Public and private partnership platform for quick and effective implementation of digital transport infrastructure

Lei Chen, Anders Johnson

RISE Research Institutes of Sweden

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Executive summary

This pre-study aims at analyzing the needs of digital infrastructure for connected and automated transport systems in Sweden and building roadmaps with concrete actions for accelerating the implementation of digital infrastructure. The pre-study has conducted extensive literature studies on projects, activities, and policies related to digital infrastructure in Sweden, the EU, and globally. The pre-study focuses on supporting existing activities, goals, and roadmaps within the Swedish transport sector and follows closely the roadmap for a connected and automated road transport system from Trafikverket. Expert interviews with both public and private stakeholders have been conducted to collect opinions and to formulate concrete actions.

The report consists of mainly two parts, the description of physical and digital transport infrastructure, and the identified focus areas, roadmaps, and action plans. Also, state-of-the-art digital transport infrastructure is given as an appendix to support the roadmap.

The report describes physical digital transport infrastructure as the IT, communication, and data infrastructure that together with regulations and standards enables interoperable and digital cooperation between connected vehicles, people, infrastructure, and other data sources. It is a system of systems that requires both bottom-up and top-down approaches with balanced public and private investments. A layered description is given including the communication infrastructure, transport data eco-system, applications and services, and organizational partnership.

The report proposes the establishment of a long-term public-private partnership platform to join forces to accelerate the implementation of physical digital transport infrastructure. The platform requires strong engagement from all stakeholders for addressing common challenges and for stimulating innovative policies and business models. As a trigger, eight focus areas are proposed including connectivity, positioning, control tower, data, architecture, evaluation, policies and regulations, and business models. For each area, the roadmap describes in detail the actions that should be taken together with the expected results for the year 2021 to 2025.

The transport system is a system of systems that evolves fast. Stakeholder roles and responsibilities may change with new business models and new actors emerge all the time. To accommodate such evolution, the roadmap proposes iterative development processes. The proposed actions are by no means fixed, instead, the stakeholders need to yearly conduct evaluations, agree on prioritized tasks and expected results, identify gaps, and decide on new prioritized activities.

The pre-study is financed by the strategic innovation program Drive Sweden, which is a joint investment by Vinnova, Formas and Energimyndigheten, and Trafikverket through the project *Plattform för snabb och effektiv implementering av digital infrastruktur för transportsystem* with project number 2019-04787.

Introduction

Sweden will be the best in the world in using the possibilities of digitalization in 2025 [1,2]. A well-developed and interoperable digital infrastructure is the foundation for all digital development, including the transport systems. Transport and mobility are under transformation to being connected cooperative and automated. Cooperative intelligent transport systems (C-ITS) allow road infrastructure, vehicles, and citizens to be connected. Autonomous vehicles (AVs) are on the way to be introduced where connectivity allows real-time high-definition map updating, rich and real-time sensor information collection and sharing, as well as remote maneuvering. The digital-twin technology creates a digital version of road and transport infrastructure, allows real-time information updating and sharing. All those emerging and rapidly developing technologies are supporting a fully connected and automated transport system. Due to the increasing connectivity, automation, and intelligence, the transport system is evolving into a system of systems (SoS), where multiple stakeholders from the public and private sector cooperate to enable safe, efficient, and green transport that is accessible at all places and to all citizens.

In Sweden, there are initiatives, pilot projects related to digital transport infrastructure such as ITS Sweden, the strategic innovation program Drive Sweden, InfraSweden2030, and Vinnova FFI. What is missing, however, is a long-term and strategic coordination platform for jointly driving the digital infrastructure implementation. As said, digital transport is a system of systems that will be built on existing infrastructure and will evolve with new technologies, actors, businesses, and regulations. Strong and long-term engagements are thus needed to design, build, and incrementally deploy the digital infrastructure, and to accommodate the evolution. While the public sector holds the responsibility of connected roads infrastructure, regulations, etc., the private sector holds the responsibility of connected vehicles, telecom infrastructure, etc. Rapid implementation of digital infrastructure requires a balanced investment from both sectors. After all, all sectors share a common mission to enable sustainable transport and mobility, and a long-term collaboration platform will facilitate the activities to address common challenges and to accelerate the deployment of digital infrastructure.

This report is based on a project that aims to strengthen Swedish competitiveness by creating cross-functional collaboration in the area of digital infrastructure for the road transport system. The report proposes the creation of a public and private stakeholder partnership platform where actors can collaborate on strategies, research agendas, and roadmaps to agree on priorities and build competences in the field of digital infrastructure. In addition, the report identifies needs and prioritized focus areas regarding digital infrastructure and proposes roadmaps with concrete actions and goals for the year 2021 to 2025. It is expected that through cooperation, interested actors will identify their current and future roles, responsibilities, needs in the digital transport systems, develop solutions to address the common challenges, build new products and services to create economic values, and stimulate new policy and regulations to support the transport evolution.

[1] https://www.regeringen.se/regeringens-politik/digitaliseringspolitik/
[2] https://www.regeringen.se/rattsliga-dokument/skrivelse/2017/11/skr.-20171847/

Methodologies and connection to existing roadmaps

This report aims at accelerating the implementation of digital infrastructure in Sweden with proposals on the establishment of a long-term public and private stakeholder partnership platform with concrete roadmaps. The report uses the Swedish transport administration roadmap on connected and automated road transport system[3] (referred to as TrV CAT Roadmap hereafter) extensively to explore the synergies. While the TrV CAT Roadmap has proposed concrete actions at the service level to work proactively on introducing connected and automated transport services, this roadmap focuses on concrete activities on how digital infrastructure should be developed to support those actions.

The report is done through a deep analysis of the literature available in Sweden, the EU, as well as major countries that lead the implementation of autonomous driving. Detailed literature studies are summarized in the Appendix while a summary is given here.

> The report aims at accelerating the implementation of digital infrastructure in Sweden by supporting existing activities and roadmaps such as the TrV CAT Roadmap. While the TrV CAT Roadmap has proposed concrete actions at the service level to work proactively to enable connected and automated transport, this roadmap focuses on how digital infrastructure should be developed to support the actions.

At the EU level, major work regarding digital transport infrastructure can be found within cooperative intelligent transport systems (C-ITS) where detailed descriptions of communication infrastructure, information that needs to be exchanged can be found. Besides, the topic has been addressed in the series of supporting projects including VRA, CARTRE, and ARCADE[4]. Especially in the latest project ARCADE, a thematic area on digital physical infrastructure was established and actions have been identified. Furthermore, within the EU-wide Single Platform on Cooperative, Connected, Automated and Autonomous Mobility (CCAM), two working groups are established related to the digital infrastructure, one on *physical and digital infrastructure*, and the other on *connectivity and digital*. As digital infrastructure relates closely to road operators, projects such as Inframix[5] and MANTRA[6] have analyzed the needs of infrastructure for future autonomous driving.

