

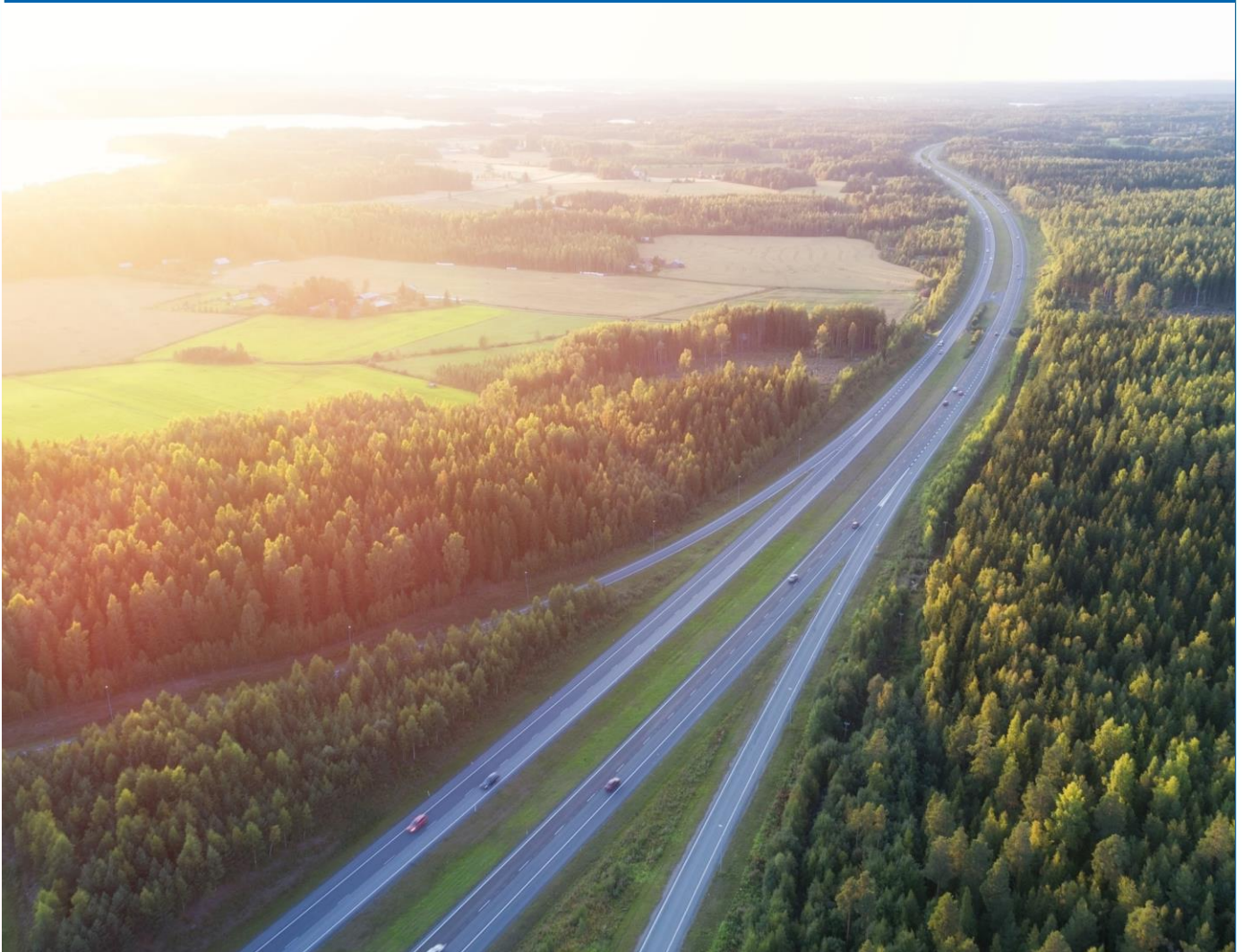


Finnish Transport  
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# **Automated Driving on Motorways (AUTOMOTO)**

Study of Infrastructure Support and Classification  
for Automated Driving on Finnish Motorways





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**Key words:** Automated driving, traffic management, infrastructure

## Abstract

The goals of the project were to 1) assess the feasibility of the selected motorway section for the operation of SAE Level 3 and 4 automated vehicles, 2) propose a framework for service level classification for automated vehicles and 3) prepare a proposal for further research, R&D and international cooperation.

The feasibility of the current road network for automated vehicles was assessed with a detailed inventory of the selected motorway section on E12 highway between Helsinki and Tampere, the overall length of 160 km per direction. Overall, the assessment proved, that the current physical and digital infrastructures provide good support for the basic use cases of level 3 or 4 highway autopilot. The project team did not identify any major defects that would require immediate corrective actions with regards to supporting automated driving on motorways.

The service level classification builds on the ISAD (Infrastructure Support for Automated Driving) levels but has been extended to other relevant attribute areas of physical infrastructure, environmental conditions, and dynamic elements. The five ISAD levels from E to A have been maintained and the new attribute areas have been labeled following the original logic in digital infrastructure. The level thresholds are partly quantitative, where applicable data exists, and partly qualitatively described.

The likely ODD attributes were compiled based on existing literature, and the validation and reformulation of the attributes based on the implemented field measurements and the views of subtask experts. The ODD attribute list was compressed to the most critical attributes, that are applicable in motorway environment and that can be provided with threshold values between the service levels, based on the current knowledge. The accomplished work should give the national authorities and operators a solid understanding of the most critical parts of the infrastructure regarding conditionally or highly automated driving. The created framework should work well in the communication of the overall and thematical AV support for the users and developers.

There are many topics that require active follow-up of international standardization of AV support and related technological development. Topics suitable for national development include the need and requirements for positioning-support landmarks, new solutions for fast detection of road surface defects, and the development of improved road weather information. The next steps regarding the classification are to widen the mapping of the current Finnish motorway network against the classification and the development of similar type of classifications to other road environments. It would also 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, even though the classification was designed especially the Finnish conditions in mind.

**Automaattiajaminen moottoriteillä (AUTOMOTO) - Tutkimus infrastruktuurin tarjoamasta tuesta ja sen luokittelusta automaattisen liikenteen kannalta Suomen moottoriteillä.** Väylävirasto. Helsinki 2021. Väyläviraston julkaisuja 21/2021. 94 sivua ja 1 liite. ISSN 2490-0745, ISBN 978-952-317-857-1.

**Asiasanat:** automaattinen ajaminen, liikenteen hallinta, infrastruktuuri

## Tiivistelmä

Projektin tavoitteena oli a) arvioida valitun moottoritiejakson soveltuvuutta SAE tasojen 3 ja 4 automaattiajoneuvoille, 2) laatia viitekehys moottoriteiden palvelutasoluokittelusta automaattiajoneuvoille sekä 3) tunnistaa aiheita tulevaisuuden tutkimus- ja kehitystyölle sekä kansainväliselle yhteistyölle.

Nykyisen moottoritieverkon soveltuvuutta automaattiajamiselle tutkittiin E12-tien Helsinki–Tampere-välin 160 kilometrin pituisella tiejaksolla. Yleisesti ottaen tutkimus osoitti, että nykyinen fyysinen ja digitaalinen infrastruktuuri antaa hyvän tuen SAE-tasojen 3 ja 4 automaattiajoneuvojen peruskäyttötapauksille. Projektin aikana ei tunnistettu merkittäviä puutteita, jotka edellyttäisivät välittömiä toimenpiteitä automaattiajamisen mahdollistamiseksi.

Palvelutasoluokittelu perustuu ISAD (Infrastructure Support for Automated Driving) -luokitteluun, jota on laajennettu kattamaan olennaiset ominaisuudet fyysisessä ja digitaalisessa infrastruktuurissa, ympäristöolosuhteissa sekä dynaamisissa elementeissä. Luokittelu sisältää viisi tasoa E:stä A:han, joista E-tasolla infrastruktuuri ei tarjoa erityistä tukea, kun taas korkeimmalla A-tasolla vuorovaikutteinen automaattinen liikenne on täysin tuettua. Luokkien raja-arvot on määritelty osittain määrällisesti ja osittain laadullisesti sen mukaan, onko soveltuvaa dataa ollut saatavilla.

Suunniteltua toimintaympäristöä kuvaavat ominaisuudet (ODD-attribuutit) koottiin perustuen olemassa olevaan kirjallisuuteen ja ne validoitiin ja osin muotoiltiin uudelleen perustuen toteutettuihin kenttätutkimuksiin ja asiantuntijoiden näkemyksiin. ODD-attribuutit tiivistettiin lopuksi niihin, jotka soveltuvat moottoritieympäristöön ja joille on nykytiedon valossa esitettävissä luokkien väliset raja-arvot. Laadittu luokittelu antaa kansallisille viranomaisille ja operaattoreille sekä ajoneuvojen käyttäjille ja kehittäjille selkeän kuvan automaattiliikenteen kannalta olennaisesta infrastruktuurista sekä sen tarjoamasta tuesta automaattiajamiselle.

Tutkimuksen aihepiirit edellyttävät kansainvälisen standardointityön aktiivista seurantaan automaattiliikenteen tuen ja siihen liittyvien teknologioiden osalta. Tunnistettuja, kansallisesti edistettäviä teemoja ovat erityisesti ajoneuvon paikantamiseen liittyvä tuki, tien päällystevaurioiden entistä nopeampi havaitseminen ja tiesääntiedon kehittäminen. Jatkotoimenpiteinä, laadittua palvelutasokehikkoa sovelletaan muuhun moottoritieverkkoon sekä kehitetään kattamaan myös alemman tieverkon osia. Vaikka palvelutasoluokittelu on laadittu Suomen liikenneympäristöä ja olosuhteita silmällä pitäen, sen testaaminen on myös laajemmalla eurooppalaisessa viitekehyksessä tärkeää.

**Automatiserad körning på motorvägar (AUTOMOTO). Studie av infrastruktur-stöd och klassificering för automatiserad körning på finska motorvägar.** Trafikledsverket. Helsingfors 2021. Trafikledsverkets publikationer 21/2021. 94 sidor och 1 bilaga. ISSN 2490-0745, ISBN 978-952-317-857-1.

**Ämnesord:** Automatiserad körning, trafikledning, infrastruktur

## Sammanfattning

Syftet med projektet var att a) bedöma lämpligheten för det valda motorvägs-avsnittet för automatiserade fordon på SAE nivå 3 och 4, 2) utveckla en ram för klassificering av motorvägsnivåer för automatiserade fordon, och 3) identifiera ämnen för framtida forskning och utveckling samt internationellt samarbete.

Det aktuella vägnätets lämplighet för automatiska fordon studerades med en detaljerad inventering av motorvägsavsnittet E12 mellan Helsingfors och Tammerfors. Avsnittets längd är 160 km. Sammantaget visade inventeringen att den nuvarande fysiska och digitala infrastrukturen ger bra stöd för grundläggande användningsfall för automatiserade fordon på SAE nivå 3 och 4. Under projektet identifierades inga betydande brister som skulle kräva omedelbara korrigerande åtgärder för att stödja driften av automatiserade fordon.

Servicenivåklassificeringen är baserad på ISAD (Infrastructure Support for Automated Driving)-klassificeringen, som har utökats till att omfatta andra viktiga funktioner inom fysisk infrastruktur, miljöförhållanden och dynamiska element. Fem ISAD-nivåer från E till A har behållits och nya attributområden har fått namn efter logiken i ISAD-ramverket för digital infrastruktur. Gränsvärdena för kategorierna kvantifieras dels om lämpliga data finns tillgängliga och dels kvalitativt.

Troliga ODD-attribut sammanställdes baserat på befintlig litteratur och validerades och delvis omformulerades på grundval av fältstudier som utförts och expert-uppfattningar. Slutligen sammanfattades ODD-listan i de relevanta attributen som är lämpliga för motorvägsmiljön och för vilka gränsvärden mellan kategorier kan presenteras mot bakgrund av aktuell information. Klassificeringen ger nationella myndigheter och operatörer en tydlig bild av kritisk infrastruktur för automatiserad trafik. Klassificeringen kan användas för att kommunicera det automatiska trafikstödet som finns tillgängligt på allmän och tematisk nivå till både fordons-användare och utvecklare.

I framtiden kommer flera ämnen att kräva aktiv övervakning av internationellt standardiseringsarbete, både vad gäller stöd för automatiserade transporter och tillhörande teknik. Ämnen som är lämpliga för nationellt befrämjande omfattar kraven på landmärkesstödjande positionering, metoder för snabb identifiering av vägbeläggningsskador och utveckling av vägväderinformation. Följande åtgärder beträffande servicenivåklassificering är relaterade till kartläggning av hela det finska motorvägsnätet med hjälp av en modell, samt utvidgning av modellen utanför motorvägsnätet. Det skulle också vara användbart att testa klassificeringen i praktiken i europeiska projekt för att få information om dess tillämpbarhet i andra länder och under olika omständigheter, även om klassificeringen utformades särskilt med tanke på finska förhållanden

## Foreword

Automated vehicles are entering the market in the near future, and among the first automated driving applications is highway autopilot. The automated driving system takes responsibility of all driving tasks and lets the driver focus to work, entertainment or rest. Being able to use time efficiently while driving may bring a significant societal benefits in terms of productivity, in addition to the significant traffic safety benefits that are expected as the automated vehicle makes much less mistakes than a human driver. Therefore it is in the interest of the road owner to enable automated driving on as large a section of the road network as possible, should it not take too large investments to enable such applications to function as planned.

The goal of the AUTOMOTO project was to create knowledge, how well the current Finnish motorway network enables SAE level 3 and 4 vehicles operate in an automated mode and what are the most significant factors to which the road authorities and operators should invest in the near future in their research and development as well as international cooperation activities.

The project has been implemented and Finnish Transport Infrastructure Agency, where Jari Myllärinen, Jan Juslen and Petri Antola have been responsible of project management and steering of the work. During the project valuable input has been received from the Coordination group consisting of Kirsi Miettinen from the Ministry of Transport and Communications, Heidi Himmanen and Mikko Räsänen from the Finnish Transport and Communications Agency, Jani Poutiainen and Janne Miettinen from the Finnish Meteorological Institute and Mika Ahvenainen and Sakari Lindholm from the Fintraffic Road Ltd. The project team consisted of experts from four Finnish consultation and research organisations: Risto Kulmala and Matti Huju from Traficon Ltd; Juha-Pekka Piuva, Olli Jokinen, Pekka Eloranta, Mikko Mäkipää and Jaakko Valkonen from Sitowise Ltd; Satu Innamaa, Ari Virtanen, Kimmo Kauvo, Matti Kutila, Pertti Peussa, Maria Jokela, Mikko Tarkiainen and Johan Scholliers from VTT and Tomi Laine, Juha Äijö and Mikael Sulonen from Ramboll Finland Ltd.

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The project was part of the Nordicway 3 project ([www.nordicway.net](http://www.nordicway.net)), which receives funding from the Connecting Europe Facility -programme during 2019-2023.

