camera is sensitive to weather conditions in three ways:

- The first condition is the sensor or its shielding being so covered with water/slush/snow that it cannot send and receive its signal, thus becoming blind. In this study, this alternative is not analysed: partly because majority of the material accumulation may have taken place before entering the motorway, and partly because future automotive cameras will probably be located behind windshield, or integrated in headlamps with some kind of cleaning system.
- The second condition is the focus of this study; how does airborne fog, mist, rain and snowfall reduce the perception capability of the vehicle sensors.
- The third condition is the detectable object being so covered with slush/snow that the object becomes impossible to identify or detect. In this study this alternative is not analysed, because the motorway is considered so well maintained that not the road nor the vehicles have time to become seriously hidden.

Since a camera-based system needs its targets to be illuminated, it always needs an additional light source for e.g. night operation. In this study, it is assumed that the automotive manufacturer has designed the subject vehicle with a lighting system sufficient for at least the same operation range as the assumed lidar system above (including visibility requirement). It is also assumed that majority of automated cars do not have long wave infrared cameras - also known as thermal cameras.[2]

Since the visibility information is available from the road weather stations, the visibility of the cameras is assumed to be the same. However, since automated vehicles use cameras for object recognition, the quality of the image needs to be good enough for recognition algorithms. Since the requirements of image quality regarding e.g. contrast, amount of details etc. is not known, it is assumed for simplicity and safety that the reliable detection range of the camera subsystem is (the same as with lidars):

[2] Thermal camera has three benefits: it does not need illumination (most objects radiate some thermal energy), it has better detection range than visible wavelength cameras at visibilities 100m … 300m, and in average Finnish conditions the warm living objects or vehicles with warm engines and exhaust pipes are easier to detect. However, they have higher cost than many other cameras, and they may be subject to export limitations due to the Wassenaar arrangement. They may enter automated vehicles later, if their cost is lower and export limitations are solved.

- 0.25 times visibility in daytime, or in illuminated areas
- 0.25 times visibility in night time (vehicle headlights are designed appropriately)

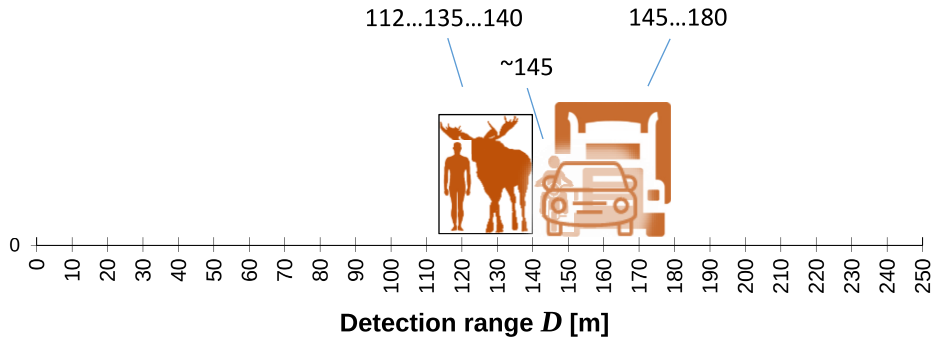

Figure 5 Camera detection ranges are assumed to be similar to the lidar detection ranges; this image is the same as Figure 4.

2.6 Tyre-road friction

Road surface affects the tyre-road friction values. The friction coefficient μ changes a lot if the road surface is dry, wet, snowy, or icy. In practice this means that the friction coefficient can change between 0.15 … 1.0. Vehicle owner should use quality tyres suitable for the current conditions, but especially in winter conditions the road maintenance is an essential method for friction improvement.

Based on the assumptions made earlier in chapter 2, the speed v, from which the subject vehicle can brake itself to standstill, can be estimated by

$$v = \mu g \left(-t_d + \sqrt{t_d^2 + 2\frac{D}{\mu g}} \right) \quad (2)$$

where D is both the braking distance, and minimum sensor detection range of the subject vehicle
t_d is the response time of the subject vehicle from the first moment of obstacle detection to the beginning of emergency braking
μ is the current physical tyre-road friction coefficient
g is 9,82 m/s^2 in Finland

Figure 6 visualises the equation above, when the tyre-road friction varies. The response time t_d is assumed to be 0.7 seconds, a challenging but possible value for a well-designed automated vehicle.

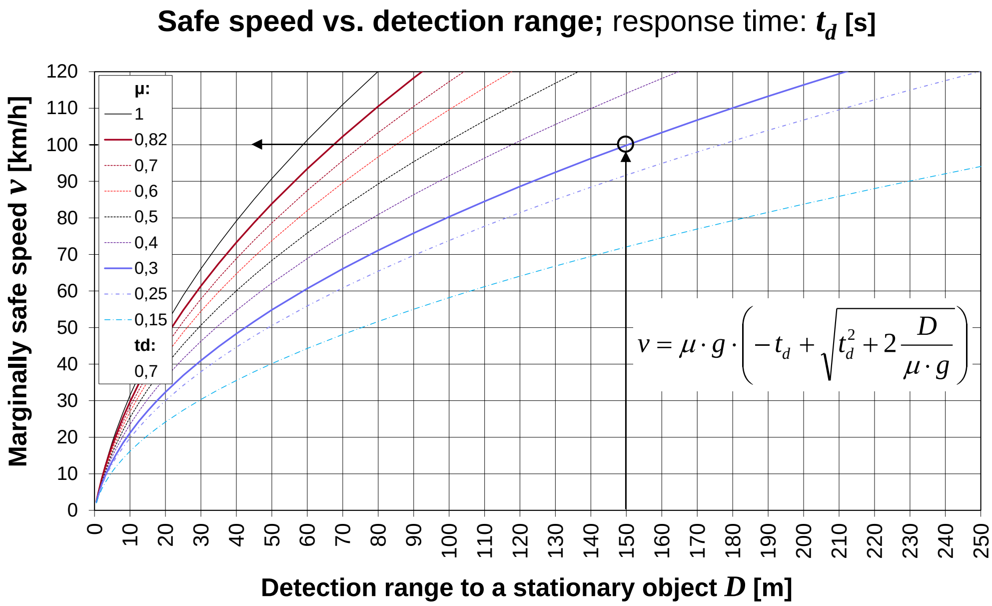

Figure 6 Visualisation of equation 2 with t_d = 0.7 s. Marginally safe speed ***v*** *means that the subject vehicle can stop to a standstill just barely within the distance* ***D****. E.g. when µ is 0.3, a braking distance (≈ detection distance) of 150 m allows the vehicle to stop from max 100 km/h velocity without hitting the obstacle.*

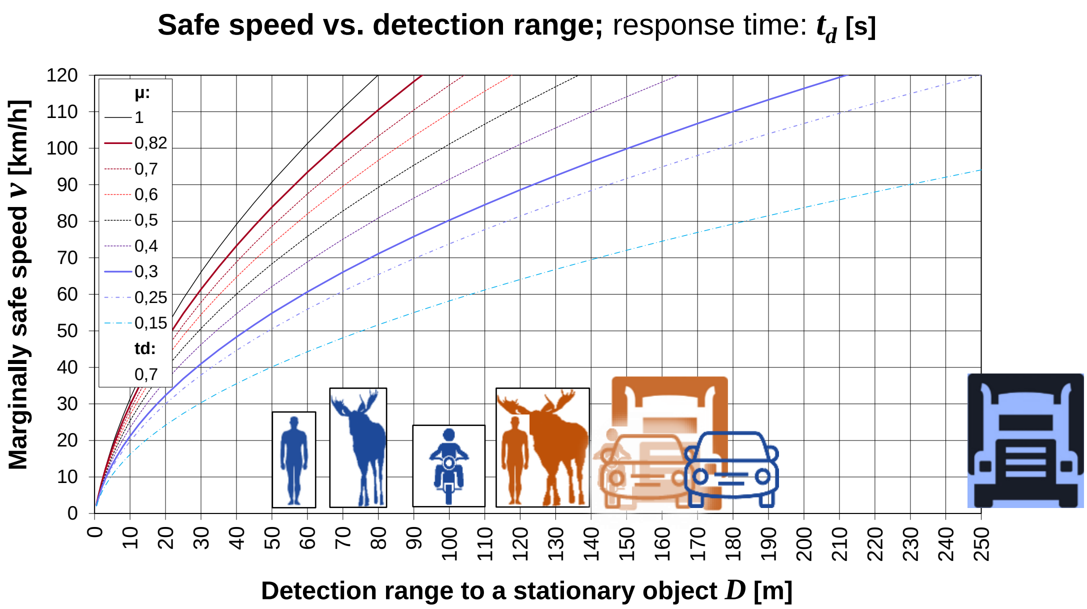

Figure 7 Radar (blue) and lidar (orange) detection ranges to the various objects analysed in this study, and safe stopping distance from different speeds with varying tyre-road friction coefficient. The delay t_d (see equation 2) from the first obstacle detection to the beginning of emergency braking is assumed to be 0.7 seconds.

Although an automated vehicle can make a lane change or avoidance manoeuvres on its own, it will have difficulties when the friction coefficient μ is less than 0.3 … 0.4. This conclusion is partly justified by the quite low friction value, to which the OEMs might not have designed their vehicle controls for. Such friction values also often imply other less conventional road features (e.g. snowy patch between the lanes) which will require new skills in lane changing and other manoeuvres. The first foreseeable automated vehicles will probably not be capable of performing such actions, e.g. low friction conditions are not in their Operational Design Domain (ODD).

Based on the braking distances (same as detection range $\boldsymbol{D}$ above) at different friction values, Table 3 below shows the minimum required visibility needed for reliable obstacle detection from the distance of $\boldsymbol{D}$. Since a darkly dressed 150cm tall human is the most difficult object to detect, the table is constructed based on the detection distance of such human. As said before, it is assumed that the automated vehicle has both radar and optical perception sensors, so that if radar has detection difficulties with human (detection range about 50 … 63 m), the optical sensors can still detect them at reasonable distance (detection range about 112 … 135 m), and cause the vehicle to react.

Table 3 Detection ranges of a small (150 cm) human in dark matt clothes (reflectivity 10%) at different friction levels using foreseeable 905 .. 850 nm lidars or camera systems designed for motorway operations. The estimated detection range $\boldsymbol{D}$*, which allows reliable detection of the human, is shown in green. Detection of the prescribed human could be possible at 112 - 135 m range, but probably with lower detection reliability, and shown in orange. The red detection range would probably need a 1550nm, or very sophisticated lidar, which might not be found from the first cost efficient automated vehicles. In addition, the friction levels in the conditions marked red might not be in the Operational Design Domain of the first automated vehicles. The estimated minimum visibility condition (=four times the detection range /7/ /8/) for the reliable detection is also shown.*

Tyre-road μ range	120 km/h (1.4. - 31.10.)		100 km/h (1.11. - 31.3.)	
	$\boldsymbol{D}$ [m]	min Visibility [m] (= 4$\boldsymbol{D}$)	$\boldsymbol{D}$ [m]	min Visibility [m] (= 4$\boldsymbol{D}$)
$0.3 \leq \mu < 0.4$	210	840	150	600
$0.4 \leq \mu < 0.5$	165	660	120	480
$0.5 \leq \mu < 0.6$	135	540	100	400
$0.6 \leq \mu < 0.7$	120	480	85	340
$0.7 \leq \mu < 0.8$	105	420	75	300
$0.8 \leq \mu$	95	380	70	280

3 Results

Data was collected from 15 different road weather stations (RWS) from eight different locations on highway 3 (pictured in Figure 8).

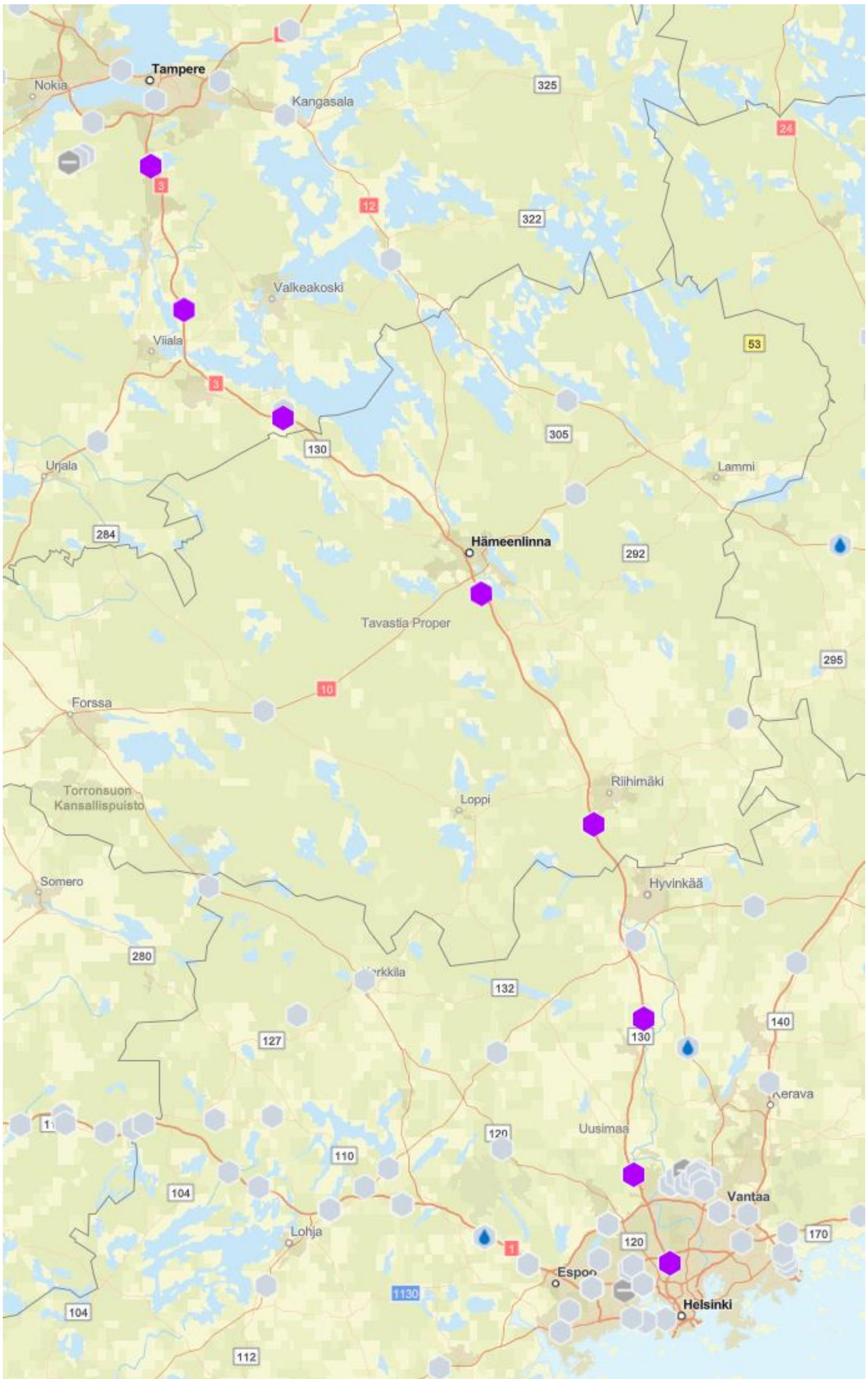

Figure 8 Road weather stations on highway 3 used in data collection and analysis marked with purple. Map from https://liikennetilanne.fintraffic.fi/, 11th of May 2021.

All of the RWSs measure at least the following variables:

- Meteorological visibility (m)
- Icy rain: icy rain or drizzle
- Road surface quality: dry, moist, wet, wet&salty, frosty, snowy, icy, moist&salty
- Rainfall intensity (mm/h)
- Rain: light, moderate, heavy rain/snowfall
- Hourly rainfall (mm)

Seven of them are also equipped with optical sensors that measure amount of ice, snow and water on the road.

The RWSs have been collecting measurement data for years but because of hardware updates some older data has been ignored. The used data covers still 2 to 11 years of road weather measurements, average being 10 years. Actually, only the second RWS in Nurmijärvi has been measuring for a few years only.

Based on the reasoning and calculations in the previous chapter, we defined conditions for each variable to filter the most challenging weather phenomena. From this data the Finnish Meteorological Institute (FMI) calculated how many hours per each month each weather condition and its different categories occurred. In this study, we have used average values of those hours to rather have too many hours outside ODD than give too optimistic view on the conditions on the road.

Since we are investigating the effect of environmental conditions on automated driving from sensor performance's point of view, the most relevant variables are visibility and friction. Thus, here in our data analysis we will concentrate on those two. Unfortunately, because of the way the data is collected and the measures calculated, there is no possibility to investigate the combined effect of different weather phenomena. Therefore, from the available data, it is not possible to identify for how long decreased visibility and lower friction conditions occur simultaneously. Visibility measurements were divided into categories for every beginning 100 meters. Based on the calculations presented in Table 3, visibility under 600 meters is considered too short for the automated vehicles to react to a stationary object ahead of them. Average hours for visibilities under 600 meters are presented in Figure 9. Again, we have chosen the more pessimistic view to provide absolutely safe estimation for automated driving's possibilities.

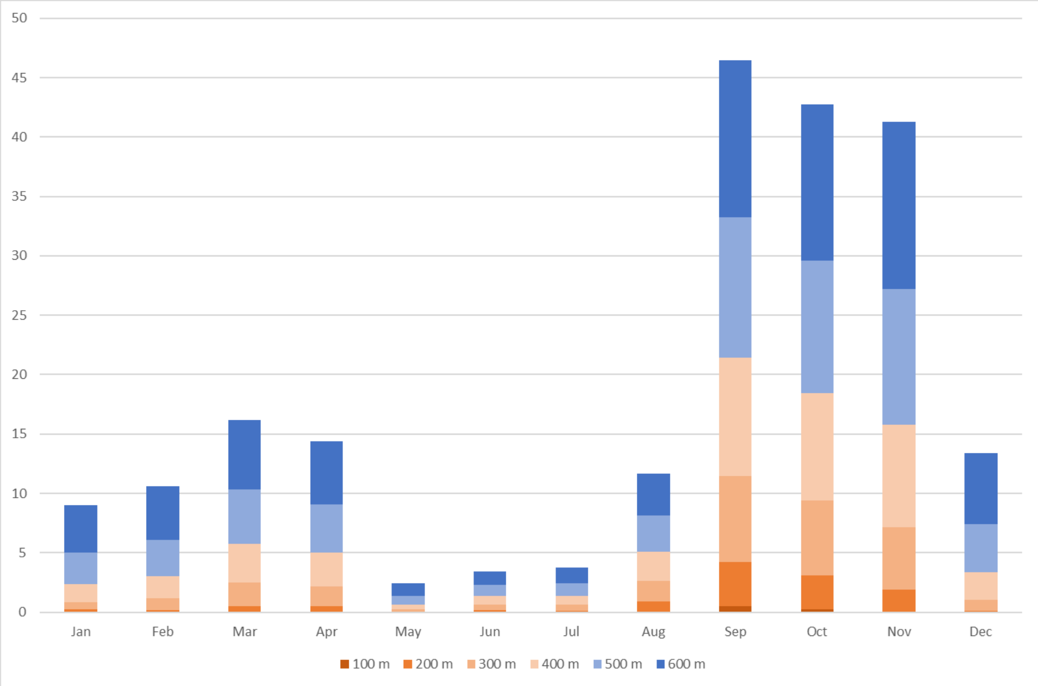

Figure 9 Average hours per month for visibilities under 600 meters.

Visibilities in Figure 9 are divided into categories so that the limit value tells the largest visibility value for that category. E.g. 300 m category covers visibilities from 200 to 300 meters (]200, 300] m exactly). Figure shows only visibility values under 600 meters because greater visibilities are considered fairly safe for AVs and thus, not very interesting for this study. As expected, quantitatively greatest low visibilities occur in the autumn months. Then it typically rains a lot and fogs are common, too.

When considering the highest peak from September, there are circa 46 hours when the visibility is less than 600 meters, and circa 21 hours when the visibility is less than 400 meters. Same numbers for October are ~41 hours and 18 hours, and for November ~40 hours and ~15 hours. In total, these three months have 2184 hours. Therefore, the visibility is less than 600 meters for *5.8 %* of the time and less than 400 meters for *2.5 %* of the time. For other remaining nine months, the percentage is even less.

To provide more information on that the high peaks are not an effect of a single or few RWSs, station-specific visibility hours are included in the Annex.

Another condition that deteriorates visibility for the AVs and their perception sensors is the snow and water on the road that is raised into the air by the leading vehicle. It creates fine mist blocking not only the visible light cameras but lidars, too. The RWSs do not directly measure this. However, in /3/ there are conditions describing exceptional snowstorm when it is likely that snow will accumulate on the road surface creating conditions where vehicles will lift the snow in the air. These conditions are:

1. Continuous snowfall at least 10 cm in 4 hours
2. Continuous snowfall at least 5 cm in 4 hours and air temperature is less than -2°C and there is strong wind (gusts more than 8 m/s)

FMI calculated the average hours per month when these conditions are met. As expected, exceptional snowstorms are not very common even in the winter months (here

October, November, December and January). Based on FMI's calculations, it can be said that on average such a snowstorm happens once a winter month and lasts for a few moments only. However, their effect to AVs' sensor performance lasts longer than that because of the accumulating snow on the road.

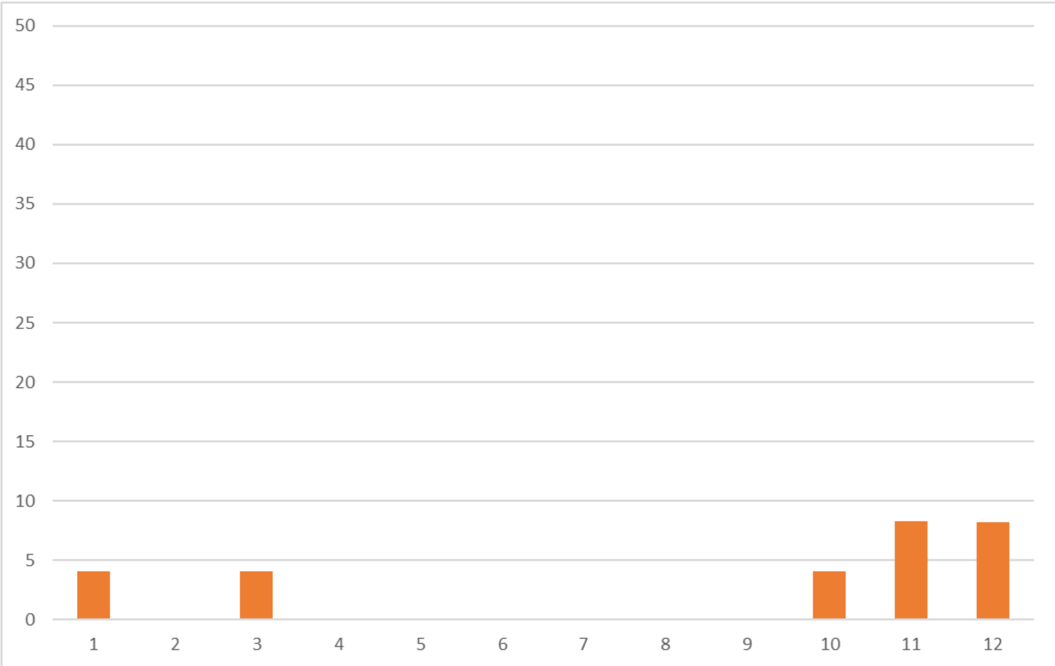

Figure 10 Effect of exceptional snowstorms in hours.

The highway in question belongs to the highest winter maintenance class Ise. During a normal snowfall, Ise road should be cleared of snow within 2.5 hours after the maximum snow depth (4 cm during the snowfall) has been reached /3/. There has been no exact time limit set for exceptional snowstorms in /3/ but we estimated that it would take at least 4 hours until the road is entirely cleared of snow after such a storm. This temporal effect is added to the actual average hour values of the data and shown in Figure 10. During that time the traffic would raise snow from the road and decrease visibility of the following vehicle. Therefore, for each winter month there are few hours when the AVs cannot drive. Occasionally, these snowstorms happen also later in spring when the effect is assumed the same.

For friction estimation, we used RWSs' direct estimate about the road surface quality. As mentioned in the beginning of this chapter, there are several different categories for this measurement. Of these, we have taken into account only the icy road surface because other conditions are not assumed to be too slippery for the AVs to handle. The friction value is assumed to be no more than 0.3 for icy road surface. Another assumption is that especially the first generation AVs are not prepared to handle slippery conditions or changes in road friction. Thus, low friction conditions are considered outside their design domain, i.e. they cannot drive then.

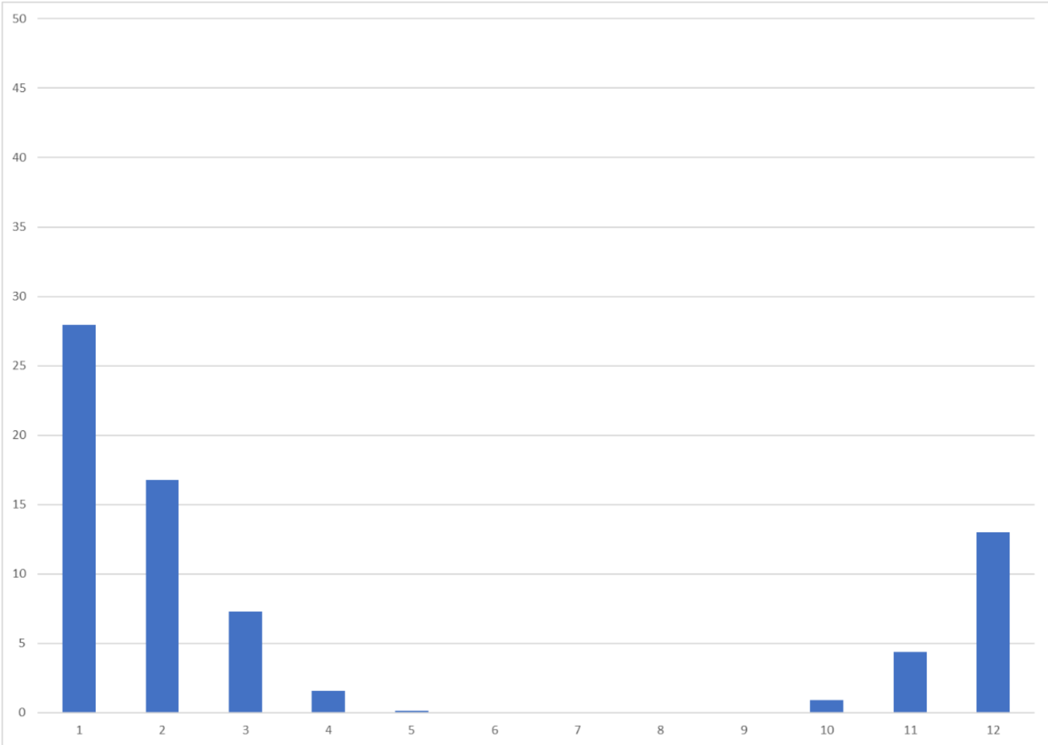

Figure 11 Average hours per month of icy road surface.

In Figure 11, monthly average hours when the road surface is icy are presented. Naturally, highest figures appear during winter time. In January, road is icy *3.4%* of the time; in February *2.4%*; in March *1%*; in December *1.5%*. Spring and autumn months show up as well since in the cold mornings the road surface can be icy before temperature rises enough for the ice to melt. For roads in winter maintenance class Ise, the road friction requirement is 0.3 /3/ (this is a computational friction value, as a physical friction value it translates to 0.38). Situations with lower friction values need to be taken care of immediately. Thus, it is not surprising that icy road conditions do not appear more often.

Since our data does not contain the information when the different weather and road conditions occur at the same time, we have continued to follow our pessimistic and thus, safer approach. We have simply summed the hours of three phenomena discussed in this chapter to create an overall view of the weather conditions likely outside of the future

AVs' ODD.

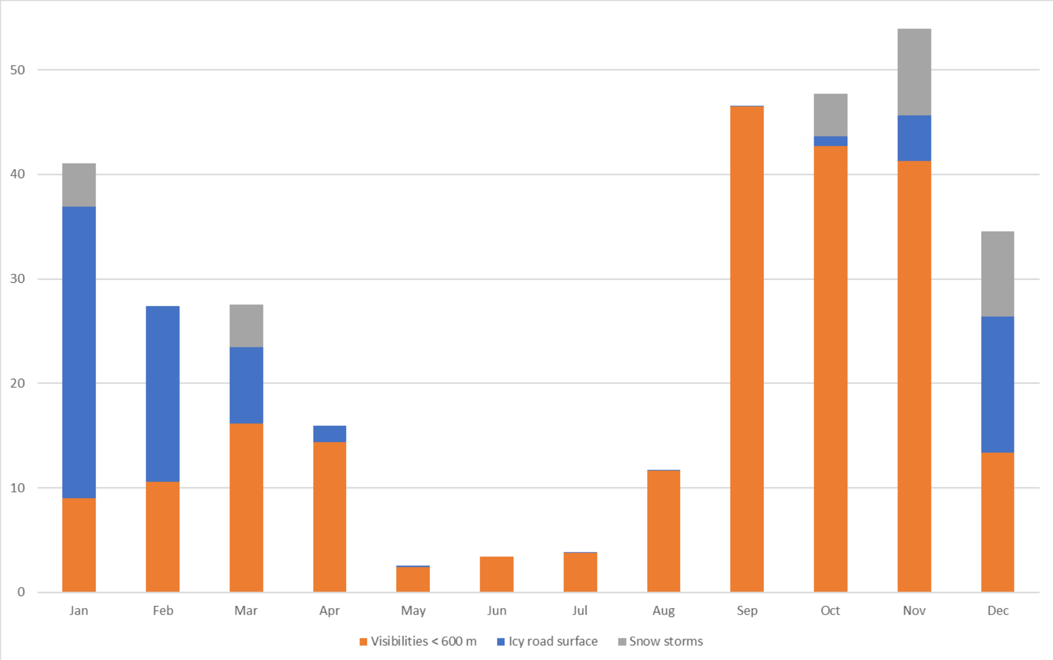

Figure 12 Total hours of adverse weather conditions causing the most challenges for the AVs.

As seen in Figure 12, when all three phenomena are combined the low visibilities during autumn months do not stand out as much. In winter months, the slippery road causes most of the challenging periods even though the motorway in question is well maintained. Difference between summer and other seasons is significant. In May, June and July the total hours stay under *4 hours* per month (less than *1%*). From September to March, the total hours vary from November's *52 hours* (*7.3%*) to February's *25 hours* (*3.8%*).

As has been mentioned earlier, there are limitations and uncertainties in the used data. There is no automatic quality inspection for the recorded sensor data and no such manual examination was performed during this project. The RWSs have been located to places where weather-related issues have been noticed. Thus, they might create more severe view on the weather conditions on the inspected motorway. However, this is in line with our pessimistic but safer approach of limitations to AVs.

4 Conclusions and recommendations

Available friction and necessary perception range go hand in hand; if it is slippery, the vehicle needs more meters for braking and avoidance maneuvers. The first conclusion is that it is best to analyze these together. Since this study focuses on motorway environment, the analysis is based on straight driving case, where braking is the default avoidance maneuver.