In Sweden, digital infrastructure has been mentioned in several of the key roadmaps including the Vinnova FFI roadmap on effective and connected transport system (EUTS)[7], TrV CAT Roadmap, and the roadmap on combined mobility as a service[8]. Besides, both EU projects such as SHOW[9], Nordic Way[10], and national projects such as those financed by FFI, Drive Sweden address the digital infrastructure one way or the other. While a lot of results and progress have been achieved, a long-

[3] Trafikverket. Färdplan för ett uppkopplat och automatiserat vägtransportsystem. (2019).
[4] https://connectedautomateddriving.eu/
[5] https://www.inframix.eu/
[6] https://www.mantra-research.eu/
[7] Vinnova. Effektiva och uppkopplade transportsystem (EUTS). (2015).
[8] Kombinerad Mobilitet Som Tjänst I Sverige. (2018).
[9] https://www.ri.se/sv/vad-vi-gor/projekt/h2020-show-shared-automation-operating-models-worldwide-adoption
[10] https://www.nordicway.net/

term platform to accelerate the digital infrastructure implementation is missing. The report takes advantage of the already established actions from the TrV CAT Roadmap, analyses and proposes roadmaps on key areas to accelerate the digital infrastructure implementation.

In the first step, four transport services (åtgärder) have been analyzed to potentially guide the implementation of digital infrastructure. Based on the descriptions in TrV CAT Roadmap, public information, and expert consultancy, a potential development roadmap for the prioritized applications is summarized as follows. Also, potential implementation paths on C-ITS, connectivity, and autonomous vehicles are assumed. Notice that the impacts of the Corona pandemic have been considered where some of the pilot activities are assumed to happen at a later time. *Figure 1* illustrates the potential TrV CAT roadmap relating to the chosen services followed by more detailed descriptions in

Table 1.

Figure 1 Potential development roadmaps for four of the actions from the TrV CAT Roadmap, C-ITS, telecom, and autonomous vehicles

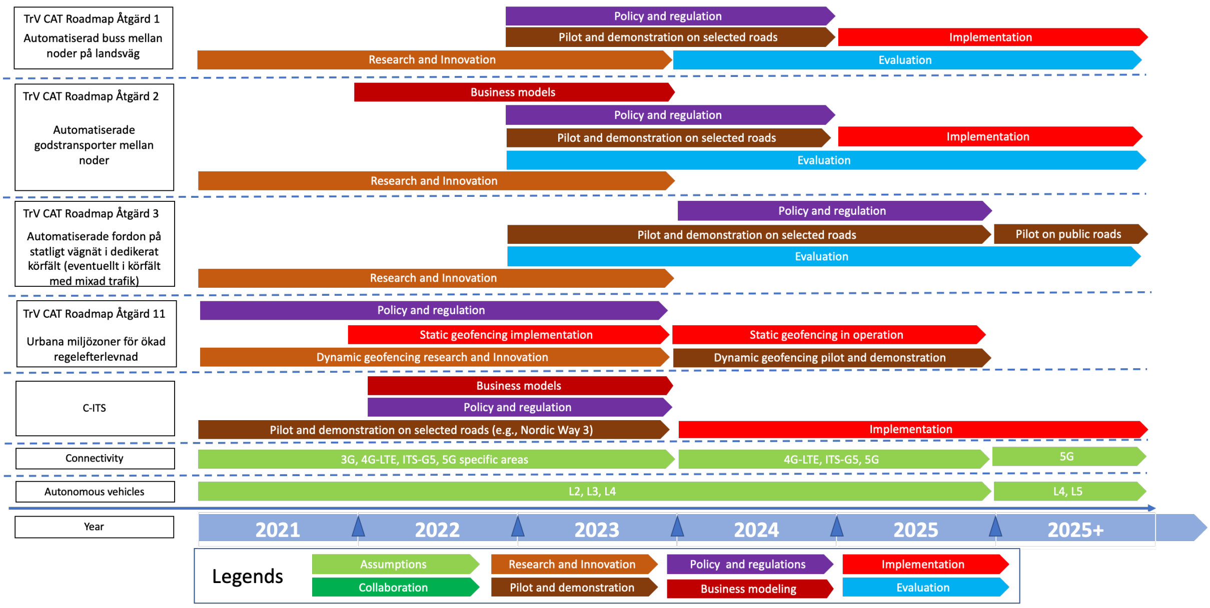
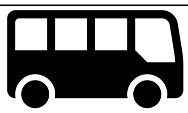


Table 1 Detailed descriptions of activities to support the TrV CAT Roadmap

 **Å1** Åtgärd 1 – Autonomous bus on country roads	**Description:** Through a pilot project with a full or partial automated bus line between two specific points on the national country roads at the level comparable to manual driven buses to understand the requirements of future technologies on the national road transport system. **Status:** One bus line in Linköping has been chosen and the preparations are ongoing. **Roadmap:** ⇒ 2021 – 2023: Research and innovation activities to prepare the pilot project regarding technologies, digital infrastructure, etc. ⇒ 2023 – 2024: Pilot with autonomous buses on the chosen lines. Policy and regulation works are started to prepare potential implementation. ⇒ 2024 and after: Evaluation is started to analyze the pilot project and the societal impacts of such applications.

	⇒ 2025 and after: A commercial line may be available
Å2 Åtgärd 2 – Autonomous goods transport	**Description:** Through pilot projects with an autonomous and electric goods transport between two specific places together with industry partners to understand what benefits the most from autonomous goods transport and what is required to have such transport solutions. **Status:** Some pilot projects have been initialized by industry partners in specific areas. **Roadmap:** ⇒ 2021 – 2023: Research and innovation activities to prepare the pilot project regarding technologies, digital infrastructure, etc. ⇒ 2023 – 2024: Pilot projects with industry partners at specific areas such as factories, harbors. Policy and regulation works are started to prepare potential implementation. ⇒ 2022 and after: Business modeling is started to prepare a market introduction. ⇒ 2024 and after: Evaluation is started to analyze the pilot project and the societal impacts of such applications. ⇒ 2025 and after: Commercial services may be available.
Å3 Åtgärd 3 - Autonomous cars on the national road with dedicated lane or mixed traffic	**Description:** Through demonstration projects on selected national roads with overcapacity where a lane is dedicated to autonomous cars to understand the functionalities of autonomous vehicles, requirements on infrastructure, and how autonomous vehicles integrate with the surroundings. **Status:** There have been pilots such as the Drive Me project and from 2021 the new regulations on public road tests will be applied. **Roadmap:** ⇒ 2021 – 2023: Research and innovation activities to prepare the pilot project regarding technologies, digital infrastructure, etc. ⇒ 2023 – 2025: Pilot projects with autonomous cars on dedicated lanes on national roads. Evaluation is started in parallel with the autonomous system as well as societal impacts. ⇒ 2024 and after: Policy and regulation works are started based on the identified needs during the pilot for potential increased pilots and commercial introduction.
Å11 Åtgärd 11 - Urban environment zones for increasing the compliance	**Description:** Through the usage of geofencing to create environment zones to assist the municipalities to introduce geofencing solutions to ensure compliance within environment zones. **Status:** Geofencing has been demonstrated and environment zones services are already provided by OEMs. Infrastructure for static geofencing is available while policies and regulations are needed for the introduction and vehicle compliance. **Roadmap:** ⇒ 2021 – 2023: Investigate the policy and regulation needs to introduce environment zones with geo-fencing and build policies and regulations for implementation. In the meanwhile, research and innovation activities are conducted to prepare the introduction of dynamic geofencing. ⇒ 2022 – 2024: Environment zones with static geofencing are implemented with certain municipalities and cities.