Helsinki, November 2021

Finnish Transport Infrastructure Agency  
Information Management Department



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## Glossary

API	Application Programming Interface
AV	Automated vehicle
CAV	Connected automated vehicle
CCAM	Cooperative, connected and automated mobility
C-ITS	Cooperative Intelligent Transport Systems
DENM	Decentralized Environmental Notification Message
ETSI	European Telecommunications Standards Institute
EU EIP	European ITS Platform (project)
GNSS	Global Navigation Satellite System
ISAD	Infrastructure Support for Automated Driving
IVIM	Infrastructure to Vehicle Information Message
LIDAR	Light detection and ranging
MCM	Manoeuvre Coordination Message
MRM	Minimal Risk Manoeuvre
ODD	Operational Design Domain
PPP	Precise Point Positioning
PVD	Probe Vehicle Data
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematics
SAE level	Society of Automotive Engineers levels of driving automation
SNR	Signal-to-Noise ratio
VMS	Variable message sign
TMC	Traffic Management Centre

# 1 Goal and Scope of the Project

## 1.1 Background

Cars capable of Level 3 and 4 (according to SAE level definitions, see Figure 1) automated driving are entering the market in the near future. Among the first are expected to be cars capable of automated driving on highways. In such a car, the driver can let the automated driving system take responsibility for car handling on the line section of the whole journey that occurs on the highway while simultaneously enabling them to focus on work, entertainment, or resting. If and when automated driving systems make fewer errors than human drivers, automated driving is estimated to significantly increase traffic safety. Due to this, it is useful for road owners to enable automated driving on as large a section of the road network as possible, within reasonable investment and socio-economically profitable limitations.



# SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You <b>are</b> driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You <b>are not</b> driving when these automated driving features are engaged – even if you are seated in “the driver's seat”		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
Example Features	<ul style="list-style-type: none"> <li>• automatic emergency braking</li> <li>• blind spot warning</li> <li>• lane departure warning</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering OR</li> <li>• adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering AND</li> <li>• adaptive cruise control at the same time</li> </ul>	<ul style="list-style-type: none"> <li>• traffic jam chauffeur</li> </ul>	<ul style="list-style-type: none"> <li>• local driverless taxi</li> <li>• pedals/steering wheel may or may not be installed</li> </ul>	<ul style="list-style-type: none"> <li>• same as level 4, but feature can drive everywhere in all conditions</li> </ul>

Figure 1. Levels of Driving Automation (SAE 2018).

The goal of this work was to provide knowledge on how the current motorway network in Finland could support Level 3 or 4 automated driving and to identify the key factors related to automated driving that officials and road maintenance and traffic management agencies should focus on for research and development actions and in international collaboration during the upcoming years. The project expands upon previous work performed in the field via many EC funded projects such as Inframix, EU EIP, and CCAM. The Inframix project has already provided a simple classification scheme that can be assigned to parts of the network in order to give automated vehicles and their operators guidance on the “readiness” of the roadway network for automated vehicles (Lytrivis et al 2019). The ISAD classification developed in the Inframix project concentrates mostly on digital

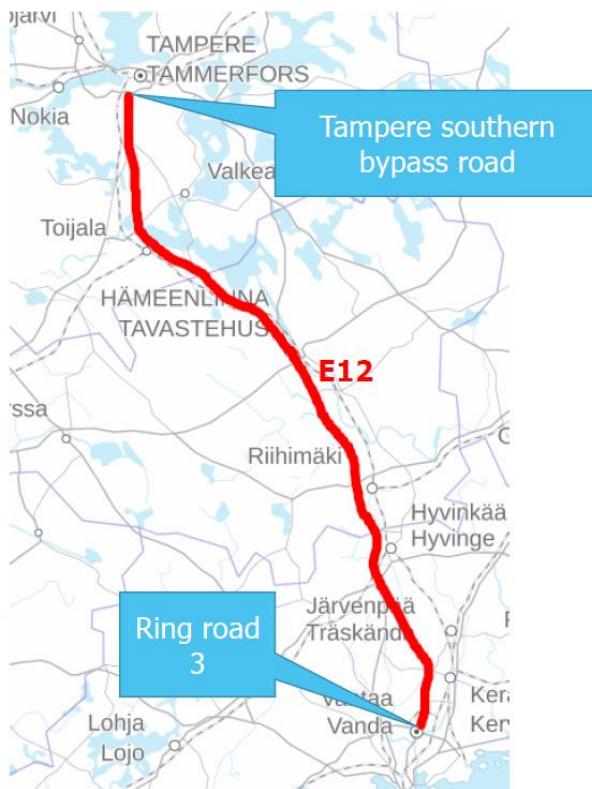
support for autonomous driving, where there is a need to widen the perspective to all physical and digital elements that can support or have an effect on autonomous driving on motorways.

## 1.2 Goal and Scope of the Project

The Finnish Transport Infrastructure Agency initiated a national study which aimed to

- 1) assess the feasibility of the selected motorway section (Highway E12 between Helsinki and Tampere) for the operation of SAE Level 3 and 4 automated vehicles
- 2) propose a framework for service level classification for automated vehicles
- 3) prepare a proposal for further research, R&D, and international cooperation.

Feasibility of the current roadway network for automated vehicles was assessed via a detailed inventory of a selected motorway section along the E12 highway (see Figure 2), with an overall length of 160 km per direction.



*Figure 2. Selected motorway section for the inventory.*

The inventory focused on roadway attributes that are relevant for the Operational Design Domain (ODD) for automated vehicles i.e. the circumstances in which SAE L3 and L4 vehicles are able to operate automatically. The inventory contained both an analysis of data from the current road and traffic databases as well as field measurements regarding, e.g. positioning services, telecommunication services, and road structures and their condition.

Based on the inventory and earlier research, a proposal for the service level framework was developed. The service level framework provides information on the main physical and digital features of the roadway network that should be provided in order to facilitate the operation of Level 3 and 4 automated vehicles. The classification did not target any specific automated driving use case as such; rather, it focused on broader motorway-oriented use cases such as highway chauffeur, highway autopilot, automated freight vehicles on open roads, and truck platooning as listed by ERTRAC (2019).

Also, needs for future follow-up actions were identified and a proposal was provided to progress those topics both in national and international activities.

The project was part of the NordicWay 3 project ([www.nordicway.net](http://www.nordicway.net)) which is funded by the European Commission's Connecting Europe Facility programme during the period of 2019-2023.

## 1.3 Project Tasks

Project implementation was broken down into the following eight (8) coordinated subtasks:

1. Assess the feasibility of the selected motorway section (Highway E12 between Helsinki and Tampere) for the operation of SAE Level 3 and 4 automated vehicles with respect to:
  - 1.1 Physical infrastructure, including static and dynamic features
  - 1.2 Communication networks
  - 1.3 Positioning services
  - 1.4 Weather conditions
  - 1.5 C-ITS and other information services
  - 1.6 The roadway network features' field measurements
2. Prepare a framework for service level classification for automated vehicles in a motorway environment.
3. Prepare a list of further actions for research- and development work and follow-up.

Leaders and experts in the sub-tasks regarding existing inventory also contributed to the development of the service level framework by proposing service level attributes and their threshold values. Furthermore, the experts in their part identified topics for future research as part of their analysis work.

## 1.4 Organisations

The Finnish Transport Infrastructure Agency (FTIA) is an expert agency concentrating on planning, developing, and maintaining road, rail, and maritime transport infrastructure and the coordination of transport and land-use. In addition, it is also responsible for arranging traffic control and winter navigation. FTIA operates in the planning of transport systems as the primary partner of regional councils, municipalities, urban regions, and other players. FTIA deals with the service level of transport, thus promoting well-being in Finnish society and Finnish business competitiveness. FTIA's task is to respond efficiently and

responsibly to customer needs arising from changes in transportation and to produce a growth platform for society in the form of a functional and safe infrastructure.

The Finnish Transport and Communications Agency (Traficom) is an authority on permit, licence, registration, approval, safety and security matters in the transport and communications sectors. Traficom's mission is to build the connections that keep people, data, and goods moving smoothly, securely, and sustainably.

The Finnish Meteorological Institute (FMI) produces observation and research data on the atmosphere, the near space and the seas, as well as weather, sea, air quality, and climate services for the needs of public safety, business life, and citizens. The Finnish Meteorological Institute is an administrative branch of the Ministry of Transport and Communications.

Fintraffic Road is responsible for road traffic management in Finland. Fintraffic Road is dedicated to providing and developing services that ensure safe and fluid transportation. Fintraffic Road invests in reforming and developing services that reflect future needs in a constantly changing operational environment.

The Finnish Ministry of Transport and Communications is responsible for the provision of safe and secure transport and communications connections and services. It also enables the use of new digital services. A major part of transport and communications legislation is being drafted in the European Union. The Ministry is responsible for national-level preparations and follow-up of transport and communications matters. The Ministry guides and supervises the operation of its agencies (mentioned above) and monitors their development.

The project work was carried out as a collaboration between four Finnish consultancies and research organisations Traficon Ltd., VTT Technical Research Centre of Finland Ltd., Sitowise Ltd, and Ramboll Finland. The consultants have worked extensively in the field of automated driving and the related technologies in numerous national and international projects and activities, such as EU EIP and CCAM.

## 2 Key findings from the Feasibility Study on the E12 Highway between Helsinki and Tampere

Key findings from the study will be presented in this chapter based on the subtask division.

### 2.1 Physical infrastructure and the related static and dynamic information

The objective of this task was to gather the available data from the databases 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

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:

- To provide continuity for automatic operation of AVs throughout the motorway connection.
- To ensure that conditions that are outside the ODDs of automated vehicles (e.g. severe weather problems) that result in large numbers of Minimal Risk Manoeuvres (MRMs) to be performed along the motorway do not cause severe accident nor congestion problems.
- To make sure that all relevant automated driving use cases should be covered.

#### 2.1.1 Methodology

The work was carried out through an inventory of the databases 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 analysed datasets can be categorised to

- link-based information regarding the road infrastructure
- spot-oriented datasets regarding the road infrastructure
- information related to traffic management and information systems
- traffic-related information.

The link-based data was organised in homogeneous road sections so that a new section starts always when the value of at least one of the attributes changes. The analysed road datasets were downloaded from Finnish Transport Infrastructure Agency's open data service and contain the following static 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.

Locations of the spot-oriented attributes such as junctions and traffic signs were coded as a road address containing of road number, road section number, distance (m) from the beginning of the road section.

Information and data related to traffic management and information services contains information of the existence of variable message sign locations and traffic monitoring devices (cameras, road weather stations, inductive loop traffic detectors).

Various traffic related factors were analysed from respective sources and documented to the same Excel sheet. These attributes included:

- Traffic volumes (vehicles/day, ADT 2019) and the percentage of heavy vehicles (2019).
- Number of accidents leading to personal injuries (accidents/year/100 million vehicle km of a 5 year period).
- Traffic conditions (estimated based on traffic announcement, road work message and contractor measures).

In addition to database analysis, field measurements while driving were conducted in order to complement and validate the information collected from the databases:

- The dimensions and locations of road infrastructure were measured using front-view photography, 360 panoramic photography and mobile laser scanning equipment. From the interpretation of the point cloud dataset it was possible to validate the physical dimensions of road elements in the database, and to map the areas suitable for MRMs (Minimal Risk Manoeuvre).
- Road marking measurements were done with measurement vehicle equipped with measurement devices for retroreflection (LTL-M Mobile retroreflectometer), line condition (line laser) and lane departure warning system LDW (Mobileye system).
- The MobilEye system has a Traffic Sign Recognition protocol that was used. It detects the traffic sign type and it has also ability to identify the text in signposts.

Road surface condition information was collected by FTIA as part of annual condition information collection.



## 2.1.2 Key features

### 2.1.2.1 Physical infrastructure

Looking at the elements regarding the physical road infrastructure and its dimensioning, the following main features of the road infrastructure can be presented from the road registry:

- The speed limit on the motorway is mostly 120 km/h, except the section close to Ring road III (80 km/h), the Hämeenlinna tunnel (100 km/h) and the northernmost part of the motorway (100 km/h). During wintertime the whole section has speed limit of 100 km/h, except the section close to Ring road III.
- The width of one carriageway is mostly 7.5m, with exception in the Hämeenlinna tunnel (7.0m) and the northernmost part of the motorway (7.0–7.2m).
- The width of the shoulder on the right varies mostly between 3.0–3.5 m, being at its lowest in 1.5m in two short sections.
- The width of the shoulder on the left side of the carriageway varies mostly between 1.0–1.5 m, the lowest short parts having only 0.5–0.75 m width.
- There are several sections where animal fence is not present.
- The winter maintenance class is 1SE (the highest class in Finland, meaning that slipperiness will be tried to be prevented every time it may occur).
- The bearing capacity is estimated to be on a good level.

The laser measurements presented different results than what is available on road registry. The width of one carriageway was measured on average as 7.9 m, having a total of 5293 m where the carriageway is narrower than in RR database, and a total of 77163 m where the carriageway is wider than in RR database. The differences are explained by some of the third lanes missing from the Road Registry, as well as different definitions in the measurements and the road registry data.

- 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

Shoulder width on the right was on average 2.7 m without the gravel, and with the gravel on average 3.7 m. Shoulder width on left was on average 1.4 m without the gravel, and with the gravel on average 2.0 m. Summary of the findings are:

- road length right edge (paved + gravel) narrower than FTIA's registry data on:
  - carriageway 1 26.1km
    - Average difference -0.7 m
  - carriageway 2 32.3 km
    - Average difference -0.6 m
- road length right edge (paved + gravel) wider than FTIA's registry data on:
  - carriageway 1 119.8 km
    - Average difference 1.3 m
  - carriageway 2 111.8 km
    - Average difference 1.4 m
- road length left edge (paved + gravel) narrower than FTIA's registry data on:
  - carriageway 1 11.1 km
    - Average difference -0.2 m
  - carriageway 2 8.8 km
    - Average difference -0.2 m
- road length left edge (paved + gravel) wider than FTIA's registry data on:
  - carriageway 1 136.2 km
    - Average difference 1.0 m
  - carriageway 2 138 .7km
    - Average difference 1.1 m

For bearing capacity, there was no measurement done within the project subtask. Observation was made that on some roads the pavement layers are thinner on the second lane than on the main lane, leading to unbalance in bearing capacity between the drivable area. Data is missing on shoulders' capacity and on driving lanes the data quality is observed to be poor (10+ years old, low number of measurements).

### ***2.1.2.2 Road markings and their condition***

In order to get information of a "worst case scenario", the road marking condition measurements were conducted in early spring, at the time before the road maintenance operators had conducted the cleaning/repairs of the road markings. There were many locations where high amount of salt/dust was covering the road markings (see example in Figure 3), the amount varying between lanes and road sections to some extent. Such conditions occur on most motorways annually and may last several weeks depending on the delay related to cleaning of the markings. For this reason, it can be concluded that AV's should be designed to operate in such conditions in which the road markings may be covered to some extent with reflection-hindering elements.

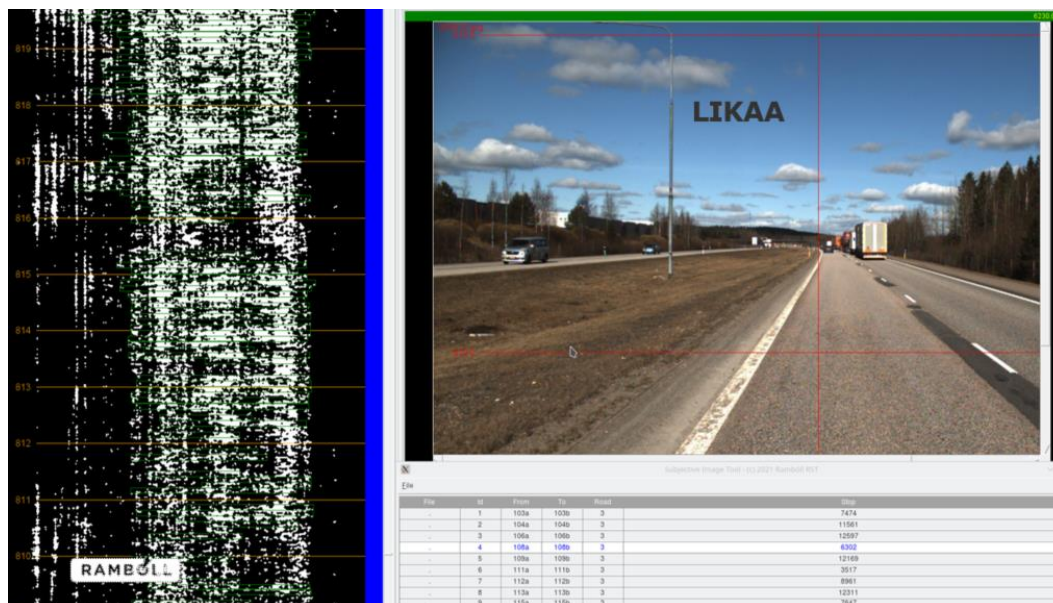


Figure 3. Sand on line is shown as missing marking on 10m analysed section.