The estimation of the expectable perception sensor capabilities in Chapter 2 is somewhat pessimistic regarding next generation radar performance, and vague regarding the performance of the camera-illumination-recognition algorithm combinations. Nevertheless, the analyzed combination of perception range – friction provides the minimum level of requirement combinations for motorway environment. The results in Chapter 3 are more conservatively selected – partly for safety reasons and partly due to the limitations in the weather data collected from the road weather stations. These limitations also prevent analysis of the simultaneous effects of the conditions, such as what was the visibility when friction was low.

The most vague condition to identify from weather data is the snow dust or water mist raised by the vehicle in front, and how seriously it reduces the perception range of the sensors in the subject vehicle. This condition is not measured directly, meaning that its estimation needs to be carried out indirectly. Therefore, the results are also estimations.

The main reason, which puts an automated vehicle outside its ODD is probably poor visibility, BUT since the analysed data does not provide the simultaneous friction level, this conclusion is somewhat oversimplified. It should be refined once friction and visibility can be analysed at the same time.

Safe perception capability of automated vehicles needs long enough detection distance of both radar and optical sensing. Optical sensing is more dependent on weather conditions, and based on Figure 12, the most common reason for compromised sensing is low visibility. The road weather station data does not reveal, which weather condition is the most common reason for this, but based on the annual distribution of low visibility it can be assumed that rain and fog are to be blamed.

It is expected that because of the climate change, extreme weather conditions are more frequent than before. The need for road condition monitoring, and reacting with focused maintenance operations is not reducing in the near future.

A road operator cannot do much for the weather, except road maintenance. Providing easy and standardized access to local road weather forecasts helps both manual and automated vehicles, especially when bad weather is approaching. The suitable information content for a human user has already settled over the years, but for automated vehicles the information content could include e.g. expected signal attenuation in all relevant sensor wavelengths and frequencies – measured across the road at about 1 meter height to include also the effects of snow and spray raised by previous vehicles. Increasing the number of road weather stations would increase the accuracy of provided information.

Probably the second and third generation automated vehicles are able to sense, if their perception capability is currently reduced. Perhaps they can also estimate the current available friction for avoidance maneuvers. Those vehicles are likely to be able to adjust their speed and safety distances to match conditions. Since these vehicles are also capable of communicating their findings to other vehicles and infrastructure operators in real time, this information source could be included in the future data infrastructure plans, and establish a European wide (or global) standard for the content and interface.

4.1 Recommendations for further work and development

The quality of the stored road weather and condition data could be better, if it will be utilized more in the future. For the ODD analysis it is important that at least friction and visibility combinations are available at every time instant, so that their combinations are easily available. If friction cannot be measured directly, at least reliable road surface category (is it icy, snowy, wet, dry, …) should be systematically available. Also, reliable data about other simultaneous environmental conditions (like accumulation of snow, and when it has been cleared) becomes more interesting in the future. It would also be useful to be able to combine both road weather station data, appropriate measurements of the Finnish Meteorological Institute, and information from road maintenance logs, since analysis needs will develop more complex in the future.

Road side visibility measurement system could also be developed to measure visibility from each lane at about one meter height across the lane. This way we could monitor also snow dust and water fog raised by the traffic in front of the subject vehicle. Today this phenomenon is not captured by road weather stations. Additionally, the attenuation of non-visible wavelengths could be measured. Such wavelengths include at least 850 - 1550 nm used by lidars and some IR cameras. This measurement should be part of the road side measurement arrangement just described.

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Annex

Here, average visibility hours from each RWS location are presented in Figures Figure 13 toFigure 20 to clarify if there are any stations that have significantly different values than rest of them. This is the case with RWS in Helsinki (Pirkkola) where the autumn months do not appear to have any less lower visibilities than rest of the year. Specific reason for this is not known but there could be a faulty sensor, some errors in the data or perhaps the location is truly particular in this way.

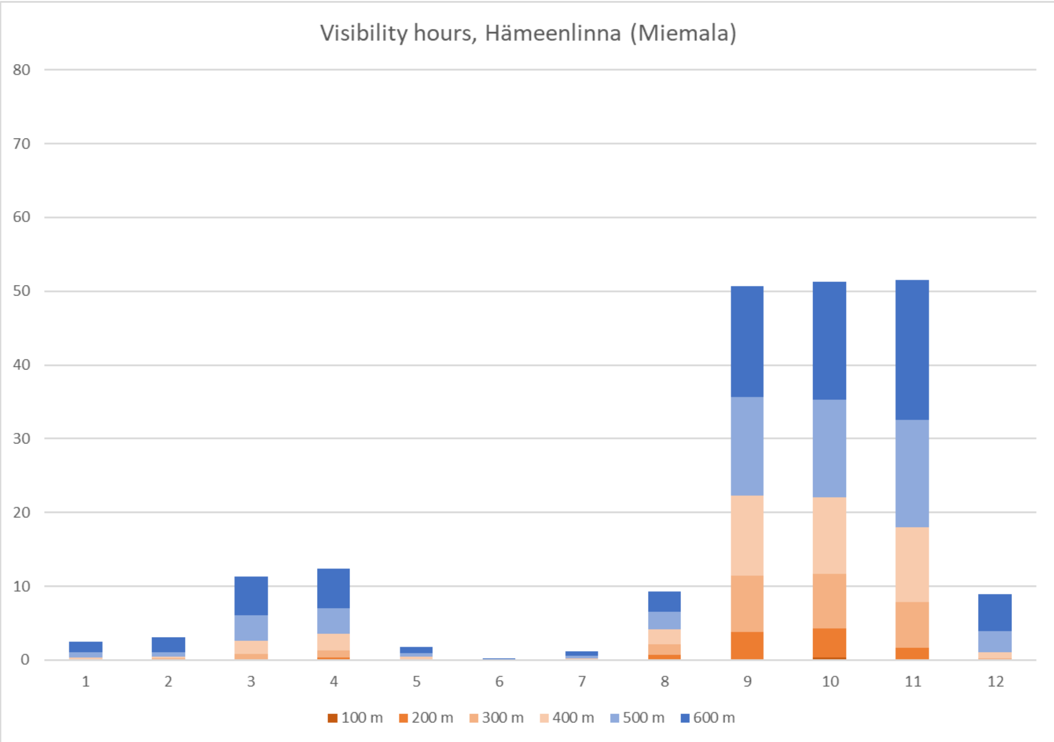

Figure 13 Average hours per month for visibilities under 600 meters from RWS in Hämeenlinna, Miemala.

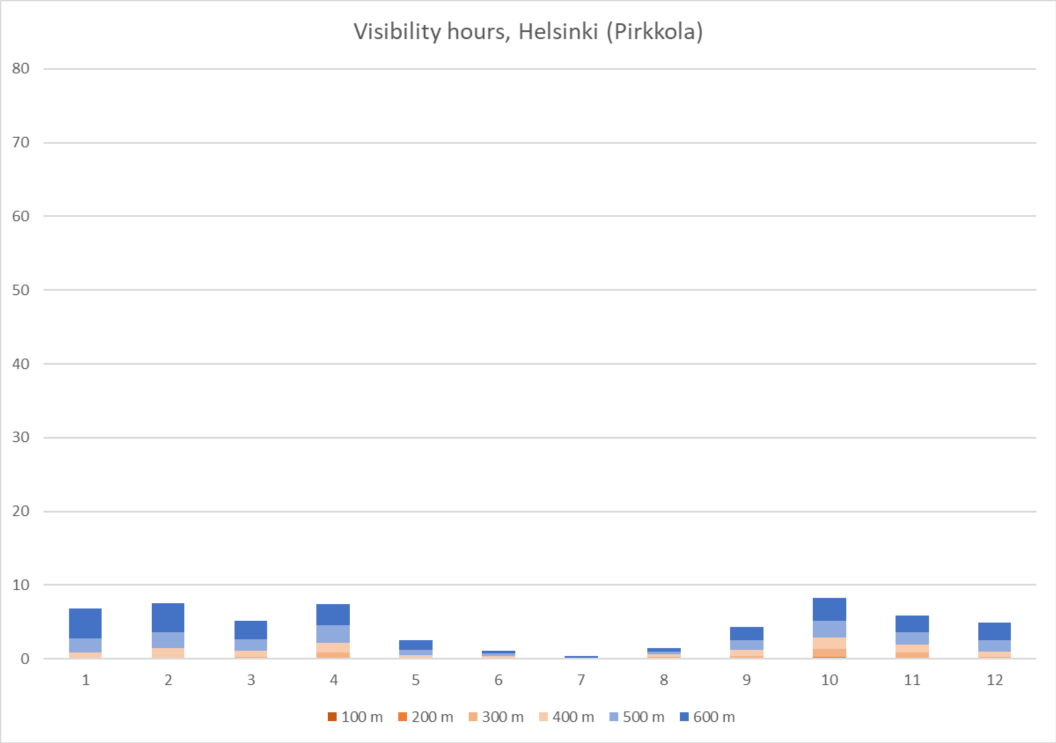

Figure 14 Average hours per month for visibilities under 600 meters from RWS in Helsinki, Pirkkola. When compared to other stations' numbers, there is a significant difference in September, October and November. There are far less hours of low visibilities than in any other RWSs.

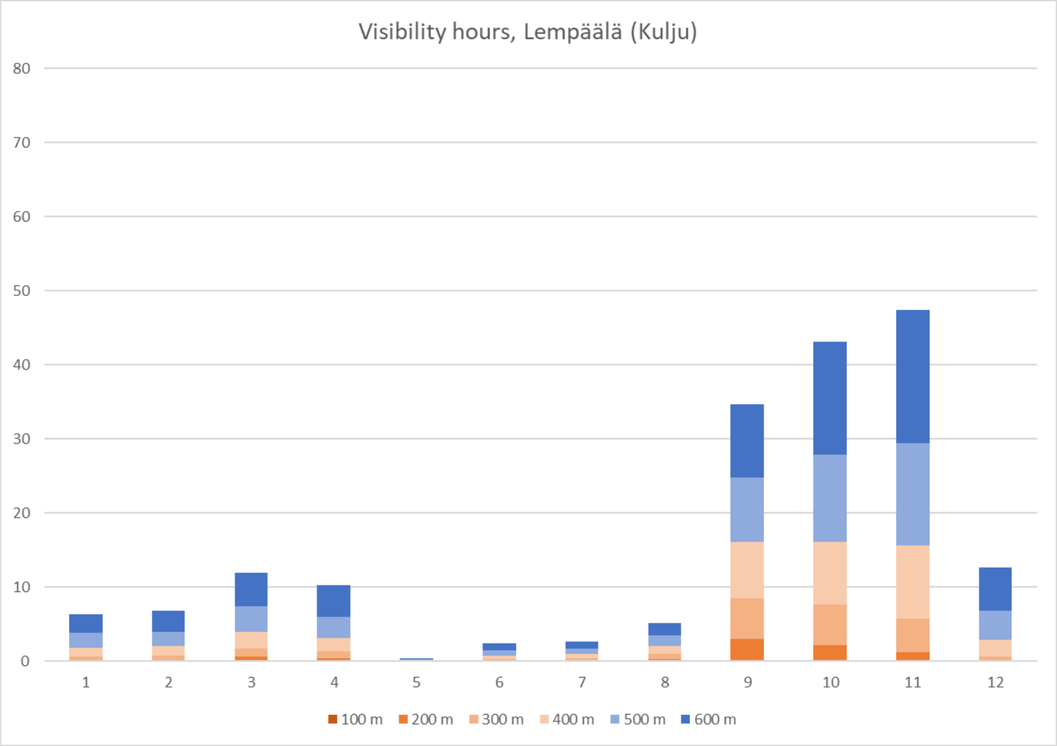

Figure 15 Average hours per month for visibilities under 600 meters from RWS in Lempäälä, Kulju.

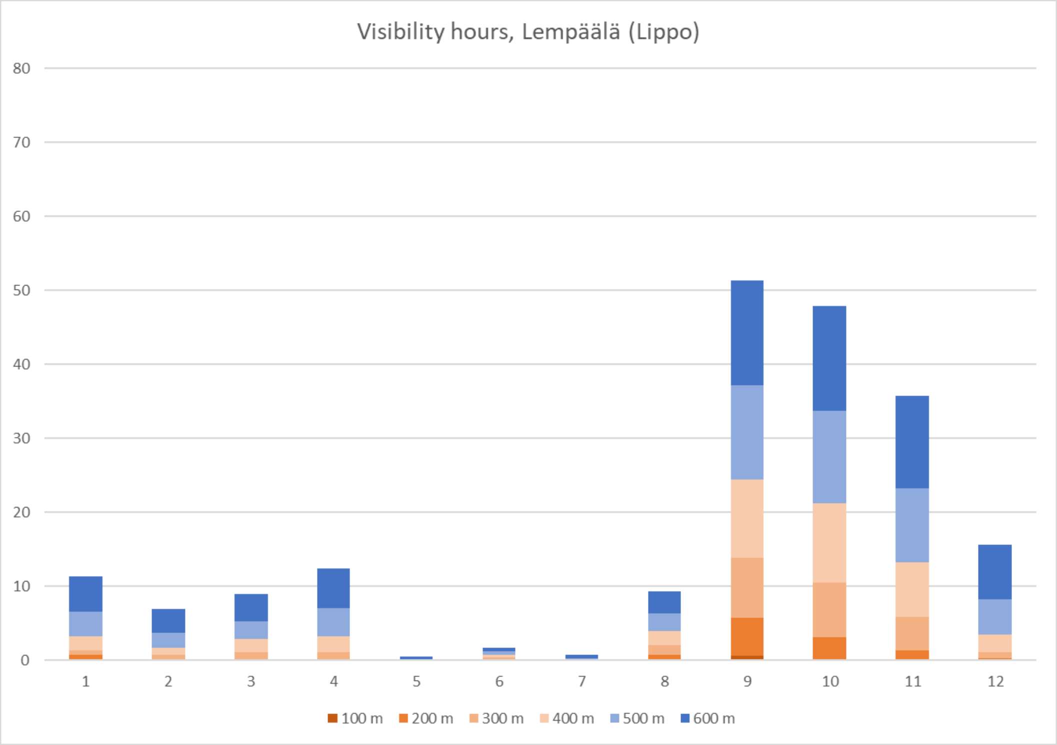

Figure 16 Average hours per month for visibilities under 600 meters from RWS in Lempäälä, Lippo.

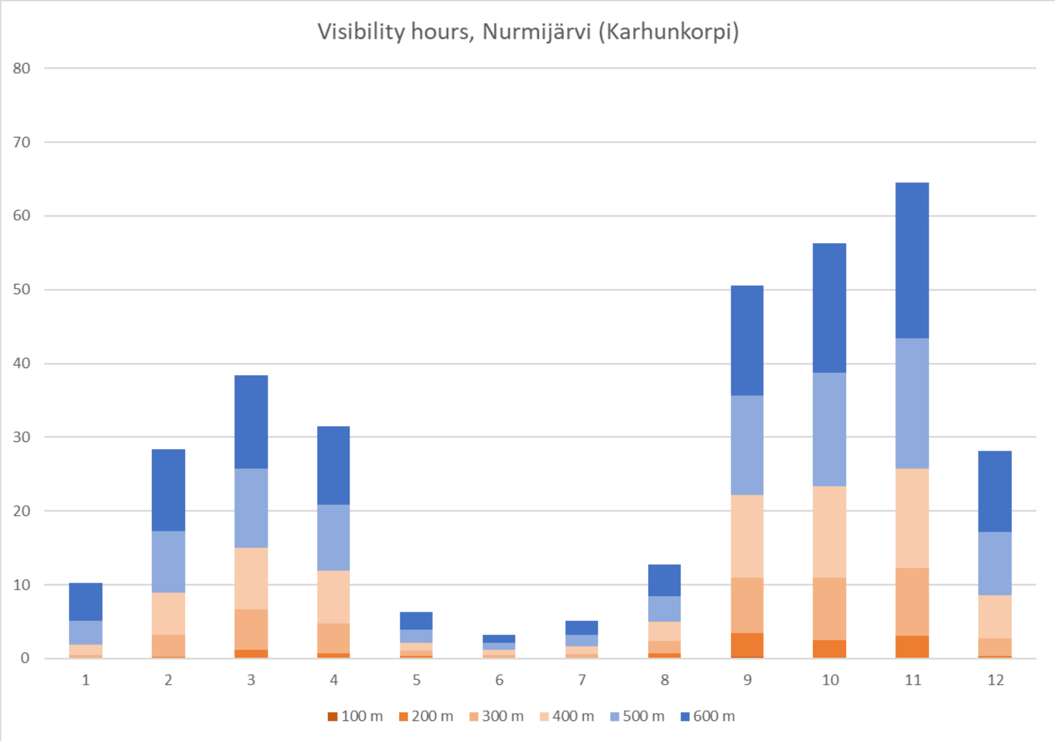

Figure 17 Average hours per month for visibilities under 600 meters from RWS in Nurmijärvi, Karhunkorpi.

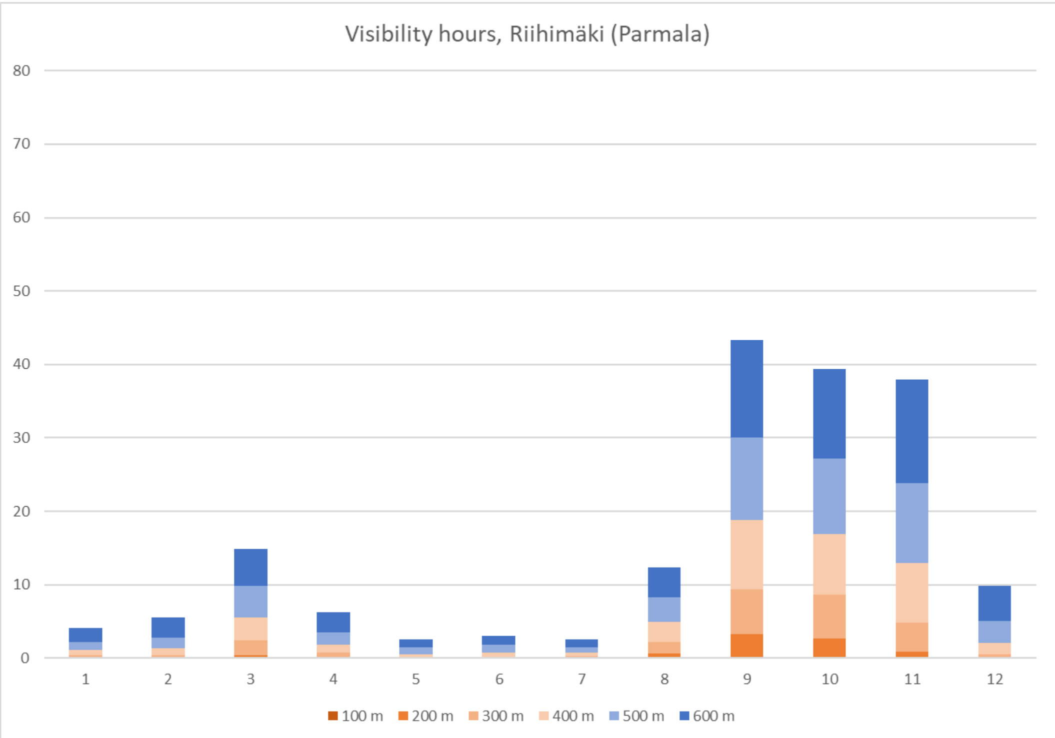

Figure 18 Average hours per month for visibilities under 600 meters from RWS in Riihimäki, Parmala.

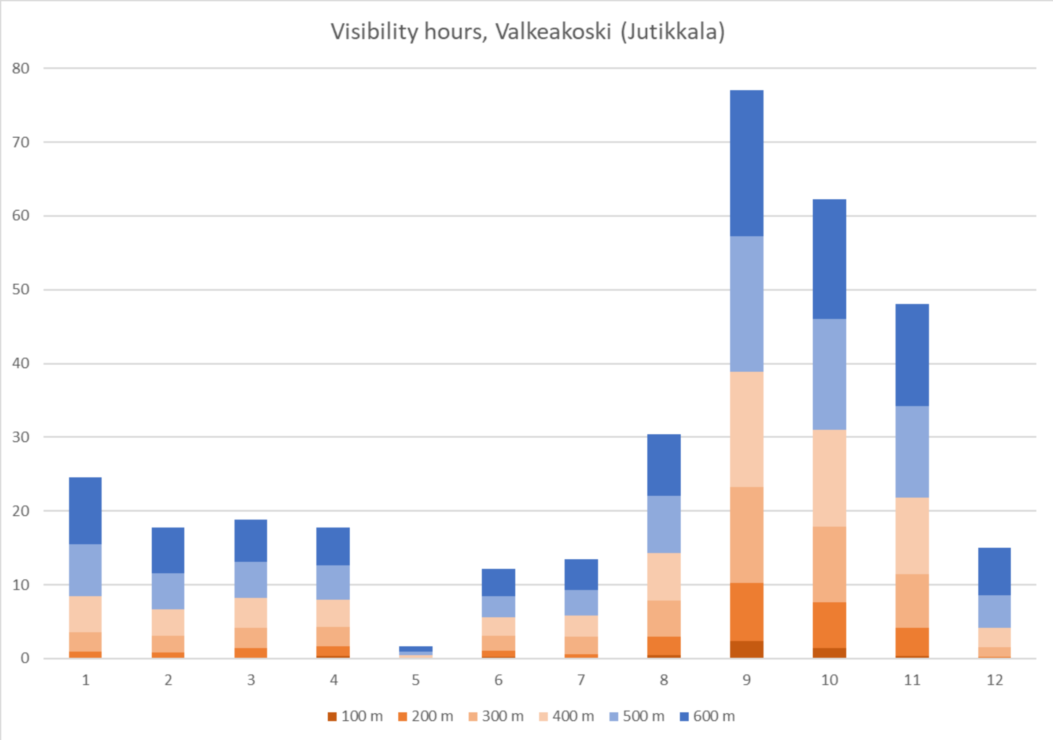

Figure 19 Average hours per month for visibilities under 600 meters from RWS in Valkeakoski, Jutikkala.

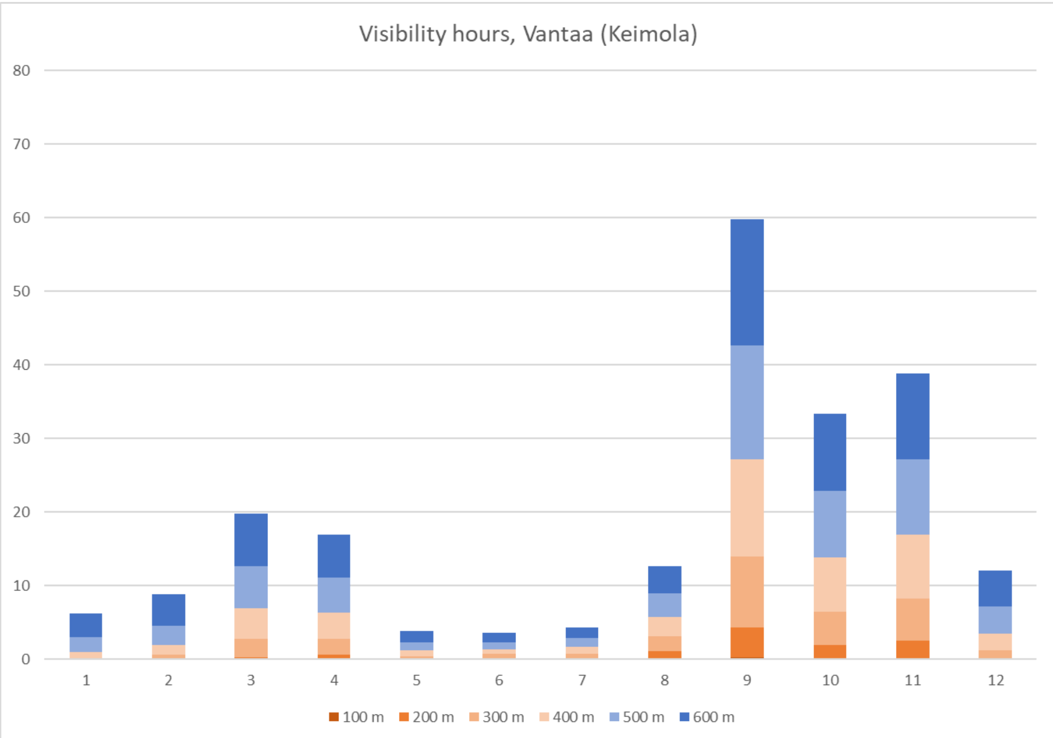

Figure 20 Average hours per month for visibilities under 600 meters from RWS in Vantaa, Keimola.

Finnish Transport Infrastructure Agency

Nordic WAY 3

Co-financed by the Connecting Europe Facility of the European Union

Working report
22/04/2021

Service level framework for automated road transport

Task 1.5 C-ITS and other mobility services

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Sisällysluettelo

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Annex 1 Questions to the service providers

1 Goal of the Task

The goal of the task was to find out what kind of services are available on the Helsinki – Tampere motorway providing traffic, road weather and conditions and traffic disturbance information that would be useful for automated driving. The study included both public and commercially available services and information sources.

2 Methodology

This quick inventory study of currently available services and information sources was conducted during February and March 2021. An initial list of known services and information sources and a list of questions to the service providers was created by the VTT and Sitowise experts together with the Finnish Transport Infrastructure Agency. The list of questions was sent to the listed Finnish Service Providers (SP). The international SPs were not contacted but the information about their services and application programming interfaces (API) was taken from their web sites. The results from the information collection from the SPs was included to the report as such. The summary result table was compiled. After this, a short introduction of Cooperative Intelligent Transport Systems (C-ITS) was written and final conclusions of how the currently available services and data sources support automated driving or Cooperative, connected and automated mobility (CCAM), including also C-ITS, was described based on the feedback from the SPs and the expert analysis. Finally, conclusions and recommendations to the service level framework and for further research were summarized in the end.

2.1 Limitations of the study

This review of available C-ITS and mobility services will focus only on services data sources which could potentially be utilised to support automated driving. Therefore, only relevant services, data or information sources providing traffic, road weather and conditions and traffic disturbance information in machine readable format through a well-defined API have been included to the study. This inventory does not cover (HD) map service providers or mobile network strength services (see sub-report 1.2), which are also very relevant and could be also utilised to support automated driving.

3 Introduction

Services and information sources which provide real-time traffic, road weather, condition and traffic disturbance information could be useful for automated driving. Automated driving relies mainly on in-vehicle sensors, but these kinds of services could provide additional information and therefore extend the limits of on-board sensors. Services, which could support automated driving, include Cooperative Intelligent Transport Systems (C-ITS) and other real-time data and information sources. This chapter provides a short introduction to C-ITS.

3.1 C-ITS services and automated driving

When it comes to C-ITS in automated driving, the European Commission states in https://ec.europa.eu/transport/themes/its/c-its_en that in the very near future vehicles will interact directly with each other, with the road infrastructure and with other road users. This interaction is the domain of Cooperative Intelligent Transport Systems (C-ITS), which will allow road users and traffic managers to share information and use it to coordinate their actions. This cooperative element – enabled by digital connectivity between vehicles and between vehicles and transport infrastructure – is expected to significantly improve road safety, traffic efficiency and comfort of driving, by helping to take the right decisions and adapt to the traffic situation by utilising accurate and real-time traffic, incident and condition data. Communication between vehicles, infrastructure and other road users is also crucial to increase the safety of future automated vehicles and their full integration with the overall transport system. Cooperation, connectivity, and automation are not only complementary technologies; they reinforce each other and will over time merge completely.

The European Commission adopted in 2016 a European Strategy on C-ITS, a milestone initiative towards Cooperative, Connected and Automated Mobility (CCAM). The objective of the C-ITS Strategy has been to facilitate the convergence of investments and regulatory frameworks across the EU, in order to see deployment of mature C-ITS services. Developments of CCAM are happening fast and hold the promise of further increased safety and more inclusive mobility solutions. To be successful, however, there is a need to carefully assess the integration both in the existing traffic and on the existing infrastructure. To this end the Commission has initiated a discussion within the ITS Committee. The goal is to establish a European roadmap with short and long-term targets for testing and deployment of CCAM.

C-ITS allow vehicles to communicate with infrastructure (vehicle-to-infrastructure; V2I) or with cloud via mobile networks (vehicle-to-network; V2N), with other vehicles (vehicle-to-vehicle; V2V) and in future with pedestrians (vehicle-to-pedestrian; V2P). All these communication types are included in vehicle-to-everything (V2X) communication, see Figure 1. C-ITS can be transmitted either over short range directly or long range over mobile networks. Currently, the short-range technology is ITS-G5, in the near future also cellular-V2X (C-V2X) PC5 sidelink will be available. The combination of short- and long- range communication is called hybrid communication.

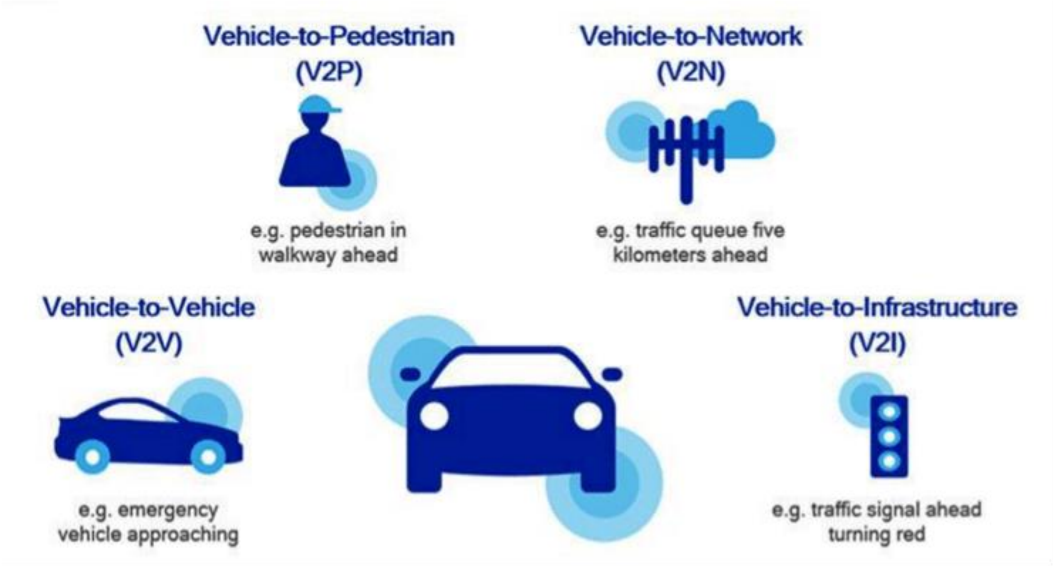

Figure 1. Vehicle to everything (V2X) communication /1/.

The European Commission defines Cooperative Intelligent Transport Systems (C-ITS) as "intelligent transport systems that enable ITS users to cooperate by exchanging secured and trusted messages through the EU C-ITS security credential management system" /2/. Hence, C-ITS should include certificates according to the ETSI standards from organisations included in the ECTL (European Commission Trusted List).

The most important C-ITS messages for highway scenarios are DENM (Distributed Environmental Notification Message) and IVIM (In-Vehicle Information Message). In addition, there are CAM (Cooperative Awareness Message), which are broadcasted from the vehicles.