	⇒ 2024 and after: Environment zones with static geofencing becomes part of the transport system, and pilot projects on dynamic geofencing solutions start.
 C-ITS	**Status**: While the EU continues the work to harmonize the C-ITS service implementation, many C-ITS services are already available with the existing cellular communications. The second Nordic Way project will finish in 2020 and a new one will start and continue the C-ITS pilot. Different C-ITS services generally require the same architecture so common requirements on infrastructure are expected. **Assumptions:** ⇒ 2021 – 2023: Pilot projects such as Nordic Way on C-ITS services. ⇒ 2022 – 2023: Identify the policy regulation needs and build business models for large scale deployment of C-ITS services. ⇒ 2023 and after: Large scale deployment of C-ITS services.
 Connectivity	**Status:** Connectivity in digital transport consists mainly of the cellular networks, and the ITS-G5 through the EU C-ITS delegated act. EU has adopted an implementing decision on the harmonized usage of the 5.9 GHz spectrum for ITS where both ITS-G5 and cellular communications (LTE-V2X) are considered. **Assumptions:** ⇒ 2021 – 2023: The current 3G, 4G will be the main connectivity method. Deployment of ITS-G5 follows the EU Delegated Act. 5G starts to appear within certain areas such as big cities. ⇒ 2023 – 2025: 4G is the main connectivity method and 5G catches up with increased coverage. ITS-G5 follows the EU Delegated Act. ⇒ 2025 and after: 5G becomes available on major roads and more advanced use cases are supported.
 Autonomous vehicles	**Status:** There remain debates on the large-scale deployment of autonomous vehicles. While certain manufacturers such as Tesla is moving forward with L4 and L5 vehicles sooner, other manufacturers are conservative. **Assumptions:** ⇒ 2021 – 2025: Automation level up to L4 will be the main type of AVs on roads. ⇒ 2025 and after: L4 vehicles are used in mobility services and pilots with L5 vehicles start.

Physical and digital infrastructure for the transport system

The physical digital infrastructure for the transport system can roughly be defined as the IT and communication and data infrastructure that together with regulations and standards enables interoperable and digital cooperation between connected vehicles, people, infrastructure, and other data sources. This roadmap approaches digital infrastructure from the perspective of the system of systems and considers all aspects regarding the digitalization of transport systems. As illustrated in Figure *2*, this report analyzes digital transport infrastructure with four layers including from bottom to top the communication infrastructure, the transport data eco-system, the connected and automated vehicle applications and services, and the stakeholder partnership. For each layer, the report considers the public sector and the private sector. As shown, digital transport infrastructure covers all major public and private actors, organizations, and systems that relate to the transport system. It is a public and private collaborative infrastructure that requires strong public and private cooperation.

Figure 2 Digital transport infrastructure scope: balanced public and private investments for secure, interoperable, and scalable communication infrastructure and transport data eco-system to support the prioritized applications and services through a strong public and private partnership.

National road administration, regional and city traffic offices, infrastructure owners, operators, cities, interntional organizations, e.g., CEDR, FEHRL, PIARC.	Build public and private stakeholder **partnership** regarding physical and digital infrastructure	OEMs & suppliers, telecom vendors & operators, industry alliances and standardization bodies, e.g., 5GAA, EATA, ACEA, EARPA, CLEPA, ASAM, EARPA, ENISA, C2C-CC, UNECE, SAE, ETSI, CEN ...
Traffic control and management, infrastructure maintainance, C-ITS infrastructure to vehicle (I2V) services ...	Follow **prioritized application and services** from existing roadmaps, e.g., C-ITS, Swedish roadmap on ITS (2016), and Trafikverket connected autonomous transportssytem roadmap (2019)	Connected and autonomous driving, fleet management, C-ITS V2X services, connected automated transport, Mobility as a Service ...
Static road information e.g., road design, geometry, travel routes, digital traffic regulations ... Dynamic and temporary road information, e.g., road works, dynamic geofencing, real time traffic information, digital traffic lights, digital variable message sign, road sensors ... Positioning data Standards e.g., DATEXII, C-ITS, ISO/TC 204, CEN/TS 17268 ...	Build **transport data eco-systems, ontologies and semantics** with explicit specification on data ownership and needs, security and privacy	HD maps, e.g., all static and dynamic information Vehicle sensor and control, e.g., sensor data, camera data, floating car data, vehicle control information ... Opertional Design Domain (ODD) attributes on digital information Standards and specifications, e.g., VSS, VISS, ISO 20078, ISO 20080, Neutral Vehicle, C-ITS ...
Physical road elements that could be digitalized and connected: traffic signs, road sensors, traffic lights, QR codes, variable message signs (VMS) ... Position infrastructure: e.g., reference stations, C-ITS and IT infrastructure: e.g., road side unit, traffic management servers ...	Public and private partnership to design and deploy **communication infrastructure** that is with high security, availability, reliability and capacity to support data exchange among all stakeholders.	Connected vehicles, e.g., vehicle sensors, vehicle cameras ... Positioning, e.g., GPS Connectivity, e.g., C-ITS, ITS-G5, 4G/5G, WiFi ... OEM IT infrastructure, e.g., cloud Smart phones and devices ...
Public Road infrastructure, IT infrastructure, regulations, etc.	**Cooperation**	**Private** Automotive, telecom, service providers, citizens, etc.

Communication infrastructure

Design and deploy communication infrastructure that is with high security, availability, reliability, and capacity

The communication infrastructure is the physical backbone of the digital infrastructure. It connects all the elements within the transport system and allows them to communicate and share information to enable sustainable transport services.