The minimum requirement for retroreflection in FTIA's Road marking service contracts is 100 mcd/m<sup>2</sup>/lx. For road marking condition the acceptance limit is 55–70% of full condition. It was assumed that the same threshold values can be used for this analysis, which is backed up with findings from literature proposing the same threshold values.

The preview time is the number of seconds taken to drive a distance equal to the road marking visibility distance. It is a postprocessed value and here it is calculated for 20 cm lines. The recommendation for preview time is 3 seconds (at 120 km/h = 100 m) for road safety reasons (more time for elderly drivers to react). Minimum value in studies has been 1.8 second (at 120 km/h = 60 m) for manual drivers.

Regarding retroreflectivity, the results vary to some extent between carriageways. The right edge line presents mostly acceptable level of retroreflectivity in northbound direction, but is acceptable only on some sections southbound. This is a typical result when there is salt on top of line, which dims the line's reflection. For some reason, there is more salt on the northbound direction. Regarding lane line, the retroreflectivity is poor on both carriageways, but on the left edge line the result is acceptable on both carriageways.

The measurement results regarding road marking condition also vary to some extent. Regarding right edge line, the condition is quite poor because gravel on top of line in both carriageways. On lane line, the condition is acceptable half or most of the road, depending on direction. On left edge line, the condition is acceptable northbound, but mostly poor southbound due to dirt.

Regarding results on preview time, none of the sections reached the 3 second value, that was set as a threshold for acceptance. Average values for the right and left edge lines were 2.0 s, which means 67 meters distance while driving 120 km/h. The average preview time was worst on lane line, only 1.7 s.

The ability of MobilEye to recognise the lane marking was excellent despite the varying amount of salt and dirt on top. The length of sections where MobilEye did not recognise the lane marking was only 100 m (on each line) on the whole 160 km

motorway section. According to experts, this result proves the previous finding that for MobilEye and similar technologies the contrast between the asphalt and the lane marking is more significant than the retro-reflectivity of the marking.

Regarding the recognition of traffic signs, at best the MobilEye system found 45 out of 45 traffic speed signs on side of the carriageway, at worst it found 26 out of 37. The MobilEye system identified the signs' text correctly between 51% and 75% of the time. The results indicate that such recognition system is not trustworthy enough to act as a sole source of traffic restriction related information for automated vehicles.

Regarding the lane markings width, the measured width, on average, differs from the standard width by more than 10% of the desired width on 10% of the measured lanes total length for 90% of the lane lines total length, the width is within 10% of the desired width. The lane marking width is exactly to the standard on 34% of the measured lanes total length. Table below presents the results.

*Table 1. Length of lane markings according to the width on AUTOMOTO sections, in km.*

LANE MARKING WIDTH (CM)	LENGTH OF MARKINGS (km)					
	LEFT		CENTER		RIGHT	
	northbound	southbound	northbound	southbound	northbound	southbound
7			2	0		
8			10	2		
9			28	23		
10			<b>83</b>	<b>53</b>		
11			34	69		
12			1	11	1	
13		1		1	1	1
14	0	0			1	2
15	<b>0</b>	<b>0</b>			<b>1</b>	<b>2</b>
16	1	1			3	3
17	2	7			9	9
18	14	25			27	21
19	55	57			47	43
20	<b>55</b>	<b>45</b>			<b>36</b>	<b>44</b>
21	21	14			8	10
22	7	4			3	3
23	2	2			2	2
24	1	0			1	2
25		0			2	1

### ***2.1.2.3 Road surface condition***

Existence of potholes and major damages was not studied in this project. However, the rut depth condition variable is used to classify the pavement surface effect to automated driving. The rut measurements were conducted in end of April 2021. The rut level is high after the winter period and before maintenance actions. FTIA's maintenance standard defines 100m section as poor if the rut is over 13 mm and extreme poor when over 17 mm. The proposed classification recommendations for automated driving is "maximum rut depth less than 20 mm".

- road rut depth poor / very poor on FTIA standards:
  - carriageway 1      52 km / 23 km
    - right lane    37 km / 19 km
    - left lane     15 km / 4 km
  - carriageway 2      74 km / 24 km
    - right lane    40 km / 15 km
    - left lane     34 km / 9 km

Compared to the proposed classification recommendations, only a few sections of the studied road are rated under the proposed minimum requirement. On Carriageway 1, 4.8 km of the road rate as poorer than the proposed standard on the right lane and only 0.3 km on the left lane. On Carriageway 2, 4.0 km of the road rate as poorer than the proposed standard on the right lane and 0.7 km on the left lane. The poor conditions were located close to cities.

### ***2.1.2.4 Traffic features and traffic management***

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), comprising of variable speed limits, VMS's and Park & Ride guidance systems.
- Travel time information service Helsinki ring road III - Nurmijärvi (19 km), based on floating car data information service.
- Traffic management system Hämeenlinna tunnel (2.5 km), comprising of various traffic management and tunnel safety systems.
- Traffic management system Lempäälä–Tampere variable speed limits (12 km).
- Tampere traffic information system, comprising of VMS's on the road stretches approaching the city of Tampere.

VMSs 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 Traffic Management Centre (TMC) operators.

In addition, there are monitoring devices along the way. Traffic and weather conditions are monitored also on road sections that are not managed by any traffic management system (listed above). 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. Inductive loop traffic detectors collect traffic data for statistical purposes. Road weather and traffic data as well as CCTV camera still images are published as open data through Fintraffic's Digitraffic service (<https://www.digitraffic.fi/en/>).

Traffic volumes and percentages of heavy vehicles were gathered from FTIA's road data bank. 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 estimated annual amounts of personal injury accidents for the road links were gathered from FTIA's database. 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 data analysis, the following key results can be drawn:

- The average (weighted with section length) daily traffic volume is 14 238 vehicles/day, the maximum being almost 30 000 vehicles/day on the southernmost road section.
- The average share of heavy vehicles is 8.9%, the highest value being 11.1% in the section north of Hämeenlinna.
- The average personal injury accident rate is 2.32 accidents/year/100 million vehicle kms, the highest value being 5.88 accidents/year/100 million vehicle kms in Lempäälä.
- Traffic announcement rates (amount/km/year) regarding incidents, road works and animal warnings were also studied, but they should be used as rough estimates due to uncertain event coverage.

### **2.1.3 Conclusions**

Concerning the continuous support for the AV's 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 pavement damages and excessive ruts. In addition, it has been deemed as essential that the AVs have the capability to correctly interpret the lane markings e.g. at intersections with exit lanes and the respective markings.

With regard to the MRMs, the question is how and where to reserve space for carrying out them. 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 passenger 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, provided that the whole vehicle fleet has the same lane-keeping ability. 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 existing motorway rest areas and service areas may be used as areas for coupling and uncoupling of truck platoons. In the longer term the platoons may be performed ad-hoc while driving, if the speed differences can be managed in a safe manner. Furthermore, it is likely that the currently typical bearing capacity of motorway shoulders may not be sufficient for MRMs of truck platoons. The weaving section just north from Helsinki Ring Road III and the sections following that seem to be congestion prone so that could affect the operation of a number of automated driving use cases such as truck platooning.

The road sections with 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, at least until such information is provided by vehicle-to-vehicle communication. 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.

Conclusion regarding the condition and retro-reflectivity of the lane markings was, that during springtime there are periods of time when the lane markings are covered with salt and dirt due to which the values may fall below the acceptable values for AVs. However, regarding the lane-keeping assistance MobilEye, same technology being used also on AVs, the results were encouraging as the MobilEye was able to recognise the lane markings majority of the time despite the covering dirt. The result indicates that the contrast between the road surface and the lane marking is more significant factor for the system than retro-reflectivity. In addition, during wintertime the lane markings might not be visible partially or even at all, due to snow cover, for long periods of time. The existence and frequency of such winter conditions were not studied in this project and may require further studies.

Regarding the machine-readability of the roadside traffic signs, the results indicate that such solution is not reliable enough, especially taking into account possible worse conditions than encountered during the field measurements, and alternative digital solutions are needed to facilitate the provision of traffic sign information to AVs.

## 2.2 Communication networks

### 2.2.1 Methodology

The first goal of the task was to identify and define communication service level requirements (V2N) for the key intelligent transport systems (ITS) use cases. AV use cases and their requirements for communication networks were studied as a literature survey. In several studies the use cases were described in great level of detail, but exact information related to mobile network requirements were only described on 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 analysed and the service level requirements were later defined.

The capabilities of the current 4G and 5G mobile networks along the E12 were measured as a field measurement and the results were briefly analysed against the defined mobile communication service level requirements. Field measurements of the mobile networks on the E12 between Helsinki and Tampere were conducted 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 performances of the network. Three key figures were measured download speed, upload speed and latency (ping). These figures were measured only from 4G and 5G networks.

Alongside mobile phones, a scanner was used on one of the measurements to gather information about the signal strength of mobile frequencies.

The current coverage of passive infrastructure for mobile communications, namely mobile base stations and fibre access points on both sides of the road were studied. Data was collected directly from the three largest mobile operators in Finland. As the coverage of a single cell of 3.5 GHz 5G frequency band was expected to be 1–2 km, an assumption was made that a 3.5 GHz 5G base station cannot be deployed further than 1 km away from the road. The 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.

### 2.2.2 Key findings

#### *2.2.2.1 Requirements of the use cases*

The most demanding use cases for communication networks are related to cooperative driving and tele-operated driving. In these use cases there is a need for high-capacity data transfer capability to both directions and the network must be available reliably on demand. Some demanding use cases require also low latencies. In use cases like Coordinated Cooperative Manoeuvring and Tele-



Operated Driving, data service needs might emerge at the same time from various sensors and systems.

Depending on the surrounding infra, other vehicles and availability of edge computing, there might be multiple sources of data that needs to be sent 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 and the capacity demand per vehicle varies heavily during the drive and is not dependent only on the user and the vehicle, but surrounding traffic and infra as well.

### ***2.2.2.2 Field measurements***

In general, mobile networks have reasonably good performance along the E12. The 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 already 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 any 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.

All though 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 has been deployed. On the other hand, latency in the networks is good on the whole length of the E12 seldom exceeding 50 ms. The service levels do not form homogeneous stretches along the E12, but instead, the service level categories are scattered along the road.

The measurement results regarding the set service levels are presented in chapter 4.

### ***2.2.2.3 Inventory of the 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, capable of providing sufficient mobile networks service level for most use cases, if not all.

Using the received data from two mobile operators it can be determined that E12 has fibre access points available almost the whole length of the road in close proximity.

*Table 2. Availability of the passive infrastructure based on the support classification (E-A).*

Class	A	B	C	D	A-D	E
<b>Criteria 1.</b> REQUIRED PROXIMITY OF A MOBILE BASE STATION	<100m	100- 250m	250- 500m	500- 1000m	0- 1000m	>1000m
LENGTH OF ROAD MEETING THE CRITERIA 1	3km	19km	35km	43km	100km	60km
<b>Criteria 2.</b> REQUIRED PROXIMITY OF A FIBRE ACCESS POINT		100- 250m	250- 500m	500- 1000m	0- 1000m	>1000m
LENGTH OF ROAD MEETING THE CRITERIA 2		64km	43km	44km	151km	9km

Fibre access points are available close to the road on most areas of the studied road section. Of these areas 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.

### 2.2.3 Conclusions

As automated vehicles become more common, the demand for reliable high capacity – low latency networks on the roads will also increase. The current mobile networks along most of the 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. Although these use cases do not require continuous data, for example tele-operated driving is most likely to be used only as fall-back / fail-safe system, and therefore 100/100 Mbit/s has to be continuously available. These type of data rates can only be achieved in high capacity 5G networks that are operated in 3.5 GHz and 26 GHz frequency bands or other high frequency short range communication technologies. The bandwidths on high frequencies can ensure delivery of 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. It is crucial to understand that the capacity of one cell is divided between all the users connected to the cell, hence in cases in which several users require high capacity, the fast data transfer might not be available. In other words, heavy traffic on the road decreases the capacity available per vehicle, therefore on the road sections prone to traffic jams and other hot spots, capacity of the network must be increased by deploying high frequency radios such as 26 GHz, by decreasing the cell size and effectively deploying more

radio units, or by doing both. This in turn will drive the cost of the required investment up.

In theory the listed service level requirements can be achieved with current 4G and 5G technologies although achieving them in practice requires rethinking how mobile networks and provided mobile services are executed. Many use cases require 99.99% reliability for communication networks, which in turn means that vehicles can't rely on cellular networks, if deployed using the current standards for 4G networks and early phase 5G networks. However, the future 5G networks are planned to withstand 99.99% reliability requirements. In addition, high capacity, up to a point, can be ensured for automated vehicles through network slicing, technology utilized in 5G.

Mobile network seems like the best option to provide general connectivity for automated 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 as a fallback network through prioritised roaming? Can mobile network coverage be complemented with other wireless connectivity solutions to provide access over shorter distances to less critical services?

## 2.3 Positioning services

### 2.3.1 Introduction to positioning and correction services

Basic level GNSS receiver's absolute accuracy is approximately 20 metres. Tall buildings, elevated landscapes and e.g. tunnels 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. The positioning accuracy can be improved using more than one frequency from a satellite. GNSS systems today offer several civil signals. This improves the accuracy by a tenth, but this still represents a number of metres.

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. One base station can serve an area which is about 10–20 km in radius. 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. In Finland one can get commercial services from Trimble and Hexagon and a public one from The National Land Survey of Finland (NLS/MML).

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 of accuracy:

*Table 3. GNSS modes and their estimated accuracies.*

MODE		ACCURACY
0	No fix	n/a
1	3D	~10-40 m
2	DGNSS	~2 metres
4	Fixed	~few centimetres
5	Float	~few decimetres

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.

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 can be sent either from the satellite or using the cellular network. Therefore, PPP does not require a local base station nearby.

GNSS systems work with certain coordinate frames. GPS uses WGS84, which is based on the ITRF (International Terrestrial Reference Frame). 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. The GLONASS broadcast ephemeris is given in the Parametry Zemli 1990 (Parameters of the Earth 1990) (PZ-90) reference frame. The Finnish coordinate system EUREF-FIN is a 3D realisation of the European terrestrial ETRS89 reference system. The corresponding frame in ETRS89 is the ETRF89. 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. In practice, this means that GNSS coordinates given by the receiver are 0,8 m off compared to the map coordinates. Earlier this misalignment has been insignificant, because the receiver error has been tens of meters, but to support automated vehicles, this drift must be taken into account by using the necessary conversions. 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 important to know when to use conversion and when not.