The C-ROADS platform provides a specification for C-ITS use cases and the C-ITS messages delivered by road operators. The use cases are divided over several services:

- Hazardous Location Notification (HLN). Delivery of SRTI (Safety Related Transport Information) is a subset of the C-ROADS use cases.
- Road Works Warning (RWW)
- In-vehicle Signage (IVS)
- Signalised Intersections (SI). [This service is not treated in this report, as there are no signalised intersections on the motorway Helsinki-Tampere, and the issue is discussed in another NordicWay3 report.]
- Probe Vehicle Data (PVD).

Within the framework of NordicWay, also DATEX is used to communicate C-ITS information by utilising cloud to cloud hybrid communication. The NordicWay pilots have been concentrated on the delivery of SRTI, using DATEX II protocols. C-ITS messages are standardised by ETSI and ISO. ETSI has finalised the "Release 1" set of standards, including CAM, DENM and IVIM. In addition to the maintenance of Release 1 standards, ETSI is working on Release 2 set of standards, which will support automated driving, including e.g. CPM (Collaborative Perception Messages) and MCM (Manoeuvre Coordination Messages) and digital maps.

3.1.1 NordicWay 2 and NordicWay 3

NordicWay 2 was a C-ITS pilot project between public and private partners in Finland, Norway, Sweden, and Denmark. It was co-financed by the European Union within the Connecting Europe Facility programme 2017-2020. The piloted C-ITS services enabled vehicles, infrastructure, and network operators to communicate safety hazards and other information from roads between stakeholders by utilising cloud to cloud hybrid communication. NordicWay 2 has now been completed and NordicWay 3 project has started.

In Finland, the aim of the NordicWay 2 pilot was to enhance traffic safety and fluency by creating a new way to share C-ITS messages between traffic information suppliers so that end users would get more information of better quality. The pilot aimed at establishing ecosystems around three contracted suppliers/ecosystem leaders (Posti, Infotripla and EEE Innovations). The suppliers were obliged to set up an interchange node and exchange their ecosystem's C-ITS messages with other suppliers. In total three suppliers and 15 service providers participated to the pilot. /3/

Now as the NordicWay 2 project has ended, the three NordicWay interchange nodes are not anymore in operation, but most of the service providers still provide their services. In addition, the NordicWay 2 suppliers (at least Infotripla and EEE innovations) are actively providing and developing their data collections, and information or service provision to other service providers, see chapter 4.

4 Results from the inventory

This chapter presents the results from the service and information source inventory. The study was implemented with a questionnaire, which was sent to the Finnish service providers, or information collected from the service provider web site (of international service providers). Currently there are no providers in Finland who exchange ETSI standardised messages including certificates complying to the EC Certificate and Security Policy. Hence, there are – according to the European Commission's definition of C-ITS services – no C-ITS services currently in Finland. Therefore, this inventory focuses on data and information services.

4.1 Public (open data) information services

4.1.1 Fintraffic - DigiTraffic

1. Service provider

   Fintraffic https://www.fintraffic.fi/en

2. Service name and web link to more detailed information

   Digitraffic https://www.digitraffic.fi/en/road-traffic/

3. Service description

   Digitraffic is a service operated by Fintraffic offering real time traffic information. Currently the service covers information about road, rail and marine traffic. The information is open data, which is distributed through open APIs. As a term Digitraffic refers to digital traffic, a model representing traffic.

4. Information contents

   - Road weather cameras
   - Weather camera image history for the last 24 hours
   - Current journey times
   - Current free flow speeds
   - Road weather forecasts. Currently long-term forecasts. In the near future a service (v1) from Vaisala involving short term forecasts is planned to be used in Traffic Management Centre operations.
   - Current data from TMS stations. The TMS documentation contains descriptions of TMS data.
   - Traffic incidents. The emergency centre and first responders provide information on traffic accidents to the Traffic Management Control System. The quality of the information depends on the source of the information

(phone caller informing accident to emergency centre, first responders…).

- Weight restrictions
- Long-term Roadworks. digitraffic.fi service offers long term Road Works Warnings Safety Related Traffic Information (list of shared types: https://tie.digitraffic.fi/api/v2/data/maintenance/trackings/tasks). Fintraffic uses Traffic Management Control System (T-LOIK) to communicate the information to digitraffic.fi.

  Roadwork contractors inform about their road works on the national webpage (https://tietyoilmoitus.tieliikennekeskus.fi/). Information includes time and location of the road works. This process is under automation.
- Road maintenance information. digitraffic.fi provides location and operation information from maintenance vehicles from road maintenance contractors, consisting of the vehicle latest location and tracking data. The latest location data is delayed with 15 minus due to privacy and security reasons.
- TMC/ALERT-C location data
- Current data of road weather stations. Sensor history for the last 24 hours
- Variable signs

a. Data format (standards used, e.g. DATEX ver. X)

   i. Traffic disorders. Road traffic center provides information about traffic accidents and other disorders like road works. Messages are available in Datex II v2.0 format.

   ii. Weight restrictions are available in DATEX II 2.0 format.

   iii. Roadworks are available in DATEX II 2.0 format.

b. API description

   i. REST/JSON -APIs. Full API description is available.

   ii. WebSocket API. TMC-data can be tracked from following Web Socket APIs. Protocol is MQTT over WebSockets. This allows user/developer to subscribe only those topics they are interested in.

c. Timeliness / update frequency of the data

   i. Current free flow speeds. Data is updated once a day.

   ii. Road weather station data is updated once per minute.

iii. Road weather forecasts. Content is updated every five minutes.

iv. Event data

d. Origin of the data

Road traffic information is gathered from the operational traffic management systems of ITM Finland Ltd (a subsidiary of Fintraffic).

i. TMS data (Traffic Measurement System). Information is gathered from an inductive loop which is installed inside the pavement. When a vehicle passes over the loop it creates information about average speeds and traffic amounts.

ii. Road weather station data. The road weather stations measure e.g. temperature, wind, rain, relative humidity and dew point.

iii. Road weather cameras. Cameras provide information on current traffic flow and weather conditions.

FTIA's HARJA system (road maintenance) receives dynamic road works information from the maintenance vehicles (e.g. winter maintenance, cleaning). The dynamic information partly offered in Digitraffic.fi

In addition, there are data sources from other traffic data providers listed here are based on the providers own notifications following the EU ITS Directive 2010/40/EU.

iv. TomTom Intermediate Traffic Service - Flow and Incidents. Unexpected events (non-safety related), Real-time traffic data, Safety-related Traffic. TomTom provides information on e.g traffic flow in the Helsinki region up to Klaukkala. The data is used for operative work by the Trafic Management Centre. See https://www.digitraffic.fi/en/NAP/

v. The use of Waze is under assessment by Fintraffic.

e. Coverage

Whole road network in Finland. Variable coverage in different data types.

i. Currently, there are over 450 traffic measuring stations in Finland.

ii. Currently, there are over 350 road weather stations on the Finnish road network.

5. Data pricing, usage restrictions, licences, other limiting conditions

The information distributed through Digitraffic is based on data collected by the Fintraffic, the Finnish Transport Infrastructure Agency and the Finnish Transport and Communications Agency Traficom. The data is collected for operative purposes and shares the data according to open data principles. Using the data is free and does not require a contract with the Fintraffic. However, the licensing terms must be followed. All content from the service and the service documentation is licenced under the Creative Commons 4.0 BY license.

6. Currently known issues with data, API or limitations

   Timeliness of the data varies. Event data must be validated, which involves time delays. For vehicle location data (e.g. winter maintenance) information is delayed for e.g. security and privacy reasons.

   Accuracy and quality of the information depends on data source. For instance, for roadworks, information may depend on road maintenance contractor.

7. Current level of service and development plans (near term)

   API is in operational stage. Current and scheduled development plans are listed here: https://www.digitraffic.fi/en/development-roadmap/

8. Current number of users / customers

   List of road traffic applications using open data provided by the Fintraffic is available, see https://www.digitraffic.fi/en/applications/

4.1.2 Fintraffic - HALI

HALI (hälytysajoneuvojen liikennevaloetuudet) is a national system, which is based on satellite positioning of emergency vehicles. HALI allows traffic light priority for emergency vehicles. The development of HALI started in Oulu, and at this moment there are 20 municipalities involved, including Tampere, Helsinki, Vantaa and Espoo. For security reasons the information in the HALI is only available for authorities. The potential to use the HALI system for the EVA (Emergency Vehicle Approaching) use case has been studied in NordicWay3 by Ramboll /4/.

4.1.3 Finnish Transport Infrastructure Agency - Digiroad

1. Service provider

   The Finnish Transport Infrastructure Agency, https://vayla.fi/en/

2. Service name and web link to more detailed information

   Digiroad - National Road and Street Database
   https://vayla.fi/en/transport-network/data/digiroad

3. Service description

   Digiroad is a national database that contains the geometry of the Finnish road and street network featured with the most important road attribute data. The Digiroad Database provides a comprehensive and up-to-date description of the Finnish road and street network online. The data enables and supports the development and commercialization of services and applications for e.g. route planning, navigation, and intelligent transportation systems (ITS) purposes.

4. Information contents

Digiroad data consists the center line geometry of the transport network, traffic-related attribute data and other transport system objects. The **center line geometry** covers the vehicle-accessible roads, ferry and cable ferry connections for cars, railways and separate pedestrian and cycle routes. Traffic-related **attribute data** include the attribute data of traffic elements as well as the restrictions, limits and other features of the road and street network. It is the most comprehensive road data in Finland. The data includes information about **official road numbers, names, address numbers, bridges, tunnels, lit roads, bus stops**, **traffic lights** and **volume, road width** as well as **pavement type** and **public transport lanes**. It also includes information about the restrictions like **speed limits**, **restricted manoeuvres**, **maximum allowed** information, and **services**.

a. Data format
ESRI Shapefile -format

b. API description
Digiroad documentation: https://vayla.fi/en/transport-network/data/digiroad/documents

Changes occurred in Digiroad data is available in TN-ITS API and they are released here: http://tn-its.herokuapp.com/rosattedownload/download/queryDataSets

c. Timeliness / update frequency of the data
Datasets are updated once a day

d. Origin of the data

The National Land Survey of Finland, the Finnish Transport Infrastructure Agency, municipalities, and a few other authorities provide source data for Digiroad.

e. Coverage

Digiroad data covers the entire Finland

5. Data pricing, usage restrictions, licences, other limiting conditions

Open data, free of charge. When using the data, follow the Creative Commons BY 4.0 license specifications.

6. Currently known issues with data, API or limitations

None

7. Current level of service

In production

8. Current number of users / customers

-

4.1.4 FMI - open data sets

9. Service provider

Finnish Meteorological Institute - FMI, https://en.ilmatieteenlaitos.fi/

10. Service name and web link to more detailed information

FMI open data sets,
https://en.ilmatieteenlaitos.fi/open-data-sets-available

11. Service description

FMI has published a major part of its meteorological data sets as Open Data using open standard web service interfaces (only data sets relevant to the automated driving topic are listed here). FMI also distributes the road weather observations from the Fintraffic's Digitraffic since 2010

a. Real-time observations

i. Weather observations

ii. Radar images

iii. Air quality observations

iv. METAR weather reports

v. Road Weather Observations

b. Time series of observations contains calculated values from the measurements and observations made at FMI's observation stations, can be mean or extreme values of day, month or longer period

c. Weather forecast models RCR HIRLAM and HARMONIE

d. Warnings: traffic weather, heavy rain, severe thunderstorm, wind, hot/cold weather

12. Information contents

a. Data format (standards used, e.g. DATEX ver. X)
Data format: WMS/WFS (XML)
Standard: open standard web service interfaces for geospatial data defined by the Open Geospatial Consortium (OGC)

b. API description
https://en.ilmatieteenlaitos.fi/open-data-manual
https://en.ilmatieteenlaitos.fi/open-data-manual-api-access-csw

c. Timeliness / update frequency of the data
New forecast is commonly produced for a model more often than ones a day.

d. Origin of the data

FMI

e. Coverage

Finland and beyond

13. Data pricing, usage restrictions, licences, other limiting conditions

Open data, Creative Commons Attribution 4.0 International license (CC BY 4.0)

14. Currently known issues with data, API or limitations

None

15. Current level of service

In production, weather forecast models are been constantly developed

16. Current number of users / customers

-

4.2 Commercial traffic information, weather, and road conditions services

4.2.1 FMI - Road Weather Forecasts

1. Service provider

Finnish Meteorological Institute - FMI, https://en.ilmatieteenlaitos.fi/

2. Service name and web link to more detailed information

FMI Road Weather Forecasts,
https://www.ilmatieteenlaitos.fi/teiden-kunnossapito
https://en.ilmatieteenlaitos.fi/contact-commercial-services

3. Service description

Forecast is based on the numerical weather prediction models

a. Road surface condition forecasts (temperature, condition etc.)

b. Notifications for reduced driving conditions (ITS-Day 1 services and beyond)

c. Winter road maintenance forecasts

4. Information contents

a. Data format (standards used, e.g. DATEX ver. X)

Data format agreed with user or standards such as WMS, WFS

b. API description

API to be tailored by customer needs

c. Timeliness / update frequency of the data

1h steps, up to 5 days, update every hour or as negotiated.

d. Origin of the data

FMI

e. Coverage

Typically, Scandinavia and Baltics

5. Data pricing, usage restrictions, licences, other limiting conditions

Details depend on service need

6. Currently known issues with data, API or limitations

Dependent on the background forecast model and its availability.

7. Current level of service and development plans (near term)

On production and ongoing research and development of the model.

8. Current number of users / customers

-

4.2.2 Infotripla - DATEX2 Premium Feed

1. Service provider

Infotripla, http://infotripla.fi/

2. Service name and web link to more detailed information

DATEX2 Premium Feed, https://www.datex2.eu/implementations/nodes_directory/infotripla-finland

3. Service description

   Traffic incidents and warning data

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      DATEXII ver. 2.3. Cities: D2Light.

   b. API description

      https://www.datex2.eu/datex2/specifications

   c. Timeliness / update frequency of the data

      If data source is traffic management center (TMC), the latency is 1-30 minutes. In case of other sources, the latency is a few seconds.

   d. Origin of the data

      Governmental and cities' TMC. Also, various other data data sources used by Infotripla.

   e. Coverage

      Finland

5. Data pricing, usage restrictions, licences, other limiting conditions

   To be decided, when there is a real business case.

6. Currently known issues with data, API or limitations

   All city centres are not covered. When automated driving will be reality, determining the location should be paid more attention especially in TMC's.

7. Current level of service and development plans (near term)

   Commercial product.

8. Current number of users / customers

   Several significant user organisations (service providers).

4.2.3 Infotripla - Crowdsourced traffic warning data

1. Service provider

Infotripla, http://infotripla.fi/

2. Service name and web link to more detailed information

   Crowdsourced traffic warning data, https://www.nordicway.net/

3. Service description

   Traffic incidents data provision based on the Nordicway 2 project in Finland

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      DATEXII ver. 3.0

   b. API description

      https://www.datex2.eu/datex2/specifications

   c. Timeliness / update frequency of the data

      Almost real time; latency from the observation to the API a few seconds

   d. Origin of the data

      API from Infotripla. Observation data collection from vehicles and mobile apps from Sitowise, RoadCloud and Aebi Schmidt (previous Arctic Machine).

   e. Coverage

      At least the Helsinki – Tampere motorway

5. Data pricing, usage restrictions, licences, other limiting conditions

   To be decided, when there is a real business case. The companies are willing and able to provide the service together when there is a real business case.

6. Currently known issues with data, API or limitations

   The backend technology exists in Infotripla. The applications to register data on the vehicles may need updates.

7. Current level of service and development plans (near term)

   Tested during project pilot in 2020. To be redeveloped, if needed.

8. Current number of users / customers

   No existing business case at the moment for the entity as such. The technologies are used separately by the companies.

4.2.4 EEE - E3 REST API

1. Service provider

   EEE Innovations, https://e3inno.fi/

2. Service name and web link to more detailed information

   E3 REST API, https://e3inno.fi/

3. Service description

   REST API for road conditions (Slippery data, potholes, bumps)

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      JSON

   b. API description

      JSON REST API

   c. Timeliness / update frequency of the data

      varies, search parameters apply for REST APIs

   d. Origin of the data

      Professional drivers, data is collected automatically from CAN interface

   e. Coverage

      Finland. Mostly Helsinki metropolitan area and main roads

5. Data pricing, usage restrictions, licences, other limiting conditions

   Available for selected customers

6. Currently known issues with data, API or limitations

   -

7. Current level of service and development plans (near term)

   In production

8. Current number of users / customers

   -

4.2.5 Safety4Traffic - Road Weather service

1. Service provider

   Safety4Traffic, https://www.safety4traffic.com/en/

2. Service name and web link to more detailed information

   The Road Weather service, https://www.safety4traffic.com/en/services/

3. Service description

   Warns of sudden changes on the road surface conditions in the road area.

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      DATEX v.1, ALERT-C

   b. API description

      XML and JSON REST interfaces

   c. Timeliness / update frequency of the data

      Every 1 min

   d. Origin of the data

      FMI + Safety4Traffic

   e. Coverage

      Finland: All roads which are on OSM (OpenStreetMap)

5. Data pricing, usage restrictions, licences, other limiting conditions

   Premium commercial service. Variable pricing depending on usage.

6. Currently known issues with data, API or limitations

   Datex II data format is on development.

7. Current level of service and development plans (near term)

   Production

8. Current number of users / customers

   Business secret

4.2.6 Safety4Traffic - Crosswind Warning service

1. Service provider

   Safety4Traffic, https://www.safety4traffic.com/en/

2. Service name and web link to more detailed information

   The Crosswind Warning service, https://www.safety4traffic.com/en/services/

3. Service description

   Warns of strong crosswinds affecting to the vehicle.

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      DATEX II, ALERT-C

   b. API description

      XML and JSON REST interfaces

   c. Timeliness / update frequency of the data

      Every 1 min

   d. Origin of the data

      FMI + Safety4Traffic

   e. Coverage

      Finland: All roads which are on OSM (OpenStreetMap)

5. Data pricing, usage restrictions, licences, other limiting conditions

   Premium commercial service. Variable pricing depending on usage.

6. Currently known issues with data, API or limitations

   Datex II data format is on development.

7. Current level of service and development plans (near term)

   Production

8. Current number of users / customers

   Business secret

4.2.7 Safety4Traffic – Elk/Reindeer/Deer Warning services

1. Service provider

   Safety4Traffic, https://www.safety4traffic.com/en/

2. Service name and web link to more detailed information

   The Elk/Reindeer/Deer Warning services, https://www.safety4traffic.com/en/services/

3. Service description

   Warns of high regional elk collision risk and of elks/reindeers/deer on the road.

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      DATEX II, ALERT-C

   b. API description

      XML and JSON REST interfaces

   c. Timeliness / update frequency of the data

      Every 1 min

   d. Origin of the data

      Safety4Traffic + Porokello (for reindeer warning)

   e. Coverage

      Finland: All roads which are on OSM (OpenStreetMap)

5. Data pricing, usage restrictions, licences, other limiting conditions

   Premium commercial service. Variable pricing depending on usage.

6. Currently known issues with data, API or limitations

   Datex II data format is on development.

7. Current level of service and development plans (near term)

   Production (deer warning service soon in production)

8. Current number of users / customers

   Business secret

4.2.8 Safety4Traffic – Accident Warning services

1. Service provider

   Safety4Traffic, https://www.safety4traffic.com/en/

2. Service name and web link to more detailed information

   The Accident Warning service,
   https://www.safety4traffic.com/en/services/

3. Service description

   Warns in real-time of accidents in the road area.

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      DATEX II, ALERT-C

   b. API description

      XML and JSON REST interfaces

   c. Timeliness / update frequency of the data

      Every 1 min

   d. Origin of the data

      Fintraffic and Drivers on roads

   e. Coverage

      Finland: All roads which are on OSM (OpenStreetMap)

5. Data pricing, usage restrictions, licences, other limiting conditions

   Premium commercial service. Variable pricing depending on usage.

6. Currently known issues with data, API or limitations

   Datex II data format is on development.

7. Current level of service and development plans (near term)

   Production

8. Current number of users / customers

   Business secret

4.2.9 Safety4Traffic – Road Work Warning services

1. Service provider

   Safety4Traffic, https://www.safety4traffic.com/en/

2. Service name and web link to more detailed information

   The Road Work Warning service,
   https://www.safety4traffic.com/en/services/

3. Service description

   Warns of the road works and road workers in the road areas.

4. Information contents

   a. Data format (standards used, e.g. DATEX ver. X)

      DATEX II, ALERT-C

   b. API description

      XML and JSON REST interfaces

   c. Timeliness / update frequency of the data

      Every 1 min

   d. Origin of the data

      Fintraffic, Municipalities and Drivers on roads

   e. Coverage

      Finland: All roads which are on OSM (OpenStreetMap)

5. Data pricing, usage restrictions, licences, other limiting conditions

   Premium commercial service. Variable pricing depending on usage.

6. Currently known issues with data, API or limitations

   Datex II data format is on development.

7. Current level of service and development plans (near term)

   Production

8. Current number of users / customers

   Business secret

4.2.10 RoadCloud - Premium connected vehicle data service

1. Service provider

   RoadCloud, www.roadcloud.com

2. Service name and web link to more detailed information

   Premium connected vehicle data service, www.roadcloud.com

3. Service description

   Data collection from commercial vehicles equipped with additional road conditions sensor.

   Concept video: https://youtu.be/vs3hw4Z6CXY

   in-car demo: https://youtu.be/CvF2qplSAho

4. Information contents

   Data types: road friction (continuous optical measurement), road state (dry, wet, moist, pool, snow, ice, slush), all accelerations and rotational velocities of vehicle, CAN-bus data (temperature, wipers, fog lights, wheel speeds, ASR,ABS,ESC)

   a. Data format (standards used, e.g. DATEX ver. X)

      Raw data mapped to segments (10m and 500m segments), warning available e.g. HTTP POST xml

   b. API description

      https://api.roadcloud.com/v4/docs

   c. Timeliness / update frequency of the data

      Anonymized real-time

   d. Origin of the data

      Originally from our fleet partners (taxis, buses, trucks)

   e. Coverage

      Southern-Finland, Lapland (Sweden & Finland), Gothenbourg & Landvetter, Enköping & Västerås

5. Data pricing, usage restrictions, licences, other limiting conditions

   Depends on data licence

6. Currently known issues with data, API or limitations

-

7. Current level of service and development plans (near term)

   Tested during project pilot in 2020. To be redeveloped, if needed.

8. Current number of users / customers

   Hundreds of business users for road maintenance data and data tools

4.2.11 Sitowise - Carrio

1. Service provider

   Sitowise, https://www.sitowise.com/fi

2. Service name and web link to more detailed information

   Carrio, https://carrioapp.com

3. Service description

   Infotainment app to make driving more safe and enjoyable utilizing maps, traffic info, speech and entertainment services.

   Video: https://www.youtube.com/watch?v=CgTA9NP4ImQ

4. Information contents

   A number of Day-1 C-ITS messages supported (reporting, displaying), piloted in NordicWay-2.

   a. Data format (standards used, e.g. DATEX ver. X)

      JSON

   b. API description

      JSON REST API

   c. Timeliness / update frequency of the data

      Not updated on regular basis

   d. Origin of the data

      Users and national traffic information provide, HERE location platform

   e. Coverage

      Europe

5. Data pricing, usage restrictions, licences, other limiting conditions

   Not defined yet

6. Currently known issues with data, API or limitations

   -

7. Current level of service and development plans (near term)

   Launched

8. Current number of users / customers

   Approx. 500

4.2.12 Sitowise - Routa

1. Service provider

   Sitowise, https://www.sitowise.com/fi

2. Service name and web link to more detailed information

   Routa, https://www.sitowise.com/fi/digitaaliset-palvelut/tuoteratkaisut/infran-kunnossapitojarjestelma-routa

3. Service description

   Routa is a system for road maintenance and infra structure management used by number of municipalities and infra companies e.g. to track maintenance vehicles and work as well as to publish maintenance information.

4. Information contents

   Various road infrastructure maintenance information including observations and winter maintenance status.

   a. Data format (standards used, e.g. DATEX ver. X)

      JSON

   b. API description

      JSON REST

   c. Timeliness / update frequency of the data

      Realtime

   d. Origin of the data

Users

e. Coverage

Finland - Used now in municipalities but can be applied to government roads as well.

5. Data pricing, usage restrictions, licences, other limiting conditions

   Use requires licenses (user/ month).

6. Currently known issues with data, API or limitations

   -

7. Current level of service and development plans (near term)

   Production

8. Current number of users / customers

   Approx. 400

4.3 International service providers

4.3.1 HERE - HERE Traffic API

1. Service provider

   HERE https://www.here.com/

2. Service name and web link to more detailed information

   HERE Traffic API, https://developer.here.com/documentation/traf-fic/dev_guide/topics/what-is.html

3. Service description

   The HERE Traffic API is a REST API that provides traffic flow and incidents information.

4. Information contents

Content	Description
Traffic Incident Data	The API provides aggregated information about traffic incidents in XML or JSON, including the type and location of each traffic incident, status, start and end time, and other relevant data. This data is useful to dynamically optimize route calculations.
Traffic Map Tile Overlays (Traffic Tiles)	The API delivers pre-rendered map tile overlays with traffic information that can be readily displayed with a mapping application.
Traffic Flow Data	The API provides access to real-time traffic flow data in XML or JSON, including information on speed and congestion for the region(s) defined in each request.
Traffic Flow Availability	The API allows client applications to access traffic flow information (excluding incidents) in an area, if available.

a. Data format (standards used, e.g. DATEX ver. X)

   i. Traffic incident and flow data - XML or JSON

b. API description

   https://developer.here.com/documentation/traffic/dev_guide/topics/resources.html

c. Timeliness / update frequency of the data

   Traffic information is updated every minute

d. Origin of the data

   HERE Real-Time Traffic integrates live vehicle data from several sources including real-time vehicle sensor data from consortium members Audi, BMW, and Daimler, combined with probe data from OEM clients and partners.
   (source: https://www.here.com/sites/g/files/odxslz166/files/2019-01/THE%20FUTURE%20OF%20MAPS.pdf)

e. Coverage (should be at least the Helsinki – Tampere motorway)

   Global including Finland for incidents and traffic flow.

5. Data pricing, usage restrictions, licences, other limiting conditions

   Pricing: https://developer.here.com/pricing

   HERE Developer Terms and Conditions:
   https://developer.here.com/terms-and-conditions

4.3.2 Tomtom

1. Service provider

   TomTom https://www.tomtom.com/fi_fi/

2. Service name and web link to more detailed information

   a. TomTom Intermediate Traffic Service (for business)
   https://developer.tomtom.com/intermediate-traffic-service

   b. TomTom Traffic API (for developers)
   https://developer.tomtom.com/traffic-api

3. Service description

   a. The TomTom Intermediate Traffic enables business customers to download real-time TomTom traffic data for their server-based systems. Target customers for TomTom Intermediate Traffic include automotive OEMs, web and application developers and governments.

   b. The Traffic API is a suite of web services designed for developers to create web and mobile applications around real-time traffic.

4. Information contents (of the Intermediate Traffic service)

   TomTom Intermediate Traffic Events provides information on the current observed congestion and incidents on roads in all countries where we offer this service. Traffic 'incidents' in this context includes information like closed roads, lane closures, construction zones and accidents.

   TomTom Intermediate Traffic Flow contains information on the current observed speed on roads in all countries where TomTom live traffic information services are available.

   a. Data format (standards used, e.g. DATEX ver. X)

Data	Description	Data format
Traffic Events	Current locations and related delays of traffic jams, road closures, road works, accidents.	DATEX II
Traffic Flow	Current measured speeds and travel times by road segment.	DATEX II and Protobuf
Traffic Flow Detailed	Current measured speeds and travel times by detailed road segment.	Protobuf

   b. API description

   See https://developer.tomtom.com/intermediate-traffic-service/intermediate-traffic-service

c. Timeliness / update frequency of the data

Intermediate Traffic Events and Intermediate Traffic Flow updates every minute

Intermediate Traffic Flow up-to-the minute

d. Origin of the data

TomTom Our real-time traffic products are created by merging multiple data sources, including anonymized measurement data from over 650 million GPS- enabled devices

e. Coverage (should be at least the Helsinki – Tampere motorway)

Global coverage, including Finland

5. Data pricing, usage restrictions, licences, other limiting conditions

   TomTom Intermediate Traffic usage includes licence and fee

   Intermediate Traffic is a secure service that uses an API-key in combination with IP-address whitelisting. Customers accessing the service must connect from a (set of) fixed IP address(es) that were previously assigned to the profile, or access to the service is rejected.

6. Currently known issues with data, API or limitations

   -

7. Current level of service and development plans (near term)

   Service is in production

8. Current number of users / customers

   Customers globally. In Finland, e.g. TomTom Intermediate Traffic Service - Flow and Incidents is used by Digitraffic (https://www.digitraffic.fi/en/NAP/)

4.3.3 Waze - Waze Transport SDK and Connected Citizens Program

1. Service provider

   Waze https://www.waze.com/

2. Service name and web link to more detailed information

   Waze Transport SDK https://developers.google.com/waze/intro-transport

   Waze Connected Citizens Program https://www.waze.com/fi/ccp

3. Service description

The **Waze Transport SDK** links your app to Waze and provides free driving data. Waze Transport SDK provides fastest routes, ETA & routing points based on Waze's real-time traffic and location data. The SDK does not support server-side access to Waze data, like traffic reports and driver speed. The Waze Transport SDK is available for mobile devices with Android or iOS and Waze application installed.

The **Waze Connected Citizens Program** is a free, two-way data exchange empowering municipal decisions to achieve concrete community impact. WAZE provides real-time, anonymous, proprietary incident and slow-down information directly from the source: drivers themselves. PARTNERS provide real-time and advance information on government-reported construction, crash and road closure data.

9. Current number of users / customers

   Over thousand cities and authorities are in the Waze Connected Citizens Program. In Finland Fintraffic is assessing the use of the Connected Citizens Program.

4.4 Vehicle manufacturers

In the past few years vehicle manufacturers (OEMs) have started to open data access to their vehicles via cloud services. For example, Volvo has launched Volvo developer API (https://developer.volvocars.com/volvo-api/). Additionally BMW, MINI, Ford and Mercedes-Benz have opened access to their cars through a single API called High Mobility (https://about.high-mobility.com/). Data sharing in both previously mentioned examples is based on the Extended vehicle (ExVe) concept. The Extended vehicle concept, which has been standardized by ISO (ISO standards 20077-20080), allows service providers to access vehicle data in a standardised and interoperable way. However, access to vehicle data needs consent of the vehicle’s owner. The Extended Vehicle API enables access to all the information from a vehicle’s dashboard including the odometer, fuel or battery level, etc. as well as a set of vehicle status data such as door and window status. In addition, the High mobility API also include one weather condition (rain intensity) parameter. Therefore, currently these APIs does not provide very much relevant information for automated driving, but the development of the concept should be monitored.