For the public sector, this relates to the IT infrastructure that connected all physical road elements such as traffic signs, traffic lights, and different types of road sensors. Such infrastructure allows information collection and aggregation on roads and traffic at different levels including the local, regional, national, and even EU.

For the private sector, the communication infrastructure relates to the connected vehicles with rich information from sensors and cameras, positioning infrastructure such as through satellites and vehicle sensors, telecom infrastructure such as ITS-G5 short-range communications, 4G and 5G cellular communications, as well as IT infrastructure for the automotive OEMs and suppliers. This relates also to the citizens to whom the smartphones allow Internet access.

Sweden has in general good mobile broadband services which allows C-ITS services implementation and certain prioritized applications such as geofencing. However, to accommodate the growing demand for real-time information delivery among national and local road and traffic authorities and operators, as well as between public and private stakeholders, improvements on existing infrastructure are needed and new infrastructure is anticipated. Through a public and private partnership, connectivity can be supported at a satisfying level for transport services with improvement on the existing communication infrastructure and building of new infrastructure. Eventually, communication infrastructure with high security, availability, reliability, and capacity should be deployed to address the needs of prioritized applications and services.

Transport data eco-system

Build transport data eco-systems, ontologies, and semantics with explicit specification on data ownership and needs, security and privacy

Data is the blood in the digital transport infrastructure. Different stakeholders own different types of data and have needs on other types of data from other stakeholders. Cross-domain data exchange is key to enable cooperative and automated mobility. It is thus important to keep conversations on the ownership and needs of data among stakeholders for the joint development of data-driven services.

For the public sector, this relates to the static data such as road geometry, dynamic data such as road sensor data, traffic regulations in their digital form, as well as potential positioning information from infrastructure. The public sector takes the concept of "open by default" to gradually make many types of data available through NVDB[11], NAP[12] following certain standards such as ISO TC204, CEN/TS 17268, C-ITS, and DATEXII. At the same time, it also wishes to get access to data that is collected by vehicle sensors for traffic safety and even other data-enriched

[11] https://www.nvdb.se/sv
[12] https://www.trafficdata.se/

services such as road maintenance, traffic management, etc., as shown by the collaboration of Trafikverket and Volvo Cars on digital winder road data[13].

For the private sector, data becomes new assets for e.g., automotive manufacturers and service providers, as the connected vehicles provide large amounts of data that can be used for different purposes. There are different initiatives and standards to explore the usage of such data including Vehicle Signal Specification (VSS), Vehicle Information Service Specification (VISS), ISO 20078 extended Vehicle, ISO 20080 Information for remote diagnostic support, Neutral Vehicle[14], and so on. The vehicle industries are working on common frameworks and methods such as ontologies and semantics to make vehicle data available with consideration of data security, data privacy, and economy.

It is generally agreed data is valuable by both the private and public actors, while how to efficiently explore such values systematically remains challenging. There is a strong need to improve communication between stakeholders regarding data ownership and needs, data quality, privacy, and application purposes. It is also important to recognize that breaking the data silos will take a longer time while concrete applications can already be done through joint or ad hoc collaborations. Such best practices can be used to stimulate the construction of systematic frameworks for data sharing. Through the building of a long-term conversation platform, stakeholders can explicitly communicate their data ownership and needs, build ontologies at the transport system level covering individual domain-specific ones, design interoperable semantics across all related stakeholders with international standardization, build business cases, propose new policy and regulations, and jointly move forward for e.g., a transport semantic web.

Applications and services

Take advantage of the identified prioritized applications and services with high societal impacts to analyze the digital infrastructure supporting needs

Digital transport infrastructure supports the realization of transport applications and mobility services. As improving the existing infrastructure and building new infrastructure involves a significant investment, it is extremely important to understand the needs of transport applications and mobility services.

The public sector aims at providing transport applications and mobility services that are safe, efficient, green, and accessible for all. This can be done through e.g., infrastructure to vehicle (I2V) services to provide real-time traffic information and infrastructure adaptations for future autonomous transport. It may also be done through infrastructure and traffic control to guide the traffic flow. Another key task from the public and road operators is to maintain the road infrastructure at a satisfying level. For such purposes, not only road sensor information is important, the floating and probing data from connected vehicles may contribute significantly to better infrastructure maintenance.

The private sector aims at providing new mobility services with connected and autonomous vehicles including autonomous first/last mile services, autonomous taxi services, autonomous goods transport, as well as combined mobilities as a service. Before AVs can handle all situations i.e., L5 vehicles, they will need to operate within the operational designed

[13] https://www.trafikverket.se/om-oss/pressrum/pressmeddelanden/Nationellt/2020/2020-10/digital-vintervaglagsdata-ger-okad-sakerhet-och-framkomlighet/

[14] https://neutralvehicle.com/index.html

domain (ODD) and they will need real-time information on the environment such as road, infrastructure, weather, and traffic information. This will require connectivity for e.g., real-time informant, HD map updating, and potentially positioning support.

The public and private sectors have different needs on the digital infrastructure to support their core application area, while they have mutual needs on data for serving their objectives and they share a joint mission to enable safe, efficient, green, and accessible mobility services. Many of the applications and services will be built on common infrastructure, e.g., road infrastructure, connectivity, and transport data. Through explicitly communicate with the application and service requirements on data and connectivity, the public and private stakeholders can map out the needs and capabilities among themselves. With proper policies, regulations, and business modeling, common challenges can be addressed jointly.

Partnership

Build a long-term strategic public and private stakeholder cooperation platform to join efforts for accelerating the digital infrastructure implementation

Investment in digital transport infrastructure requires many decisions from the related stakeholders, both public and private.

The public sector consists of national, regional, and local road authorities. They work closely with the road operators to ensure well functional road infrastructure and the availability of high-quality road and traffic information. To accommodate the forthcoming connected and automated transport, the public sector needs to understand the roles of infrastructure and to prioritize the investment in services with clear societal impacts such as accessibility. Proper policies and regulations need to be in place to support the rapid evolution of the mobility sector.

The private sector consists of industry partners including automotive manufactures, service providers, telecom vendors, and operators, as well as citizens. The increasing mobility needs drive the evolution of mobility services and stakeholders are seeking opportunities to locate themselves in the connected and autonomous mobility era. The telecom industry needs to identify themselves in the mobility sector with viable business models to justify significant infrastructure investment. While the automotive and service industry needs to identify new mobility services and business potentials for the rapid mobility transformation.