### 2.3.2 Methodology

The field measurements were conducted by driving in both directions in the morning and repeated by driving in the evening. The following measurement arrangements were established.

- Four GNSS receivers with an antenna splitter, connected to one high-quality GNSS antenna, configured for different constellations (GPS, GLONASS, Galileo).
- Use of correction services from Trimble, Hexagon and NLS.

The following data was stored for each GNSS receiver using a single correction 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 correction signals are saved in the file.

Data analysis focused on the following:

- 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.

### 2.3.3 Key findings

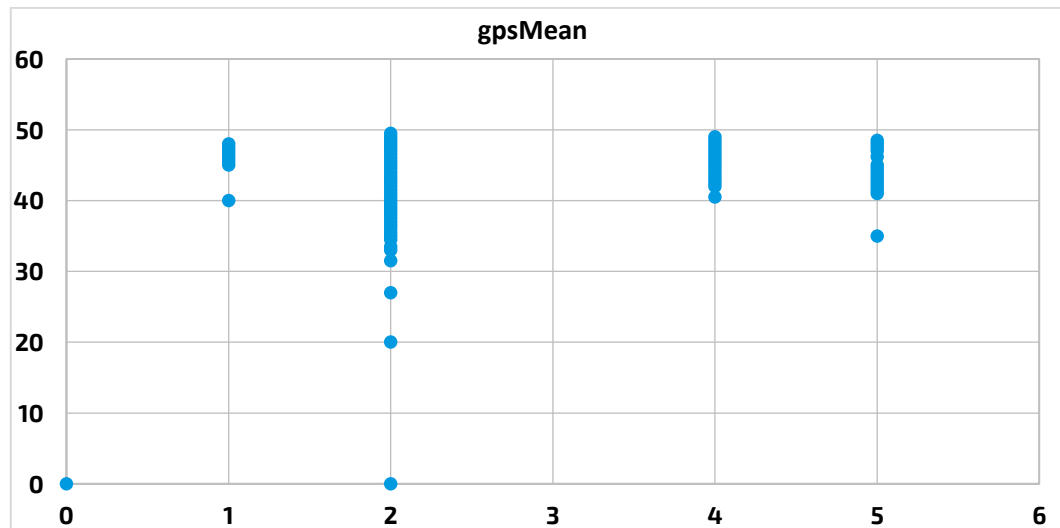
In Table 1 percentages of the availability of the different positioning modes achieved by each constellation are presented. As expected the reference receiver, which used all the constellations, had the best availability compared to individual constellations. It offers the best quality 83.4 % of the 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%. Table 4. visualises the results.

*Table 4. 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

Another finding is, that there is no difference of accuracy between constellations. Galileo and GPS difference was one centimeter and the Glonass was two centimeter away from the others.

The criteria for the RTK-fixed mode is said to be at least five satellites and Signal-to-Noise-Ratio (SNR) over 40 dB. In the field study, the fixed mode was achieved only, when SNR was over 40 dB. Therefore, this criteria is valid and it can be used to classify road sections. Overall signal strength for each constellation show that Glonass has slightly higher signal strength. Most of the time SNR values are over 30 dB as seen in figure 4, and there is only one place, where SNR value drops to zero. This place is the tunnel at the Hämeenlinna. There are no other remarkable shadow areas on route. Short drops are due to overpasses.



*Figure 4. 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.*

Comparison of the correction services were done with the same hardware, but different configuration. The best availability was achieved by Provider 2 where the best mode was available 93.6 % of the samples during the route as seen in Table 5. The second was the Provider 1 and third was the PPP correction. Provider 3 had only 79.1 % availability, due to service freeze during the measurement. There were no differences between service providers achieved relative accuracy.

*Table 5. 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

Last finding is related to the hypothesis of truck traffic weakening the satellite signal. Situations where the measurement vehicle was surrounded with trucks were carefully examined to inspect whether it had effect on the GPS coverage. The result was that no effect was found.

### 2.3.4 Conclusions

The key findings from the field measurements were that there are some differences on the availability between GNSS services. The use of all constellations gives better results in availability than using only one constellation. There is no meaningful difference in accuracy between constellations nor between service providers. The main conclusion of this subtask is, that three independent positioning service technologies are needed for safe automated driving, as this significantly increases the proportion of time with at least decimeter-level positioning accuracy.

Coordinate reference systems are very important and content providers should be aware of used frame and provide metadata where used frame is clearly announced.

An issue to consider is the disappearance of the satellite signal when entering the tunnel, and the time taken to recover accurate satellite positioning after exiting the tunnel. Modern satellite receivers present calculation processes that prevent lateral jumping of the vehicle position in the event of signal disruption. However, in case of turning geometry in a tunnel, different solutions are required to ensure lane-keeping until the satellite signal is recovered. Together with good visibility road markings the supporting machine vision system will work better. On the other hand, AVs likely use many systems for lane-keeping in tunnel environment where satellite positioning is not available. When vehicle exits a tunnel, good visibility of the lane marking ensures sufficient positioning support until the satellite signal is restored.

The study confirmed that the service level indicator for positioning services could be the measured signal strength (SNR) over 40 dB using five strongest satellites from each constellation. Signal-to-Noise-Ratio below 40 dB indicates a shadowed region and probability for the most accurate positioning result is low.

## 2.4 Weather conditions

### 2.4.1 Methodology

This study estimated what kind of automotive sensing performance is to be expected in the near future and in what kind of environmental conditions automated vehicles would be able to drive Finnish motorways using such sensors. The perception sensors considered are automotive radar, automotive lidar, and automotive vision system consisting of illumination, camera, and image processing algorithms.

The optical subsystem may consist of automotive camera subsystem alone, automotive lidar subsystem alone, or both. They are analyzed by studying each sensor subsystem separately, to utilize more accurately the knowledge of their capabilities in different weather conditions. The sensor systems have been analyzed 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.) It 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.

The study has focused on the question, how does airborne fog, mist, rain and snowfall reduce the perception capability of the vehicle sensors. There are also other ways how weather may prevent proper functioning of the sensors, e.g. the sensor or its shielding being so covered with water/slush/snow that it cannot send and receive its signal, but these are not analysed in this study.

First, the likely detection range of the three different sensor subsystems to different objects 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.

## 2.4.2 Estimates of the detection ranges of various vehicle sensors

### 2.4.2.1 Radar

The average detection range of automotive radar 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.

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.

The results are illustrated in figure 5. 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.

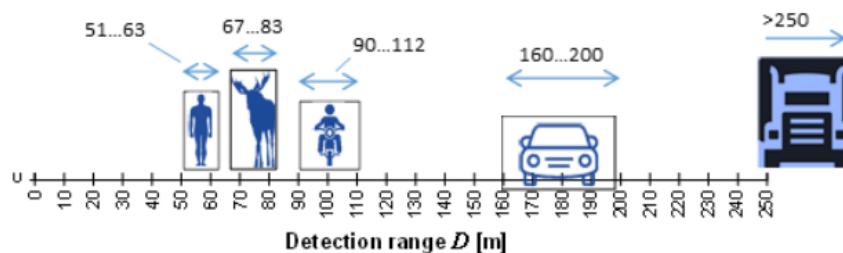


Figure 5. Radar detection ranges visualised: How far a typical automotive radar can detect an average human, elk, motorbike, car, and truck/bus.



### 2.4.2.2 LIDAR and camera

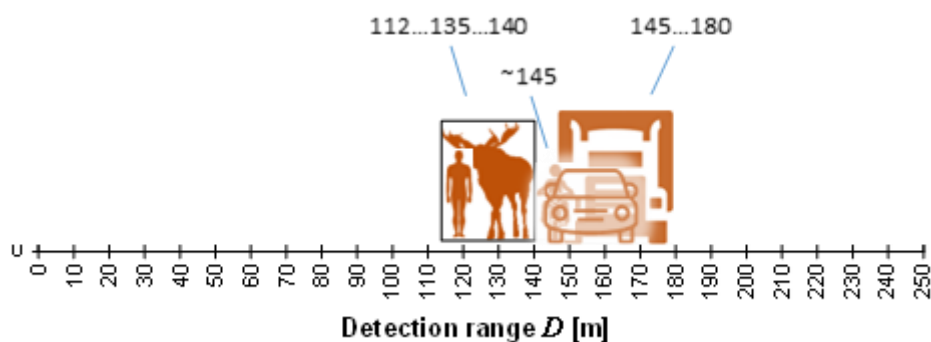
Main focus in this study is on lidars using wavelengths 850...905 nm, e.g. very near to the wavelengths visible to human eye. These lidars are cost efficient, and majority of automotive lidars use these wavelengths. Their detection range is limited by two factors:

- a) The 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.
- b) The point cloud density at the target decreases, when the distance to the object increases. 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.

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 studied condition is estimated by assuming that lidars designed for highway speeds and detection ranges can detect objects having 10% reflectance (e.g. black clothes) from 140 m distance and 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.

The estimated maximum Lidar detection ranges are presented in the following figure.



*Figure 6. 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.*

For the third type of vehicle sensors, camera-based subsystems, it is assumed for simplicity and safety that the reliable detection range of the camera subsystem is the same as with lidars (as illustrated above). This assumption is valid only when the automotive manufacturer has designed the vehicle with a lighting system sufficient for at least the same operation range as the assumed lidar system above.

## 2.4.3 Key findings

### 2.4.3.1 Minimum visibility requirements in different conditions

In this study it was estimated through expert analysis, that an automated vehicle may have difficulties to manoeuvre safely, when the friction coefficient  $\mu$  is less than 0.3. 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.

Table 6 shows the required distance, that is needed to detect an obstacle and start braking, in order to be able to stop before collision. This distance is called "Minimum detection distance". When the friction coefficient between vehicle's tyres and the road surface decreases, the vehicle requires a longer distance for stopping. The estimated minimum visibility condition, that is required for a reliable detection of an object with non-reflecting surface, is four times the minimum detection distance. The detection distances presented in green are distances where reliable detection of a small (150 cm) human in dark matt clothes is possible using foreseeable 905... 850 nm lidars or camera systems designed for motorway operations. Distances presented in orange are values where detection could be possible, but probably with lower detection reliability. The red detection distance 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 ODD of the first automated vehicles.

*Table 6. Detection distances 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.*

Tyre-road $\mu$ range	120 km/h (1.4. - 31.10.)		100 km/h (1.11. - 31.3.)	
	Minimum detection distance D[m]	Min Visibility [m] (= 4D)	Minimum Detection Distance D [m]	Min Visibility [m] (= 4D)
$0.3 \leq \mu < 0.4$	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

### 2.4.3.2 Results of the road weather station data analysis

Data was collected from 15 different road weather stations (RWS) from eight different locations on highway 3. The used data contains 2–11 years of road weather measurements, the average being 10 years.

Based on the reasoning and calculations in the previous chapter, we defined conditions for each variable to filter the most challenging weather phenomena. The most relevant variables are visibility and friction. For friction it was assumed that the existence of icy road surface means, that the friction value falls below critical value 0.3. In addition, the presence of intensive snowfall was studied, based on the assumption that during intensive snowfall (continuous snowfall at least 10 cm in 4 hours, or continuous snowfall at least 5 cm in 4 hours and air temperature less than -2°C accompanied with strong wind) the functioning of the sensors is prevented by the snow dust raised to the air by traffic. 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.

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 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.

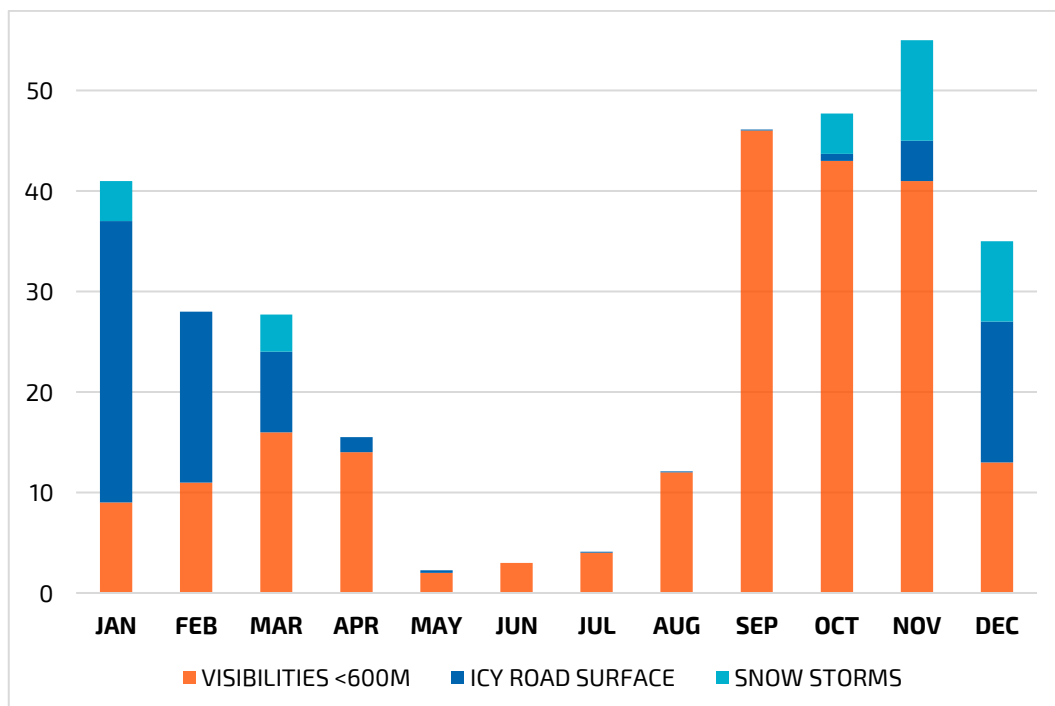


Figure 7. Total hours of adverse weather conditions causing the most challenges for the AVs.

As seen in figure 7, the problematic weather conditions during autumn months are related to low visibility. This most likely occurs due to fog. 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.

#### **2.4.4 Conclusions**

The estimation of the expectable perception sensor capabilities in this study 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. Unfortunately, due to the limitations in the weather data collected from the road weather stations, the combined analysis of friction and perception range was not possible in this study.

The main reason, which puts an automated vehicle outside its ODD is probably poor visibility, especially during the autumn months when fog becomes more common. The second most likely reason is low friction during icy road surface, which conditions occur most often during the winter months. The occurrence of these phenomena is rather low at least in the studied road section.

The vaguest 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, and therefore the presented results are also estimations.

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. It is a matter of future studies to analyze, how such information is best produced. As it is likely that the second and third generation automated vehicles are able to sense individually the experienced perception capability and friction, and also able to communicate their findings to

other vehicles and infrastructure operators, this type of information source could be included in the future data infrastructure plans.

## 2.5 Traffic information services

### 2.5.1 Methodology

Services and information sources which provide real-time traffic, road weather, condition and traffic incident 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.

The goal of the task was to find out what kind of services are available on the Helsinki – Tampere motorway. The study included both public and commercially available services and information sources.

This quick inventory study of currently available services and information sources was conducted during February and March 2021 as an email questionnaire and web search. The results from the information collection from the service providers was included to the report as such. Only relevant services, providing information in machine readable format through a well-defined API have been included to the study.

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, were written based on the feedback from the service providers and the expert analysis. Finally, conclusions and recommendations to the service level framework and for further research were summarized in the end.

### 2.5.2 Key findings

A key finding was that currently there are no providers in Finland who exchange C-ITS 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 focused on data and information services. Findings are summarised in table 7.

Table 7. Summary of available services and information sources.