4.4.1 Data Task Force and Safety Related Traffic Information Ecosystem

According to the Delegated Regulation 886/2013 (priority action c) road-safety related data should be made available free of charge to the users. The Data Task Force builds on the Extended Vehicle concept, and targets to make SRTI available. Figure 2 shows the concept. OEMs collect data from vehicle and the data are made available either directly or through an intermediate party, who aggregates and enriches the data, to the National Access Point, which makes it available to service providers and road operators. (Note: the link from Road Operator to vehicle is used in some Western European countries, where national authorities send C-ITS information direct to vehicles).

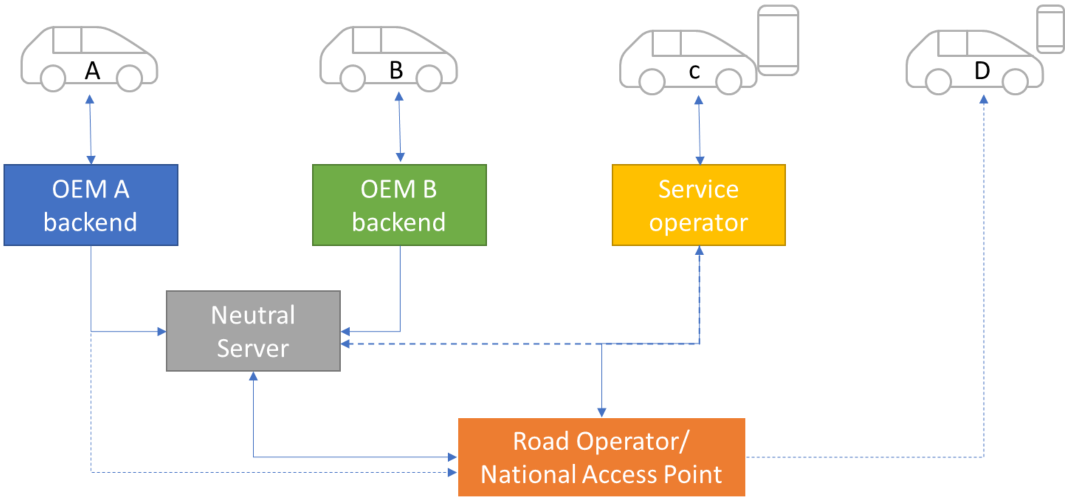

Figure 2 Extended Vehicle concept.

The Data Task Force pilot ended in 2020 and Safety Related Traffic Information Ecosystem (https://www.dataforroadsafety.eu/) continues this work. The Safety Related Traffic Information Ecosystem is a public-private partnership that delivers enriched data to improve road safety, where any industry partner in the transportation, mobility & traffic data domain and public authorities can join and start using to exchange safety related traffic data and information. It must be noted that the data is exchanged for the sole purpose of road safety, i.e. to create SRTI. In Finland Fintraffic is part of the ecosystem.

4.4.2 C-ITS in vehicles on the market

In 2019 Volkswagen introduced the first vehicle model (Golf 8) in the European market with C-ITS technology. Currently also VW ID.3 and ID.4 includes this technology (available also in Finland). It can communicate with other vehicles (vehicle-to-vehicle; V2V) and infrastructure (vehicle-to-infrastructure; V2I) to exchange relevant information and warning about accidents, broken down vehicles, tail ends of traffic jams, roadworks, emergency braking and approaching and emergency vehicles /5/. With standardized C-ITS technologies (ITS-G5) it is possible to transfer information between vehicles of all brands as well as the infrastructure. Direct information and warning sharing via V2V communication will also benefit automated driving in the future when penetration rate of vehicles with C-ITS technology increases.

4.5 Summary of available services

The Table 1 summarizes all services providers, services or data sources, data types and pricing, and link to the description chapter with more detailed information.

Table 1. Summary of available services and information sources.

SP	Service	Data			Open data	Detailed infor-mation, see chap-ter
		*Traffic, disturb-ances	Weather & road condi-tions	Other		
Fintraffic	DigiTraffic	x	x	x	x	4.1.1
FTIA	Digiroad			x	x	4.1.3
FMI	Open data		x		x	4.1.4
FMI	Road Weather Forecasts		x			4.2.1
Infotripla	DATEX2 Premium Feed	x	x			4.2.2
Infotripla	Crowdsourced traffic warning data	x	x			4.2.3
EEE	E3 REST API	x	x			4.2.4
Safety4traffic	Accident, Crosswind, Elk, Deer, Reindeer, Road weather and Road work warning services	x	x			4.2.6 4.2.7 4.2.8 4.2.9
Roadcloud	Premium connected vehicle data service		x			4.2.10
Sitowise	Carrio, Routa	x	x	x		4.2.11
Here	Traffic API	x				4.3.1
TomTom	Intermediate Traffic service, Traffic API	x				4.3.2
Waze	Transport SDK, Connected Citizens Program	x				4.3.3
OEM & public authorities	Safety Related Traffic Information Ecosystem	x	x			4.4.1

* Event, incident and other hazardous location information, Roadworks information (stationary and mobile), etc.

5 Conclusions and recommendations

In general, real-time and forecasted traffic, disturbance, weather and road condition information can and should be utilised in automated driving, especially in Nordic conditions. As discussed earlier, these kind of real-time information sources can be used to extend the limits of on-board sensors. Additionally, possibilities to utilise C-ITS (and similar real-time data and information sources) in automated driving has been listed in sub-report 2. These currently includes for example

- Warning of hazard ahead
- Warning of roadworks ahead
- Awareness of prevailing road conditions
- Status of surrounding road network situation
- Routing advice
- Routing and behavioural advice

Currently there are C-ITS services in Finland that utilise ETSI standardised messages including certificates complying to the EC Certificate and Security Policy. However, this inventory shows that in Finland there are available many data and information sources, which could be utilised to support automated driving. Almost all services are provided in the whole target area (Helsinki – Tampere motorway) and most of the services cover entire Finland.

5.1 Recommendations for the service level framework

5.1.1 Quality of the C-ITS services and data

The quality of the C-ITS services and data/information sources is currently under development in Europe. Therefore, this study and inventory of services and data sources did not include this aspect. For example, EU EIP has started to work with a framework of C-ITS service (C-ITS Quality package), which presents initial quality definitions and concepts. There are already EU EIP Quality Packages available for safety-related traffic information (SRTI) and real-time traffic information (RTTI), which provide the basis for the quality framework development for the C-ITS services. The first draft of the C-ITS Quality package is now available, but the work continues. The first draft contains quality-related definitions and concepts for the data and service provision of C-ITS /6/.

This report identified the current service providers, which may provide information that could be used for supporting automated driving as well as providing C-ITS services. When comparing the information provided by the services providers (here only Digitraffic is compared) listed in this report versus the requirements of C-ROADS (https://www.c-roads.eu/) C-ITS services:

- Hazardous Location Notification: almost all service providers contribute to this service, by providing information on the events on the road.
    - An event reported manually by a single road user, is not always accepted according to the C-ROADS specifications. The data field regarding the probability of the event (DENM data field informationQuality) requires at

least "*Automatic detection under conditions where the results are not very reliable. Or reports from experienced or trustworthy third-party organisations*." /7/

    - The quality of the data may not be sufficient enough for potential customers. For instance, Car2Car requires an accuracy of max. 10 meter for the event position, otherwise the message will be discarded.

- Road Works Warning. The C-ROADS service includes both static road works, as well as mobile, including winter maintenance.
    - Information on road works is included in Digitraffic. The data should be further analysed to verify that all data fields needed in the C-ITS messages are available. For instance, for winter maintenance, Digitraffic contains information on the latest reported position, but not on the speed.
- In-Vehicle Signage. This service informs the road users on static or dynamic road sign via in-car systems
    - Digitraffic contains information on dynamic traffic signs. The representation of traffic signs in IVIM uses the pictogram coding of ISO 14823.
        - ISO 14823 currently cannot distinguish between different wild animals, such as elk, deer, and reindeer.
- Probe Vehicle Data. This C-ROADS service includes both the collection of aggregated data from vehicles (PVD-VDC) and event data collection (PVD-EDC).
    - Aggregated data collection is not relevant for C-ITS delivered over mobile networks, as it is already provided on a commercial basis by several providers.
    - Event data collection: several vehicle manufacturers provided SRTI data, either directly from their server or through a neutral server
- RTK services. A C-ITS message (RTCMem) is defined for the delivery of GNSS correction data. This is mainly used for ITS-G5 but can also be used for mobile connections. The service is already provided on a commercial basis by several providers to end users, and has therefore not further been discussed in this report.

Regarding the applicability of the C-ITS messages, it has to be noted that DENM and IVIM messages have been developed for increasing the awareness of the drivers, and are hence not designed for supporting automated driving. For instance, DENM does not contain accurate information regarding the size of obstacles.

As a summary, if we mirror these initial C-Roads requirements to e.g. Digitraffic, the data available currently in the Digitraffic could be used as basis for C-ITS services (and for automated driving). The data quality in the Digitraffic is on the EU EIP quality framework 'best effort' level. Data from VMS should be of sufficient quality for generating IVIM. However, the quality of the data for hazard related use cases may not be sufficient for C-ITS services (and not for automated driving). For instance, roadworks information is based on the manual information provided by the contractors. The informed time validity may differ from the actual, and information regarding the impact on traffic (e.g. which lanes are closed at which time) may be missing. The geographical accuracy is estimated to be in the order of 100 m, which is much worse than the accuracy required by OEMs (e.g. 10 m for VW Golf 8).

The new version of the IVIM, based on ISO 19321:2020 contains an Automated Vehicle Container, which contains information related to real or virtual roads signs, specific for automated vehicles. Use cases, proposed in C-ROADS include providing information on the allowed SAE class of vehicles, and provision of parameters regarding platooning. There are however conflicting views within Europe regarding the role of the road operator, i.e. should road operators give guidelines, are is it completely up to the automated vehicles and the OEMs.

Currently ETSI is defining "Release 2" messages, including CPM (Cooperative Perception Message) and MCM (Maneuver Coordination Message). The MCM, allowing coordination of vehicle maneuvers either through vehicle negotiation or through advice from a Roadside Unit (RSU), are especially targeted to automated vehicles. These new C-ITS services are closely related to the Infrastructure Support Levels for Automated Driving (ISAD) discussed in sub-report 2.

5.2 Recommendations for further research and development

Further research in this topic should cover the quality frameworks and specific requirements of C-ITS and data sources, which could be used for automated driving. These quality aspects are currently under development. The quality requirements will most likely be variable in different C-ITS services and different ISAD levels, see sub-report 2. The quality, accuracy and reliability requirements will increase as the focus moves from C-ITS services for drivers towards C-ITS and data sources supporting automated driving. This will also affect to the data acquisition process with higher quality requirements. This quality framework will be needed to help automated driving developers (e.g. vehicle manufacturers) to select suitable data and information sources, which can enable future automated driving functions in variable conditions. The data availability in a vehicle is also always related to connectivity and capacity of mobile networks, which should be studied in parallel. The quality aspects could be a part of service-level agreements (SLA) between service providers and information or data users. The data quality may also reflect to the liability issues related to automated driving in the future.

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Annex 1: Questions to the service providers

Questions to the Service / information providers:

1. Service name
2. Service provider
3. Web link (to more detailed information)
4. Service description
5. Information contents (for each data set/source)
    a. Data format (standards used, e.g. DATEX ver. X)
    b. API description
    c. Timeliness / update frequency of the data
    d. Origin of the data
    e. Coverage (should be at least the Helsinki – Tampere motorway)
6. Data pricing, usage restrictions, licences, other limiting conditions
7. Currently known issues with data, API or limitations
8. Current level of service and development plans (near term)
9. Current number of users / customers

[Optional] Possibilities to utilise data in C-ITS and automated driving

Finnish Transport Infrastructure Agency

Nordic WAY 3

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Working report
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Service level framework for automated road transport

Task 1.6. Infrastructure data collection

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Bibliography

1 Goal of the Task Infrastructure data collection

The overall objectives of the project ”Service level framework for automated road transport” for the Finnish Infrastructure Agency (FTIA) were to

- assess the feasibility of the selected motorway section (Highway E12 between Helsinki and Tampere) for the automated operation of SAE Level 3 and 4 automated vehicles
- propose classification for the Finnish road network from the automated vehicles operations’ point of view, i.e. a framework for service level classification for automated vehicles
- propose further actions in research- and development work, as well as in international cooperation.

The objective of work reported in this document was the plan and conduct field measurements to provide needed data to estimate the feasibility of selected motorway section and assure the current content and quality of FTIA’s road registry data. The work is done in co-operation with task 1.1 where the needed ODD attributes are collected from FTIA’s registers.

The needed measurement methods are defined for:

- Front view images (FTIA’s existing practice)
- 360 images
- mobile laser scanning (point cloud)
- road marking measurements (condition and retroreflection)
- pavement condition measurements (FTIA’s existing practice)
- minimum risk manoeuvre space; survey of accessible spaces, obstacles, devices and interchange ramps

The quality assurance is performed for measurements, the results are summarized, and findings are reported in this report.

2 Methodology

The ODD attributes for physical infrastructure is revised and provided through measurement for following features (according to the ISAF4FI classification):

- Drivable area lane specifications
  - Lane dimensions [width]
  - Lane marking [width]
  - *Lane marking [retroreflectivity]*
    - *Luminance contrast ratio*
    - *Lane marking consistency*
- Drivable area edge
  - Line markers (left, center and right lane marking)
  - *Shoulder (paved);*
  - *Shoulder width (outside)*
  - *Shoulder width (inside)*
  - Widening or lay-by
  - Shoulder (grass **e.g. gravel**)
  - Solid barriers (e.g. grating, railings, curb, cones)
- Drivable area surface
  - *Drivable area induced road surface conditions*
  - *Bearing capacity of lane (DA lane specifications, task 2 table)*
  - *Shoulder bearing capacity (DA edge, task 2 table)*
- Drivable area signs (signposts, portals)
- Junctions
- Special structures
  - Bridge (bridge, bridge pillars/wall)
  - Tunnel
  - Ports
- Fixed road structures
  - Streetlights
  - Street furniture e.g. bollards (reflector/marker posts)
    - *Landmarks*

The methodology to conduct measured are based on FTIA's existing standard procedure for data collection in terms of images, condition measuring. New and developing routines are used to identify features and dimensions from point cloud datasets.

The following data sources have been available for this task:

- Road condition measurements conducted as option project. The results are reported in document (AUTOMOTO 1.6options_Data collection results.pdf). The results covered: Front view images, 360 images and mobile laser scanning (point cloud), road marking measurements and field measurement in terms of MRM spaces.
- Pavement condition measurements from FTIA's production measurements, spring 2021.
- Features classification from point cloud data (AUTOMOTO 1.6options_Features from point cloud.pdf)

The accuracy and qualitative statements are based on point cloud data, use of images and statistical analysis on data variation.

3 Results

The first task was to create definitions and guidelines how to conduct the measurements to generate the needed ODD attributes. This document is based on the existing practices with FTIA's different measurement contracts in terms of measurement methods, instruments, and quality demands (Optioiden määrittelyt – Data collection definitions.pdf).

The length of the road section is 158 km (vt 3/103 – 135), carriageways 1 and 2. The results from measurements are presented in next chapters for each ODD attribute with the quality related notes and conclusions.

3.1 Drivable area - lane specifications

The drivable area - lane is specified with following *ODD attributes*

- Lane dimensions [width]
- Lane marking [width]
- Lane marking [retroreflcetivity]

3.1.1 Lane dimensions

The *FTIA's registry data* covers the lane dimensions with following variables:

- WIDTH OF CARRIAGEWAY

The definition for the variable of "width of carriageway" distance between road markings, if missing the width of pavement (Road registry data description 6.2021).

Features extracted from point cloud data were:
Line geometries for each carriageway:

- left road marking – chosen as the **reference** for distances in cross profile
- center line road marking
- lane 1 right road marking
- right road marking

From these data set we can calculate the following attributes:

- Width of carriageway
- Width of lane 1
- Width of lane 2
- Distance from reference line to FTIA's road address geometry
- Distance between reference lines (left road marking on both carriageways)

The selected motorway section (Highway E12 between Helsinki and Tampere) is divided during the project to homogenous section (137 pcs). The width of carriageway based on the point cloud data extraction is presented according these sections as:

- road length narrower than FTIA’s registry data
- road length wider than FTIA’s registry data
- average carriageway width

The Figure 1 and present the width of carriageways on both carriageways.

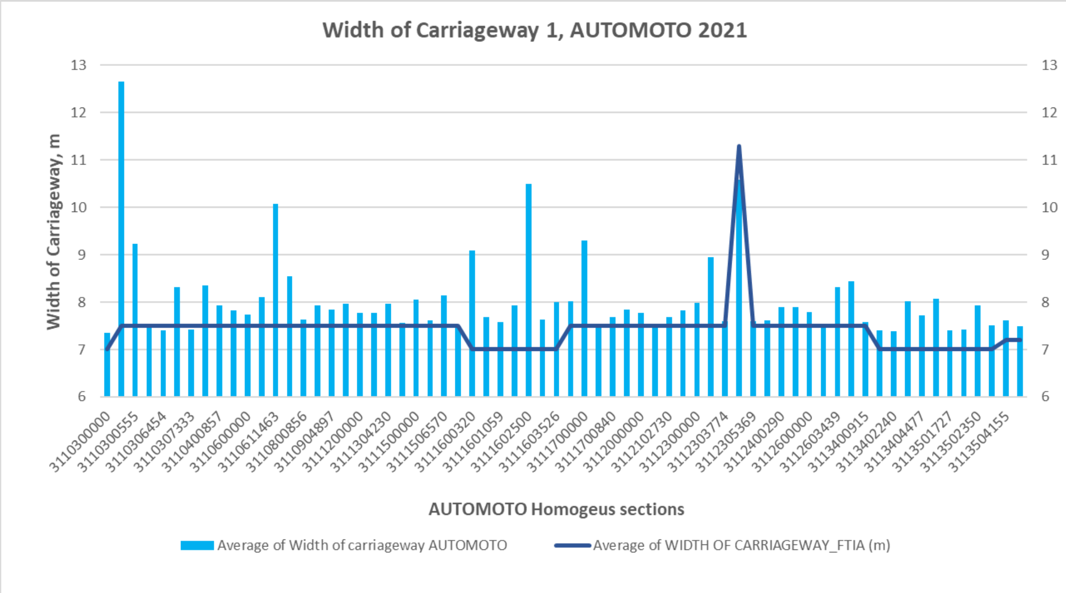

Figure 1. Average width of carriageway 1 (northbound), pointcloud and registry data, vt 3 AUTOMO 2021 homogenous sections

Mainly the carriageway width is wider that the registry information, in most cases the extra lanes are missing from registry data.

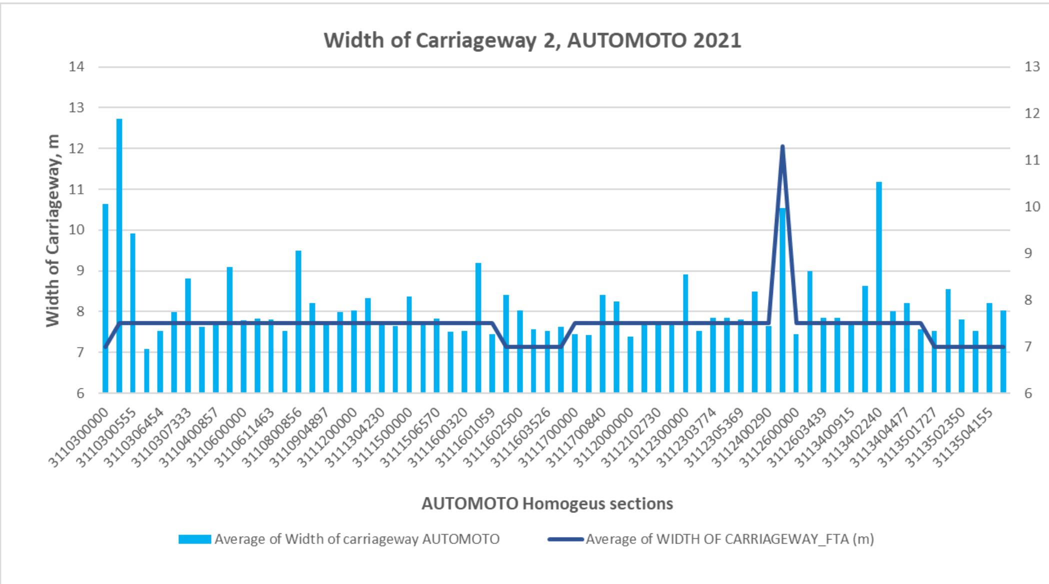

Figure 2. Width of carriageway 2 (southbound), pointcloud and registry data, vt 3 AUTOMO 2021 homogenous sections

The results are included to the MS excel table about the physical infrastructure. Summary of the finding are:

- road length narrower than FTIA's registry data on carriageway 1 2.1 km
    - average difference -0.1 m
- road length narrower than FTIA's registry data on carriageway 2 3.2 km
    - average difference -0.2 m
- road length wider than FTIA's registry data on carriageway 1 39.1 km
    - average difference +0.9
- road length wider than FTIA's registry data on carriageway 2 38.1 km
    - average difference +0.9 m

The results are available as line geometry objects in project deliverables. Figure 1 present the distribution of all identified carriageway widths from project area.

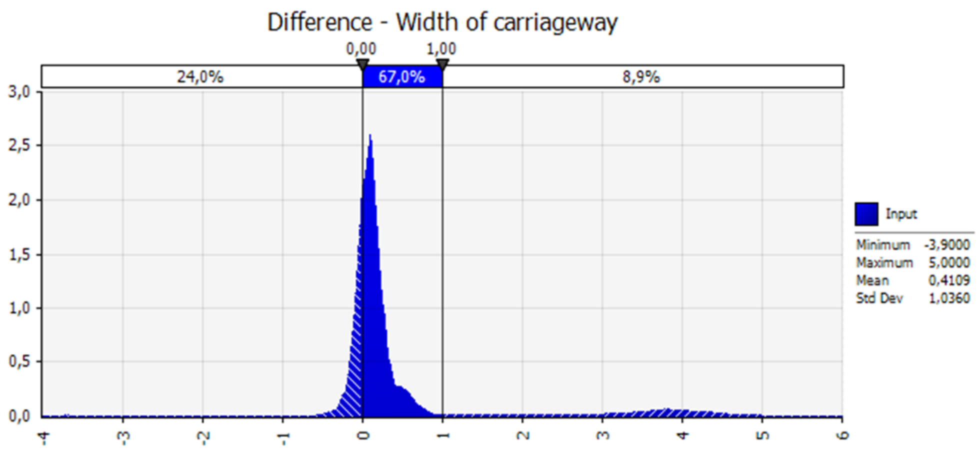

Figure 1 Difference between FTIA registry widths and carriageways identified from point cloud data.

About 10 % of length is wider than the FTIA's registry data. The main reason for this is the routines to define carriageway. When identifying the width of carriageway, the principle was to identify drivable space.

Conclusion

The measurements provide possibility to precise the current FTIA's registry data. Result was mainly in positive direction, more drivable space.

Recommendation

The definition of carriageway width should be defined according to the automated driving perspective. The new cross profile definition in VELHO project provides flexible framework for that purpose.

3.1.2 Lane marking [width]

The lane marking width and retroreflectivity was measured with a measurement vehicle equipped with measurement devices for retroreflection (LTL-M Mobile retroreflectometer), line condition (line laser) and lane departure warning, LDW (Mobileye system). All three lines was measured and reported separately. The FTIA quality assessment is based on 100 m sections and due the early measurement time, the lines were dirty, and dust caused problems for measurements. The total amount of missing data was 117 km, mainly from the left road marking (Table 3).

Table 1 presents the length of measured lane marking width for each road marking on both carriageways.

Table 1. Length of lane markings according to the width, AUTOMOTO sections, April 2021, km

	Lenght of markings					
	Left		**Center**		**Right**	
Lane marking width (cm)	**CA1**	**CA2**	**CA1**	**CA2**	**CA1**	**CA2**
7			2	0		
8			10	2		
9			28	23		
10			83	53		
11			34	69		
12			1	11	1	
13		1		1	1	1
14	0	0			1	2
15	0	0			1	2
16	1	1			3	3
17	2	7			9	9
18	14	25			27	21
19	55	57			47	43
20	55	45			36	44
21	21	14			8	10
22	7	4			3	3
23	2	2			2	2
24	1	0			1	2
25		0			2	1

The maintenance standard for centerline is 10 cm and for left and right line 20 cm. This can be seen in results.

3.1.3 Lane marking [retroreflectivity]

Minimum requirement for retroreflection in FTIA's Road marking service contracts is 100 mcd/m^2/lx. All measurement results are reported on report: *AUTOMOTO 1.6options_Data collection results.pdf* /2/.

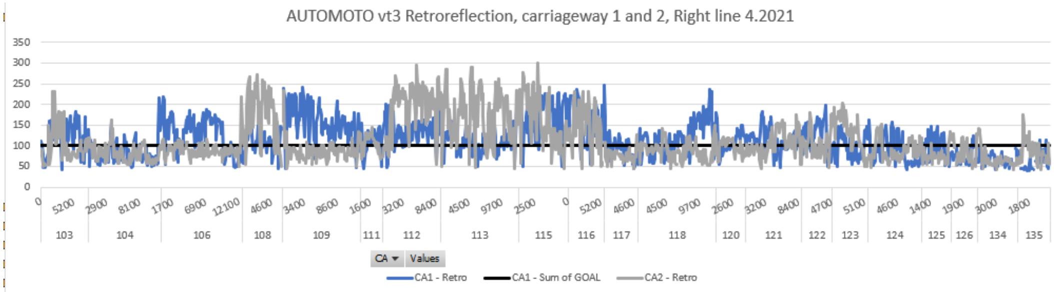

Figure 3. Right line, lane marking retroreflectivity, both carriageways, measurement data April 2021, vt 3 AUTOMO 2021 road sections

The results shows that there is difference between road sections and carriageways, although in most cases the retroreflectivity meets the maintenance standards after the winter.

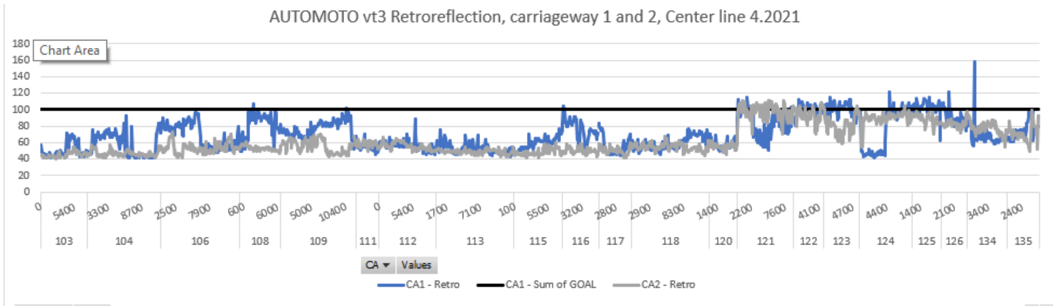

Figure 4. Center line, lane marking retroreflectivity, both carriageways, measurement data April 2021, vt 3 AUTOMO 2021 road sections

Retroreflectivity for the centerline was very poor in April 2021.

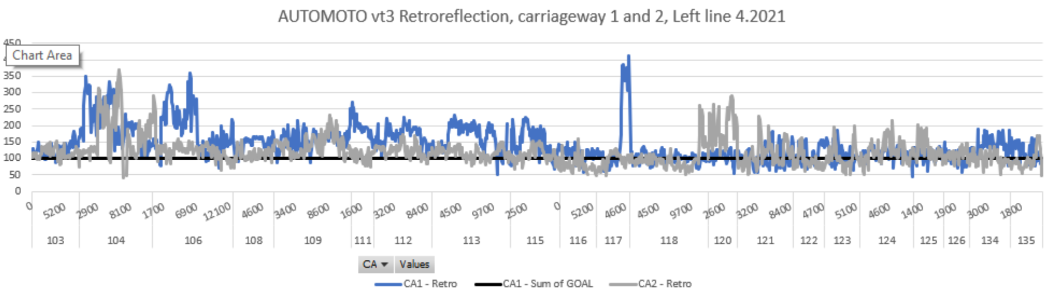

Figure 5. Left line, lane marking retroreflectivity, both carriageways, measurement data April 2021, vt 3 AUTOMO 2021 road sections

The retroreflectivity of left line meets the maintenance standards after the winter.

Lane markings and readiness for automated driving

The proposed classification recommendations for AUTOMOTO sections are based on work done by Sommers in 2019 (Table 2).

Table 2. Longitudinal line marking thresholds. (Somers 2019)

Aspect of line quality		Lower threshold		Upper threshold	
Line width	Infrastructure quality below this level is unlikely to be suitable	100 mm	Infrastructure quality may be suitable	150 mm	Infrastructure quality above this level is very likely to be suitable
Luminance contrast ratio (daytime, dry)		2:1		3:1	
Retro-reflectivity – dry		100 mcd/lx/m²		150 mcd/lx/m²	
Retro-reflectivity – wet		50 mcd/lx/m²		75 mcd/lx/m²	

The current road marking measurement practice do not support the variables Luminance contrast ratio and Retroreflectivity dry.

According to the thresholds the vt3 readiness for automated driving can be determinate when the principles will be established:

- Should every meter fulfill all demands
- The section class is defined according to the worst variable (all variables):
    - Left line
    - Centerline
    - Right line

In Automoto sections there are 117 km missing lines and 14 km lines less the 100 mm in terms of line width.

Table 3 presents the classified retroreflectivity per line type.

Table 3. Classified Readiness for Automated Driving, lane marking length and percentage, Vt 3, AUTOMOTO sections

Readiness for Automated Driving Class	Carriageway 1			Carriageway 2					
	Left road marking	Centerline	Right line marking	Left road marking	Centerline	Right line marking	Sum CA1	Sum CA2	Total
Good	47,1	0,0	33,0	18,5	0,0	30,2	80,1	48,8	128,8
Medium	47,6	7,1	59,9	61,1	1,5	38,5	114,6	101,1	215,7
Poor	14,3	148,8	61,0	25,6	155,3	83,2	224,1	264,1	488,2
Missing value	49,3	2,4	4,4	53,2	1,5	6,3	56,1	61,0	117,1
Sum Length	158,3	158,3	158,3	158,3	158,3	158,3	474,9	474,9	949,9
Good	30 %	0 %	21 %	12 %	0 %	19 %	17 %	10 %	14 %
Medium	30 %	4 %	38 %	39 %	1 %	24 %	24 %	21 %	23 %
Poor	9 %	94 %	39 %	16 %	98 %	53 %	47 %	56 %	51 %
Missing value	31 %	2 %	3 %	34 %	1 %	4 %	12 %	13 %	12 %
Sum (%)	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %

The centerline does not meet the quality demand (94 % & 98 % in poor condition and 2 % & 1 % missing results).

Table 4 and Table 5 present the length of classified retroreflectivity for each road section after the winter period.