Sweden has a strong cooperation environment with many of the already established programs such as Drive Sweden. However, a long-term digital infrastructure public private partnership (DI-PPP) is yet to be developed. Such a DI-PPP requires commitment from involved stakeholders for long-term involvement with anticipation that their roles may change during the mobility transformation. The DI-PPP needs firstly to communicate with the current capabilities and needs of all stakeholders for different purposes. The platform focuses on the common challenges while the businesses of individual stakeholders should be kept within the market competitions. The DI-PPP needs to keep in mind that the digital transport system is a system of systems with its unique characteristics. For example, stakeholders join a system of systems to enable a common goal at the system level instead of maximizing their individual goals. In most cases, this requires compromising and balancing. Furthermore, the evolution of a system of systems never stops, and the roles and responsibilities of individual stakeholders may change, and new actors may emerge. It is thus important DI-PPP follows an iterative development process, conducts follow-ups, and formulates new strategies frequently, e.g., yearly.

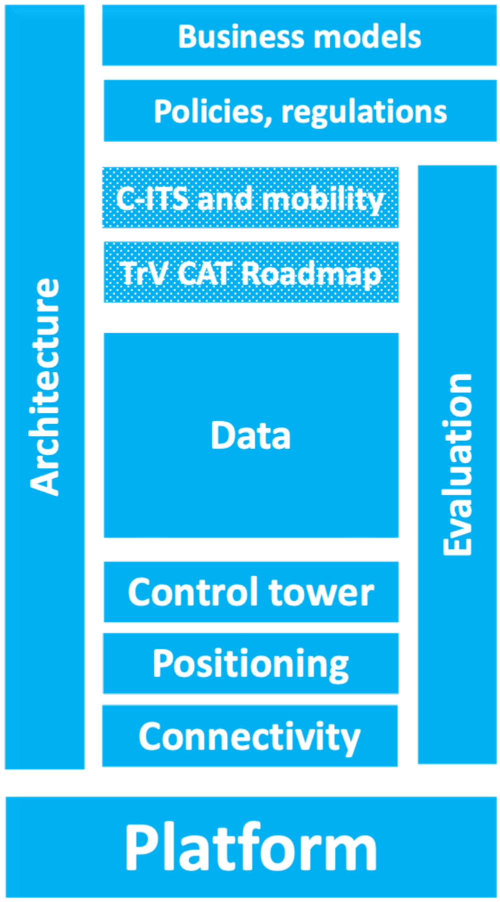
Ultimately, the already established Drive Sweden digital infrastructure thematic area should go a step further to enable DI-PPP with strong engagement from all relevant public and private stakeholders. As all stakeholders agree that cooperation is the key to move forward, actions need to be taken to move from words to implementations. This report proposes key focus areas with concrete actions and roadmaps as an ignition for such activities as will be presented in the following chapter.

Focus areas and roadmaps

The report identifies focus areas following the descriptions of digital transport infrastructure, as summarized in the following part. Notice that applications and services have been identified within e.g., C-ITS and the TrV CAT Roadmap, and they have been discussed in the previous section. This report focuses on how digital infrastructure supports those already identified applications to create societal impacts. The focus areas are summarized as follows.

Business models - Develop collaborative business models together with all stakeholders to accelerate digital infrastructure implementation

Policies and regulations – Innovation for new policies and regulations to support digital infrastructure implementation



Applications and services - Support identified applications and services in existing roadmaps

Evaluation - Evaluate technologies and services from the technical, organizational, and societal perspective

Architecture – Integrate efforts from other areas and build a scalable, secure, and interoperable public private digital infrastructure architecture with open standards

Data - Build transport data eco-systems, ontologies, and semantics with explicit specification on data ownership and needs, security and privacy

Control tower - Design and develop future traffic control and management systems with autonomous vehicles

Positioning – Research on positioning technologies and build positioning strategies and HD maps for connected autonomous transport and mobility

Connectivity - Improve and deploy communication infrastructure that is with high security, availability, reliability, and capacity

Platform - Build a long-term public and private stakeholder partnership platform to accelerate the digital infrastructure implementation

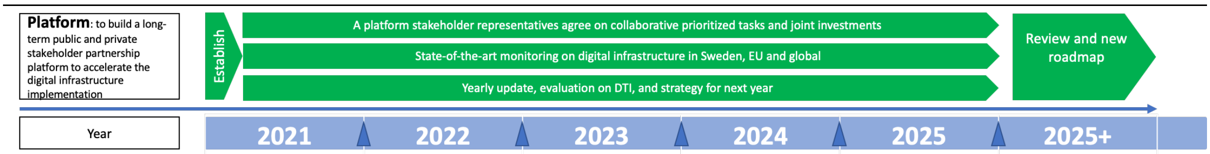
In the following part, we present the identified roadmaps including backgrounds, actions, and expected results. The same legends as shown in *Figure 1* are used.

Platform

Build a long-term public and private stakeholder partnership platform to accelerate the digital infrastructure implementation

This area focuses on building a long-term digital infrastructure public and private partnership (DI-PPP) platform to lead and coordinate the implementation of digital transport infrastructure and to accommodate its continuous evolution.

Table 2 Roadmap for public private stakeholder partnership platform



There is a gap in understanding the roles, responsibilities, and development paths of relevant stakeholders on digital transport infrastructure. The development has mostly been done by ad-hoc activities among stakeholders through voluntary collaboration, business contracts, etc. While all stakeholders agree that cooperation is important, concrete implementation plans at the system level are missing.

Action points:

2021:

- Collect interests and contact persons from all stakeholders for DI-PPP joint declaration
- Build focus groups and committees with relevant experts and prioritize activities
- Identify stakeholders to coordinate the DI-PPP and lead each focus areas

2021 – 2025:

- Establish necessary processes and frameworks to facilitate the collaboration
- Agree on the focus areas for the next year with concrete action plans e.g., the leading and involving actors, expected goals, and impacts.
- Monitor the global development of digital infrastructure and conduct gap analysis by leveraging the experts involving international activities
- Conduct yearly follow-up against the yearly goals

2025 and after: Review of the DI-PPP for a new roadmap

Milestones:

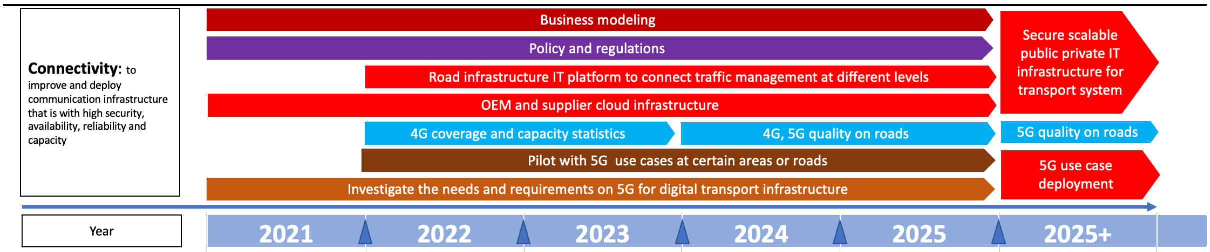
- A long-term DI-PPP platform is established with strong engagement and appointments of coordinating and involving partners
- Yearly status update on the global development of digital infrastructure
- Yearly follow-up report on the Swedish implementation and new strategy for next year

Connectivity

Improve and deploy communication infrastructure that is with high security, availability, reliability, and capacity

Connectivity is the core enabling technologies for connected and autonomous transport systems. The future communication infrastructure needs to be with high security, availability, reliability, and capacity which requires joint public and private investments.