SERVICE PROVIDER	SERVICE	DATA			OPEN DATA
		*Traffic, disturbances	Weather & road weather conditions	Other	
<b>FINTRAFFIC</b>	DigiTraffic	x	x	x	x
<b>FTIA</b>	Digiroad			x	x
<b>FMI</b>	Open data		x		x
<b>FMI</b>	Road Weather Forecasts		x		
<b>INFOTRIPLA</b>	DATEX2 Premium Feed	x	x		
<b>INFOTRIPLA</b>	Crowdsourced traffic warning data	x	x		
<b>EEE</b>	E3 REST API	x	x		
<b>SAFETY4 TRAFFIC</b>	Accident, Crosswind, Elk, Deer, Reindeer, Road weather and Road work warning services	x	x		
<b>ROADCLOUD</b>	Premium connected vehicle data service		x		
<b>SITOWISE</b>	Carrio, Rوتا	x	x	x	
<b>HERE</b>	Traffic API	x			
<b>TOMTOM</b>	Intermediate Traffic service, Traffic API	x			
<b>WAZE</b>	Transport SDK, Connected Citizens Program	x			
<b>OEM &amp; PUBLIC AUTHORITIES</b>	Safety Related Traffic Information Ecosystem	x	x		

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

### 2.5.3 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 include at least the following. These currently includes for example:

- Warning of hazard or roadworks ahead
- Awareness of prevailing road conditions
- Real-time status of surrounding road network (including, traffic signs, traffic lights and intersections)
- Routing and behavioural advice

Currently there are no 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. Some services that are provided by public authorities are based on Open Data licences, but most services are provided with commercial licences.

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. A general note is that there are many existing services regarding Hazardous Location Notification, but the quality of the data may not be sufficient to fulfil the strict requirements of the specifications. For example, roadworks information is based on the manual information provided by the contractors, and therefore the time validity, information regarding impact on traffic, and the geographical accuracy is likely to be not sufficient for OEMs. It is also crucial that all required data fields in the C-ITS specifications are filled in the data sources.

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. 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.

Currently ETSI is defining "Release 2" messages, including CPM (Cooperative Perception Message) and MCM (Manoeuvre Coordination Message). The MCM, allowing coordination of vehicle manoeuvres 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 chapter 4.

## 2.6 Summary of the current feasibility

The purpose of the inventory of the E12 highway between Helsinki and Tampere was to study what is the current status of the physical and digital infrastructure in the target area, how that has been estimated to support AV use cases in the motorway environment and what concerns or development needs can be identified with regards to providing continuity of operation of the automated vehicles currently on the market. These study results are valuable for the developers of automated vehicles and their various technologies, as well as the users and owners of automated vehicles. The inventory focused on the likely ODD attributes that support automated operation of SAE level 3 and 4 vehicles. In addition, attention has been paid to the conditions that are likely outside the ODDs of automated vehicles, and the ability of the infrastructure to support the vehicles in performing a minimal risk manoeuvre (MRM) in such circumstances.

The key findings from the inventory regarding different aspects of the physical and digital infrastructure support have been presented in the following tables.

*Table 8. Summary of the feasibility of the current motorway.*

AREA OF SUPPORT	FEASIBILITY FOR AVs	CONCERNS/ DEVELOPMENT NEEDS	OTHER REMARKS
<b>Physical infrastructure and the static and the dynamic features</b>  <b>Design</b>	The design requirements are likely sufficient.	The development of Minimal Risk Manoeuvre (MRMs) policies should be followed up in international collaboration, some requirements may arise in the future.	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.
<b>Road register data</b>	Data is inaccurate for many datasets, but mainly on the "safe side." Inaccuracies are mainly due to different definitions of the measured road features.	There were a lot of smaller sections with data misrepresenting the reality. Need to develop depends a lot on vehicles' capabilities, ie. Is 100% exact data even necessary.	
<b>Condition of pavement</b>	Based on the results, the road pavement is in good condition for almost all of the sections.	Current maintenance standard is sufficient.	
<b>Condition of lane markings</b>	The physical condition of markings is likely to be sufficient.	There will be significant amount of periods when markings are not visible due to snow or are only partially visible, also due to salt/dirt in the springtime.	



AREA OF SUPPORT	FEASIBILITY FOR AVs	CONCERNS/ DEVELOPMENT NEEDS	OTHER REMARKS
<b>Traffic features</b>	No restrictive traffic features of AVs.	Dense traffic flow occurs during rush hours in both ends of the study area. Hämeenlinna tunnel is closed occasionally due to maintenance or possible incidents. Detours through street network need to be planned for AVs.	
<b>Traffic management</b>	Feasibility is sufficient in the whole road section, but in the road sections with traffic management systems and services are better suited for highly automated driving due to provision of more accurate information.	Traffic management systems need to support C-ITS communication standards.	
<b>Communication networks</b>			
<b>Current mobile communication services</b>	Currently data speed rates vary heavily from below 1 Mbit/s to above 500 Mbit/s. Latency on a good level in the whole road section. Demanding AV use cases are currently supported only in the proximity of largest urban areas.	The most demanding use cases require 100 Mbit/s capacity in both directions, or even higher. Together with passenger entertainment, the requirement for download capacity may be as high as 350-500 Mbit/s.	The mobile data service is expected to further improve after mobile network operators migrate 3G frequency bands to 4G/5G technologies.
<b>Availability of passive infrastructure</b>	Density of mobile base stations in the proximity of the road section is good. There is an excellent availability of fibre access points in the corridor.	By updating the existing base stations in 1 km distance from the road with 3,5 GHz 5G network, it is possible to provide high capacity 5G network to two thirds of the road section length.	The good coverage of fibre access points enables operators to provide high capacity 5G networks beyond the current base station network without heavy investment to fibre optics network.
<b>Positioning services</b>	Likely to be sufficient when GNSS combination is used; positioning accuracy at least on decimeter level 96% of time in the test area.	At locations with likely signal strength reduction (shade of hill) or disappearance (tunnel) positioning needs to be managed with other technologies.	

AREA OF SUPPORT	FEASIBILITY FOR AVs	CONCERNS/ DEVELOPMENT NEEDS	OTHER REMARKS
<b>Weather conditions</b>	Poor weather conditions that hinder functioning of the vehicle's sensors are rare in the test area.	The poor weather conditions may cause AV's to shift outside their ODD's on average 35 hours/month during winter months.	Current road weather stations may provide information of the occurrence of critical conditions (e.g. friction, visibility), but the measurements of these sensors may not represent the experienced conditions at the ground level.
<b>C-ITS- and other information services</b>	There is a variety of public and private information services that provide relevant information regarding weather and traffic conditions.	The currently used data models and formats are not aligned to C-ITS standards. The accuracy of information content need to be improved to be sufficient for AVs.	Close attention needs to be paid for the full compliance of the data provision standards.

## **3 Service Level Classification for Highly Automated Driving on Motorways**

### **3.1 Objectives and requirements for classification**

This subtask of the project concentrates on presenting a framework for the classification of the Finnish road network from the perspective of automated driving. The purpose of the road network classification is

- a) to provide basis for authority and road operator views about what parts of the road network should be prioritized with regard to conditionally or highly automated driving
- b) 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
- c) 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 classifications 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. 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.

The road network to be prioritised in terms of facilitating highly automated driving should reflect user needs. The user needs were assessed primarily for the part of long-distance commuting and work-related journeys ("an hour of work in the car") and the improved effectiveness and cleanness of heavy goods transports. The long-term objective not reached with the subtask study is to determine a road network, where the investments required by highly automated driving likely are socio-economically feasible when considering the benefits to a safe, efficient and clean transport system. The analysis will not provide a quantitative cost-benefit evaluation but a high-level expert assessment carried out together by the consortium and FTIA.

The service level of the road network will be based on the current status of the ODD attributes on the studied roadway, classification objectives and the requirements of the highly automated vehicles. The ODD related requirements were acquired from projects, literature, and other existing sources. No new research on ODD requirements was to be carried out.

The service level framework focuses on motorway environment and the related AV applications (level 3 highway chauffeur and level 4 highway autopilot). In addition, the arising viewpoints regarding the service level framework on other road environments will be documented.

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) as the service level framework.

## 3.2 Existing classifications

### 3.2.1 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:

## ISAD E

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 9 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 9. Components of ISAD E "Conventional infrastructure" and their justification. (Lytrivis et al. 2019)*

COMPONENTS	JUSTIFICATION
<b>AVs need to recognize road traffic signs; colours, position</b>	Information about the accurate road characteristics could prevent ADAS misuse
<b>Signs with speed limits, road curvature and inclination</b>	Accurate speed limit recognition facilitates the AV operational domain perception (and is necessary for ISA function)
<b>Lane markings complied to regulations and standards on both sides</b>	Safety-related automated functionalities need proper lane condition and recognition (supporting accurate localization, e.g. automated lane positioning, automated lane change)
<b>Lane width based on standards</b>	Change on lane width could pose safety related challenges even in conventional traffic
<b>Working zone signalization</b>	Working zone signalization could prevent the misuse of automated functions in the specific road segment, and the human driver could timely take over
<b>Partial CCTV coverage for real-time vehicle detection</b>	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 10 for the components of ISAD D "Static digital information" and their justification.

*Table 10. Components of ISAD D "Static digital information" and their justification. (Lytrivis et al. 2019)*

COMPONENTS	JUSTIFICATION
<b>Digital map with static road signs (incl. accurate position of traffic signs)</b>	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.
<b>Variable Message Signs</b>	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 11 for components of ISAD C "Dynamic digital information" and their justification.

*Table 11. Components of ISAD C "Dynamic digital information" and their justification. (Lytrivis et al. 2019)*

COMPONENTS	JUSTIFICATION
<b>HD maps (incl. accurate position of signs, dynamic update of lane topology)</b>	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.
<b>Dense location referencing points</b>	
<b>Data fusion from on-board sensors, other vehicles and RSUs</b>	Automated vehicle localisation.
<b>Advanced TMC/iTMC software</b>	Prioritisation, Class upgrade/downgrade only to specific vehicle types (of different SAE Level, different size etc.)

COMPONENTS	JUSTIFICATION
	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)
<b>Advanced Infrastructure to Vehicle / V2X communication</b>	Vehicles recognition of traffic signs through TMC – Third Party Services
	Speech and screen V2I interaction (optional and provided mainly by OEM and third parties)
<b>Automatic data processing</b>	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)
<b>Automated update of digital infrastructure</b>	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)

### ISAD B

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 12 for Components of ISAD B "Cooperative perception" and their justification.

*Table 12. Components of ISAD B "Cooperative perception" and their justification. (Lytrivis et al. 2019)*

COMPONENTS	JUSTIFICATION
<b>HD maps (cloud based digital maps incl. the accurate position of signs, dynamic update of lane topology, location of emergency stop zones)</b>	Cloud based digital maps could enhance traffic perception, supporting traffic flow optimisation.
<b>Weather (High precision meteorological stations, in-pavement sensors to detect moisture, temperature, strain)</b>	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

COMPONENTS	JUSTIFICATION
	support the automated vehicle in perceiving its operational domain, thus preventing incidents of automated functions misuse.
<b>Advanced TMC/iTMC software</b>	I2V Highway Merge Assistance
<b>Data exchange with cloud services</b>	Data exchange with service providers supports services such as the provision of travel and route recommendations, with alternatives depending on time arrivals and distance.
<b>Elements to ensure continuous connectivity (enabling I2V) along the segment (e.g. RSUs)</b>	I2V connectivity should be ensured to enable the communication of advanced perception info to vehicles and related recommendations
<b>Microscopic traffic situation (in some cases speed and gap advice)</b>	Driving style monitored and taken into consideration for route recommendations and traffic advices (speed, gap, change of driving style)

### ISAD A

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 13 for the components of ISAD B "Cooperative driving" and their justification.

*Table 13. Components of ISAD B "Cooperative driving" and their justification. (Lytrivis et al. 2019)*

COMPONENTS	JUSTIFICATION
<b>Advanced TMC/iTMC software</b>	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.
<b>Sensors for trajectories of the vehicles</b>	
<b>Dynamic Guidance: speed, gap, lane advice</b>	
<b>Elements to ensure continuous connectivity (enabling I2V) along the segment (e.g. RSUs)</b>	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.

### 3.2.2 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 parameter 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 14.

Table 14. 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 8.

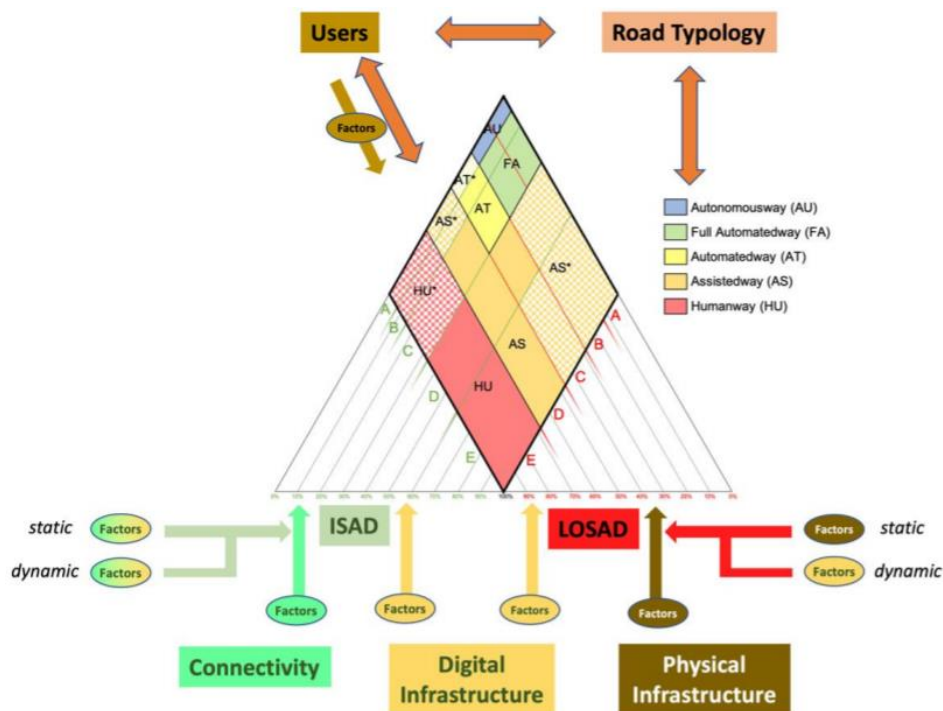


Figure 8. Smart Road Classification, including source data and interaction with other road classification systems. (Garcia et al. 2021)

### 3.2.3 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 15.

*Table 15. 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 INFRA- STRUCTURE 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 16. 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 16. Longitudinal line marking thresholds. (Somers 2019)

ASPECT OF LINE QUALITY	INFRA-STRUCTURE QUALITY BELOW THIS LEVEL IS UNLIKELY TO BE SUITABLE	Lower threshold	INFRA-STRUCTURE QUALITY MAY BE SUITABLE	Upper threshold	INFRA-STRUCTURE QUALITY ABOVE THIS LEVEL IS VERY LIKELY TO BE SUITABLE
LINE WIDTH		100 mm		150 mm	
LUMINANCE		2 : 1		3 : 1	
CONTRAST RATIO (DAYTIME, DRY)					
RETRO-REFLECTIVITY – DRY		100 mcd/lx/m <sup>2</sup>		150 mcd/lx/m <sup>2</sup>	
RETRO-REFLECTIVITY – WET		50 mcd/lx/m <sup>2</sup>		75 mcd/lx/m <sup>2</sup>	

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 17 compares the three components.