Table 4. Classified retroreflectivity (Sommers 2019) on carriageway 1 for each line, measurement data April 2021, vt 3 AUTOMO 2021 road sections, length (km)

Carriageway 1	Right line				Center line				Left line			
Road section	Good	Medium	Poor	Missing value	Good	Medium	Poor	Missing value	Good	Medium	Poor	Missing value
103	2	3	2	0	0	0	7	1	1	4	0	2
104	0	2	9	0	0	0	11	0	7	1	0	4
106	5	4	4	0	0	0	13	0	5	4	0	3
108	0	4	2	0	0	0	6	0	3	2	0	1
109	7	4	1	0	0	0	12	0	7	3	0	1
111	0	3	1	0	0	0	4	0	3	0	0	0
112	2	6	1	0	0	0	9	0	7	2	0	0
113	1	7	4	0	0	0	12	0	7	3	0	3
115	5	2	1	0	0	0	8	0	3	2	0	2
116	3	2	1	0	0	0	5	0	0	4	0	1
117	0	2	3	0	0	0	5	0	1	2	1	2
118	3	6	4	0	0	0	12	0	0	6	4	3
120	0	2	2	0	0	0	5	0	0	2	1	1
121	1	6	2	0	0	2	7	0	1	3	3	2
122	1	2	1	0	0	3	1	0	1	1	2	1
123	0	2	3	1	0	3	2	0	0	1	0	4
124	0	2	6	0	0	2	6	0	0	3	0	5
125	0	2	2	0	0	4	1	0	0	2	0	2
126	0	0	3	1	0	1	3	0	0	1	1	3
134	0	0	6	1	0	0	6	0	1	1	0	4
135	0	0	4	1	0	0	5	0	0	0	0	4
Total	**33**	**60**	61	4	**0**	**15**	141	2	**47**	**48**	14	49
Percentage		**59 %**	**41 %**			**10 %**	**90 %**			**60 %**	**40 %**	

Most of the centerline has poor retroreflectivity.

Table 5. Classified retroreflectivity (Sommers 2019) on carriageway 2 for each line, measurement data April 2021, vt 3 AUTOMO 2021 road sections, , length (km)

Carriageway 2	Right line				Center line				Left line			
Road section	Good	Medium	Poor	Missing value	Good	Medium	Poor	Missing value	Good	Medium	Poor	Missing value
103	1	2	4	1	0	0	7	0	0	4	0	3
104	0	2	8	1	0	0	12	0	5	3	0	4
106	0	3	10	0	0	0	13	0	1	9	1	2
108	4	1	1	0	0	0	6	0	0	4	1	1
109	0	2	10	0	0	0	12	0	4	5	0	3
111	0	2	1	0	0	0	4	0	0	2	1	1
112	7	1	1	0	0	0	9	0	1	7	1	1
113	8	3	2	0	0	0	12	0	0	8	1	3
115	3	3	2	0	0	0	8	0	0	3	1	3
116	2	2	1	1	0	0	6	0	0	0	2	3
117	0	0	5	0	0	0	5	0	0	3	2	0
118	0	3	9	0	0	0	12	0	1	2	7	2
120	0	2	2	0	0	0	5	0	2	0	0	3
121	1	3	4	0	0	4	5	0	1	3	2	3
122	0	2	2	0	0	2	3	0	0	0	2	2
123	2	2	1	0	0	1	5	0	1	2	2	1
124	0	2	6	0	0	0	8	0	2	3	0	4
125	0	0	4	0	0	0	5	0	1	2	0	2
126	0	1	3	0	0	0	4	0	0	1	0	3
134	0	1	5	0	0	0	6	0	0	1	1	4
135	0	2	3	1	0	0	5	0	0	1	1	3
Total	**30**	**39**	83	6	**0**	**7**	150	1	**19**	**61**	26	53
Percentage		**43 %**	**57 %**			**4 %**	**96 %**			**50 %**	**50 %**	

The retroreflectivity on carriageway 2 is worse than on CA1 and only 4 % of the centerline length is over the maintenance standard (100 mcd/m^2/lx).

Luminance contrast ratio

Luminance contrast ratio is a calculated value based on road marking measurements. It is calculated as a relation between luminance factor on road marking and asphalt surface next to road marking only with daylight.

This is possible to generate from the measurement data but is not included in FTIA's standard data delivery.

Lane marking consistency

Lane marking consistency was not studied separately, but during the data process to extract the lane width, the joining and diverging lanes and road markings were identified. On AUTOMOTO sections the lane marking consistency is simple and no deviation was detected.

Conclusion

The condition of line markings after winter is very poor and do not meet the proposed requirements for ISAD classes.

Recommendation

It is recommendable to do measurements on normal condition or in fall, after the line markings are maintained.

3.2 Drivable area – edge

The drivable area - edge is specified with following ODD attributes

- Line markers (left and right lane marking)
- Shoulder (paved);
  - Shoulder width (outside e.g. right)
  - Shoulder width (inside e.g. left)
- Shoulder (grass-> gravel)
  - Gravel shoulder width (outside e.g. right)
  - Gravel width (inside e.g. left)
- Widening or lay-by
- Solid barriers (e.g. grating, rails, curb, cones)

3.2.1 Shoulder e.g. Edge

The FTIA's registry data covers the lane dimensions with following variables:

- SHOULDER WIDTH, SIDE 1 (RIGHT)
- SHOULDER WIDTH, SIDE 2 (LEFT)

The definition for the variable of "shoulder width" is the area between carriageway and slope. (Road registry data description 6.2021).

> *Pientareella tarkoitetaan ajotien osaa, joka jää ajoradan ja luiskan väliin. Piennar voi olla päällystettyä ja/tai soraa (tukipiennar). Reunaviiva on osa päällystettyä piennarta. Mikäli piennarta ei ole osoitettu ajoratamaalauksin, katsotaan sen alkavan päällysteen reunasta. Sorateille kirjataan tieto "ei piennarta". "Ei piennarta" kirjataan myös silloin, kun ajorataan liittyy korotettu tai maalauksella erotettu kävelyn ja pyöräilyn väylä. Kävelyn ja pyöräilyn väylillä ei ole piennarta eikä sitä tarvitse kirjata. Tieto inventoidaan yhtenäisinä jaksoina lähimpään 5 cm pyöristäen. Lyhyitä pientareen leveyden muutoksia tai katkoksia ei huomioida (esim. kaarteet, liittymäalueet, pysäkit, kaiteet jne).*

Features classified from point cloud data were:

- left & right paved edge
- left & right slope edge

This is based on extracted road markings from the point cloud data. From these data sets we can calculate the following attributes:

- Paved shoulder width, side 1 (right) and 2 (left)
- Gravel shoulder width, side 1 and 2

  -> Shoulder width, side 1 and 2

The following figures present the edge width from point cloud data with the road registry records. When the focus in AUTOMOTO project has been the paved edge, the road registry data presents both paved and gravel edge. In many sections the paved edge is narrower that the width of edge from registry data, especially on left side.

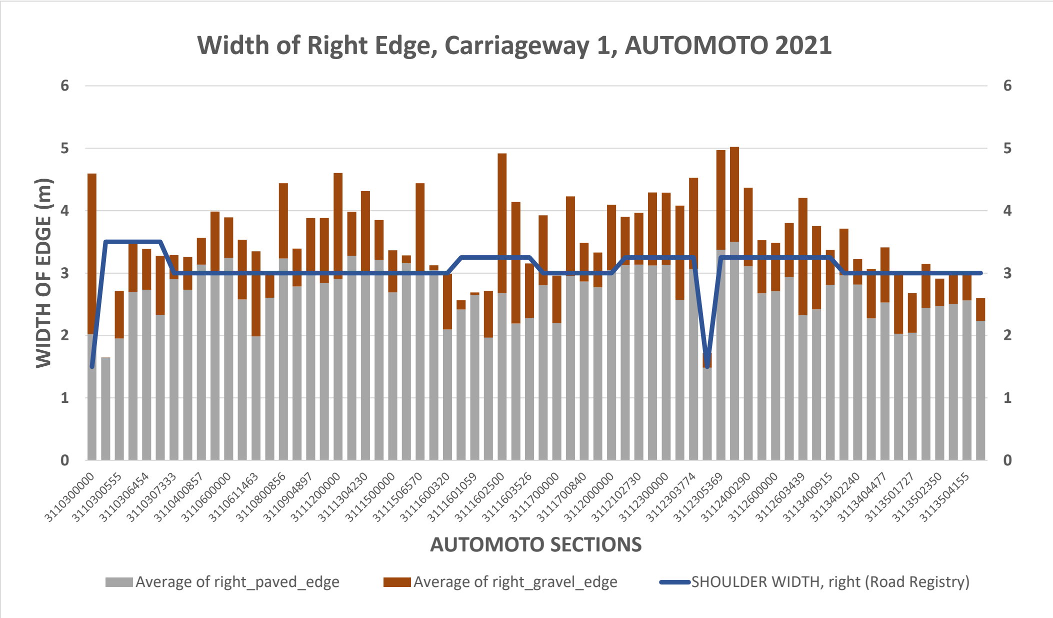

Figure 6. Width of right edge, carriageway 1, point cloud and registry data, vt 3 AUTOMO 2021 homogenous sections

Figure 6 presents the average width of paved edge as grey color, the gravel edge as brown color and the blue line presents the width of edge from road registry data for each AUTOMOTO 2021 homogenous section on right side of carriageway 1.

Average value for all sections is 2.7 m.

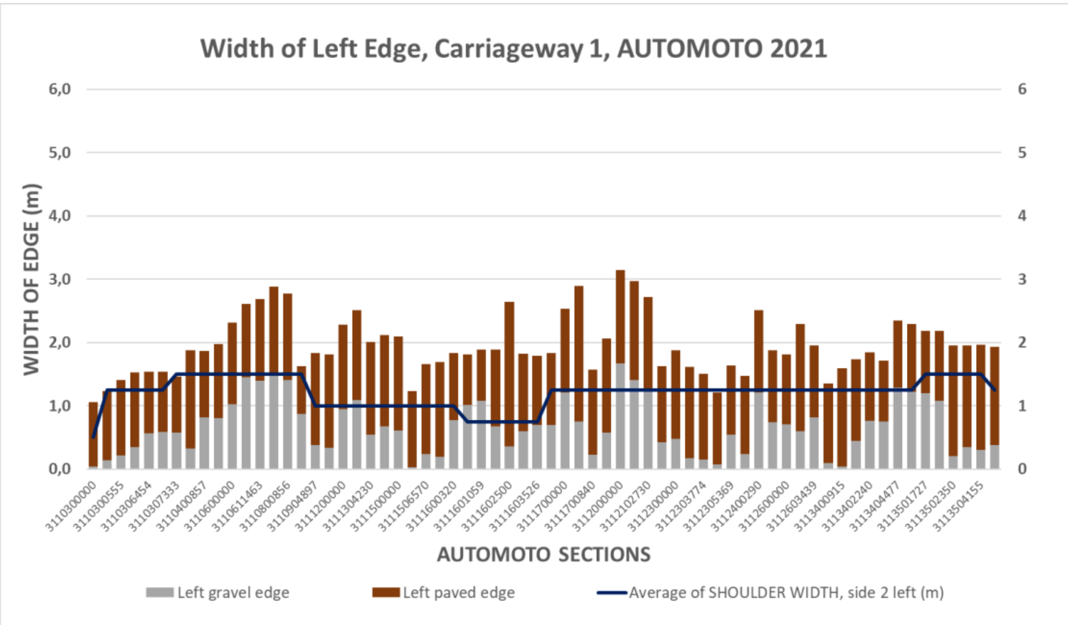

Figure 7. Width of left edge, carriageway 1, point cloud and registry data, vt 3 AUTOMO 2021 homogenous sections

Average value for all sections is 1.3 m.

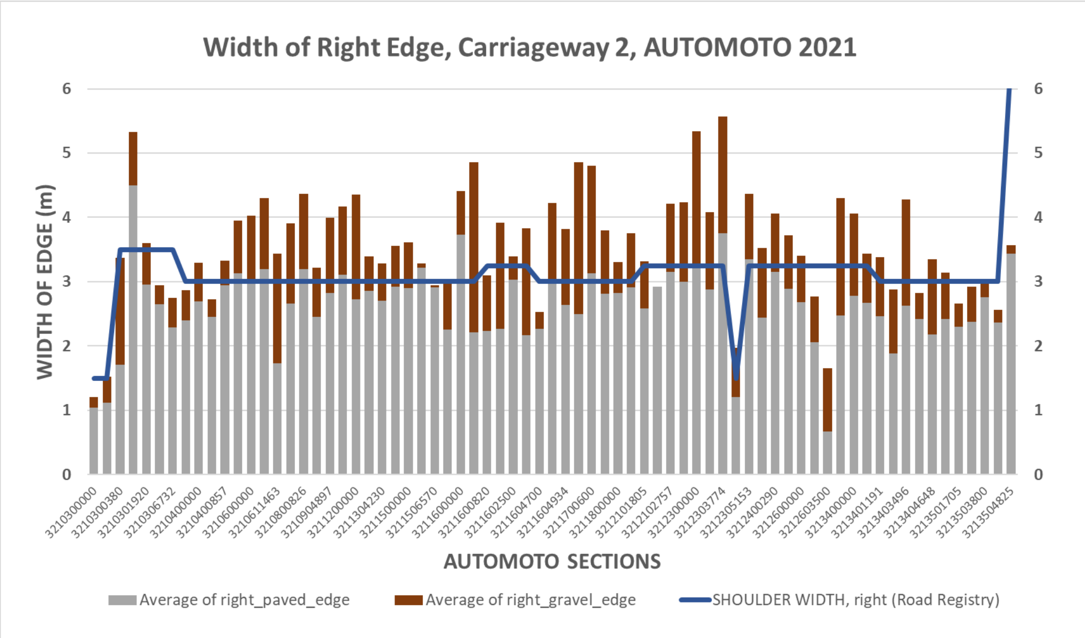

Figure 8. Width of right edge, carriageway 2, point cloud and registry data, vt 3 AUTOMO 2021 homogenous sections

Average value for all sections is 2.6 m.

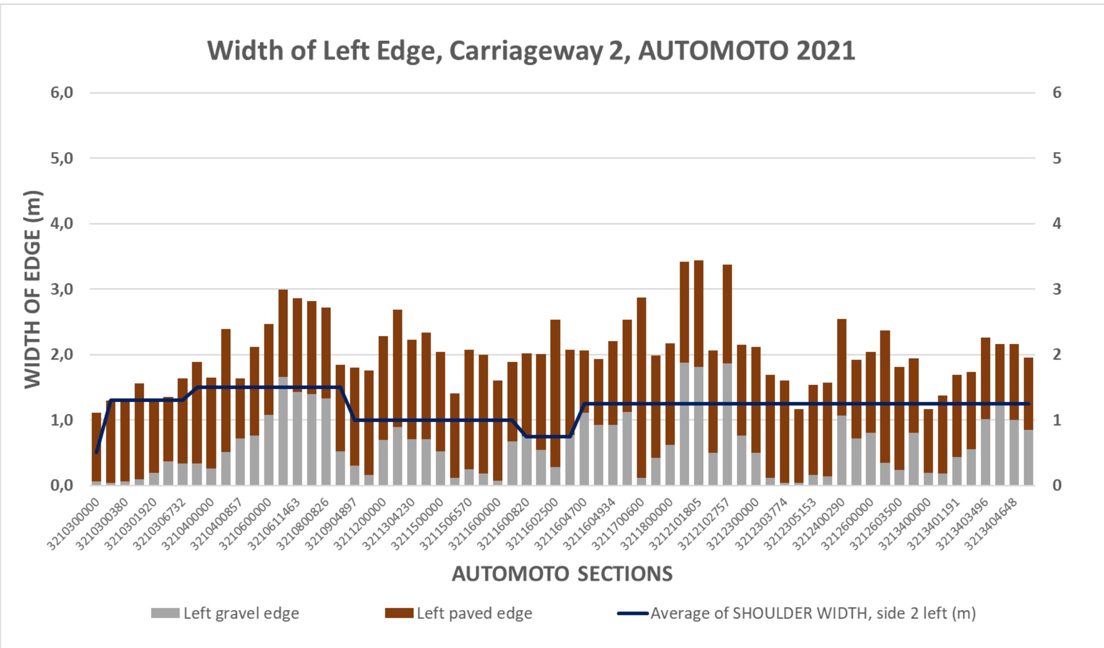

Figure 9. Width of left edge, carriageway 2, point cloud and registry data, vt 3 AUTOMO 2021 homogenous sections

Average value for all sections is 1.4 m.

The proposed classification values for right edge are 2000 mm (classes D & C) and 3000 mm (classes B & A) and for the *for left edge* are 1250 mm (classes D & C) and 2000 mm (classes B & A). The Table 6 present how the measured edge widths meet these requirements. The total length of this AUTOMOTO sections per carriageway is 158 km.

How many meters can be outside the limit?

Table 6. Length (km) of edge widths from AUTOMOTO sections according to the proposed classification

Carriageway&Side	EDGE	Classes D&C	Classes B&A
1 - Right	Paved	153	77
2 - Right	Paved	153	50
1 - Left	Paved	108	1
2 - Left	Paved	135	1
1 - Right	Paved+Gravel	156	150
2 - Right	Paved+Gravel	156	149
1 - Left	Paved+Gravel	156	94
2 - Left	Paved+Gravel	156	112

The results are included to the MS excel table about the physical infrastructure. Summary of the finding are:

- road length right edge (paved + gravel) narrower than FTIA's registry data on:
  - carriageway 1 26.1km
  - carriageway 2 32.3 km
- road length right edge (paved + gravel) wider than FTIA's registry data on:
  - carriageway 1 119.8 km
  - carriageway 2 111.8 km
- road length left edge (paved + gravel) narrower than FTIA's registry data on:
  - carriageway 1 11.1 km
  - carriageway 2 8.8 km
- road length left edge (paved + gravel) wider than FTIA's registry data on:
  - carriageway 1 136.2 km
  - carriageway 2 138 .7km

Conclusion

The measurements provide possibility to precise the current FTIA's registry data.
Right paved edge meets well the proposed classification for classes D & C.
For classes B & A, there is 312 km (of 316 km) edge wider that 3 000 mm if the gravel edge will be included.
Left paved edge meets the proposed classification for classes D & C most of the section, 243 km (of 316 km).
For classes B & A, there is 208 km (of 316 km) edge wider that 2 000 mm if the gravel edge will be included.

Recommendation

The definition of edge width should be defined according to the automated driving perspective.

3.2.2 Widening or lay-by

There are no extra widenings on the section nor are there any lay-by type of areas except for those provided in connection with the rest areas.

The only extra spaces for drivable area are junction areas and ports which are presented in respective chapters in this report.

Recommendation

New widenings or lay-by's should be designed and constructed for these section for the automated driving.

3.2.3 Solid barriers (e.g. grating, rails e.g. barriers, curb, cones)

Line geometry for barriers was identified and created from the point cloud data. The attributes for line geometry for barriers are location, both longitudinal and transverse, distance from the reference line and side according to the reference line (left, right).

On left side on carriageway 1 was 195 barrier objects, total length 53.9 km and on right side 143 barriers, total length 40.9 km.

On left side on carriageway 2 was 189 barrier objects, total length 54.3 km and on right side 152 barriers, total length 42.1 km.

Average distances are on left side about 3.2 m, minimum distance 0.6 m and maximum distance 9 m, average on right side 11.7 m, minimum distance 9.5 m and maximum distance 50.5 m. All distances are from the reference line e.g. left road marking.

Conclusion

Barriers are limiting strongly of the drivable are on both side of carriageway. Exact location can be measured efficiently with help the object extraction based on point cloud measurements.

Recommendation

The definition of barriers should be homogenized in road registry data and defined according to the automated driving perspective. As an example; barrier going over a river is divided in three object, south side, bridge, north side barrier identified as one object to limit the drivable area.

3.3 Drivable area surface

The drivable area surface is specified with following *ODD attributes*

- Drivable area induced road surface conditions
  also called as “Drivable area surface features” in some literature
  - Bearing capacity of lane
  - Shoulder bearing capacity

3.3.1 Drivable area induced road surface conditions

Drivable area induced road surface conditions is also called as “Drivable area surface features” in some literature. It is defined as “Aim: No potholes nor major damages, rut depth <20 mm; corrective measures as instructed in prevailing road guidelines”.

In terms of FTIA’s maintenance policy this is followed with help of:

1. pavement surface crack/defect inventories
2. level-of-service measurements
3. maintenance action policy

Potholes and major damages

FTIA is not conducting crack inventories on high volume highways. It is also assumed that the maintenance standard is so high that no disturbing defect exists on AIUTO-MOTO sections. Also, maintenance policy is implemented as emergency repairs or maintenance actions performed within one week.

No data was studied for this parameter.

Level-of-service measurements

The rut depth condition variable is used to classify the pavement surface effect to automated driving. FTIA has a long history with rut measurements from 80’s. The most common variable is the maximum rut depth of transverse profile 3.2 m wide. This is reported per 1 and 100 m interval.

The rut measurements were conducted in end of April 2021. Figure 10 and Figure 11 present the maximum ruth depth on both carriageways and lanes. The rut level is high after the winter period and before maintenance paving actions. FTIA’s maintenance standard defines 100m section as poor if the rut is over 13 mm and extreme poor when over 17 mm.

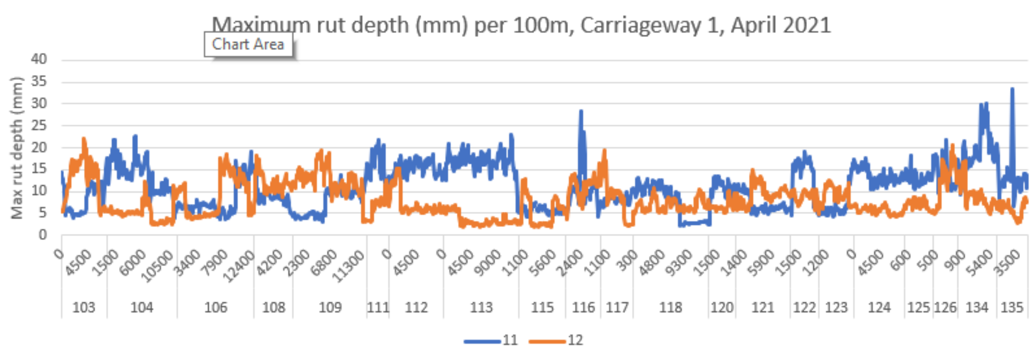

Figure 10. Max rut depth, both lanes, carriageway 1, measurement data April 2021, vt 3 AUTOMO 2021 road sections

About 52 km is in poor condition (37 & 15 km, lane 1/2) and 23 km extreme poor condition (19 & 4 km, lane 1/2).

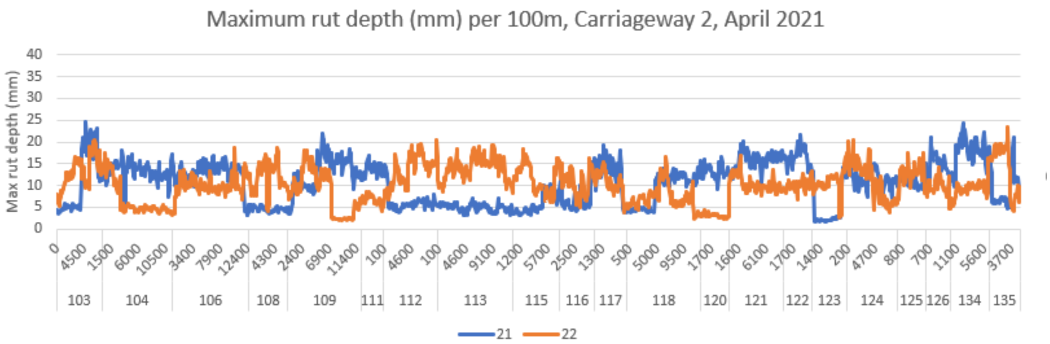

Figure 11. Max rut depth, both lanes, carriageway 2, measurement data April 2021, vt 3 AUTOMO 2021 road sections

About 74 km is in poor condition (40 & 34 km, lane 1/2) and 24 km extreme poor condition (15 & 9 km, lane 1/2).

Rut depth and readiness for automated driving

The proposed classification recommendations for AUTOMO sections is maximum rut depth less than 20 mm.

Table 7. Classified Readiness for Automated Driving, Rut measurements length, Vt 3, AUTOMOTO sections

Carriageway	lane	Good	Poor	Grand Total
1	11	152,8	4,8	157,6
	12	157,5	0,3	157,8
2	21	153,3	4,0	157,3
	22	156,7	0,7	157,4
Total		**620,2**	**9,8**	

There are quite few sections under the proposed condition classification.

Table 8. Classified ruth depth on both carriageways, measurement data April 2021, vt 3 AUTOMO 2021 road sections, length (km)

	Lane							
	11		12		21		22	
Section	Good	Poor	Good	Poor	Good	Poor	Good	Poor
103	7,5	0,0	7,3	0,2	6,2	1,3	7,3	0,2
104	11,2	0,4	11,6	0,0	11,4	0,0	11,6	0,0
106	12,6	0,0	12,6	0,0	12,6	0,0	12,6	0,0
108	6,3	0,0	6,3	0,0	6,3	0,0	6,3	0,0
109	12,2	0,0	12,2	0,0	11,8	0,4	12,2	0,0
111	3,0	0,5	3,5	0,0	3,5	0,0	3,5	0,0
112	9,0	0,0	9,0	0,0	8,9	0,0	8,9	0,1
113	11,6	0,7	12,3	0,0	12,3	0,0	12,3	0,0
115	7,3	0,0	7,6	0,0	7,7	0,0	7,3	0,0
116	5,3	0,4	5,7	0,0	5,7	0,0	5,7	0,0
117	5,2	0,0	5,2	0,0	5,3	0,0	5,2	0,0
118	12,3	0,0	12,3	0,0	12,2	0,0	12,2	0,0
120	4,5	0,0	4,5	0,0	4,5	0,0	4,5	0,0
121	8,8	0,0	8,8	0,0	8,7	0,1	8,8	0,0
122	4,7	0,0	4,7	0,0	4,4	0,3	4,7	0,0
123	5,7	0,0	5,7	0,0	5,7	0,0	5,7	0,0
124	8,3	0,0	8,3	0,0	8,3	0,0	8,1	0,2
125	4,6	0,0	4,6	0,0	4,5	0,0	4,6	0,0
126	4,0	0,1	4,0	0,1	3,7	0,1	4,1	0,0
134	3,9	2,4	6,3	0,0	4,6	1,7	6,3	0,0
135	4,7	0,3	5,0	0,0	4,9	0,1	4,8	0,2
Total	**152,751**	**4,8**	**157,472**	**0,3**	**153,254**	**4**	**156,688**	**0,7**

The poor condition is located close to big cities.

Recommendation

Defect measurements should be introduced on regular bases on section provided for automated driving with automated crack detection methods.

3.3.2 Bearing capacity of lane

FTIA's road registry has bearing capacity data variable as an average value over road section or as point result.

On AUTOMOTO sections all data was over 10 years old and the number of measurements behind this information is poor. This means that data is unreliable and not usable to estimate the bearing capacity od current road sections.

It is assumed that the road standard for AUTOMO sections is so high that there are no bearing capacity problems on driving lanes.

No reliable data available for this parameter. On some roads have thinner pavement layers on second lane than on the main lane. This creates unbalance between the existing bearing capacity between drivable area.

Recommendation

Continuous bearing capacity measurements should be conducted on sections provided for automated driving with nowadays available continuous and mobile bearing capacity measurement method.

3.3.3 Shoulder bearing capacity

FTIA do not have any information about the bearing capacity of edges (road shoulders). Paved edges are also less maintained than main lanes.

No data available for this parameter.

Recommendation

Continuous bearing capacity measurements should be conducted on sections provided for automated driving with continuous and mobile bearing capacity measurement method. Benefits for these measurements are; up-to-date knowledge of the state of road structure, possibility to compare the difference between old existing road registry data (-> knowledge of the condition change over time), possibility to compare the state of different lanes and carriageways and knowledge of the bearing capacity difference between lanes and edges.

Conclusion

FTIA has all possibilities to generate needed condition data to cover the needs of automated driving, like with level-of-service measurements (rut data) which is up-to-data and is used effectively to steer the maintenance actions.

3.4 Drivable area signs

Signs are registered in FTIA’s road registry. They were also extracted from the point cloud data as:

- Sign
- Portal

3.4.1 Signs

The attributes for point geometry are location, both longitudinal), distance from the reference line and side according to the reference line (left, right).

In the point object *.shp file is extracted *568 pcs sign features:*

- Right side of carriageway 1 255 pcs
    - Distance (average/min/max) 15.1 m / 10.4 m / 35.9 m
- Right side of carriageway 2 253 pcs
    - Distance (average/min/max) 14.9 m / 10.0 m / 35.2 m

- Center zone 60 pcs
    - Distance (average/min/max) 3.5 m / 1.3 m / 4.8 m

Average distances are on carriageway 1 about 20.7 m, on carriageway 2, 20.2 m and in center zone 5.4 m.

Conclusion

Signs are located in the slope or behind the barriers, so they do not limit the drivable are, especially if we limit it to the paved edge.

3.4.2 Portals

In the point object *.shp file is extracted *30 pcs portals*:

Average distances are on carriageway 1, left side is about 3.2 m and on right side is about 17.1 m, on carriageway 2, left side is about 3.4 m and on right side is about 16.1 m.

Heights identified are the following:

- Carriageway 1 15 pcs
    - Clearance (average/min/max) 5.8 m / 4.8 m / 7.7 m
    - Left line (B) 6.2 m / 4.8 m / 8.0 m
    - Right line (C) 6.2 m / 4.9 m / 7.7 m
- Carriageway 2 15 pcs
    - Clearance (average/min/max) 5.9 m / 5.3 m / 6.6 m
    - Left line (B) 6.3 m / 5.8 m / 7.6 m
    - Right line (C) 6.3 m / 5.6 m / 7.1 m

Conclusion

Portal pillars are located in the slope or behind the barriers, so they do not limit the drivable are. The clearance height is important for the drivable area and the road registry data was up-to-date with the identified clearance heights from the point cloud data.

3.5 Junctions

Diverging and joining lane dimensions were defied in junctions with location reference and distance from the reference line. Location is defined for three points; ramp lane starting (A), full ramp lane width (B) and drivable are ends (C) (sign, barrier, ditch etc).

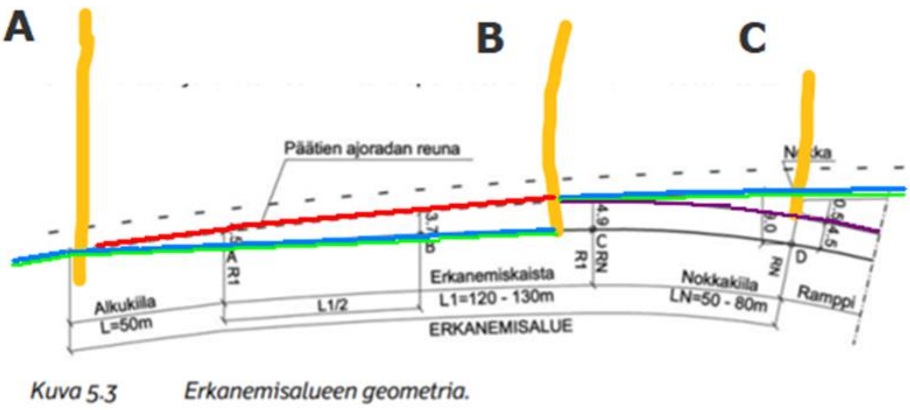

Figure 12. Schema to identify junction

The attributes for junctions are location (longitudinal) for points A, B and C and distance from the reference line to the road marking (drivable space).