Table 3 Connectivity roadmap for improving and deploy communication infrastructure



Sweden enjoys good telecom infrastructure with good coverage and capacity, and it is yet to understand in detail the statistics of coverage, capacity, and the number of available operators on the road networks including rural areas. C-ITS services are available under the current networks for certain services, while 5G may be required for advanced services. While infrastructure investment and evolution take a longer time, it is important to be realistic and understand the capabilities of the existing infrastructure, specify the communication needs at the service level for gap analysis, and find public and private initiatives for gradually improving the infrastructure.

Action points:

2021 – 2025:

- OEMs continue with the implementation of connected vehicle cloud platform
- Build policy and regulations on connectivity for C-ITS
- Build business models for public and private joint investment in communication infrastructure
- Research and innovation activities regarding 5G for future transport
- Specify needs on connectivity at the service level for agreed use cases such as through ODD

2022 – 2025:

- Public sector to improve and adapt road IT infrastructure and to digitalize traffic regulations
- Conduct surveys on 4G, 5G for the road transport networks including rural areas
- Pilot project with 5G at coverage areas

2025 and after:

- Continue the road IT infrastructure evolution with new needs
- Potential deployment of 5G transport services

- Conduct surveys on national 5G coverage and capacity

Milestones:

- Updated needs and requirements on connectivity at the service level
- Status report on national road IT infrastructure to connect national, regional, and local traffic management systems for efficient information reporting and sharing
- Cross-stakeholder connected vehicle and transport cloud platform
- Statistics on 4G and 5G on the road network including rural areas and gap analysis report
- Recommendation to policy and recommendation on connectivity
- Public private investment models to accelerate the implementation

Relation to TrV CAT Roadmap:

Å1, Å2, Å3 mostly will have similar requirements on connectivity for autonomous driving. The industry needs to explicitly communicate the needs of connectivity with detailed specifications on quality and purposes. The industry can assist the collection and analysis of telecom data to understand connectivity quality and to suggest improvements. The public sector needs to collaborate actively with telecom operators on a strategy for the connectivity on road networks.

The connectivity infrastructure for **Å11** static geofencing is available. Geofencing information can be retrieved from NVDB and the focus is on the vehicle side to implement proper solutions to ensure compliance. Potentially, the industry and public sector can jointly develop mechanisms to ensure compliance. For dynamic geofencing, connectivity and communication infrastructure gaps need to be analyzed such as how the dynamic geofencing can be handled and to what quality it should be handled.

Positioning

Research on positioning alternatives and build positioning strategies and HD maps for connected autonomous transport and mobility

C-ITS services are mostly location-based and autonomous vehicles require high precision positioning. Different positioning alternatives exist including satellite-based, infrastructure-based, vehicle sensor-based, and cooperative positioning with C-ITS, 4G, 5G networks. In addition, high definition (HD) maps are under development by the industry partners with support from the public sector with e.g., geographical information.

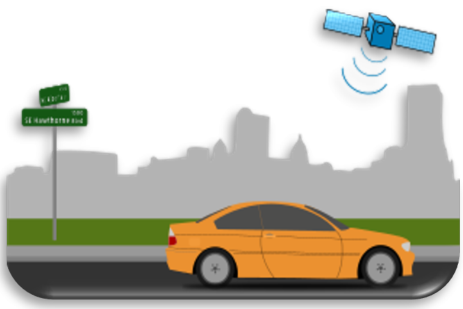
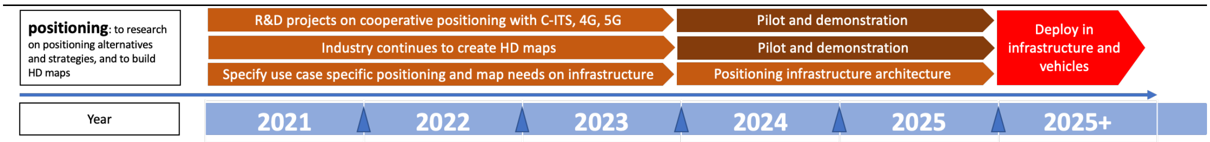


Table 4 Roadmap on positioning for positioning alternatives and strategies



In Sweden, the Landmäteriet takes care of the positioning infrastructure to provide related services such as Swepos. In the meanwhile, the vehicle industry continues enhancing the sensor-based positioning so that vehicles can handle situations without GPS. Experiments on landmark-based positioning are also conducted. 5G-based positioning is under standardization within the telecom sector. There are needs to understand the current positioning alternatives and how a nationwide positioning strategy can be established to support services with higher positioning requirements. In addition, HD maps is mostly under development by industry partners while certain data with high accuracy is needed from the public sector.

Action points:

2021 – 2023:

- Specify scenario-based positioning needs on infrastructure and gaps
- Create HD maps in combination with high precision positioning
- Investigate the usage of ODD to communicate the positioning needs
- Research and innovation activities on positioning alternatives such as cooperative positioning

2024 – 2025:

- Pilot projects on positioning together with TrV CAT Roadmap pilots and with HD maps
- Design heterogenous positioning architecture to cover different applications

2025 and after:

- Technologies deployed in infrastructure and vehicles
- New strategy and challenges identified

Milestones:

- Research and pilot results on different positioning strategies
- Recommendations on ODD regarding positioning
- Swedish strategy on high precision positioning to support connected and autonomous road transport

Relation to TrV CAT Roadmap:

For **Å1** and **Å3**, public roads are used and dedicated lanes may be assigned. High accuracy positioning methods such as to the lane level will be needed. Similar needs for **Å2**, while if the goods transport is in the industrial areas with less traffic, the positioning requirements may be different.

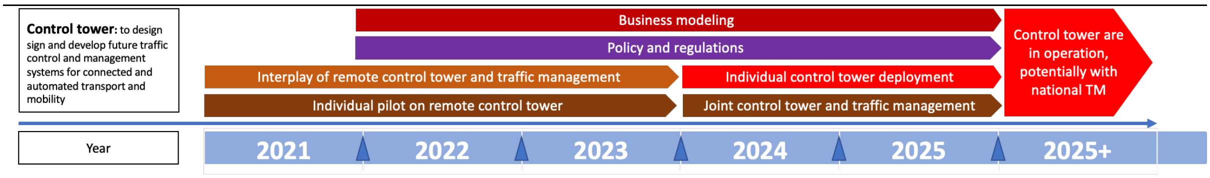
For **Å11**, geofencing is location-based which requires that vehicles should be able to position themselves. For environment zones, this is not safety-critical where the current GPS positioning may be enough. For geofencing applying to other applications, higher precision positioning may be needed depending on the applications.