*Table 17. Complementary methods to build situational awareness. (Somers 2019)*

METHOD:	ASSESSED IN REALTIME BY VEHICLE USING ON- BOARD SENSORS	SOURCED FROM MAPS COLLECTED BY SURVEY VEHICLES	SOURCED FROM CROWDSOURCING
<b>Sensors used to collect data</b>	Likely to be commodity grade	May be commodity or survey grade	May be commodity or survey grade
<b>Processing of collected data</b>	In real-time on hardware that has a limited power budget	Post-processing on high power hardware	Post-processing on high power hardware
<b>Can processing consider also things that lie beyond immediate range (i.e. beyond 20-40m)?</b>	Generally only real-time processing, but some potential to consider recent past	Yes, due to post-processing	Yes, where post-processing used
<b>Currency</b>	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.

### 3.2.4 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.

### 3.3 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).

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.

### 3.4 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.

The results were validated in two ways. First, the values of the ODD attributes on the E12 motorway between Helsinki and Tampere were acquired from data bases as well as field studies carried out in the first half of 2021. Second, the proposed motorway service levels were sent for consultation to experts in and outside Europe. The experts consisted of people employed by road operators, vehicle industry, universities and research organisations. Service level definitions are presented as follows in table 18.

*Table 18.1 Service level definitions for all attribute categories, levels E and D.*

SERVICE LEVEL	INTERPRETATION			
	Physical infra-structure	Digital infrastructure	Environ-mental conditions	Dynamic elements
<b>E: Conventional (physical) infrastructure only, no AV support</b>	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 be recognised by AVs on their own	Road side stations measure environmental condition but no direct access to the data available	Traffic management provided according to current operational guidelines
<b>D: Static digital information/map support</b>	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

Table 18.2 Service level definitions for all attribute categories, levels C ... A

SERVICE LEVEL	INTERPRETATION			
	Physical infrastructure	Digital infrastructure	Environmental conditions	Dynamic elements
<b>C: Dynamic digital information</b>	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>B: Cooperative perception</b>	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
<b>A: Cooperative driving</b>	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.

## 3.5 ODD attributes and their relevance

The subchapters below present the ODD attributes found relevant in the analysis. The relevant aspects of each ODD attribute for automated vehicles are also described.

### 3.5.1 Physical infrastructure

Attributes related to physical infrastructure, their definitions and relevance are described in the tables below.

*Table 19. ODD attributes for physical infrastructure.*

	ATTRIBUTE	DEFINITION	RELEVANCE
<b>DRIVEABLE AREA LANE SPECIFICATION</b>	Lane marking retro-reflectivity	The visibility of the marking to human eye and vehicle sensors. (mcd/lx/m <sup>2</sup> )	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.
<b>DRIVEABLE AREA EDGE</b>	Shoulder width	Width of paved area on side of driving lane.	Provision of room for stopping due to MRM. Relevant sub-attributes: <ul style="list-style-type: none"> <li>• Outside</li> <li>• Inside</li> </ul>
	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.

	ATTRIBUTE	DEFINITION	RELEVANCE
<b>DRIVABLE AREA INDUCED ROAD SURFACE</b>	Drivable area induced road surface condition	The condition of the road surface with regard to damage and wear.	Safety of road use.
<b>FIXED ROAD STRUCTURES</b>	Landmarks	Fixed structure. (building, street light pole, bollard, gantry or specific conspicuous landmark)	Supporting GNSS or other form of ego-positioning for AVs.
<b>TEMPORARY ROAD STRUCTURES</b>	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.

### 3.5.2 Digital infrastructure

Attributes related to digital infrastructure, their definitions and relevance are described in the tables below.

*Table 20. ODD attributes for digital infrastructure.*

	ATTRIBUTE	DEFINITION	RELEVANCE
<b>CONNECTIVITY</b>	Cellular communication	4G, fourth generation of broadband cellular network technology.	Can be used for connectivity between infrastructure and vehicle.
		5G, fifth generation of broadband cellular network technology.	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.

ATTRIBUTE		DEFINITION	RELEVANCE
	Communication performance	Overall performance of communication (potentially using multiple technologies or networks) in a single location: <ul style="list-style-type: none"> <li>• Download and upload speed (Mbit/s)</li> <li>• Latency (s)</li> <li>• Reliability</li> </ul>	Performance describes the overall capability and reliability of communication.
<b>POSITIONING</b>	GNSS	Satellite positioning, accuracy affected e.g. by: <ul style="list-style-type: none"> <li>• Dual frequency receiver</li> <li>• Localisation assistance services</li> </ul>	Positioning required for automated driving.
<b>HD Map</b>		High-definition map which includes e.g. following attributes: <ul style="list-style-type: none"> <li>• Road type and geometry</li> <li>• Traffic signs</li> <li>• Lay-by and parking areas</li> <li>• Bearing capacity</li> </ul>	HD map required for automated driving.
<b>C-ITS (OR SIMILAR)</b>	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.		

ATTRIBUTE		DEFINITION	RELEVANCE
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 infrastructure.		Availability of ODD, 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.

### 3.5.3 Environmental conditions

Attributes related to environmental conditions, their definitions and relevance are described in the tables below.

Table 21. ODD attributes for environmental conditions.

ATTRIBUTE	DEFINITION	RELEVANCE
Visibility	<p>Visibility measures the distance at which an object can be clearly seen.*</p> <p>Visibility can be affected e.g. by</p> <ul style="list-style-type: none"> <li>• Rainfall</li> <li>• Snowfall, hail, freezing rain</li> <li>• Fog, mist</li> <li>• Smoke, air pollution</li> </ul>	<p>As visibility is 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</p>



ATTRIBUTE	DEFINITION	RELEVANCE
	<ul style="list-style-type: none"> <li>Standing water or snow on road               <ul style="list-style-type: none"> <li>causing mist or snow dust in front of the following vehicles</li> </ul> </li> </ul>	<p>composition and size distribution of the particles in question**</p> <p>In this classification, the visibility is addressed not only from human but also from optical AV perception viewpoint.</p> <p>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.</p>
<b>Friction</b>	<p>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.</p> <p>Friction can be affected e.g. by</p> <ul style="list-style-type: none"> <li>Temperature</li> <li>Snow or ice on road</li> <li>Surface               <ul style="list-style-type: none"> <li>contamination</li> </ul> </li> </ul>	<p>Conditions with low friction (e.g. icy road) likely outside ODD.</p> <p>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.</p>
<b>Water on road</b>	<p>Standing water tends to occur if there is a depression in the road** or during heavy rainfall.</p> <p>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.**</p>	<p>1. When water depth is higher than the ground clearance of subject vehicle.</p> <p>2. When vehicle speed and water thickness causes aquaplaning (applies mainly to cars).</p>
<b>Wind</b>	<p>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.**</p>	<p>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.)</p>

\*Met Office, UK, <https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/>

\*\*BSI (2020)

### 3.5.4 Dynamic elements

Attributes related to dynamic elements, their definitions and relevance are described in the table below.

*Table 22. ODD attributes for dynamic elements.*

	MONITORING SYSTEMS/ SERVICES	INFRASTRUCTURE- BASED TRAFFIC, WEATHER, AND ENVIRONMENT MONITORING SOLUTIONS	PROVISION OF ENVIRONMENTAL INFORMATION TO AV's LOCAL DYNAMIC MAPS
TRAFFIC MANAGEMENT	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.

## 3.6 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).

### 3.6.1 Proposed classification

#### 3.6.1.1 Physical infrastructure

Table 23. Classification for physical infrastructure

ATTRIBUTE		E: CONVEN- TIONAL (PHYSICAL) INFRA- STRUCTURE ONLY, NO AV SUPPORT	D: PHYSICAL INFRA- STRUCTURE ADAPTATIONS FOR AV	C: ENHANCED INFRA- STRUCTURE WRT MAINTEN- ANCE	B: IMPROVED INFRA- STRUCTURE WRT MRM	A: IMPROVED INFRASTRUCTURE WRT POSITIONING AND SUPERVISION
DRIVABLE AREA LANE SPECIFI- CATION	Lane marking retro-reflectivity	According to national guidelines	min 100 mcd/lx/m <sup>2</sup> 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
	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 Inside > = 1250 mm	Same as level D	Outside >= 3000 mm Inside >= 2000 mm	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 inter-sections	Same as level C	Every 500 m

ATTRIBUTE		E: CONVENTIONAL (PHYSICAL) INFRA-STRUCTURE ONLY, NO AV SUPPORT	D: PHYSICAL INFRA-STRUCTURE ADAPTATIONS FOR AV	C: ENHANCED INFRA-STRUCTURE WRT MAINTENANCE	B: IMPROVED INFRA-STRUCTURE WRT MRM	A: IMPROVED INFRASTRUCTURE WRT POSITIONING AND SUPERVISION
DRIVABLE AREA SURFACE	Drivable area induced road surface condition	Aim: No pot-holes 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 carriage-way)	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 MANAGEMENT	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
	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

### 3.6.1.2 Digital infrastructure

Table 24. Classification for digital infrastructure.

	ATTRIBUTE	E: CONVENTIONAL (PHYSICAL) INFRA- STRUCTURE 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%
POSITIONING	GNSS	Only local correction service (RTK) which requires conversion from local to global	Same as level E	WGS84 correction service via satellite available	The 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
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 - Temporary changes in bearing capacity of	Same as level C	Same as level C

	ATTRIBUTE	E: CONVEN- TIONAL (PHYSICAL) INFRA- STRUCTURE ONLY, NO AV SUPPORT	D: STATIC DIGITAL INFORMATION / MAP SUPPORT	C: DYNAMIC DIGITAL INFOR- MATION	B: COOPERATIVE PERCEPTION	A: COOPERATIVE DRIVING
				road, bridge and shoulder - Variable message sign display		
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	TMC provides information on incidents and events	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 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
TRAFFIC MANA- GEMENT	Traffic flow information	None required	Historic traffic performance status available, updated annually, EU EIP 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

	ATTRIBUTE	E: CONVENTIONAL (PHYSICAL) INFRA- STRUCTURE ONLY, NO AV SUPPORT	D: STATIC DIGITAL INFORMATION / MAP SUPPORT	C: DYNAMIC DIGITAL INFOR- MATION	B: COOPERATIVE PERCEPTION	A: COOPERATIVE DRIVING
	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	Same as level B
FRAME- WORK	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 infrastructure	Documentation available only in human readable form	Digitalisation of physical infrastructure attributes (especially those related to ODD)	Dynamic updating of physical 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

### 3.6.1.3 Environmental conditions

Table 25. Classification for environmental conditions.

ATTRIBUTE	E: O AV SUPPORT	D: STATIC DIGITAL INFORMA- TION ON ENVIRO- NMENTAL CONDIT- IONS	C: DYNAMIC DIGITAL INFORMA- TION ON ENVIRO- NMENTAL CONDIT- IONS	B: COOPERATIVE PERCEPTION ON ENVIRON- MENTAL CONDITIONS	A: COOPERATIVE DRIVING, TAKING INTO ACCOUNT THE ENVIRONMENTAL CONDITIONS
<b>Visibility</b>	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
<b>Friction</b>					
<b>Water on road</b>					
<b>Wind</b>					



### 3.6.1.4 Dynamic elements

Table 26. Classification for dynamic elements.

ATTRIBUTE		E: CONVENTIONAL TRAFFIC MANAGEMENT	D: TRAFFIC MANAGEMENT AS PERCEIVED	C: DYNAMIC TRAFFIC AND INCIDENT MANAGEMENT	B: ENHANCED TRAFFIC AND INCIDENT MANAGEMENT	A: LOCAL TRAFFIC MANAGEMENT FOR AVS
FRAME- WORK	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 VSL 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	Same as level D	Provision of local traffic management arrangement in digital form for local dynamic maps for tunnels during service breaks and tube closures including trajectory guidance
	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;	Provision of local traffic management arrangement in digital form for local dynamic maps for incident sites including trajectory guidance

ATTRIBUTE		E: CONVENTIONAL TRAFFIC MANAGEMENT	D: TRAFFIC MANAGEMENT AVPERCEIVED	C: DYNAMIC TRAFFIC AND INCIDENT MANAGEMENT	B: ENHANCED TRAFFIC AND INCIDENT MANAGEMENT	A: LOCAL TRAFFIC MANAGEMENT FOR AVS
FRAME- WORK	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 HW	Self-healing HW & SW	Self-learning SW	Self-management systems

### 3.7 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 and C. 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 27 presents the measured ISAD levels on the road sections from ring road III to Tampere. The results are similar to the other driving direction.





## 4 Proposal for Main Road Classification

### 4.1 Relevant road types and automated driving use cases

The Finnish main roads contain the following:

- motorways
- four-lane roads, i.e. undivided 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.

Motorways have been treated in earlier chapters. This chapter addresses the other main road types described above.

Roads may be located in rural, sub-urban or urban surroundings with speed limits typically within the range of 50 km/h for urban locations to 100 km/h in other contexts. Intersections may be of different configurations, both with and without traffic control signals. In addition, there may also be pedestrians and bicyclists both on and crossing the drivable area.

Automated driving use cases may contain automated buses and shuttles, robot taxis, and goods transport robots.

### 4.2 Attributes to be Considered

#### 4.2.1 Physical infrastructure

Physical attributes relevant for motorways were also deemed relevant for non-motorway main roads.

Physical infrastructure related attributes include a number of additions, partly due to additional use cases as well as changes in roadway type. New, relevant attributes are listed in the following table.

*Table 28. Physical infrastructure attributes for non-motorways*

ATTRIBUTE		DEFINITION	RELEVANCE
DRIVEABLE AREA GEOMETRY	Transverse-divided	Separation of driving direction by different means (barriers, fences, etc.)	Safe operation of AVs
	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 unsignalized roundabouts	Areas for merging, crossing, turning
	Intersections	T-, X-, Y-, staggered with/without signals; grade separated	Same as above
SPECIAL STRUCTURES	Pedestrian crossing	Marked crossing for pedestrians and cyclists for road crossing	Safety of vulnerable road users
	Separation of pedestrians 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

### 4.2.2 Digital infrastructure

All digital infrastructure attributes regarded as relevant for motorways were also deemed relevant for non-motorways.

An addition to the attributes relevant for main roads other than motorways is signal related C-ITS services.

*Table 29. Digital infrastructure attributes for non-motorways.*

ATTRIBUTE		DEFINITION	RELEVANCE
<b>C-ITS</b>	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 related to public transport, taxi, and delivery use cases will likely include fleet management and fleet supervision facilities which may require specific digital infrastructure. However, fleet supervision centres and facilities as such are considered as part of services, and therefore not part of the ODD.

### 4.2.3 Environmental conditions

Attributes related to environmental conditions relevant for motorways were also relevant for non-motorway main roads. No new attributes were found relevant.

### 4.2.4 Dynamic elements

Attributes related to dynamic elements relevant for motorways were also relevant for non-motorway main roads. No new attributes were found relevant.

## 5 Subjects Identified for Further Research

As part of the project, leaders and experts of the individual subtasks were instructed to collect needs and ideas for further research. Input from different subtasks were collected in a joint workshop and presented in the four areas of the ISAD framework. The proposals and related responsibilities are presented in the following tables.