There are 139 identified junctions. The distances from the reference line are:

- C joining (average/min/max) 12 m / 10.1 m / 13.9 m
- B joining (average/min/max) 8 m / 7 m / 11 m
- A joining (average/min/max) 8 m / 7 m / 11.3 m
- A diverging (average/min/max) 8 m / 7.4 m / 8.5 m
- B diverging (average/min/max) 8 m / 7.3 m / 8.2 m
- C diverging (average/min/max) 11 m / 10 m / 12.6 m

The beginning and ending road addresses (A & C) provide the location information for extra space for drivable area.

Conclusion

Junctions and the diverging and joining lanes provide extra space as drivable area even their functionality is planned for other purposes.

3.6 Special structures

- Bridge
- Tunnel
- Port

3.6.1 Bridge

The bridges are well presented in road registry. From the point cloud data was identified the dimensions from the point-of-view of automated driving.

Bridges are identified as line objects with start and end location. The distances to the possible bridge pillars or walls are identified. Only bridges going over the vt 3 is extracted.

The attributes for Bridge line geometry are longitudinal location (start and end), distance from reference line to measurement point (A and B) and clearance (C and D).

There are 130 identified bridges on both carriageways.

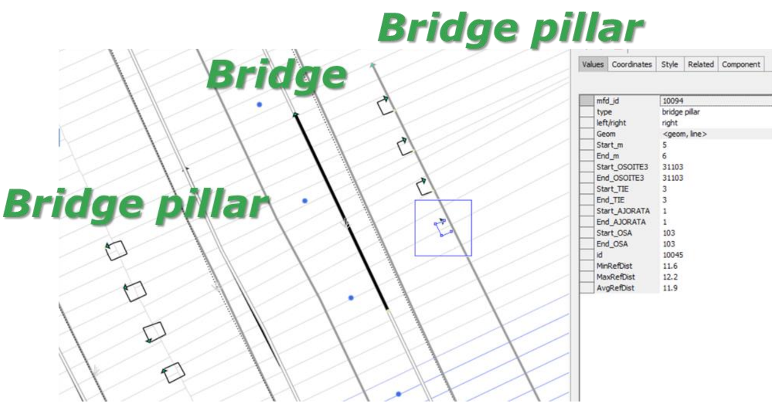

Figure 13. The Bridge features

The Clearance is defined from road markings:

- Left road marking (average/min/max) 5.3 m / 4.6 m / 8.4 m 121 pcs
- right road marking (average/min/max) 5.4 m / 4.7 m / 8.4 m 121 pcs

The attributes for *Bridge pillar and wall* line geometry are longitudinal location (start and end) and distance from reference (left and right).

Walls are usually related to bridges and they were extracted as higher and more far away abject than barrier. Wall is solid and concrete object.

It was extracted 107 bridge pillar and 107 wall objects on carriageway 1 and 95 bridge pillar and 110 walls objects on carriageway 2. Average distance for Bridge pillars are 17.3 m, minimum distance 3.1 m and maximum distance 71.6 m. Average distance for walls are 25.4 m, minimum distance 2.0 m and maximum distance 84.1 m.

Conclusion

Bridge pillars are in most cases behind the barriers and bridges do not limit the drivable area if it is limited to the paved edge.

3.6.2 Tunnel

Drivable areas for tunnels are defined in similar way as with bridges. If there do not exists barriers, the distance to wall is defined.

There is one tunnel, 282/277 m in road section 3/166. There are three lanes on carriageway 1 and two lanes on carriageway 2.

The attributes for tunnel are location, distance from the reference line in terms of paved edge and wall (line objects) and clearance.

The drivable area in tunnel is following:

- Carriageway 1 distance right (average/min/max) 11.3 m / 10.8 m / 12.1 m
- Carriageway 1 minimum clearance 5.4 m (based on 13 points)
- Carriageway 2 distance right (average/min/max) 7.5 m / 7.3 m / 7.7 m
- Carriageway 2 minimum clearance 5.1 m (based on 14 points)

Conclusion

The northbound tunnel provides extra space with 3rd lane.

3.6.3 Port

Altogether 48 service port were identified. The service port related devices like boom, barrier or device box are presented as line or point geometry.

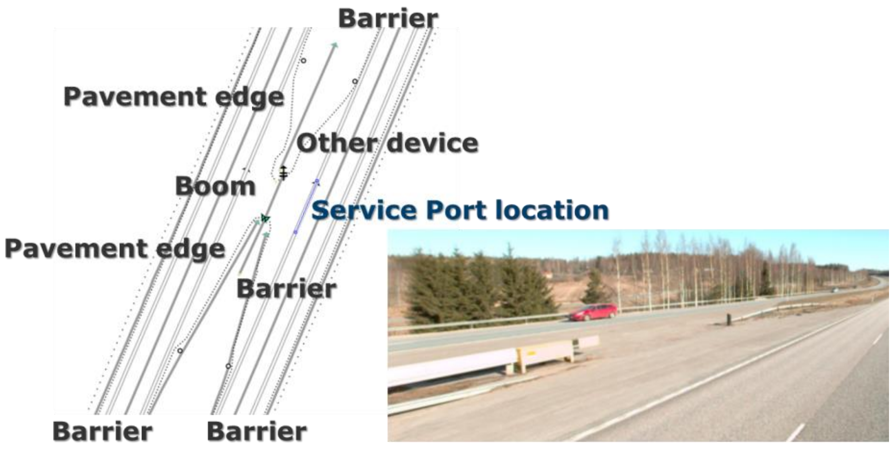

Figure 14. Service port identification based on point cloud data

Altogether 48 service port were identified. The service port related devices like boom, barrier or device box are identified as line or point geometry.

The average distance to the boom in service port area was 7.6 m but the length is quite short, average 26 m and the length of the widening to service port varies individually.

Conclusion

Service ports are located on left side of carriageway and in that sense, they provide easily accessible space from lane 2. Although they are quite short/small.

3.7 Fixed road structures

- Streetlights
- Street furniture e.g. reflector posts
- Fences

3.7.1 Streetlights

Streetlights are identified from point cloud as straight, high objects located on right side of carriageway or in the midzone as *point objects*.

The attributes for point geometry are location, both longitudinal (according to the FTIA's road address and transverse), distance from the reference line and side according to the reference line (left, right, centerzone).

It was extracted 1008 pcs street light features:

- Right side of carriageway 1 249 pcs
- Right side of carriageway 2 252 pcs
- Centerzone 507 pcs

Average distances are on carriageway 1 about 19 m, on carriageway 2 18 m and in centerzone 5.8 m.

Conclusion

Streetlights are located in slope, so they are outside the drivable are. In centerzone they are located behind the barriers.

3.7.2 Street furniture e.g. reflector posts

It was possible to identify the reflector/marker posts from the point cloud data as a point object.

The attributes for reflector posts are location, both longitudinal and transverse (left/right), distance from the reference line.

It was extracted 4526 reflector objects. Average distance on left side is 1.9 m and on right side 11.8 m:

- Carriageway 1 minimum distance (left/right) 0.7 / 9.9 m

- Carriageway 2 minimum distance (left/right) 0.8 / 9.6 m
- Carriageway 1 maximum distance (left/right) 8.9 / 39.1 m
- Carriageway 1 maximum distance (left/right) 7.2 / 37.8 m

Conclusion

Reflector posts are located in slope e.g. outside the paved and gravel edge. On the other hand, automated vehicles recognize those poles as solid objects to be avoided.

3.7.3 Street furniture e.g. fences

Fences were extracted with average distance of 22.6 m, minimum 14.9 m. On vt 3 the fences are not limiting drivable area.

4 Conclusions and recommendations

The following conclusions can be noted:

- Drivable area signs: Signs are located in the slope or behind the barriers, so they do not limit the drivable are, especially if we limit it to the paved edge.
- Junctions: Junctions and the diverging and joining lanes provide extra space as drivable area.
- Bridges: Bridge pillars are in most cases behind the barriers and bridges do not limit the drivable area if it is limited to the paved edge.
- Fixed road structure/Streetlights: Streetlights are located in slope, so they are outside the drivable are. In centerzone they are located behind the barriers.
- Fixed road structure/Street furniture: Reflector posts are located in slope e.g. outside the paved and gravel edge. On the other hand, automated vehicles recognize those poles as solid objects to be avoided.

4.1 Recommendations for the service level framework

The following findings are reported:

- Drivable area specifications/Lane width: The definition of carriageway width should be updated according to the automated driving perspective.
- Drivable area specifications/Line markings: Proposed ISAD variables should be implemented to the Line marking policy and processes.
- Drivable area specifications/Edge: The definition of edge width should be defined according to the automated driving perspective.
- Drivable area specifications/Edge/Solid barriers: The definition of barriers should be homogenized in road registry data and defined according to the automated driving perspective.
- Drivable area surface/ FTIA should generate the needed condition data to cover the needs of automated driving, like with level-of-service measurements (rut data) which is up-to-data and is used effectively to steer the maintenance actions.

4.2 Recommendations for further research and development

- Drivable area specifications/Edge: New widenings or lay-bys should be designed and constructed for these sections for the automated driving.
- Drivable area specifications/Line markings: Current measurements were done in April, after winter and before maintenance actions, so the condition of line markings was very poor. It is recommendable to do measurements on normal condition or in fall, after the line markings are maintained.
- Drivable area surface/Drivable area induced road surface conditions/Potholes and major damages: Defect measurements should be introduced on regular bases on section provided for automated driving with automated crack detection methods.
- Drivable area surface/Drivable area induced road surface conditions/Bearing capacity of lane: Continuous bearing capacity measurements should be conducted on section provided for automated driving.
- Drivable area surface/Drivable area induced road surface conditions/Bearing capacity of egde: Continuous bearing capacity measurements should be conducted on section provided for automated driving.

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Finnish Transport Infrastructure Agency

Nordic WAY 3

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Working report
24/09/2021

Service level framework for automated road transport

Task 2 Service level classification for highly automated driving on motorways

Service level framework for automated road transport

Task 2 Service level classification for highly automated driving on motorways Working Report

24 September 2021

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1 Background

1.1 Goal of service level classification

The overall objectives of the project ”Service level framework for automated road transport” for the Finnish Infrastructure Agency were to

- assess the feasibility of the selected motorway section (Highway E12 between Helsinki and Tampere) for the automated operation of SAE Level 3 and 4 automated vehicles
- propose classification for the Finnish road network from the automated vehicles operations’ point of view, i.e. a framework for service level classification for automated vehicles
- propose further actions in research and development work, as well as in international cooperation.

The objective of work reported in this document was the second one on the list, i.e. propose classification for Finnish road network with regard to its ability to facilitate automated driving.

The primary goal was to classify the motorway network as it is likely that the first SAE level 3 or 4 automated vehicles appearing on the markets will be capable of driving on motorways only. The proposed classification will be validated utilizing the data collected from the E12 motorway connection between Helsinki and Tampere.

Another goal of the task was to propose classification for the other main road network in Finland.

More specifically, the purpose of the road network classification is

- to provide basis for authority and road operator views about what parts of the road network should be prioritised with regard to conditionally or highly automated driving

- to inform the owners, drivers, manufacturers and developers of conditionally and highly automated vehicles about the current state of the physical and digital infrastructure on a specific road section or connection

- to provide a level of service hierarchy for the motorway network’s support to conditionally or highly automated driving.

The authority and road operator views on targeted service level influence also the actors, actions and processes in traffic management, road and winter maintenance, road planning and building. Hence, the classifications should also give implications to such actors.

For the use by automated vehicles, the classification should describe the road network’s properties in relation to the Operational Design Domains (ODDs) of conditionally or highly automated vehicles. It is acknowledged that the ODD is different for different automated driving systems. Thus, attributes of likely relevant factors are considered in the classification. In practice, the automated vehicles will instead of a network classification need to know the exact values of numerous classification attribute values to assess their ODD.

1.2 Existing classifications

1.2.1 ISAD

The ISAD or Infrastructure Support for Automated Driving classification was developed by the Horizon 2020 funded INFRAMIX project. The classification for the physical and digital road infrastructure was made from the road operator perspective. This chapter is based on Lytrivis et al. 2019, but a further refinement of it towards e.g. more technology neutrality is being proposed by Sigl et al. 2021.

The road operator acts within the bounds of the applicable regulations such as national or international laws. Therefore, the most basic point from which any classification of infrastructure must start is a road with no additional equipment whatsoever other than the one required by the applicable laws and regulations. Any change of this status is connected with costs, with road closings for installations of new equipment, but also with often time-consuming approval processes for the installation of such equipment.

As, on the part of the automotive industry, automated driving functions such as lane-keeping assist or traffic jam assistant have already been introduced, it is a realistic scenario that a vehicle with several automated driving functions is operated on a road with the very basic equipment. This means that the car might receive no specific additional support from the infrastructure whatsoever and still drive in the automated mode. Therefore, the lowest class E of the ISAD classification consists of a road that complies with the legal framework but has no additional equipment whatsoever aimed to specifically support automated vehicles.

From the point of view of the infrastructure provider, the classification needs to be made along the functionalities offered to the automated vehicle on a road section of a certain class. The ISAD classes are described in the following manner:

<u>ISAD E</u>

For most of today's "conventional" infrastructure, in general, no digital infrastructure data is available, and therefore, no explicit AV support can be provided. The vehicle has to rely on the on-board sensor system exclusively and perhaps has no redundant second source of information. Additionally, road geometry and road signs have to be recognised by automated vehicles on their own. See Table 1 for the components of ISAD E “Conventional infrastructure” and their justification.

However, cellular networks cover most of the main road networks and many vehicles are already connected to data from external sources even though road infrastructure data is not always available.

Table 1. Components of ISAD E "Conventional infrastructure" and their justification. (Lytrivis et al. 2019)

Components	**Justification**
AVs need to recognize road traffic signs; colours, position	Information about the accurate road characteristics could prevent ADAS misuse
Signs with speed limits, road curvature and inclination	Accurate speed limit recognition facilitates the AV operational domain perception (and is necessary for ISA or intelligent speed adaptation function)
Lane markings complied to regulations and standards on both sides	Safety-related automated functionalities need proper lane condition and recognition (supporting accurate localization, e.g. automated lane positioning, automated lane change)
Lane width based on standards	Change on lane width could pose safety related challenges even in conventional traffic
Working zone signalization	Working zone signalization could prevent the misuse of automated functions in the specific road segment, and the human driver could timely take over
Partial CCTV (closed circuit television) coverage for real-time vehicle detection	Traffic detection through camera could reduce the concerns related to the safety of mixed traffic flows in the near future

ISAD D

If a road is classified as ISAD D within the ISAD classification, static digital information in the form of automated vehicle specific map support of this road section is available. Map support means that the infrastructure provider, the road authority or another relevant body offers digital map data (including static road signs). However, automated vehicles will still have to recognise traffic lights, short-term road works and variable message signs (VMS) on their own. The provided data needs to be requested and downloaded by the respective map service provider in advance. See Table 2 for the components of ISAD D "Static digital information" and their justification.

Table 2. Components of ISAD D "Static digital information" and their justification. (Lytrivis et al. 2019)

Components	**Justification**
Digital map with static road signs (incl. accurate position of traffic signs)	The accurate position of the speed limit signs is necessary, e.g. for ISA function. This information being integrated into the digital map could complement the on-board vehicle sensors
Variable Message Signs	Visualise information related to warning, incidents, and weather.

ISAD C

To be classified as ISAD C, dynamic digital information of sufficient quality has to be available on the network in question. This means that information of dynamic road signs (e.g. variable speed limits) and dynamic information about warnings, incidents and weather warnings is available. A very relevant data exchange standard, which is wide-spread in Europe, for such dynamic information is DATEX II. See Table 3 for components of ISAD C “Dynamic digital information” and their justification.

Table 3. Components of ISAD C “Dynamic digital information” and their justification. (Lytrivis et al. 2019)

Components	**Justification**
HD maps (incl. accurate position of signs, dynamic update of lane topology)	Precise vehicle localisation is of high importance in hands-off automated functionalities, e.g. reference points can support localisation (also applicable in urban areas), dynamic update of lane topology through the HD map could support automated vehicles passing through a roadworks zone with new lane markings, automated lane change requires accurate lane recognition
Dense location referencing points	
Data fusion from on-board sensors, other vehicles and road side units	Automated vehicle localisation
Advanced traffic management centre software	Prioritisation, Class upgrade/downgrade only to specific vehicle types (of different SAE Level, different size etc.)
	Vehicle technical problem identification and vehicle/ driver warning, I2V warnings for the existence of aggressive, dangerous drivers.
	I2V truck parking advice, road condition (road friction, potholes) information (not always in real-time)
	I2V traffic regulation compliance
	Pay-as-You Go Toll service (optional)
Advanced Infrastructure to Vehicle / V2X communication	Vehicles recognition of traffic signs through TMC – Third Party Services
	Speech and screen V2I interaction (optional and provided mainly by OEM and third parties)
Automatic data processing	Provision of digital information from multiple sensors and/or sources requires automatic data processing (e.g. from in-pavement sensors, camera for detection of stopped vehicles, ramp metering)
Automated update of digital infrastructure	Provision of timely dynamic information (e.g. roadworks warnings, weather conditions, traffic information) requires an automatic update of the traffic signs (not always in real-time)

<u>ISAD B</u>

The classification ISAD B requires the capability of "cooperative perception", which means that the infrastructure is capable of perceiving microscopic traffic situations and also of communicating to vehicles. Microscopic traffic data can be acquired by various sensor types. The infrastructure can react in real time and inform vehicles about traffic situations, e.g. via I2V communication using C-ITS (cooperative ITS) messages. See Table 4 for Components of ISAD B “Cooperative perception” and their justification.

Table 4. Components of ISAD B "Cooperative perception" and their justification. (Lytrivis et al. 2019)

Components	**Justification**
HD maps (cloud based digital maps incl. the accurate position of signs, dynamic update of lane topology, location of emergency stop zones) Weather (High precision meteorological stations, in-pavement sensors to detect moisture, temperature, strain)	Cloud based digital maps could enhance traffic perception, supporting traffic flow optimisation. The frequency of the emergency stops and their accurate positioning in the HD maps could support the transitions to minimal risk condition if a human driver does not take over. Info about weather conditions relevant to road status (e.g. slippery road, strong side wind, heavy rain, snow, reduced visibility) could support the automated vehicle in perceiving its operational domain, thus preventing incidents of automated functions misuse.
Advanced TMC/iTMC software	I2V Highway Merge Assistance
Data exchange with cloud services	Data exchange with service providers supports services such as the provision of travel and route recommendations, with alternatives depending on time arrivals and distance.
Elements to ensure continuous connectivity (enabling I2V) along the segment (e.g. RSUs)	I2V connectivity should be ensured to enable the communication of advanced perception info to vehicles and related recommendations
Microscopic traffic situation (in some cases speed and gap advice)	Driving style monitored and taken into consideration for route recommendations and traffic advices (speed, gap, change of driving style)

<u>ISAD A</u>

For the highest class ISAD A, the infrastructure has to be capable of perceiving vehicle trajectories and of guiding single automated vehicles or groups of them. When driving on a road classified ISAD A, automated vehicles can be guided and orchestrated by the infrastructure to optimise traffic flow. The corresponding messages sent out by the infrastructure comprise, e.g., gap and lane change advice to control automated traffic. These advanced messages are referred to as C-ITS Day 2 for automated driving (Meckel 2019). See Table 5 for the components of ISAD B "Cooperative driving" and their justification.

Table 5. Components of ISAD B “Cooperative driving” and their justification. (Lytrivis et al. 2019)

Components	Justification
Advanced TMC/iTMC software Sensors for trajectories of the vehicles Dynamic Guidance: speed, gap, lane advice	The capability to provide dynamic guidance towards the time-gap, lane and speed a vehicle should drive results in higher traffic efficiency accompanied by an increase in safety. To perform such recommendations, the TMC requires detailed traffic data, such as the automation level of the vehicles and the traffic flow per lane.
Elements to ensure continuous connectivity (enabling I2V) along the segment (e.g. RSUs)	I2V and V2I are necessary to enable traffic tracking and monitoring. The automation level of each vehicle is critical information in that direction.

As seen from the descriptions above, the ISAD levels proposed are focused on the digital infrastructure and especially to connectivity and availability of data.

1.2.2 LOSAD

Garcia et al. (2021) propose a classification of the Level Of Service for Automated Driving (LOSAD). The proposed LOSAD is categorized in five levels, from A to E. It is determined as a function of how ready the road infrastructure is to support automated driving. The most important parameter to define the LOSAD of a road segment is the distribution of their Operational Road Sections. An Operational Road Section (ORS) can be defined as a section that fully supports automation for all driving automation systems with explicit ODDs. In other words, a section that should be ideally driven by any driving automation system. According to the SAE definition for the different levels of automation, a disengagement-free trip can only be ensured for level 4 (within their ODD sections) and for level 5. Levels 1 to 3 may present disengagements even within their ODDs, so disengagement-free trips can never be ensured. (Garcia et al. 2021)

A road segment is the road portion delimited by major intersections or an urban environment. Driveways and minor intersections may or may not suppose a road segment change. A road section refers to the minimal portion of the road that presents identical factors, including geometry, cross section, environment, etc. Every horizontal curve – as well as short tangents – should not be divided into different sections. A long tangent may be divided into different sections, if some important property differs on it. As the percentage of the road segment that does not belong to an ORS increases, LOSAD will decrease given that high automated vehicles will present lower opportunities to drive autonomously. LOSAD also decreases as ORSs become shorter. The following levels are proposed: (Garcia et al. 2021)

- LOSAD A: The road segment presents a continuous ORS that ensures a safe automated driving for high automated vehicles (levels 4-5). Levels 2 and 3 vehicles should perform with minimum disengagements due to their lower technology, i.e., a disengagement-free driving cannot be ensured from the infrastructure side (although their number would be very low or null).

- LOSAD B: Like for LOSAD A, the road segment is composed of a single ORS that must keep in automation all level 4 and level 5 vehicles. However, dynamic conditions such as weather may temporarily limit the ORS effectiveness. The LOSAD B also appears if the number of disengagements exceeds a given threshold, mostly caused by level 2-3 vehicles.

- LOSAD C-D: These levels are characterized by a non-continuous ORS within the road segment. The final level will depend on the number and length of ORSs along the segment. Most drivers may need to retake manual control of their vehicles at the non-ORSs. A minimum disengagement rate might also be expected within ORS, as for previous levels. In addition, adverse weather conditions might also trigger LOSAD C or LOSAD D conditions. Specific thresholds are still to be researched in the future, depending on how diverse CAVs are, the minimum period of time that would be adequate to be under automatic control, etc.

- LOSAD E: There are no ORSs, or their length is too short to ensure comfortable automated driving. Therefore, most level 3 and 4 drivers might be willing not to activate their systems. Level 2 drivers would not experience any remarkable benefit from lane keeping assistance, given that it would be disengaged most of the time.

The LOSAD classification is dynamic, i.e., a road segment might shift from one level to a lower one depending on dynamic factors such as disengagements and weather conditions. Two examples are given for clarification purposes: (Garcia et al. 2021)

- A LOSAD A road segment might temporarily shift to B if many disengagements are observed within a section, regardless the triggering factor (it may even be unknown). The level of the driving automation systems suffering disengagements is not relevant in this case.

- A LOSAD B road segment might temporarily shift to D if a sudden, violent rainfall takes place. Heavy rain has two effects: (i) creates a layer of water that may affect automation (this also depends on the drainage conditions), and (ii) limits visibility. The limitation of visibility might also be detected using the Visibility factor. These conditions might also trigger a high number of disengagements, which could be detected using the corresponding factor as well.

A new parameter, the disengagement rate, is necessary to apply one of the factors. This can be defined as the number of disengagements within ORSs divided by the volume of automated vehicles. Thus, it is a way of measuring how well the ORSs are performing, and a way to report unexpected or abnormal behaviour of the road infrastructure and automated vehicles. If this indicator is finally established, it would be necessary that all automated vehicles reported these events in real time, including position and time. Other data would be helpful in order to identify the triggering cause. Finally, this report should be provided by all vehicles from level 2 to level 5. road operators would then combine data from all vehicles with additional information (e.g., weather, traffic, etc.), obtaining 'disengagement maps' for the road network for a variety of situations. (Garcia et al. 2021)

The information from disengagements is considered to be very important, since it reflects how connected and automated vehicles are performing along the road segment. Unlike establishing LOSAD based on geometric and environmental factors, this parametre would reflect the consequences of unknown factors affecting automated vehicle performance.

Not only would this information be useful to more accurately tag the LOSAD of the road segment, but it would also help research to overcome these limitations, and therefore expand ORSs. (Garcia et al. 2021)

The LOSAD attributes proposed are shown in table 6.

Table 6. LOSAD attributes (Garcia et al. 2021)

Layer	Factor	Type	Domain	Parameter	Description	E	D	C	B	A
Physical Infrastructure	ORS	Static	Road Segment	Number	Number of ORS that should be within a road segment		<=5 (TBD)	<=2 (TBD)	1	1
			Road Segment	% of total length	Percentage of the total length of the road segment that should correspond to an ORS		75% (TBD)	90% (TBD)	100%	100%
Digital Infrastructure			Road Section	Maximum disengagement density and frequency rate (d/[km*h*V_AV])	Maximum allowable disengagement rate within ORSs, per time and length. All SAE levels are considered. Manual requests are not considered.				5 (TBD)	0 (TBD)
	Weather	Dynamic	Road Segment	Visibility (MOR)	Visibility range from weather stations		200 m	500 m	1000 m	1000 m
		Dynamic	Road Segment	Snow/icy pavement	Ice on the pavement may reduce the skid resistance and therefore prevent adequate automation. Snow on the pavement may prevent to distinguish road markings.		Heavy snow	Moderate snow	Light snow	Light snow
		Dynamic	Road section	Rainfall intensity	Rainfall may limit visibility.		Violent rain (<100 mm/h)	Heavy rain (<50 mm/h)	Moderate rain (<7.5 mm/h)	Light rain (<2.5 mm/h)

The different LOSAD and ISAD levels provide road segments with different characteristics related to automated and connected driving. Moreover, some interactions of these levels generate synergies that are especially interesting for road authorities and operators to foster. As a consequence of the various interactions, five different types of Smart Road segments can be distinguished with specific characteristics related to CAVs (Connected and Automated Vehicles). Although there are 25 possible combinations of the different LOSAD and ISAD levels, some of them are very similar and can be grouped together. From lower to higher CAV support, these five levels are proposed by Garcia et al. (2021):

- Humanway (HU). The road is not ready for CAVs. This means that level 2-3 vehicles would experience too many disengagements, prompting their drivers to manually disconnect the system. These segments would not present ORSs, and level 4 vehicles may not find clear ODDs – this would depend on the specific technology of the ADS – and will generally perform in manual mode. A level 5 vehicle would be able to operate along this road – provided that these vehicles are ODD-free – but connectivity to infrastructure is not guaranteed. However, even for these high-end vehicles, performance, operation, and safety might be compromised as well, if they cannot operate at a reasonable speed.

- Assistedway (AS). The road is adequate for level 2+ vehicles, meaning that it would not induce too many disengagements to levels 2-3. This would allow drivers to enable their driving automation systems. Road administrations should put special focus on ORS discontinuities and any other disengagement-prone location, to prevent driver distractions, especially for level 3. While more extensive ODDs can be found compared to HU, the road segment might be divided into many ORSs that do not provide a comfortable and automated driving experience for level 4 vehicles, limited by the physical infrastructure or the connectivity capabilities (the road cannot provide detailed information about the dynamic parameters that should be compared to ODDs).

- Automatedway (AT). The road segment presents better characteristics than AS segments, especially related to connectivity. These road segments present HD maps and can transmit digital information to CAVs, so these can better identify ODD-related factors and ODD terminals. In addition, less and more continuous ORSs can be found within. Level 2 vehicles would experience less disengagements than on AS segments, and level 3 vehicles would be able to use the digital information to foresee oncoming disengagements. The longer ORSs would allow a better, longer performance of level 4 vehicles in automated mode.

- Full Automatedway (FA). The road segment presents a continuous ORS, so all level 4 vehicles should be able to operate autonomously along the entire segment. In addition, these segments present safe harbours – including their junctions to other segments –. While the ORS is not directly related to level 2-3 vehicles – these are not required to explicit their ODDs – a much lower number of disengagements compared to AT is also expected. Connectivity is even better than AT segments, facilitating cooperative perception and including all safe harbours in the HD map. All road users would benefit from better global performance and safety levels.

- Autonomousway (AU). The road segment presents similar physical conditions than the FA segments – i.e., complete ORS along the segment, safe harbours, etc. –, and incorporates exceptional connectivity features that enable cooperative driving. In order to benefit from the best performance and safety levels, only level 4+ should operate along these road facilities or with dedicated lanes. The HD maps will also have very detailed information about the safe harbours – not only their presence but also their capacity and availability of free spaces.

The road typologies' dependence on different attributes as well as the ISAD and LOSAD classifications is illustrated in Figure 1.

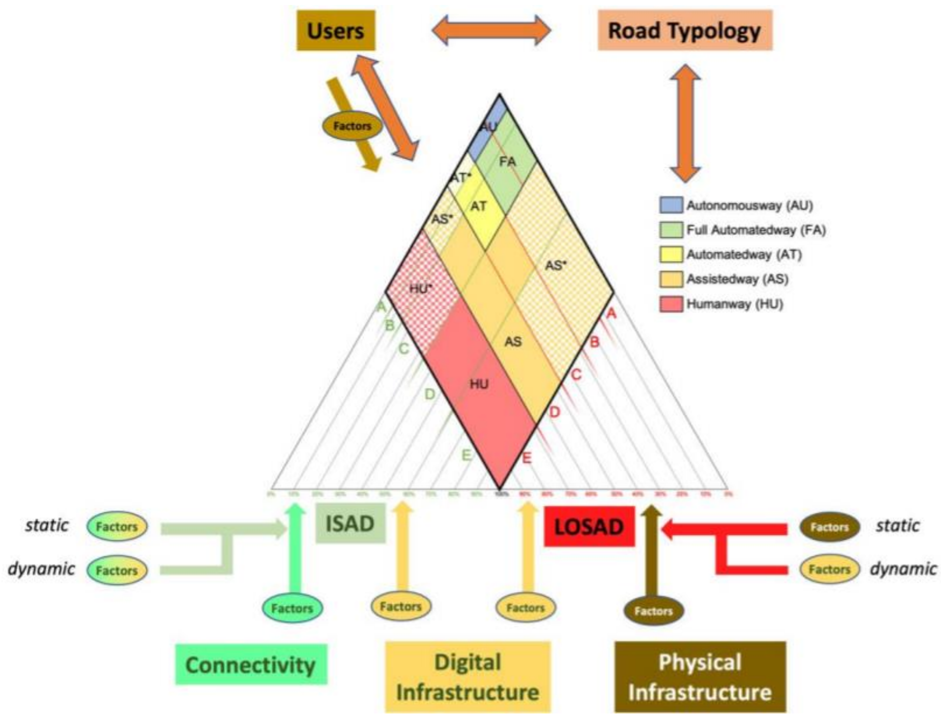

Figure 1. Smart Road Classification, including source data and interaction with other road classification systems. (Garcia et al. 2021)

1.2.3 Austroads

Austroads project undertook an extensive field audit of Australian and New Zealand freeways and highways to study their readiness for active safety systems and automated driving. The road audit included more than 8 million individual line segments and over 8 000 signs on a 25 000 km sample of the road network which represents less than 2% of the total network. The physical infrastructure attributes dealt with the existence, condition, and visibility of road markings and traffic signs. The digital infrastructure attributes covered the availability of HD maps and the availability and diversity of cellular coverage. (Germanchev et al., 2019)

The project adopted the approach of using the best available information to set two threshold values instead of a pass/fail value: (Germanchev et al., 2019)

A standard of infrastructure that is unlikely to be suitable

Lower threshold value

A standard that may be suitable – falls between the threshold values

Upper threshold value

A standard that is very likely to be suitable

Furthermore, this was related to the connected and automated vehicle readiness according to Table 7.