Control tower

Design and develop future traffic control and management systems for connected and automated transport and mobility

With connected autonomous vehicles, traffic management will be at a new level. Real-time remote control and management may be needed to assist the autonomous vehicle and its passengers. When many autonomous vehicles are on the road, traffic management will be different compared with today, and how traffic management from the public sector and vehicle control from the private sector interplays remains to be investigated.

Table 5 Roadmap on control tower for future traffic control and management



The traffic control tower is a rather new concept applied to autonomous vehicles. In Sweden, several projects are ongoing including the EU SHOW project and the Drive Sweden projects. It is mostly under research and innovation, and how it will fit the future transport remains to be understood.

Action points:

2021 – 2023:

- Continue the pilot project on remote traffic control towers
- Research and innovation on the role of traffic control towers in future traffic management
- Investigate the role of the public sector such as how traffic tower interplays with national and local traffic management systems
- Identity needs on policies and regulations regarding traffic control tower

2022 – 2025:

- Build policies and regulations regarding traffic control tower if needed
- Build business models on traffic control towers, potentially with public and private collaboration

2024 - 2025:

- Potential implementation of traffic control towers
- Conduct pilot projects on joint vehicle control and traffic management with public and private collaboration

2025 and after:

- Potential increasing deployment of traffic control towers
- Potential joint public and private collaborative traffic management with traffic control tower
- New challenges and strategy

Milestones:

- Technical and operational requirements and challenges on control towers
- Operational control towers, single stakeholder or multiple stakeholders
- Pilot project results on joint private and public control towers
- Policy, regulations, and business models regarding control towers

Relation to TrV CAT Roadmap:

For **Å1**and **Å2**, traffic control towers will play similar roles to e.g., manage the busses and its passengers, control and remote drive the logistic vehicles. Since busses have passengers in the loop, vehicle control will be different in comparison to goods transport. For **Å3** autonomous cars, the traffic control tower may have different functions such as to assist the drivers in certain situations.

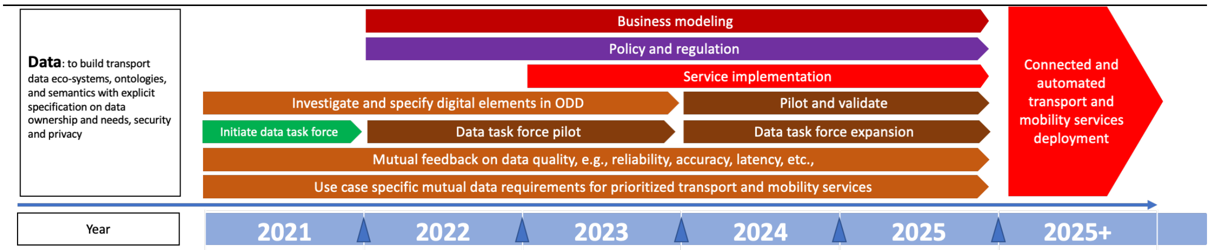
For **Å11**, traffic control towers may play a role to ensure the compliance of vehicles regarding the entrance of environmental zones.

Data

Build transport data eco-systems, ontologies, and semantics with explicit specification on data ownership and needs, security and privacy

Data holds the keys for many new advanced transport solutions such as to enable predictive road and vehicle maintenance, to improve traffic safety and efficiency, and to optimize the transport networks. The current data eco-system consists of many isolated data islands with highly heterogeneous data, and the value of data is far from explored from the transport system perspective.

Table 6 Roadmap on data eco-system for facilitating transport data exchange and innovation



In Sweden, the public sector takes the "open by default" approach and continuously make road and infrastructure data available. The vehicle manufacturers all have their own connected vehicle cloud systems to build data intelligence. Collaborations can be found such as through peer-to-peer contract and/or neutral servers, while a standardized and interoperable framework remains to be developed.

Action points:

2021 – 2025:

- Continuously communicate with mutual data needs with detail specification on quality, privacy, and security
- Continuously mutual feedback on data quality, e.g., availability, accuracy, latency

- Public stakeholders develop ontologies and semantics regarding data from road infrastructure
- Private stakeholders develop ontologies and semantics regarding the vehicle data
- Public and private cooperation on ontologies and semantics at the transport system level e.g., a transport semantic web
- Initiate data task force or similar pilots to validate the data exchange for agreed use cases
- Investigate the usage of ODD for data needs specification and conduct pilots to validate the method

2022 – 2025:

- Pilot projects on data exchange among stakeholders
- Build policy and regulations to ensure the availability and quality of certain types of data, e.g., data availability may be a prerequisite for certain public procurement
- Build business models on data exchange, e.g., through peer-to-peer contracts, neutral servers, and so on

2023 - 2025:

- Implement the agreed data exchange services under the available policy, regulation, and/or business models

2025 and after:

- Refresh the data eco-system for gap analysis and continuous evolution with the availability of 5G and highly automated vehicles

Milestones:

- Specifications on ontologies and semantics at the transport system level, e.g., what they are and by what format to represent them
- Status report on the status of data ownership, needs, and gaps
- Methods and frameworks to handle data privacy and security
- Collaborative initiatives on data exchange such as data task force or similar
- Detailed specification e.g., through ODD for the TrV CAT Roadmap use cases
- Recommendations to policies, regulations, and business models

Relation to TrV CAT Roadmap:

Å1 Å2 and **Å3** will mostly require real-time traffic and infrastructure information to make decisions at different time scales to support e.g., routing, navigating, maneuvering, and even collision avoidance. On the other hand, probe vehicle data or floating car data may augment the infrastructure sensor data to assist the public stakeholders in maintaining the road condition and infrastructure. An interoperable, secure semantic data platform with standardized machine-readable data specification will facilitate the implementation of such use cases.

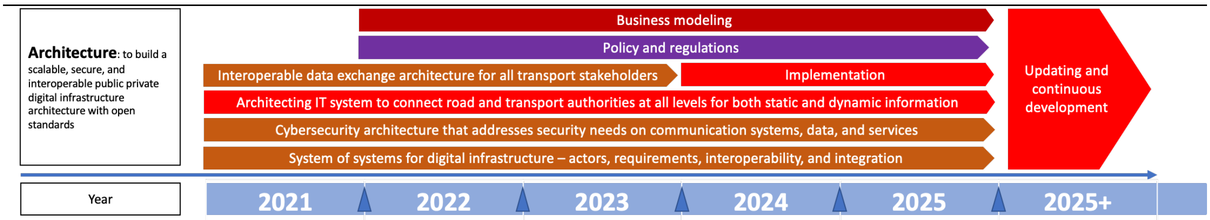
For **Å11**, it mostly regards the geofencing information. A standardized geofencing specification for environmental zones may be needed to scale up the solution.