### 5.1 Physical infrastructure

*Table 30. Proposal for further research on physical infrastructure.*

	WHAT	WHY
DEFECTS	<b>Introduce defect measurements on regular basis on sections provided for automated driving with automated pothole and other defect detection methods</b>	Good surface condition supports safe automated driving. E.g. some potholes may be difficult to detect by vehicle sensors.
	<b>Develop European solutions for lane and edge marking related problems like on non-motorway main roads at junctions with widenings made for evasive actions of left-turning vehicles and for other typical similar challenging locations (Follow actions on European level)</b>	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)
MRM	<b>Clarify detailed requirements concerning traffic management, road space, and other road operator actions required for Minimal Risk Manoeuvres (MRMs) of the various automated driving use cases</b> - for which the MRMs road operator must be prepared - of which are infrastructure requirements for these MRMs (Follow actions on European level)	MRMs may otherwise result in network lockdowns or major bottlenecks
	<b>Observe whether MRMs cause crashes due to a lack of safe space. For critical locations, consider design and construction of new widenings and lay-bys or other solutions</b>	Ensure safe MRMs
	<b>Develop MRM considering the safety and efficiency requirements of the road operators</b> (Follow actions on European level)	MRMs may otherwise result in network lockdowns or major bottlenecks
PLATOONING	<b>Investigate the impacts and demands of truck platooning on road structures and pavements, define related follow-up actions if needed</b>	To maximise the benefits of truck platooning and to minimise harm on the Finnish roadway network
	<b>Investigate whether truck platoons require changes to road and bridge structures such as higher bearing capacity than current traffic today.</b>	Sufficient road and bridge structures support safe automated driving



## 5.2 Digital infrastructure

*Table 31. Proposal for further research on digital infrastructure and communications networks.*

	WHAT	WHY
ROAD INFORMATION	<b>Enhance roadway registry data content and quality to meet the needs of automated driving support (agreed on European level)</b> <ul style="list-style-type: none"> <li>- Identify essential attributes for automated driving (ODD attributes)</li> <li>- Check the quality of those entries, define accuracy requirements for them</li> </ul> (Follow actions on European level)	Current roadway registry data for all attributes is not accurate enough, and some features should be updated according to the needs of automated driving, e.g. the width of carriageway. As the regulation/guidelines on roadway infrastructure change, compliance with current regulations should be registered
	<b>Develop a 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</b> (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 vehicles. The sharing of safety related information is a first but very small step to this direction.
CONNECTIVITY	<b>Study the effects of increase in (proportion of) traffic requiring high-capacity connectivity and requirements of new use cases</b> (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
	<b>Study if a hybrid model using means other than cellular communications would be cost effective in specific locations</b> (Follow actions on European level)	The deployed solution must be in line with what is used by vehicle manufacturers
	<b>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 these locations</b> (Follow actions on European level)	To be able to better communicate, set requirement and their cost implications
	<b>Study how identified use cases of digital infrastructure relate/localize to different road sections and how it might affect service level requirements</b> (Follow actions on European level)	To support automated driving, the service level requirements might be different for different parts of the road, incl. tunnels, sections with roadwork
	<b>Study connectivity and capacity of mobile networks from the viewpoint of reliability of information service provision</b> (Follow actions on European level)	Communication impacts the possibilities for use of C-ITS and other information services or other OTA updates
	<b>Study use cases and requirements for mobile edge computation</b> (Follow actions on European level)	Edge computation may also support communication with and between vehicles, possibly requiring localisation of processing units closer to the road

	WHAT	WHY
<b>FLEET SUPERVISION</b>	<b>Plan how to deal with fleet supervision centres and their communication needs including real-time video</b>	The requirements for reliable communication of real-time video are demanding and require special attention. Willingness to pay for communication may be higher than for other use cases. Some locations have more potential than others, like tunnels, moving roadworks, etc.

*Table 32. Proposal for further research on positioning/localisation.*

	WHAT	WHY
<b>GNSS QUALITY</b>	<b>Identify road segments planned to be provided for automated driving where GNSS quality is not sufficient, i.e. it is lower than a certain dB level (40dB) with 5 strongest satellites (e.g. tunnels, bridges)</b>	Other positioning/localisation support should be provided on these segments to ensure automated driving function use
<b>POSITIONING SUPPORT</b>	<b>Study whether permanent landmarks are required for areas with poor GNSS quality. Specify landmarks required for positioning support concerning their properties including possible radio beacons in specified locations.</b> (Follow actions on European level)	To enable reliable positioning at all times. The requirements are still unknown. Landmarks need to be cost effective to procure, install, and maintain. They need to be tall enough to be visible also during winter time (higher than snow bank).
	<b>Renew road markings every spring or provide landmarks for road segments with poor GNSS quality (e.g. 2 km before and after Hämeenlinna tunnel)</b>	Together with good visibility road markings or landmarks the supporting machine vision system will work better

Table 33. Proposal for further research on C-ITS and information services.

	WHAT	WHY
EVENT INFORMATION	<b>Conduct traffic announcements on all (mobile and stationary) roadworks which affect driving</b>	All situations that affect the usability of the road should be communicated. TMC is currently not aware of all roadworks nor on their exact timing or location
	<b>Present all information in traffic announcements according to harmonised metadata specifications instead of free-form text</b> (Follow actions on European level)	Free-form text is difficult to use for automated vehicles. All communications should be provided in standardised and machine-readable format.
	<b>Enhance information on event location and driving direction affected, ensure that event information is provided to the roadway operator (for events affecting driving)</b> (Follow actions on European level)	To be able to provide better quality information about a potential incident or other disturbance
QUALITY	<b>Develop quality frameworks and specify requirements of C-ITS and data sources for automated driving</b> (Follow actions on European level: standardisation organisations, C-ROADS, 5GAA and EU EIP)	The quality, accuracy, and reliability requirements will increase as the focus moves from information services for drivers towards data sources and C-ITS supporting automated driving. This quality framework will be needed to help AD (Automated Driving) developers to select suitable data and information sources, which can enable AD in variable conditions in the future.
	<b>Adjust all data acquisition processes to meet standard quality requirements</b>	To enhance the quality to match requirements related to data collection, fusion, enrichment, etc.
	<b>Make quality aspects a part of service-level agreements (SLA) between service providers and information or data users</b>	Data quality may impact liability issues related to automated driving in the future. Minimum quality must be defined if an automated vehicle relies on C-ITS.

## 5.3 Environmental conditions

Table 34. Proposal for further research on environmental conditions.

	WHAT	WHY
WEATHER DATA	<p><b>Enhance the quality of stored weather and road condition data. If friction cannot be measured directly, at least a reliable road surface category (icy, snowy, wet, dry, ...) should be systematically available. Also, reliable data about other simultaneous environmental conditions (e.g. accumulation of snow, and when it has been cleared) becomes more interesting in the future.</b></p> <p><b>Enable combination of both road weather station data, appropriate measurements of the FMI, and information from road maintenance logs, since analysis needs will become more complex in the future.</b></p> <p>(Follow actions on European level)</p>	<p>For the ODD analysis, it is important that at least friction and visibility combinations are available at every time interval, so that their combinations are easily available. Visibility sets minimum requirements for friction and vice versa.</p>
WEATHER MONITORING	<p><b>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.</b></p> <p>(Follow actions on European level)</p> <p><b>Utilisation of road weather sensors of vehicles to complement data from fixed road weather stations</b></p> <p>(Follow actions on European level)</p>	<p>This would enable monitoring of snow dust and water fog raised by the traffic in front of subject vehicles, not captured by road weather stations today. It is not sufficient to provide a human view on visibility conditions as the machine view is relevant for automated driving</p> <p>Better coverage of weather information preferably containing at least friction, visibility, and precipitation would allow a better understanding of prevailing conditions and support good road maintenance in winter</p>

## 5.4 Dynamic elements

Table 35. Proposal for further research on dynamic elements.

	WHAT	WHY
ROADWORKS	<b>Specification of markings and traffic management for roadworks according to the capabilities of AVs</b> (Follow actions on European level)	The Automated Driving Systems of AVs should be able to perceive correctly roadworks and the intended trajectories to navigate through roadwork sites
INCIDENTS	<b>Specification of markings and traffic management at incident sites according to the capabilities of AVs</b> (Follow actions on European level)	The Automated Driving Systems of AVs should be able to perceive correctly incident sites and the intended trajectories to bypass or drive through incident sites
AUTOMATED MAINTENANCE VEHICLES	<b>Legal framework for the use of automated maintenance vehicles</b>	The appropriate use of automated maintenance vehicles is needed by their operators
	<b>Guidelines for the use of automated maintenance vehicles</b>	The operation of the automated vehicles should be carried out in a safe and efficient manner

## 6 Summary and Conclusions

### 6.1 Assessment of current feasibility for automated vehicles on E12

The first research task of the project was to assess the feasibility of the selected motorway section (Highway E12 between Helsinki and Tampere) for the operation of SAE Level 3 and 4 automated vehicles (AVs). This assessment was implemented by identifying through expert work the likely critical attributes of physical and digital infrastructures, and then by assessing or measuring the current state using various methodologies and field measurements.

Regarding the physical features of the selected motorway section, implemented design requirements are likely to be sufficient for SAE level 3 and 4 vehicle automation. The provision of sufficient space for Minimal Risk Manoeuvres (MRM) is important (not least because of occasional poor weather conditions), and on the right shoulder a continuous width of 3 m or more is sufficient space for automated trucks as well as passenger vehicles. Currently, the hard shoulder on the left side is not wide enough to allow safe MRMs, and therefore MRMs to the left shoulder are not recommended in the Finnish motorway environment with two lanes in both directions. Instead, an MRM to the right shoulder is considered safer, as enough space can be provided. However, at high speeds and high traffic density, and especially with more than two lanes per driving direction, there are also safety concerns with right side MRMs for vehicles in the left lane, when lane changing is required.

In any case, future recommendations of the MRM policy needs to be formed in close cooperation with the automotive industry and in accordance with international standards. Today, there is still no need to make any changes to the motorway planning guidelines nor practices in this respect. Should the width of the left side shoulder become an important service level factor for AVs, narrowing of the existing lanes for the sake of a wider hard left shoulder may be considered in the future, when the penetration of AV's reaches higher levels. Another future concern regarding the design principles of motorways is the possible need in specific areas for coupling and uncoupling of truck platoons. This possible future need is dependent upon the implemented platooning solutions and their space requirements.

Rather than the design parameters of motorways, the critical attributes regarding physical support for automated driving concentrates on the condition of the infrastructure. In principle, pavement conditions should be at a good level and the maintenance of ruts or potholes should be at a high standard. The rut depth measurements performed along the E12 roadway prove that there are no major concerns regarding rut depths exceeding the set limit of 20 mm for automated driving (based on BSI 2020), as less than 2% of lane length had rut depths exceeding this limit. Therefore, it is concluded that the current road surface maintenance service level for this test segment is sufficient, and no changes are proposed in this respect.

Regarding the feasibility of lane markings to support automated driving, field measurements performed prove that the lane keeping system (MobilEye) currently on the market reliably recognized lane markings even during early spring

conditions, when the markings are typically covered with salt and dirt. However, due to winter conditions and snowfall, there will be recurrent periods when lane markings are entirely covered with snow; therefore, AV operation cannot be dependent on this feature alone. Currently, some AV developers are using cameras while others are moving away from them, relying more on radar and point cloud maps for accurate positioning of the vehicle. The latter development path would remove the necessity to introduce higher winter maintenance standards, but on the other hand, also introduces the need for permanently fixed roadside structures that support lidar-based lane-keeping functionality. The current understanding is that existing structures in the road environment, such as fences, bridges, etc., already provide sufficient support for the open road environment. Ramps, intersections, and roadway sections after tunnels require further consideration and additional support may be required. From the reliability and redundancy point of view, it is recommended to support both camera and radar-based positioning support systems.

Current traffic management systems along the test section provide useful data support for the operation of AVs. Such instrumented road sections have a higher quality of traffic and road weather monitoring and thereby a better situation and environmental condition awareness than average sections without dynamic traffic management. In addition, the existing electricity and communication supply for the traffic management devices can be utilized to also serve highly automated driving purposes. To provide full support, the current traffic management systems should support C-ITS communications standards.

Deployment of detours for a certain motorway section may occur due to a severe incident, and in tunnel sections also due to occasional but recurring maintenance works. In the short and mid-term future, the solution for such occasions is that the driver should assume responsibility for the driving task or the vehicle will perform an MRM, since planned detours likely do not fulfil the ODD requirements specified for non-motorways and it is not realistic to plan and deploy the entire detour network to fully support automated driving.

Analysis of the test section's current infrastructure and traffic related properties led to the division of the 160 km motorway into 70 physically homogenous roadway sections per direction. This means that, on average, at least one road attribute changes every 2.3 kms. This highlights the need for robust automated vehicle systems that aren't dependent on static road properties for standard motorways and that can operate in variable traffic conditions.

Service speed rates and latencies of the current communications networks (4G and 5G) were measured along E12 from all three telecom operators (DNA, Telia, Elisa). The test results show that the speed rates vary from below 1 Mbit/s to above 500 Mbit/s. It should be noted that existing 3G networks were not included in the test, and it is likely that 3G networks would provide some additional capacity in shadow areas now identified in the test section. Mobile data service is expected to further improve in the short term as mobile network operators migrate their 3G service to 4G/5G technologies by the end of 2023. Hence, if the test is repeated at the end of 2023, it is likely that there will be more continuous capacity of at least 5 Mbit/s in both directions (uplink/downlink), which is considered sufficient capacity for the basic use-cases of automated driving. It should be noted that upload performance will be equally important for more demanding use cases.

Regarding the communication networks, it is crucial to differentiate the capacity that a single vehicle requires and the capacity of a mobile network cell. The capacity of one cell is divided between all the users connected to the cell, therefore in cases where several users require high capacity, fast data transfers might not be available. In other words, heavy traffic along the roadway decreases the overall capacity available per vehicle. In practice, 5Mbit/s upload speed is difficult to achieve for 4G networks, particularly if there are many users within the same mobile cell service area.

The most demanding use cases, namely cooperative driving and tele-operated driving, require a minimum of 100 Mbit/s capacity in both directions, as well as end-to-end latency below 10ms. These features are currently only supported in the proximity of the largest urban areas. More studies are necessary to plan for the needed connectivity solution. These studies should be assessed against the requirements of higher volume AV fleets and the simultaneous use of demanding use cases. The existing passive infrastructure is at a good level in the proximity of the test motorway sections, which means decreasing cost estimates for possible future investments. For two thirds of the test section length, mobile base stations that can be used to provide high capacity 5G network services exist within 1 km of the roadway. Additionally, excellent access to existing fibre networks exists for the entire test section, which means that costly fibre network investments would likely not be needed.

The service quality of the current positioning services is high for the entire motorway test section regarding the needs of automated vehicles. GNSS-based positioning accuracy is on a centimetre level for 83% of the section and at least a decimetre level for 96% of the section, when the vehicle is using all satellite constellations (in this test, Galileo, GPS, and Glonass) as well as correction services. Positioning accuracy decreases when using any individual constellation; therefore, the use of a combination of constellations is recommended. Optimized positioning accuracy requires good signal strength (Signal-to-Noise Ratio 40 dB or above). The test proved that there are only a few locations where the signal strength drops below this threshold value, and these are explained by physical shadows or hindrances such as hill cuts, overpasses, or tunnels. In cases where the signal strength falls for a longer period of time, positioning can be managed by other technologies. Different positioning correction services may use different coordinate frames, so the need for coordinate transformations must be addressed and facilitated.