Table 7. Readiness of CAVs for existing infrastructure. (Germanchev et al., 2019)

Where infrastructure is:	That infrastructure is:	Improving the capability of the vehicle or ADS so the current infrastructure could be considered suitable
Highly likely to be suitable	Likely to be suitable for most or all current market vehicles and ADS	A small task, or unnecessary as performance is already suitable
May or may not be suitable	Likely to be suitable for only some current market vehicles and ADS	A practical task, albeit with some work required
Unlikely to be suitable	Unlikely to be suitable for most current market vehicles and ADS	A challenging task or not practical

For lane markings, the threshold values were as shown in Table 8. Furthermore, readiness for automated driving was considered to require lines of suitable quality on both sides of the lane of travel. This requires edge lines and centre lines, or right edge lines on multi-carriageway roads, to be marked as well as dividing lines between lanes.

Table 8. Longitudinal line marking thresholds. (Somers 2019)

Aspect of line quality		Lower threshold		Upper threshold	
Line width	Infrastructure quality below this level is unlikely to be suitable	100 mm	Infrastructure quality may be suitable	150 mm	Infrastructure quality above this level is very likely to be suitable
Luminance contrast ratio (daytime, dry)		2:1		3:1	
Retro-reflectivity – dry		100 mcd/lx/m²		150 mcd/lx/m²	
Retro-reflectivity – wet		50 mcd/lx/m²		75 mcd/lx/m²	

Concerning traffic signs, the readiness for automated vehicles includes: (Somers 2019)

- visual quality of signs, including size, retro-reflectivity and colours,
- requirements for electronic signs to manage LED flicker,
- maintenance of signs that are fully or partly obscured, damaged or otherwise degraded.

High-definition maps (HD maps) used for automated driving are normally highly detailed and accurate, and include both static and dynamic elements. HD maps expand the situational awareness of CAVs beyond what is possible with on-board sensors and processing power alone. Situational awareness for automated driving may be made up of three components: (Somers 2019)

- live processing for instantaneous conditions by on-board sensors
- survey-grade baseline maps collected by specialist survey vehicles
- crowd-sourced updates and other data feeds to provide an updated view of current conditions. C-ITS methods are a form of crowd-sourcing that is more immediate (of lower latency) but has limited or no central processing.

Table 9 compares the three components.

Table 9. Complementary methods to build situational awareness. (Somers 2019)

Method:	Assessed in real-time by vehicle using on-board sensors	Sourced from maps collected by survey vehicles	Sourced from crowd-sourcing
Sensors used to collect data	Likely to be commodity grade	May be commodity or survey grade	May be commodity or survey grade
Processing of collected data	In real-time on hardware that has a limited power budget	Post-processing on high power hardware	Post-processing on high power hardware
Can processing consider also things that lie beyond immediate range (i.e. beyond 20-40m)?	Generally only real-time processing, but some potential to consider recent past	Yes, due to post-processing	Yes, where post-processing used
Currency	Relevant to this instant	Periodic update (i.e. months or years)	Ongoing update, but not instant

Connected and automated vehicles require access to mobile data for a number of reasons, including to access base map information and to receive live map updates. While some methods cache and store information on vehicles, automotive manufacturers consulted in this project viewed continuous data communications of 4G or better as strongly desirable or essential to support automated driving. Although 5G communications are often talked about as relevant to automated driving and may be beneficial, no automotive manufacturers consulted by the Austroads project identified 5G communications to be a minimum requirement for automated driving. (Somers 2019)

In addition to carrier-provided commercial mobile data networks, some consulted automotive manufacturers expressed interest in C-ITS roadside units being deployed, especially in urban areas for traffic signals and smart motorways (Somers 2019). The field audit (Germanchev et al., 2019) examined both the quality of the strongest traffic signal and the availability of multiple carriers, on a road link by road link basis.

1.2.4 SLAIN

The European Commission CEF (Connecting Europe Facility programme) funded project SLAIN (Saving Lives Assessing and Improving TEN-T road Network safety) aimed to develop and demonstrate network-wide road assessment. One of the work areas was to review some relevant factors associated with the preparation of the readiness of Europe's physical infrastructure for automation. (This chapter is based on Konstantinopoulou et al., 2019)

The first factor was the machine readability of line markings. The readability of lines was assessed using both imagery and LiDAR to reflect the changes that are occurring in computer vision technology used in connected and automated vehicles. This was done particularly regarding improvements in low-cost LiDAR scanners making them more attractive to the automated vehicle market.

The imagery-based method used to determine the automated vehicle readability of lines for this project was like computer vision models used in CAVs. The line detection model was trained using Ladybug 5 imagery captured by TomTom as part of its MoMa capture program. Ladybug 5 cameras have been available for many years and have been widely used in road survey and assessment applications. The analyses focused on the line markings either side of the MoMa capture vehicle.

The second factor addressed was traffic sign readability. The method adopted to assess the automated vehicle readability of signs was to examine using TomTom's MN-R database of sign locations how many signs had been detected using automated vehicle compatible computer vision techniques TomTom has developed to assist with autonomous and assisted driving.

The assessment focused on five key signs of speed sign, overtaking restriction sign, stop sign, yield sign, and pedestrian crossing.

2 Methodology

2.1 Highly automated driving use cases

The classification is not targeting any specific automated driving use case as such, but the focus on motorway-oriented use cases such as highway chauffeur, highway autopilot, automated freight vehicles on open roads, and truck platooning as listed by ERTRAC (2019).

2.2 Requirements for classification

The road network to be prioritised in terms of facilitating conditionally or highly automated driving should reflect user needs. Those needs are to be assessed primarily for the part of long-distance commuting and work-related journeys ("an hour to work in the car"[1]), and the improved effectiveness and cleanness of heavy goods transports. The long-term objective not reached with this paper is to determine a road network, where the investments required for facilitation of conditional or highly automated driving likely are socio-economically feasible when considering the benefits to a safe, efficient and clean transport system.

The service level of the road network will be based on the current status of the ODD attributes on the Helsinki–Tampere motorway (E12 connection), classification objectives and the requirements of the conditionally or highly automated vehicles. It is acknowledged that the ODD requirements won't be the same for all automated driving systems. The ODD related requirements will be acquired from projects, literature, and other existing sources. No new research on ODD requirements will be carried out.

Already from the start, the aim was to specify five different service levels, where the requirements towards the physical and digital infrastructure will get higher as the service level increases. During the project, a consensus decision was made to utilise the existing ISAD level structure (Lytrivis et al. 2019, SIgl et al. 2021) as a basis for the service level framework as that has been widely discussed e.g. in CEDR and ERTRAC.

2.3 Determination of service level attributes

The service level attributes were first compiled to a long list based on the existing sources. These included the British ODD taxonomy (BSI 2020), the ODD attributes identified by EU EIP and MANTRA projects (Kulmala 2020, Ulrich et al. 2020), and the physical and digital infrastructure attributes from the European Commission's CCAM Platform (CCAM WG3 2021).

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[1] 28% of Finns indicated willingness to work during automated driving in a survey conducted by L3Pilot (Lehtonen & Innamaa 2019)

The attributes were divided in four main categories of
- physical (road) infrastructure
- digital infrastructure
- environmental conditions
- dynamic elements.

The last two are named in line with the related British standard (BSI 2020).

The attribute list was modified based on the input from the various task leaders of the project utilising their own expertise and lessons learned during the E12 connection inventory. The modifications were in almost all cases additions of attributes giving more detail than the original attribute. The attribute lists can be found from Annex I.

The inputs from the various tasks included:
- Task 1.1 physical infrastructure, dynamic elements
- Task 1.2 digital infrastructure/connectivity
- Task 1.3 digital infrastructure/positioning
- Task 1.4 environmental conditions
- task 1.5 digital infrastructure/C-ITS services
- task 1.6 physical infrastructure

In addition to the specification of the attributes, the task leaders also proposed the minimal values to be used for the different ISAD levels E…A for the attributes in question. These values were discussed first with Task 2 partners and then with the FTIA (Finnish Transport Infrastructure Agency) experts.

Some of the attributes were regarded as basic ones with a certain minimum standard, which is also a kind of maximum standard, i.e. the value is the same for all ISAD levels E…A. Examples are road type (motorway), pavement type (asphalt or concrete), divided (physical separation), etc.

Finally, a number of attributes were either regarded as not applicable to motorways, and for some no value could be given due to lack of knowledge about the capabilities and evolution of the sensors, artificial intelligence or other technology solutions of highly automated vehicles.

2.4 Determination of service levels for motorways

The basic service levels were set in line with ISAD classification (Lytrivis et al. 2019):

E: Conventional (physical) infrastructure only, no AV support
D: Static digital information / map support
C: Dynamic digital information
B: Cooperative perception
A: Cooperative driving

These levels were set originally for digital infrastructure, but they were considered suitable also for other areas (physical infrastructure, environmental conditions and dynamic elements) even though some extra consideration was required to set the principles for their application for them.

Table 10. Service level definitions for all attribute categories.

Service level	Interpretation			
	Physical infrastructure	**Digital infrastructure**	**Environmental conditions**	**Dynamic elements**
E: Conventional (physical) infrastructure only, no AV support	Physical infrastructure designed according to current design guidelines (made for manually driven vehicles)	No support from digital infrastructure, i.e. road geometry and road signs have to recognised by AVs on their own	Road side stations may measure environmental condition but no direct access to the data available	Traffic management provided according to current operational guidelines
D: Static digital information / map support	Infrastructure easily perceived and identified by AVs	Digital map data (incl. static road signs) complemented by physical reference points; Traffic lights, short-term roadworks and VMSs have to be recognised by AVs on their own	Historic information on environmental conditions available in machine readable format	Traffic management measures and plans provided in a way correctly perceived by AVs, self-diagnostic TMC hardware
C: Dynamic digital information	Enhanced physical infrastructure for AVs with regard to improved infrastructure maintenance	All static and dynamic information can be provided to the AVs in digital form; AVs receive infrastructure support data	Infrastructure-based weather information available	Dynamic traffic and incident management including connectivity, self-healing TMC hardware
B: Cooperative perception	Improved physical infrastructure for AVs with regard to MRMs	Infrastructure is capable of perceiving microscopic traffic situations; AVs receive infrastructure support data in real time (C-ITS Day-1)	Detailed cooperative weather information (V2I): obtained via processing and sharing perception sensor findings by vehicles present on the particular road segment and infrastructure-based information	Enhanced dynamic traffic and incident management, self-learning TMC hardware
A: Cooperative driving	Improved physical infrastructure for AVs with regard to positioning support and vehicle supervision	Infrastructure is capable of perceiving vehicle trajectories and coordinate single AVs and AV groups; Infrastructure helps to coordinate vehicle manoeuvres to optimise traffic flow (C-ITS Day-2+)	Individual trajectory recommendation available taking into account the prevailing environmental conditions	Local traffic management arrangement provision for AVs, self-management TMC systems

It should be noted that while the ISAD levels are supposed to correspond between the four attribute categories individual roads or road sections can have some attribute in a higher or lower category than the actual category as a whole or other categories. For example, a higher digital infrastructure support can compensate for a lower physical infrastructure support level.

The main emphasis was to identify all relevant ODD-related attributes that would affect the automated vehicle's capability to operate in automated mode along a long motorway section. The attributes can naturally also be applied in other uses than the ISAD classification.

2.5 Determination of service levels for other main roads

The service levels for other main roads than motorways need to take into consideration additional automated driving use cases such as automated public transport buses and robot taxis. At the same time highway chauffeur/jam pilot/autopilot and truck platooning playing a major role on motorways may also be used on some non-motorway major roads. Hence, new ODD attributes could be relevant for non-motorway main roads.

The ODD attributes of non-motorway main roads may differ from those of motorways. The list of ODD attributes was investigated by considering the two different viewpoints:

- removal of ODD attributes relevant for motorways not applicable to non-motorway main roads,
- addition of ODD attributes relevant for non-motorway main roads that are not relevant for motorways.

2.6 Validation of results

The results are validated in two ways.

First, the values of the ODD attributes on the E12 motorway between Helsinki and Tampere were acquired from databases as well as field studies carried out in the first half of 2021.

Second, the proposed motorway service levels are sent for consultation to experts in and outside Europe. The experts consisted of people employed by road operators, vehicle industry, universities and research organisations.

3 ODD attributes and their relevance

The subchapters below present the ODD attributes found relevant by the participating experts in the analysis. The relevant aspects of each ODD attribute for automated vehicles are also described.

3.1 Physical infrastructure

Attributes related to physical infrastructure, their definitions and relevance are described in the table below.

	Attribute	Definition	Relevance
Driveable area lane specification	Lane marking retro-reflectivity	The visibility of the marking to human eye and vehicle sensors (mcd/lx/m^2)	Vehicle sensors such as cameras can use the marking for lateral positioning on the driving lane
	Luminance contrast ratio	Luminance contrast ratio between the line and the surrounding pavement	As above; visibility of the marking with regard to the pavement itself
	Lane marking consistency	Continuity of markings, lack of any misleading markings on pavement	Avoidance of misinterpretations by AV software
	Bearing capacity of lane	Ability of road to carry moving vehicles without damage	Important for platooning of heavy goods vehicles
Driveable area edge	Shoulder width	Width of paved area on side of driving lane	Provision of room for stopping due to MRM. Relevant sub-attributes: • outside • inside
	Shoulder bearing capacity	Ability of shoulder to carry moving vehicles without damage	Important for MRM of heavy goods vehicles and their platoons
	Widening or lay-by	Widening of drivable area or provision of a separated area linked to the drivable area lane	Can be used for MRM, picking up or dropping off passengers, and waiting for or provision of platoon coupling

Drivable area sign	Fixed Variable	Detectability and interpretability by vehicle sensors	Safety of road use
Drivable area induced road surface	Drivable area induced road surface condition	The condition of the road surface with regard to damage and wear	Safety of road use
Fixed road structures	Landmarks	Fixed structure (building, street light pole, bollard, gantry or specific conspicuous landmark)	Supporting GNSS or other form of ego-positioning for AVs
Temporary road structures	Construction site detour	Marking of detour in case of road closure due to road construction works	Indication of need to change route i.e. to turn to another road
	Road works	Marking of the road works site and the intended trajectories	Indication of roadworks and need to adapt speed and trajectory

3.2 Digital infrastructure

Attributes related to digital infrastructure, their definitions and relevance are described in the table below.

	Attribute	Definition	Relevance
Connectivity	Cellular communication	4G, fourth generation of broadband cellular network technology 5G, fifth generation of broadband cellular network technology	Can be used for connectivity between infrastructure and vehicle Relevant sub-attributes include e.g. number of redundant cellular networks
	Short-range communication (ITS-G5, C-V2X, etc.)	Wireless communication technology that enables vehicles to communicate with each other and other road users directly, without involving cellular or other infrastructure	Can be used for connectivity between infrastructure and vehicle as well as between vehicles
	Communication performance	Overall performance of communication (potentially using multiple technologies or networks) in a single location • Download and upload speed (Mbit/s) • Latency (s) • Reliability	Performance describes the overall capability and reliability of communication
Positioning	GNSS	Satellite positioning, accuracy affected e.g. by • Dual frequency receiver • Localisation assistance services	Positioning required for automated driving

HD Map		High-definition map which includes e.g. following attributes • Road type and geometry • Traffic signs • Lay-by and parking areas • Bearing capacity	HD map required for automated driving
C-ITS (or similar)	Immediate collision warnings		Information provided by C-ITS or similar services enables early TOR and supports safe driving in special circumstances
	Event, incident and other hazardous location information		
	Road works information		
	In-vehicle signage		
	Information on weather conditions		
Traffic management	Traffic flow information	Traffic flow rate, mean speed, % of HDVs	Traffic status in surrounding road network
	Routing advice		Supports routing when road is blocked

Framework	Digital traffic rules and regulation		Prevailing regulation
	Availability of physical and digital infrastructure		Information of the availability of ODD related infrastructure attributes and their values, Framework for remote guidance, availability of infra for MRM
	Traffic management plans and real time guidance		Routing and behavioural plans
	ODD/ISAD management information	Sharing of ODD- and ISAD-status related information between AVs and traffic managers, provision of infrastructure support tools to extend ODD when/where needed and to facilitate and manage MRMs	Keeping both AVs and traffic managers aware of the availability or lack of ODD, and the automated use of AVs on the network, and use of MRMs

3.3 Environmental conditions

Attributes related to environmental conditions, their definitions and relevance are described in the table below.

Attribute	**Definition**	**Relevance**
Visibility	Visibility measures the distance at which an object can be clearly seen.* Visibility can be affected e.g. by • Rainfall • Snowfall, hail, freezing rain • Fog, mist • Smoke, air pollution • Standing water or snow on road raising mist or snow-dust in front of the following vehicles	As visibility is traditionally related to human perception it is only directly applicable to sensors operating at human-visible wavelengths. The degree of obscuration will be dependent on the amount of particulate matter, the sensor wavelength and also the composition and size distribution of the particles in question** In this classification, the visibility is addressed not only from human but also from optical AV perception viewpoint. Visibility below 300 m likely not sufficient for automated driving when speed is 100–120 km/h, and friction is reasonable (dry or wet road). If friction is low, and objects can have very low reflectivity (10%), automated driving requires 600m visibility at motorway speeds.
Friction	Friction between tyres of the vehicle and road surface. Coefficient of friction, ratio of the frictional force resisting the motion of two surfaces in contact to the normal force pressing the two surfaces together. Friction can be affected e.g. by • Temperature • Snow or ice on road • Surface contamination	Conditions with low friction (e.g. icy road) likely outside ODD. When near 0 °C, the difference between road temperature and the dew point of the air is a key parameter for potential of ice formation on road surface.

Water on road	Standing water tends to occur if there is a depression in the road** or during heavy rainfall Flooded roads result when the amount of water arriving on the road is greater than the capacity of the drainage facilities that take it away.**	1. When water depth is higher than the ground clearance of subject vehicle. 2. When vehicle speed and water thickness causes aquaplaning (applies mainly to cars).
Wind	Wind speed is specified in the unit of m/s. It shall be characterized as an average over a specified time interval (recommended 2 min to 10 min) and a gust value in m/s, which is the peak value of a 3 s rolling mean wind speed.**	Depends e.g. on vehicle mass, cross section area, center of gravity, tyre to road friction, and performance of vehicle algorithms to handle a sliding vehicle. Wind gusts when vehicle comes out of coverage. (A low profile car can handle very different winds compared to e.g. an unloaded double-decker bus.)

*Met Office, UK, https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/

**BSI (2020)

3.4 Dynamic elements

Attributes related to dynamic elements, their definitions and relevance are described in the table below.

Attribute		Definition	Relevance
Traffic management	Monitoring systems/ services	Infrastructure-based traffic, weather, and environment monitoring solutions	Provision of environmental information to AVs' local dynamic maps
	Traffic management services	Existing traffic management services on the road section	Prevailing driving regulations
	Variable speed limits	Maximum driving speed adapted to current conditions	Prevailing speed limits
	Tunnel management services	Services to ensure safe and efficient use of tunnels	Safe driving through tunnels
	Incident management	Services to detect, inform of, control traffic at, rescue victims of, and clear road incidents and their sites	Mitigation of safety, efficiency and environmental consequences of incidents to AVs
	Road works management	Management of traffic in connection with both fixed and mobile road works	Ensuring safe passing of road works
	Traffic management centre systems	Operation of traffic management services 24/7	Real-time reaction to any events, incidents and other disturbances on the route ahead

4 Infrastructure support level classification

The infrastructure support levels presented below relate to the Finnish motorway network, which is currently about 900 km long and mainly located in southern parts of Finland. The classification is not necessarily valid for the motorway networks in other parts of the world. The classification is made utilising the five ISAD levels proposed by Lytrivis et al. (2019).

4.1 Proposed classification

4.1.1 Physical infrastructure

	Attribute	**E: Conventional (physical) infrastructure only, no AV support**	**D: Physical infrastructure adaptations for AV**	**C: Enhanced infrastructure wrt maintenance**	**B: Improved infrastructure wrt MRM**	**A: Improved infrastructure wrt positioning and supervision**
Drivable area lane specification	Lane marking retro-reflectivity	According to national guidelines	min 100 mcd/lx/m^2 dry road	Same as level D	Same as level D	Same as level D
	Luminance contrast ratio	According to national guidelines	>2:1	Same as level D	>3:1	Same as level B
	Lane marking consistency	No contradictory markings	After road works e.g. repaving, new markings done without delay and temporary markings totally deleted	Same as level D	Same as level D	Same as level D

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Physical infrastructure adaptations for AV	C: Enhanced infrastructure wrt maintenance	B: Improved infrastructure wrt MRM	A: Improved infrastructure wrt positioning and supervision
	Bearing capacity of lane	According to national guidelines, should be OK for also platoons	Sufficient for platoons of 3 trucks moving with headway of 15 m	Same as level D	Same as level D	Same as level D
Driveable area edge	Shoulder width	According to national guidelines	Outside >= 2000 mm (sufficient for cars) Inside >= 1250 mm	Same as level D	Outside >= 3000 mm (sufficient for trucks) Inside >= 2000 mm (sufficient for cars)	Same as level B
	Shoulder bearing capacity	According to national guidelines	Sufficient for platoons of 3 trucks moving slowly with gap of 15 m	Same as level D	Same as level D	Same as level D
	Widening or lay-by	None required	Every 50 km	Every link between major intersections	Same as level C	Every 500 m
Drivable area sign	Fixed or variable	According to national guidelines	Detectable and interpretable by automated vehicle sensors	Same as level D	Same as level D	Same as level D

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Physical infrastructure adaptations for AV	C: Enhanced infrastructure wrt maintenance	B: Improved infrastructure wrt MRM	A: Improved infrastructure wrt positioning and supervision
Drivable area surface	Drivable area induced road surface condition	Aim: No potholes nor major damages, rut depth <20 mm; corrective measures as instructed in prevailing road guidelines	Same as level E	30% shortening of repairment contractor response times	Same as level C	70% shortening of contractor response times
Fixed road structures	Landmarks (specific structures beside carriageway)	None required in addition to existing structures	Same as level E	Conspicuous and tall enough; at problematic spots/sections with no usable landmarks	Equip with radar reflectors, where necessary	Equip with radio beacons, where necessary
Traffic manage-	Construction site detour	Marking with temporary signs or utilising existing signs	Standardised markings that can be perceived correctly by AVs	Same as level D	Same as level D	Same as level D

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Physical infrastructure adaptations for AV	C: Enhanced infrastructure wrt maintenance	B: Improved infrastructure wrt MRM	A: Improved infrastructure wrt positioning and supervision
	Road works	According to national guidelines	Markings and arrangement compatible to (pre-)standards related to AVs. Location and physical arrangement in digital form in a standard accepted by HD map	Same as level D	Same as level D	Same as level D

4.1.2 Digital infrastructure

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Static digital information / map support	C: Dynamic digital information	B: Cooperative perception	A: Cooperative driving
Connectivity	Cellular communication	None required	Available	Available	Available	Available
	Short-range communication (ITS-G5, C-V2X, etc.)	None required	None required	Available at selected hot spots	Available at all hot spots	Available at all hot spots and critical road sections
	Communication performance	None required	Download and upload speed min 5 Mbit/s, latency <5 s, reliability min 90%	Download and upload speed min 15 Mbit/s, latency <500 ms, reliability min 95%	Download speed min 100 Mbit/s and upload speed min 25 Mbit/s, latency <20 ms, reliability min 99%	Download speed min 100 Mbit/s and upload speed min 100 Mbit/s, latency <10 ms, reliability min 99.99%

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Static digital information / map support	C: Dynamic digital information	B: Cooperative perception	A: Cooperative driving
Positioning	GNSS	Only local correction service (RTK) available which requires conversion from local to global	Same as level E	WGS84 correction service via satellite available	Same as level C Decimetre level accuracy achievable with dual frequency receiver	WGS84 and IP network localisation assistance available, sub-decimal accuracy achievable together with dual frequency receiver plus navigational aid on problematic shadow road sections

Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Static digital information / map support	C: Dynamic digital information	B: Cooperative perception	A: Cooperative driving
HD Map	None required	Available with information of static infrastructure Updates on changes in infrastructure available within 24h	Same as level D plus Updates on temporary events like roadworks and on frequent changes in traffic management in real time Information of • Road condition • Variable message sign display • Temporary changes in bearing capacity of road, bridge and shoulder	Same as level C	Same as level C

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Static digital information / map support	C: Dynamic digital information	B: Cooperative perception	A: Cooperative driving
C-ITS (or similar)	Immediate collision warnings	None required	None required	None required	High-quality information available by infra-based sensors for hazards not visible by in-vehicle sensors (V2I)	Individual trajectory for collision avoidance
	Event, incident and other hazardous location information	None required	None required	Traffic Management Centre (TMC) provides information on incidents and events, and dynamic traffic information	More specific high-quality information on incident or event available (V2I)	Individual trajectory recommendation available
	Road works information	None required	None required	Dynamic information on location etc. on stationary and mobile roadworks,	Real-time high-quality information available of stationary and mobile roadworks	Individual trajectory recommendation available
	In-vehicle signage	Conventional (physical) infrastructure only, no AV support	Static signs in digital map	Information on VMS displays available in the vehicle	Same as level C	Same as level C
	Information on weather conditions	None required	None required	Road weather station information and weather or road condition warnings (I2V) available	Cooperative (V2I) high-quality and accurate weather and road condition information available	Individual trajectory recommendation available

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Static digital information / map support	C: Dynamic digital information	B: Cooperative perception	A: Cooperative driving
Traffic management	Traffic flow information	None required	Historic traffic performance status available, updated annually, EU EIP[2] Basic (*) level	Real-time information on traffic flows, EU EIP Enhanced (**) level	EU EIP Enhanced (**) quality level for cooperative services	EU EIP Advanced (***) quality level for cooperative services
	Routing advice	Available for major routes, not machine readable	Machine readable format; Digitalisation of existing detours	Dynamic smart routing	Dynamic smart routing via data exchange with vehicle manufacturer/service provider clouds	Same as level B

[2] EU EIP quality classification will be later hosted by the NAPCORE project

	Attribute	E: Conventional (physical) infrastructure only, no AV support	D: Static digital information / map support	C: Dynamic digital information	B: Cooperative perception	A: Cooperative driving
Framework	Digital traffic rules and regulation	Documentation available only in human readable form	Digitalisation of static rules and regulations according to standards (e.g. METR)	Provision of prevailing rules and regulations incl. VMS	Same as level C	Same as level C
	Availability of physical and digital infrastructure	Documentation available only in human readable form	Digitalisation of infrastructure attributes (especially those related to ODD)	Dynamic updating of infrastructure based on changes due to damages, maintenance, building, …	Dynamic updating based also on CAV data	Same as level B
	Traffic management plans and real time guidance	Documentation available only in human readable form	Digitalisation of existing TMPs	Digitalisation of TMP use in real time	Same as level C	Same as level C
	ODD/ISAD management information	Documentation available only in human readable form	Digitalisation of static ODD attributes and their value	Digitalisation of dynamic ODD attributes and their value	Provision of basic ODD management based on data exchange between infrastructure and AVs	Provision of immediate ODD management based on data exchange between infrastructure and AVs

4.1.3 Environmental conditions

Attribute	E: No AV support	D: Static digital information on environmental conditions	C: Dynamic digital information on environmental conditions	B: Cooperative perception on environmental conditions	A: Cooperative driving, taking into account the environmental conditions
Visibility Friction Water on road Wind	Road-side-stations measure or TMC receives otherwise information on meteorological visibility, friction, water on road, wind but no direct access to the data available for road users at the moment. Weather forecasts available.	Historic information on environmental conditions available in machine readable form	Infra-based weather information available	High-quality detailed cooperative weather information (V2I) or other road section weather information available: obtained via processing and sharing perception sensor findings by vehicles present on the particular road segment and infra-based information. Minimum traffic flow needed to keep information up-to-date.	Individual trajectory recommendation available taking into account the prevailing environmental conditions

4.1.4 Dynamic elements

	Attribute	E: Conventional traffic management	D: Traffic management AV-perceived	C: Dynamic traffic and incident management	B: Enhanced traffic and incident management	A: Local traffic management for AVs
Traffic management	Monitoring systems/ services	Roadside traffic, road weather and environment monitoring with 95% availability and sufficient coverage	Data available in machine readable form	Dynamic traffic and weather monitoring with 99% availability	Inclusion of in-vehicle data	Dynamic traffic and weather monitoring with 99.5% availability
	Traffic management services	Traffic information only	Traffic management plans available (via METR)	Dynamic information of current TM plans in force	Same as level C	Same as level C
	Variable speed limits	Not required	Not required	If VLS exists then it is at least either weather or traffic controlled	If VSL exists, then both traffic & weather control	Same as level B
	Tunnel management services	According to the tunnel directive	Local guidance used during tunnel or lane closures consistent with AV perception and navigation capabilities	Same as level D but ensuring cooperative communication performance in the tunnel(s)	Same as level C	Provision of local traffic management arrangement in digital form for local dynamic maps for tunnels during service breaks and tube closures including trajectory guidance

	Attribute	E: Conventional traffic management	D: Traffic management AV-perceived	C: Dynamic traffic and incident management	B: Enhanced traffic and incident management	A: Local traffic management for AVs
	Incident management	Manual reporting, management and clearance of incidents	Provision of incident-related data (exact location, impact, etc.) in machine readable form	Local guidance at incident sites consistent with AV perception and navigation; use of incident trailers where relevant	Automatic Incident Detection at critical spots utilising also data from CAVs;	Provision of local traffic management arrangement in digital form for local dynamic maps for incident sites including trajectory guidance
	Road works management	According to current guidelines	Local guidance at road works sites consistent with AV perception and navigation capabilities	Use of roadworks trailers with C-ITS transmission	Same as level C	Provision of local traffic management arrangement in digital form for local dynamic maps for road works including trajectory guidance
	Traffic management centre systems	No changes due to AVs	Self-diagnostic hardware (diagnosis of any anomalies in the operation of the system)	Self-healing hardware and software (recovery of system performance)	Self-learning software (improvement of system operation and performance on basis of earlier situations and anomalies)	Self-management systems (management of the system, traffic, and operational activities)

4.2 Application to motorway E12 Helsinki-Tampere

The results of the inventories carried out by the other tasks of the project have been compiled in the table 11 according to road sections as used by the Finnish Transport Infrastructure Agency. The inventories were carried out separately for both carriageways or driving directions. Some of the inventories involved empirical studies and measurements while some were based on data bases and expert interviews.

The inventories indicate that almost all attributes meet the category E demands except for short-range communications and ODD/ISAD management information, which both are non-existent now.

Some attributes indicate infrastructure support for highly automated driving according to levels D, C and even B. These include cellular network coverage and performance, satellite positioning, traffic flow information, weather condition information (visibility, friction, water on road, and wind), monitoring infrastructure, and traffic management centre systems.

The support exists for most of the road with regard to shoulder width and existence of widenings or lay-bys sufficient for MRMs, and variable speed limits.

*Table 11. ISAD levels on the E12 road sections from Ring road III (section 103) to Tampere (135). * denotes attributes not checked via field studies.*

Road section **ISAD attribute**	**103**	**104**	**106**	**108**	**109**	**111**	**112**	**113**	**115**	**116**	**117**	**118**	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**134**	**135**
Lane marking retro-reflectivity	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Luminance contrast ratio *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Lane marking con-sistency	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Bearing capacity of lane *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Shoulder width	C/E	C	C	C	C	C/E	E	E	E	E/C	C	C	C	C	C	C	C	C	C	C	C
Shoulder bearing ca-pacity *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Widening or lay-by	D	D	D	D	D	D	D	D	D	D	D	D	E	E	E	E	E	E	E	E	E
Drivable area sign *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Induced road surface condition	<E	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	<E	D
Landmarks (here: lighting poles	C	D	D/C	D/C	D	D	D	D/C	D	C	D/C	D	D	D	D	D/C	D/C	D/C	D/C	D/C	C
Construction site de-tour *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Road works *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Communication cellular & perform.	D	D/E	D/E	D/E	D/E	D/E	D/E	D/E	D/E	D/E	D	D/E	D/E	D/E	E/D	E/D	D/E	E/D	D/E	D/E	D/E
Short-range commu-nication *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GNSS positioning	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
HD map *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
C-ITS services	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E

Road section ISAD attribute	103	104	106	108	109	111	112	113	115	116	117	118	120	121	122	123	124	125	126	134	135
Traffic flow information *	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Routing advice *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Digital traffic rules and regulation *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Availability of phys./ dig. infrastructure *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Traffic mgmt plans & real time guidance *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
ODD/ISAD mgmt information *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Visibility	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Friction	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Water on road	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Wind	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Monitoring systems/ services *	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Traffic management services *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Variable speed limits *	C	C/E	E	E	E	E	E	E	E	C/E	E	E	E	E	E	E	E	E	C/E	C	C
Tunnel management services *	-	-	-	-	-	-	-	-	-	E	-	-	-	-	-	-	-	-	-	-	-
Incident management *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Road works management *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Traffic management centre systems *	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

Table 12. ISAD levels on the E12 road sections from Tampere (road section 135) to Ring road III (103). ** denotes attributes not checked via field studies.*

Road section / **ISAD attribute**	**103**	**104**	**106**	**108**	**109**	**111**	**112**	**113**	**115**	**116**	**117**	**118**	**120**	**121**	**122**	**123**	**124**	**125**	**126**	**134**	**135**
Lane marking retro-reflectivity	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Luminance contrast ratio *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Lane marking consistency	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Bearing capacity of lane *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Shoulder width	C/E	C	C	C	C	C/E	E	E	E	E/C	C	C	C	C	C	C	C	C	C	C	C
Shoulder bearing capacity *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Widening or lay-by	D	D	D	D	D	D	D	D	D	D	D	D	E	E	E	E	E	E	E	E	E
Drivable area sign *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Induced road surface condition	<E	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	<E	D
Landmarks (here: lighting poles	C	D	D/C	D/C	D	D	D	D/C	D	C	D/C	D	D	D	D	D/C	D/C	D/C	D/C	D/C	C
Construction site detour *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Road works *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Communication cellular & perform.	D	D/E	D/E	D/E	D/E	D/E	D/E	D/E	D/E	D/E	D	D/E	D/E	D/E	E/D	E/D	D/E	E/D	D/E	D/E	D/E
Short-range communication *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GNSS positioning	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
HD map *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
C-ITS services	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E

Road section ISAD attribute	103	104	106	108	109	111	112	113	115	116	117	118	120	121	122	123	124	125	126	134	135
Traffic flow information *	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Routing advice *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Digital traffic rules and regulation *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Availability of phys./ dig. infrastructure *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Traffic mgmt plans & real time guidance *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
ODD/ISAD mgmt information *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Visibility	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Friction	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Water on road	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Wind	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Monitoring systems/ services *	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
Traffic management services *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Variable speed limits *	C	C/E	E	E	E	E	E	E	E	C/E	E	E	E	E	E	E	E	E	C/E	C	C
Tunnel management services *	-	-	-	-	-	-	-	-	-	E	-	-	-	-	-	-	-	-	-	-	-
Incident management *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Road works management *	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Traffic management centre systems *	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

5 Proposal for main road classification

5.1 Relevant road types and automated driving use cases

The Finnish main roads contain the following:

- motorways
- four-lane roads, i.e. non-motorway 2+2 lane roads
- three-lane roads, i.e. 1+2 lane roads with separation by fence/barrier between driving directions
- two-lane roads, i.e. undivided 1+1 lane roads

The motorways have been treated earlier, and this chapter deals only with the other main roads.

The roads might locate in rural, peri-urban or urban surroundings with speed limits ranging usually from urban 50 km/h to inter-urban 100 km/h. The intersections can be of different type, including also traffic signals. There may be pedestrians and bicyclists on the drivable area and crossing it.

The automated driving use cases may contain automated buses and shuttles, robot taxis, and goods transport robots.

5.2 Attributes to be considered

5.2.1 Physical infrastructure

The physical attributes relevant for motorways are also deemed relevant for non-motorway main roads.

The physical infrastructure related attributes include a number of additions, partly due to additional use cases and especially partly due to change of road type. The new relevant attributes are listed in the table below.

Physical infrastructure attributes

	Attribute	Definition	Relevance
Driveable area geometry	Transverse-divided	Separation of driving direction by different means (barriers, fences, etc.)	Safe operation of AVs
Driveable area edge	Passenger pick-up /drop-off point	Specific areas for passenger pick-up and drop-off	Essential for public transport, robot taxi or delivery services
Junctions	Roundabout	Signalised or un-signalized rounda-bouts	Areas for merging, cross-ing, turning
	Intersections	T-, X-, Y-, staggered with/without signals; grade separated	As above
Special structures	Pedestrian crossing	Marked crossing for pedestrians and cy-clists for road cross-ing	Safety of vulnerable road users
	Separation of pedestri-ans and bicyclists		Safety of vulnerable road users
	Rail crossing	Grade crossing of railroad or tramway possibly equipped with gates or signals	Safe operation of AVs

5.2.2 Digital infrastructure

All digital infrastructure attributes regarded as relevant for motorways were deemed rel-evant for also for non-motorways.

An addition to the attributes relevant for the other main roads than motorways are signal related C-ITS services.

	Attribute	Definition	Relevance
C-ITS	Traffic signal information (GLOSA, TTG)	Cooperative traffic information service which provides time to green or optimal speed advice wrt. green light	Supports economic driving style in vicinity of traffic lights

Other possible additions are related to the use cases as the public transport, taxi and delivery use cases will likely require fleet management and thereby fleet supervision facilities which may require specific digital infrastructure. The fleet supervision centres and facilities as such are considered here part of service, not part of ODD.

5.2.3 Environmental conditions

The environmental condition related attributes relevant for motorways are also relevant for non-motorway main roads. No new attributes were found relevant.

5.2.4 Dynamic elements

The dynamic element related attributes relevant for motorways are also relevant for non-motorway main roads. No new attributes were found relevant.

6 Conclusions and recommendations

6.1 Conclusions

6.1.1 Proposed classifications

The classification has utilised the ISAD (infrastructure Support for Automated Driving) levels (Lytrivis et al. 2019) as its starting point. However, we have extended if according to the BSI (2020) ODD taxonomy to also the attribute areas of physical infrastructure, environmental conditions, and dynamic elements. We have maintained the five ISAD levels from E to A while giving the level labels descriptions corresponding to those of the original ISAD oriented towards digital infrastructure.

We learned of the LOSAD classification (Garcia et al. 2021) in a late phase of the action and thereby that was not considered when planning our classification. However, the main new aspects of the LOSAD proposal i.e. the inclusion of physical infrastructure and its maintenance are fully covered by our work. The results of the E12 section analysis using our classification did not indicate major issues in the fragmentation of Operational Road Sections (ORS) highlighted by LOSAD.

The proposed classifications have been aligned to the original ISAD level descriptions in terms of their achievability with regard to technology maturity and neutrality. Thereby, for instance, level A is regarded as a vision not to be realised within the next decades on the Finnish road network. Recommendations made for level A are not seen as realistic objectives (at least in the foreseeable future)

The classification is made for motorways in the Finnish conditions only. According to the E12 case study the Finnish motorway are likely corresponding quite nicely to the proposed classification, with most sections reaching level D and many even level C.

For other main roads than motorways, the ISAD classification does not require many changes in terms of classification attributes. All but one of the changes needed related to the physical infrastructure and were due to either road environment or use case differences. The C-ITS services related to signalised junctions was the one additional change and related to the digital infrastructure. For city streets, the changes would likely be larger.

6.1.2 Implications to practice

The most important outcome of the action is likely the identification of relevant ODD-related ISAD attributes for four different categories of physical infrastructure, digital infrastructure, environmental conditions and dynamic elements. These attributes can be classified in a number of ways for different purposes related to the support given to and the requirements of automated vehicles. The relevance of different attributes will change on the basis of the use case, the vehicle manufactures, the operating environment, technology development and other factors. Individual attributes may become redundant or need to be added but the proposed classification framework is likely suitable also for the future.

The classification has no consequences on current investment plans or programmes. Neither is there a need to make any changes in the current road operations related planning practices. The classification is largely based on assumptions related to the ODDs of automated planning to be rolled out during the next decades. Decisions of investments and operational practices must be based on real facts on automated vehicle technologies and ODDs instead of assumptions only.

Nevertheless, it would be valuable to consider actions concerning attributes for which we are still on the E level or even below as such actions would likely benefit also today's road users.

It needs to be pointed out that the ODDs of highly automated vehicles will likely differ considerably depending on the vehicle manufacturer, ADS provider, and use case. Furthermore, the automated vehicles will need to know the exact values of the ODD attributes in real time. Hence, for the automated vehicle industry stakeholders the proposed ISAD classification of today and knowledge of the ISAD category of a road section will not be very important except for some specific ODD attributes. The objective of the classification has been to provide the road operators a tool for setting the service levels for their road networks and the supporting digital and communication infrastructures rather than a classification to be used by individual automated vehicles.

The proposed sharing of ODD and ISAD information between the road operator or traffic manager and vehicles or vehicle fleet operators/managers is quite important for future traffic management, but no easy solutions exist today and such need to be developed in cooperation with the related stakeholders including agreements on any governance and liability issues.

6.1.3 Next steps

As one of the next steps all motorways should be mapped against the classification at least based on data available in the road databases as well as other relevant data bases.

The ISAD classification should be developed also for other main roads as well as city streets utilising the results of research projects, pilots and other experiences.

It would be extremely useful to test the proposed classification in practice, e.g. in European projects and actions to find out about the applicability of the classification in other countries and circumstances.

Some of the classification items require more work to increase their detail and reduce their ambiguity. One example deals with communication hot spots – it would be important to clearly specify what is meant by a hot spot.

Sharing data of the detailed ISAD attributes with the vehicles is a crucial element of the ODD/ISAD framework. Thereby discussions with TN-ITS (2021) should be initiated in order to consider extending the current TN-ITS specification to cover the additional attributes identified in this work.

6.2 Discussion

6.2.1 Transferability to other countries and conditions

The proposed classification was developed to be transferable to motorways everywhere, at least in Europe. At the same time, the Finnish conditions naturally play a major role in the results of the classification in the Finnish case study.

One example is the treatment of exit and merging sections on motorway ramps. On Finnish motorways these are not considered very problematic although in some countries with high traffic and motorway densities these are critical parts of the network.

6.2.2 Development needs

In addition to the classifications of other road types, the major need for development is linked to technology evolution related to automated vehicles. The sensor, AI and software technologies of automated vehicles determine also their ODDs and along with that the need for infrastructure and traffic management support. Hence, the ISAD levels should evolve according to the AV technology evolutions. This means that the detailed ISAD levels will likely change dynamically during the next decades and years even though the target of the classification specification now was not to limit to the technology and possibilities today. This dynamic nature of ISAD classifications needs to be kept in mind.

With regard to facilitating automated driving, an important future target is to develop, deploy, operate and maintain a secure up-to-date standardised data set containing the values of each ODD attribute utilised in the ISAD classification. This should cover all road networks where highly automated driving of SAE levels 3-5 is to be permitted. It should be noted that the proposed classification is related to the strategic and tactical decision making of the automated vehicle and the operational level decisions are expected to be made on the basis of vehicle’s onboard sensors.

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Annex 1 Potential ODD-ISAD attributes

ISAD/ODD attribute: Physical infrastructure		***Source document(s)***
Top level	**Lower lever**	
Drivable area type	Motorway with active traffic management	BSI (2020)
	Motorway without active traffic mgmt	BSI (2020)
	Horizontal-Curve	BSI (2020)
	Tranverse-Divided	BSI (2020)
	Transverse-Pavements	BSI (2020)
	Transverse-Types of lanes together	BSI (2020)
Driveable area lane specifica-tion	Lane dimensions [width]	BSI (2020), Ulrich et al (2020)
	Lane marking [width]	BSI (2020), Ulrich et al (2020)
	Lane marking [retroreflectivity]	BSI (2020), Ulrich et al (2020)
	Luminance contrast ratio	Somers (2019)
	Lane marking [consistency]	BSI (2020), Ulrich et al (2020)
	Lane type	BSI (2020)
	Bearing capacity of lane	Ulrich et al. (2020)
	Number of lanes;	BSI (2020)
	Direction of travel	BSI (2020)
Driveable area edge	Line markers	BSI (2020)
	Shoulder (paved or gravel);	BSI (2020)
	Shoulder width (outside)	Ulrich et al. (2020)
	Shoulder width (inside)	Ulrich et al. (2020)
	Shoulder bearing capacity	Ulrich et al. (2020)
	Widening or lay-by	Ulrich et al. (2020)
	Shoulder (grass)	BSI (2020)
	Solid barriers (e.g. grating, rails, curb, cones);	BSI (2020)
	Temporary line markers;	BSI (2020)
Drivable area surface	Drivable area surface type	BSI (2020)
	Drivable area induced road surface condi-tions	BSI (2020)
Drivable area signs	Fixed	BSI (2020)
	Variable	BSI (2020)
	Sign retroreflectivity class	Ulrich et al. (2020)
	Sign visibility	Ulrich et al. (2020)
	Intersections	BSI (2020)
Special structures	Automatic access control	BSI (2020)
	Bridge	BSI (2020)
	Tunnel	BSI (2020)
	Toll plaza	BSI (2020)
Fixed road structures	Buildings	BSI (2020)
	Street lights	BSI (2020)
	Street furniture e.g. bollards	BSI (2020)
	Vegetation	BSI (2020)

	Landmarks (in support of GNSS positioning)	Ulrich et al. (2020)
	Localisation assistance e.g. cabling, …	
	Gamefence	Ulrich et al. (2020)
Temporary road structures	Construction site detours	BSI (2020)
	Road works	BSI (2020)
	Road signage	BSI (2020)

Potential ISAD/ODD attributes: Digital infrastructure		***Source document(s)***
Top level	**Lower level**	
Connectivity	Cellular communication, 4G	BSI (2020)
	Cellular communication, 5G	BSI (2020)
	Number of redundant cellular networks	
	Download speed	
	Upload speed	
	Latency	
	Reliability	
	Cellular communication, 5G (mm wave)	
	Short-range communication (ITS-G5, C-V2X,…)	BSI (2020)
Positioning	Positioning: GNSS	BSI (2020)
	Localisation assistance: IP network	
	Localisation assistance: geostationary satellite	
	Localisation assistance: LEO satellite	CCAM WG3 (2021)
HD map	HD map of the road environment	CCAM WG3 (2021)
	Road type	CCAM WG3 (2021)
	Number of lanes	CCAM WG3 (2021)
	Lanes dedicated to AVs	CCAM WG3 (2021)
	Sight distance restrictions and curvature	CCAM WG3 (2021)
	Lane markings (for humans, video and lidar sensors)	CCAM WG3 (2021)
	Horizontal symbols and arrows	CCAM WG3 (2021)
	Street lighting	CCAM WG3 (2021)
	Pavement of road and skid resistance	CCAM WG3 (2021)
	Paved shoulder	CCAM WG3 (2021)
	Road condition	CCAM WG3 (2021)
	Lay-by and parking area	CCAM WG3 (2021)
	Passenger pick-up / drop-off point	CCAM WG3 (2021)
	Operating speed	CCAM WG3 (2021)
	Traffic signs	CCAM WG3 (2021)
	VMSs	CCAM WG3 (2021)
	Localisation assistance	CCAM WG3 (2021)
	Uptodateness - change in infrastructure e.g. road marking updates, etc.	
	Uptodateness - temporary events, roadworks etc.	
	Uptodateness - frequent changes e.g. traffic management	

	Bearing capacity of road, bridge, shoulder	CCAM WG3 (2021)
C-ITS (or similar online information sources)	Immediate collision warnings	CCAM WG3 (2021)
	Event, incident and other hazardous location information	CCAM WG3 (2021)
	Roadworks information (stationary and mobile)	CCAM WG3 (2021)
	In-vehicle signage	
	Information on weather conditions	CCAM WG3 (2021)
	Traffic signal information (GLOSA, TTG)	CCAM WG3 (2021)
Traffic management	Traffic performance status (historic)	CCAM WG3 (2021)
	Real time information on the traffic flows	CCAM WG3 (2021)
	Routing advice, incl. the timing of alternatives	CCAM WG3 (2021)
	Warnings and information via Variable Message Signs	
	Traffic management plans and real-time guidance	CCAM WG3 (2021)
	ODD/ISAD management information	CCAM WG3 (2021)
Framework	Digital traffic rules and regulation	CCAM WG3 (2021)
	Availability of physical infrastructure	CCAM WG3 (2021)
Remote control	Fleet supervision centre/facilities	CCAM WG3 (2021)

ISAD/ODD attribute: Environmental conditions	***Source document(s)***
"Visibility" at different wavelengths and frequencies	BSI (2020)
Rainfall	BSI (2020)
Snowfall	BSI (2020)
Hail	BSI (2020)
Freezing rain	BSI (2020)
Air temperature	BSI (2020)
Humidity	BSI (2020)
Air pressure	BSI (2020)
Non-precipitating water droplets, marine	EU EIP
Non-precipitating water droplets or ice crystals (mist/fog), other than marine	BSI (2020)
Sand and dust	BSI (2020)
Smoke and pollution	BSI (2020)
Volcanic ash	BSI (2020)
Tyre-road friction	BSI (2020)
Icy	BSI (2020)
Snow on drivable area	BSI (2020)
Flooded roadways	EU EIP
Standing water	
Wet road	
Surface contamination	BSI (2020)
Mirage	BSI (2020)
Surface temperature	BSI (2020)
Wind	BSI (2020)
Elevation of sun above the horizon	BSI (2020)
Position of sun	BSI (2020)

Night or low-ambient lighting condition	BSI (2020)
Cloudiness	BSI (2020)
Artificial illumination	BSI (2020)
Electromagnetic interference	CCAM WG3 (2021)
Solar flares	EU EIP
Clutter	EU EIP
Vibration	EU EIP

ISAD/ODD attribute: Dynamic elements		***Source document(s)***
Top level	**Lower level**	
Traffic	Density of agents;	BSI (2020)
	Volume of traffic (AADT)	BSI (2020)
	Flow rate (veh/h)	BSI (2020)
	Congested (% of HCM LoS D+E+F)	-
	Agent type	BSI (2020)
	Presence of special vehicles (e.g. ambulances or police vehicles)	BSI (2020)
Events & Incidents	Events	Ulrich et al (2020)
	Road accidents	Ulrich et al (2020)
	Vehicle breakdown or stoppage	Ulrich et al (2020)
	Road works	Ulrich et al (2020)
	Winter maintenance	Ulrich et al (2020)
	Road maintenance	Ulrich et al (2020)
Maintenance	Road maintenance incl. vegetation	Ulrich et al (2020)
	Winter maintenance	Ulrich et al (2020)
Traffic management	Monitoring systems/services	Ulrich et al (2020)
	Traffic management services	Ulrich et al (2020)
	Variable speed limits	-
	Tunnel management services	Ulrich et al (2020)
	Incident management	Ulrich et al (2020)
	Road works management	Ulrich et al (2020)
	Traffic management centre systems	Niculescu et al (2020) -

Finnish Transport Infrastructure Agency

Nordic WAY 3

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Working report
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Service level framework for automated road transport

Task 3 Follow up actions

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Task 3 Follow up actions
Working Report

2 September 2021

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1 Background

The overall objectives of the project ”Service level framework for automated road transport” for the Finnish Infrastructure Agency were to

- assess the feasibility of the selected motorway section (Highway E12 between Helsinki and Tampere) for the automated operation of SAE Level 3 and 4 automated vehicles
- propose classification for the Finnish road network from the automated vehicles operations' point of view, i.e. a framework for service level classification for automated vehicles
- propose further actions in research- and development work, as well as in international cooperation.

The objective of work reported in this document was to identify the follow up actions for this service level classification project.

2 Method

All tasks of the project, namely

- Task 1.1 Physical infrastructure, dynamic elements
- Task 1.2 Digital infrastructure/connectivity
- Task 1.3 Digital infrastructure/positioning
- Task 1.4 Environmental conditions
- Task 1.5 Digital infrastructure/C-ITS services
- Task 1.6 Physical infrastructure
- Task 2 Service level classification for highly automated driving on motorways

listed recommendations for follow up actions. These recommendations were listed and elaborated further in a workshop with the project team and FTIA.

3 Follow up actions

Most follow up actions identified below are related to following of standardisation activities that should be made on European level or globally. Therefore, it is important to ensure that these follow up actions are brought to agendas of the related collaboration bodies and platforms.

Actions assigned to national organisations are highlighted with blue in the tables below.

3.1 Physical infrastructure

What	Why	By whom
Clarify detailed requirements concerning the traffic management, road space and other road operator actions required by Minimal Risk Manoeuvres (MRMs) for the various automated driving use cases - to which MRMs road operator must be prepared for - which are infrastructure requirements of these MRMs (Follow actions on European level)	Otherwise MRMs may result in network lockdowns or major bottlenecks	Standardisation organisations, incl. OEMs and road operators
Develop European solutions for lane and edge marking related problems like on non-motorway main roads at junction with widenings made for evasive actions of left-turning vehicles and for other typical similar challenging locations (Follow actions on European level)	Lane markings may confuse driving automation. For example, if the right-hand edge line is painted according to the widening it may potentially cause confusion for the automated vehicle Relevant for all lane keeping automation	FTIA, Traficom
Investigate the impacts and demands of truck platooning on road structures and pavements, define related follow up actions if needed	To maximise the benefits of truck platooning and to minimise the harm on Finnish road network	FTIA

What	Why	By whom
To follow if MRMs cause crashes due to lack of safe space for it. For those locations, consider design and construction of new widenings and lay-bys or other solutions	Ensure safe MRMs	FTIA
Introduce defect measurements on regular basis on sections provided for automated driving with automated pothole and other defect detection methods	Good surface condition supports safe automated driving. E.g. some potholes may be difficult to detect by vehicle sensors.	FTIA
Investigate whether truck platoons require changes to road and bridge structures like the higher bearing capacity than traffic today.	Sufficient road and bridge structures support safe automated driving	FTIA

3.2 Digital infrastructure

Digital infrastructure and communications networks

What	Why	By whom
Enhance road registry data content and quality to meet the needs of automated driving support (agreed on European level) - Identify essential attributes for automated driving (ODD attributes) - Check the quality of those entries, define accuracy requirements for them (Follow actions on European level)	The current data for all attributes is not accurate enough, and some features should be updated according to the needs of automated driving e.g. width of carriageway As the regulation/guidelines on road infrastructure change, the compliance with the current regulation should be registered	FTIA
Study the effects of increase in (proportion of) traffic requiring high capacity connectivity and requirements of new use cases (Follow actions on European level)	It is important to understand what increased number of users and requirements of new use cases mean for connectivity in general and for mobile networks	Traficom
Study if a hybrid model using also other means that cellular communication would be cost effective in specific locations (Follow actions on European level)	The deployed solution must be in line with what is used by vehicle manufacturers	Traficom & Fintraffic
Study how identified use cases of digital infrastructure relate/localize to different road sections and how it might affect the service level requirements (Follow actions on European level)	To support automated driving the service level requirements might be different in different parts of the road, incl. tunnels, sections with roadwork	FTIA & Traficom
Study the use cases and requirements of mobile edge computation (Follow actions on European level)	Edge computation may support also communication with and between vehicles, possibly requiring localisation of the computation units close to the road	Traficom & Fintraffic

What	Why	By whom
Specify what is meant by "hot-spot" where short range communication is required and study how to set up a cost effective short range communication solution for them (Follow actions on European level)	To be able to communicate better the set requirement and their cost implications	FTIA & Traficom & Fintraffic
Plan how to deal with fleet supervision centres and their communication needs including real-time video	The requirements for reliable communication of real-time video are demanding and require special attention. Willingness to pay for the communication may be higher than for other use cases. Some locations are more potential than others, like tunnels, moving roadworks, etc.	Fleet operators
Develop global sharing solution for detailed ODD/ISAD attribute information among road operators, traffic managers, vehicles and vehicle fleet operators/managers including technical, operational, institutional, governance, cybersecurity and liability issues (Follow actions on European level)	The sharing of ODD information from vehicles to the road operator or traffic manager in real time is essential for safe road network operation as is also the real-time sharing of ISAD/ODD attribute values to the vehicles. The sharing of safety related information is a first but very small step to this direction.	European collaboration platforms, global standardisation bodies
Extend the current TN-ITS (2021) specification to cover the additional attributes identified in this work. (Follow actions on European level)	Sharing data of the detailed ISAD attributes with the vehicles is a crucial element of the ODD/ISAD	European collaboration platforms, global standardisation bodies

Positioning/localisation

What	Why	By whom
Identify road segments planned to be provided for automated driving where GNSS quality is not sufficient, i.e. it is lower than certain dB level	Other positioning/localisation support should be provided on these segments to ensure automated driving function use	MML

What	Why	By whom
(40dB) with 5 strongest satellites (e.g. tunnels, bridges)		
Renew road markings every spring or provide landmarks for road segments with poor GNSS quality, like 2 km before and after Hämeenlinna tunnel	Together with good visibility road markings or landmarks the supporting machine vision system will work better	FTIA
Specify landmarks required for positioning support concerning their properties including possible radio beacons in specified locations (Follow actions on European level)	The requirements are still unknown. Landmarks need to be cost effective to procure, install and maintain. They need to be high enough to be visible also in winter time (higher than snow bank).	Standardisation organisations, incl. OEMs and road operators

C-ITS and information services

What	Why	By whom
Study connectivity and capacity of mobile networks from viewpoint of reliability of C-ITS message provision reliability (Follow actions on European level)	Communication affects the possibilities for use of C-ITS services or other OTA updates	Traficom & Fintraffic
Make traffic announcements on all the (mobile and stationary) roadworks which affect driving	All situations that affect the usability of the road should be informed about. TMC is now not aware of all roadworks nor on their exact timing nor location.	Road operators, roadworks contractors
Present all information in traffic announcements according to harmonised metadata specifications instead of free-form text (Follow actions on European level)	Free-form text is difficult to use for automated vehicles. Everything should be provided in standardised and machine readable format.	Fintraffic
Enhance the information on events, incl. location and driving direction affected, ensure that event information is provided to the road operator (of events affecting driving)	To be able to provide better quality information of the potential incident or other disturbance	Fintraffic

What	Why	By whom
(Follow actions on European level)		
Develop quality frameworks and specify requirements of C-ITS and data sources for automated driving (Follow actions on European level, e.g. C-ROADS and EU EIP)	The quality, accuracy and reliability requirements will increase as the focus moves from C-ITS services for drivers towards C-ITS and data sources supporting automated driving This quality framework will be needed to help ADF (avattava – onko Automated Driving Function?) developers to select suitable data and information sources, which can enable future ADFs in variable conditions.	Standardisation organisations, incl. OEMs and road operators
Adjust data acquisition processes to meet standardised quality requirements	To enhance the quality to match requirements related to data collection, fusion, enrichment, etc.	FTIA & Fintraffic
Make quality aspects a part of service-level agreements (SLA) between service providers and information or data users	The data quality may reflect to the liability issues related to automated driving in the future. Minimum quality must be defined if an automated vehicle relies on C-ITS.	Service providers

3.3 Environmental conditions

What	Why	By whom
Enhance the quality of stored weather and road condition data (priority on friction and visibility information). If friction cannot be measured directly, at least reliable road surface category (icy, snowy, wet, dry, …) should be systematically available. Also, reliable data about other simultaneous environmental conditions (like accumulation of snow, and when it has been cleared) is of interest in the future. Enable combination of both road weather station data, appropriate measurements of the FMI, and information from road maintenance logs, since analysis needs will develop more complex in the future.	For the ODD analysis it is important that at least friction and visibility combinations are available at every time instant, so that their combinations are easily available. Visibility sets minimum requirements for friction and vice versa.	FTIA, FMI

What	Why	By whom
(Follow actions on European level)		
Develop road-side stations to measure visibility at each lane at about one meter height across the lane and to measure also the attenuation of non-visible wavelengths, to include at least 850 – 1550nm wavelengths used by lidars and some IR cameras. (Follow actions on European level)	This would enable monitoring of snow dust and water fog raised by the traffic in front of subject vehicle, not captured by road weather stations today. It is not sufficient to have the human view on the visibility but machine view is relevant for automated driving.	Road weather station industry
Utilisation of road weather sensors of vehicles to complement data from fixed road weather stations (Follow actions on European level)	Better coverage of weather information preferably containing at least friction, visibility, and precipitation would allow better understanding of prevailing conditions and support good road maintenance in winter	Road operators, vehicle manufacturers & fleet operators

3.4 Dynamic elements

What	Why	By whom
Specification of markings and traffic management at roadworks according to the capabilities of AVs (Follow actions on European level)	The Automated Driving Systems should be able to perceive correctly the road works and the intended trajectories to navigate through the road works site	FTIA, road works contractors
Specification of markings and traffic management at incident sites according to the capabilities of AVs (Follow actions on European level)	The Automated Driving Systems should be able to perceive correctly the incident sites and the intended trajectories to by-pass or drive through the incident site	FTIA, police, rescue organisations
Legal framework for the use of automated maintenance vehicles	The appropriate use of automated maintenance vehicles is needed by their operators	MinTC, Traficom
Guidelines for the use of automated maintenance vehicles	The operation of the automated vehicles should be carried out in a safe and efficient manner	Traficom, cities, road maintenance contractors

3.5 Other

What	Why	By whom
Develop MRM taking on board the safety and efficiency requirements of the road operators (Follow actions on European level)	Otherwise MRMs may result in network lockdowns or major bottlenecks	Standardisation organisations, incl. OEMs and road operators