In Northern Europe, occasional poor weather is one factor that may force SAE Level 3 and 4 vehicle automation to conditions outside their defined ODDs. The reason, for which this study focused, is that airborne fog, mist, rain, or snowfall reduce the perception capability of vehicle sensors, or the road surface becomes very slippery due to formation of ice. Data analysis in this study, based on historical data from existing roadway weather stations in the test area, proves that such conditions are quite rare at least in the test area. During autumn months (September-November), difficult weather conditions for AVs exist on average 25 hours/month (3.5% of time), mainly due to the formation of fog. During winter months (December-February), difficult conditions exist on average 35 hours/month (5% of time), the dominant reason being the formation of icy road surfaces. During summer months (June-August), difficult conditions are very rare. Although the analysis was based on partially incomplete data, it proves that poor weather conditions are recurrent in southern Finland even if these events are rather rare. Nonetheless, the effect of bad weather conditions on AV's ability to automatically



perform driving tasks needs to be addressed carefully. Automated vehicles, and their users, could be provided with accurate information and prediction of critical weather conditions to enable them to be prepared for timely speed reductions, driver take-overs, or MRMs to enhance user experience and safety.

Existing fixed road weather stations already provide relevant road weather information and are also well located for automated vehicles, but this information should be complemented to provide better support. Additional supporting 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 also include the effects of snow and spray raised by other vehicles. Increasing the number of road weather stations would also increase the accuracy of provided information. Next generation automated vehicles are likely able to sense the perception capability and even friction, as well as communicating their findings to other vehicles and road operators, and this type of information source should be included in the overall data infrastructure plans.

An inventory of existing information services shows that there is a variety of public and private information services that provide relevant information regarding weather and traffic conditions. Currently used standards are aligned towards informing a human driver instead for the use of the automatic control system of an AV. Also, the accuracy of information content should be improved to be sufficient for AVs, and to meet the agreed C-ITS standard requirements. It is recommended to follow closely the development of data provision standards for AV's and to develop information dissemination services accordingly. It can be assumed that certain changes in information production processes will be necessary as well.

Overall, the assessment proves that the current physical and digital infrastructure provides good support for the basic use cases of Level 3 or 4 highway autopilot. The project team did not identify any major defects that would require immediate corrective actions with regards to supporting automated driving on motorways.

## 6.2 Proposed service level framework and its applications

The most important goal of the AUTOMOTO project was to design a classification of the Finnish motorway network for its ability to facilitate automated driving of SAE Level 3 and 4 vehicles. The classification builds on the ISAD (Infrastructure Support for Automated Driving) levels (Lytrivis et al. 2019) but has been extended to other relevant attribute areas of physical infrastructure, environmental conditions, and dynamic elements. The five ISAD levels from E to A have been maintained and the new attribute areas have been labelled following the original logic in the ISAD classification.

The most important outcome of the action is likely the identification of relevant ODD-related ISAD attributes for the 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 presented Infrastructure Support Level Classifications are based on earlier international research in the field as well as the wide national expert pool that has served the project. The level thresholds are partly quantitative, where applicable data exists, or are otherwise qualitatively described. The qualitative threshold descriptions add robustness to the framework, as they provide more flexibility in the methods used to achieve a particular level. It is already acknowledged by the authors and the FTIA that the classifications are subject to constant change, as more empirical information on the ODD requirements of AVs becomes publicly available in cooperation between the road authorities and the automotive industry. Therefore, the classification should be taken as indicative for the time being. However, the classification already provides sound and logical grounds to present an overall picture of the current, or targeted, infrastructure support level that is based on a commonly accepted framework.

The classification is made for motorways under Finnish conditions only. According to the E12 case study, Finnish motorways likely correspond quite nicely to the proposed classification, with most sections reaching Level D and many even Level C.

Constant change of the classification also emerges from the technical development of AVs, including their sensors and control systems. Technological changes are targeted towards widening AV's ODDs, among other targets. Technological change may lead to certain currently relevant ODD attributes becoming obsolete or replaced by new attributes. An example of such change is the emergence of point cloud maps and dynamic HD map databases, that may lead to line marking recognition or traffic sign recognition by vehicle's sensors becoming obsolete features in accurate positioning or provision of traffic rules information (Shladover 2021).

The accomplished work should give national authorities and operators a solid understanding of the most critical parts of the infrastructure regarding conditional or highly automated driving. The framework directs attention to the correct attributes and sheds light on how improvements may affect levels of service. It should be remembered though, that the results do not answer the question whether automated driving is currently possible or not, because the ODD requirements are always system-specific.

The created framework should work well in the communication of overall and thematical AV support for users and developers. However, it may be advisable, when possible, to provide as much quantitative measures of the current support (inc. definitions) in parallel with the service level descriptions, in the communications. This is to ensure that, e.g. AV developers have a clear understanding and can make an accurate assessment about whether or not local circumstances and local support suit the needs of the vehicle in question.

From an operational point of view, 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. No easy solutions exist today. These solutions need to be developed in cooperation with relevant stakeholders, including agreements about any governance and liability issues.

## 6.3 Discussion

It would also be extremely useful to test the proposed classification in practice, e.g. with European projects and actions to evaluate the applicability of the classification in other countries and circumstances, even though the classification was designed especially with Finnish conditions in mind. For example, sharing data of the detailed ISAD attributes with vehicles is a crucial element of ODD/ISAD framework discussions with TN-ITS, and this may require extension of the current TN-ITS specification to cover the additional attributes identified in this work.

Numerous international forums and working groups, including the European Commission's projects, CCAM Platform, CCAM partnership, UNECE, CEDR, ASECAP, ERTRAC, and standardisation bodies, exist where infrastructure support classifications for AVs are discussed, piloted, harmonized, and applied into practice. It is crucial to aim for harmonized solutions on an European and global scale, and to find consensus between transport authorities, road operators, the automotive industry, transport service providers, fleet operators, and relevant stakeholders in other automated driving use cases. National actions such as AUTOMOTO should liaise with these forums and groups, and the results of national actions should ideally also be considered and utilized in them.

The created classification is largely based on assumptions related to the ODDs of automated vehicles to be rolled out during the next decades. Some of the classification items require more work to increase their detail and reduce their ambiguity. Developing classifications towards more concrete terms (more quantitatively described) would possibly increase the applicability of the classification among AV developers. Collaboration between road authorities and automotive industry players in developing a common understanding of infrastructure support requirements and the limits of the ODDs would add great value in this future work.

The created classification and the mapped current state invites a discussion about service levels that ought to be targeted in the future. The framework provides a good basis for such discussions and targets the attention to infrastructure elements that have the most significance to automated driving. However, more analysis is needed to assess the cost for upgrading specific attributes on, e.g. motorway networks from the current level to the next, as well as, critically, the obtained socio-economic benefit. As the penetration of conditional and highly automated vehicles may be slow, focus should be at first on the so-called "no-regret" actions, benefiting both manual and automated driving, that have been identified in the cost-benefit analyses.

A systematic approach towards goal setting will require more analytical work in the future. Some organisations, such as Austroads in Australia, have already progressed from service level classification towards socio-economic analyses of improvement actions (Somers 2021), and it is likely that this field can be approached also in international collaboration. It may very well prove in the future that the targeted level of support is not any single ISAD-level, but a combination of support elements on different ISAD-levels, depending on the local circumstances and needs.

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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 strategic and tactical decision making of the automated vehicle and the operational level decisions are expected to be made on the basis of a vehicle's onboard sensors.

## 7 Next Steps and Development Needs

The Finnish Transport Infrastructure Agency has identified, based on the AUTOMOTO-project and national and international collaboration, the needed actions to improve conditions for the automation of road transport. The actions are study-type in nature and are aimed at identifying the development needs of various processes and the related costs and timetables. The focus is on “no-regret” types of actions that are beneficial to accomplish regardless of the development pace of automation.

### Physical infrastructure

Physical infrastructure actions contain the analysis of the current guidelines, specifications, and service level requirements regarding the management, maintenance, and repair of the motorway environment. The focus is on traffic control equipment (including road markings) and road pavement. The included maintenance actions are:

- repair of the pavement defects
- maintenance or renewal of traffic control equipment
- maintenance of the road shoulder area
- winter maintenance, including antiskid treatment and snow ploughing.

In addition, the processes related to road works and their temporary traffic arrangements should be analysed.

The focus of the study is on process and action guidelines, actual compliance with guidelines and the possible shortcomings, as well as incoherencies and clear absences of guidelines. The analysis should be made against anticipated requirements of automated road transport.

The analysis should provide a clear picture of the development needs regarding processes, requirements, and guidelines. At a later stage, the cost and timetable of identified changes should be assessed.

In addition, FTIA will closely monitor policies and developments regarding the needs to develop roadway infrastructure, for example in relation to MRM areas and physical landmarks.

### Data related to physical infrastructure

In this action, the essential current and foreseen datasets related to the support of automated transport and the requirements of the ITS Directive are identified. Regarding these datasets, the study topics include current data production and management models, required accuracy and quality levels, and possible existing quality shortcomings. Based on the analysis, the possible development of roles, guidelines, and processes in data production will be defined along with the related costs and timetables.

### Traffic and weather condition information

This action concentrates on safety-related and real-time traffic and weather condition information datasets that are needed by automated transport and/or

required by the ITS Directive. A study will be carried out to assess needed information production processes, the current status of data management and data quality, as well as related future needs (within a time span of five years). It will be assured that the needs are taken into account in the development of data production processes.

### **Digital Infrastructure and telecommunications**

The following requirements regarding passive infrastructure should be met:

- dialogue between road and telecom operators functions well
- guidelines and specifications are up-to-date
- permitting processes for the deployment of passive infrastructure equipment functions appropriately
- passive infrastructure is implemented in various road construction and upgrade projects according to relevant guidelines

The preconditions by which mobile network equipment can be deployed or installed in connection with road infrastructure will be analysed. In addition, the criteria for mobile network "hot spots" and their potential locations on the road network will be defined.

### **HD maps and positioning**

The information needs of HD map producers, including data coverage and quality requirements and their evolution, will be identified in relation to the static and dynamic datasets produced by transport authorities. The needs regarding HD maps, positioning and positioning correction services, are taken into account according to the role of the Finnish Transport Infrastructure Agency.

### **EU and international cooperation**

There are different EU-level and other international collaboration groups and organisations working on the development on automated driving. The essential groups on different levels will be identified in order to prioritize the groups in which the Finnish Transport Infrastructure Agency should participate.

### **Main roadway network and street network**

The service level attributes for automated driving will be defined also on the non-motorway main roads and street networks based on the results of the AUTOMOTO project and the related ODD attributes. The essential datasets are to be addressed sufficiently in Digiroad (<https://vayla.fi/en/transport-network/data/digiroad>) and the data maintenance processes will be kept up-to-date.

### **Motorway network**

The action will define the service level requirements of automated driving on motorways and analyse the entire Finnish motorway network against these requirements. Current levels of the essential ODD attributes will be assessed and, based on the shortcomings and development needs detected, specific motorway sections requiring improvement from the viewpoint of automated driving will be identified.

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## 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.	
	Horizontal-Curve	
	Tranverse-Divided	
	Transverse-Pavements	
	Transverse-Types of lanes together	
Driveable area lane specification	Lane dimensions [width]	BSI (2020), Ulrich et al (2020)
	Lane marking [width]	
	Lane marking [retroreflectivity]	
	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	
Driveable area edge	Line markers	BSI (2020)
	Shoulder (paved or gravel);	Ulrich et al. (2020)
	Shoulder width (outside)	
	Shoulder width (inside)	
	Shoulder bearing capacity	
	Widening or lay-by	BSI (2020)
	Shoulder (grass)	
	Solid barriers (e.g. grating, rails, curb, cones); Temporary line markers;	
Drivable area surface	Drivable area surface type	BSI (2020)
	Drivable area induced road surface conditions	
Drivable area signs	Fixed	BSI (2020)
	Variable	Ulrich et al. (2020)
	Sign retroreflectivity class	
	Sign visibility	
	Intersections	BSI (2020)
Special structures	Automatic access control	BSI (2020)
	Bridge	
	Tunnel	
	Toll plaza	
Fixed road structures	Buildings	BSI (2020)
	Street lights	
	Street furniture e.g. bollards	
	Vegetation	
	Landmarks (in support of GNSS positioning)	Ulrich et al. (2020)
	Localisation assistance e.g. cabling, ...	Ulrich et al. (2020)
	Gamefence	
Temporary road structures	Construction site detours	BSI (2020)
	Road works	
	Road signage	
Connectivity	Cellular communication, 4G	BSI (2020)

ISAD/ODD ATTRIBUTE: PHYSICAL INFRASTRUCTURE		SOURCE DOCUMENT(S)
TOP LEVEL	LOWER LEVER	
	Cellular communication, 5G	
	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	
	Number of lanes	
	Lanes dedicated to AVs	
	Sight distance restrictions and curvature	
	Lane markings (for humans, video and lidar sensors)	
	Horizontal symbols and arrows	
	Street lighting	
	Pavement of road and skid resistance	
	Paved shoulder	
	Road condition	
	Lay-by and parking area	
	Passenger pick-up / drop-off point	
	Operating speed	
	Traffic signs	
	VMSs	
	Localisation assistance	
	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	
	Roadworks information (stationary and mobile)	
	In-vehicle signage	
	Information on weather conditions	CCAM WG3 (2021)
	Traffic signal information (GLOSA, TTG)	
Traffic management	Traffic performance status (historic)	CCAM WG3 (2021)
	Real time information on the traffic flows	
	Routing advice, incl. the timing of alternatives	
	Warnings and information via Variable Message Signs	
	Traffic management plans and real-time guidance	CCAM WG3 (2021)
	ODD/ISAD management information	
Framework	Digital traffic rules and regulation	CCAM WG3 (2021)
	Availability of physical infrastructure	
Remote control	Fleet supervision centre/facilities	CCAM WG3 (2021)

ISAD/ODD ATTRIBUTE: PHYSICAL INFRASTRUCTURE		SOURCE DOCUMENT(S)
TOP LEVEL	LOWER LEVER	
"Visibility" at different wavelengths and frequencies		BSI (2020)
Rainfall		
Snowfall		
Hail		
Freezing rain		
Air temperature		
Humidity		
Air pressure		
Non-precipitating water droplets, marine		EU EIP
Non-precipitating water droplets or ice crystals (mist/fog), other than marine		BSI (2020)
Sand and dust		
Smoke and pollution		
Volcanic ash		
Tyre-road friction		
Icy		
Snow on drivable area		
Flooded roadways		EU EIP
Standing water		
Wet road		
Surface contamination		BSI (2020)
Mirage		
Surface temperature		
Wind		
Elevation of sun above the horizon		
Position of sun		
Night or low-ambient lighting condition		
Cloudiness		
Artificial illumination		
Electromagnetic interference		CCAM WG3 (2021)
Solar flares		EU EIP
Clutter		
Vibration		

ISAD/ODD ATTRIBUTE: DYNAMIC ELEMENTS		SOURCE DOCUMENT(S)
TOP LEVEL	LOWER LEVEL	
Traffic	Lower level	BSI (2020)
	Density of agents;	
	Volume of traffic (AADT)	
	Flow rate (veh/h)	-
	Congested (% of HCM LoS D+E+F)	BSI (2020)
	Agent type	
	Presence of special vehicles (e.g. ambulances or police vehicles)	Ulrich et al (2020)
Events & Incidents	Events	Ulrich et al (2020)
	Road accidents	
	Vehicle breakdown or stoppage	
	Road works	
	Winter maintenance	
	Road maintenance	
Maintenance	Road maintenance incl. vegetation	Ulrich et al (2020)
	Winter maintenance	
Traffic management	Monitoring systems/services	Ulrich et al (2020)
	Traffic management services	-
	Variable speed limits	Ulrich et al (2020)
	Tunnel management services	
	Incident management	
	Road works management	
	Traffic management centre systems	Niculescu et al (2020) -





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