Architecture

Integrate efforts from other areas and build a scalable, secure, and interoperable public private digital infrastructure architecture with open standards

Digital transport infrastructure is a system of systems that requires a comprehensive architecting process for a multi-stakeholder, secure, interoperable, and scalable architecture. The architecture needs to base on open standards and accommodate the needs of both public and private sectors and allow information exchange among all stakeholders. It needs to accommodate the nature of system of systems on continuous evolution with new actors, technologies, regulations, and business cases, and needs to ensure a high level of cybersecurity due to the inter-connecting nature. Artificial intelligence should be considered to support e.g., traditional machine learning that requires large amounts of data collection and privacy-preserving machine learning (e.g., federated learning) that allows information sharing without revealing raw data. Human-centric architecting will be essential to ensure the system is designed to serve the real needs of citizens. This focus area oversees other focus areas for a high-level system architecture that integrates all aspects including technical, organizational, social-technical, and so on.

Table 7 Roadmap on architecture for a scalable secure and interoperable digital infrastructure



In Sweden, Trafikverket has been developing the architecture to collect data from different sources and make them available for the private actor to develop services. In the meanwhile, for C-ITS, an interchange architecture is under development that allows multiple stakeholder data exchange. Such interchange architecture has been also applied in the Drive Sweden innovation cloud. Besides, the stakeholder ecosystem has been discussed such as in Drive Sweden and Nordic Way project, while it remains challenging to understand the current and future roles, responsibilities of each actor, and this forms one of the barriers for digital infrastructure.

Action points:

2021 – 2025:

- Clarify the current actors, requirements, responsibilities for integration
- Identify new actors, new roles, and responsibilities for system evolution
- Architecting and implementing the IT infrastructure at the public sector to connect road and traffic management systems at different levels
- Continue developing NVDB and NAP and identify their future roles
- Architecting the digital transport infrastructure from a system of systems perspective, e.g., to support public and private real-time data exchange
- Investigate the cybersecurity architecture that addresses the security concerns on communication systems, data, and services

2022 – 2025:

- Build policy and regulations, and business models that form part of the overall architecture

2024 - 2025:

- System implementation to allow public and private data exchange based on the developed architecture, business models, policy, and regulations

2025 and after:

- Refresh the architecture for continuous evolution

Milestones:

- Status updates on nation-wide road IT architecture
- Live inventory on actors, roles, responsibilities with the potential future evolution
- Initial multi-stakeholder public private cloud information exchange architecture
- Recommendations to policies, regulations, and business models

Relation to TrV CAT Roadmap:

Å1 Å2 and **Å3** will mostly depend on the system developed by the operators and their suppliers where architectures may vary. Fitting into the future transport system requires that each system will be part of a bigger system of systems, and how exactly it will be integrated need to be investigated at the overall architecture level. System architects from all relevant stakeholders need to coordinate with the architecting process.

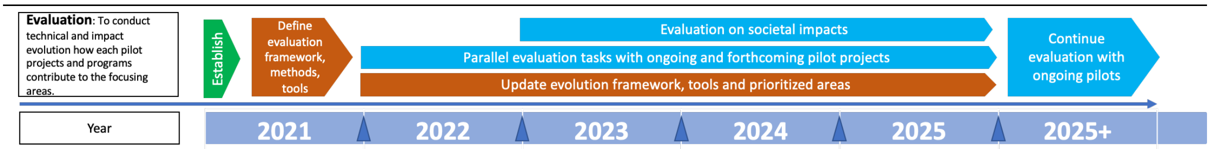
For **Å11**, it has clear needs on public and private collaboration where on the one hand geofencing information should be available from the public sector with the required quality, and on the other hand it should be consumed by the private sector following the rules/regulations which need to be built.

Evaluation

Evaluate technologies and services from the technical, organizational, and societal perspective

The technologies evolve rapidly with autonomous vehicles, 5G, artificial intelligence, and so on. Technologies enable new transport solutions and mobility services that again serve society and human needs. It is therefore important to make sure that digital infrastructure is designed and developed in a human-centric way to support the mobility transformation and to address societal and human needs.

Table 8 Roadmap on evaluation to understand the impacts of connected autonomous transport and mobility



Many projects and pilots are currently ongoing towards connected and automated transport systems. With existing infrastructure and further advancement, many services are at the point of introduction. A systematic evaluation framework with relevant stakeholders and proper processes, tools will unify those efforts and make sure that the public private collaborative investment is toward the expected societal impacts and contribute to sustainable development.

Action points:

2021:

- Establish an evaluation area and subgroups with interest experts
- Define evaluation framework with potential processes and tools

2022 – 2025:

- Agree and update prioritized evaluation topics regarding e.g., transport and mobility goals
- Each ongoing project conduct evaluation and report on the impacts regarding digital infrastructure and the society
- Continuously evaluate the telecom infrastructure on the road network
- Mutual public private evaluation to identify gaps and for improvement including data, policy, regulations, and so on
- Continue to improve the evaluation framework

2023 - 2025:

- Evaluation at the macro-level on the societal impacts based on the results from pilot and implementation projects

2025 and after:

- Evaluation continues with new strategy and roadmaps

Milestones:

- Evaluation framework, tools, processes
- Performance report from individual project regarding digital infrastructure
- Mutual public and private evaluation reports, e.g., how the public and private support each other and what needs to be improved

Relation to TrV CAT Roadmap:

Å1 Å2 and **Å3** should have parallel evaluation activities to understand the impact of such services and to identify the role of digital infrastructure in future connected autonomous transport systems.

For **Å11**, while environmental zones contribute to the climate goal, evaluation needs to focus on the compliance for solution improvement, as well as the impacts from a broader transport and mobility perspective.

Acknowledgement: The following two areas policies and regulations, and business models will be mostly integrated with the other areas and are expected to be handled within the corresponding Drive Sweden thematic areas. Detailed actions and tasks are expected to be done within the thematic areas and are less elaborated in this report.

Policies and regulations

Innovation for new policies and regulations to support digital infrastructure implementation

Policies and regulations are important tools to support and accelerate the implementation of digital infrastructure and connected and automated transport systems.

Action points:
2021 – 2025:
- Integrate with other focus areas
- Identify gaps in policies and regulations for connected automated transport and mobility services
- Identify and involve responsible authorities
- Policy and regulation innovation to support other areas

Milestones:
- Policy and regulations supporting concrete needs from other areas

Business models

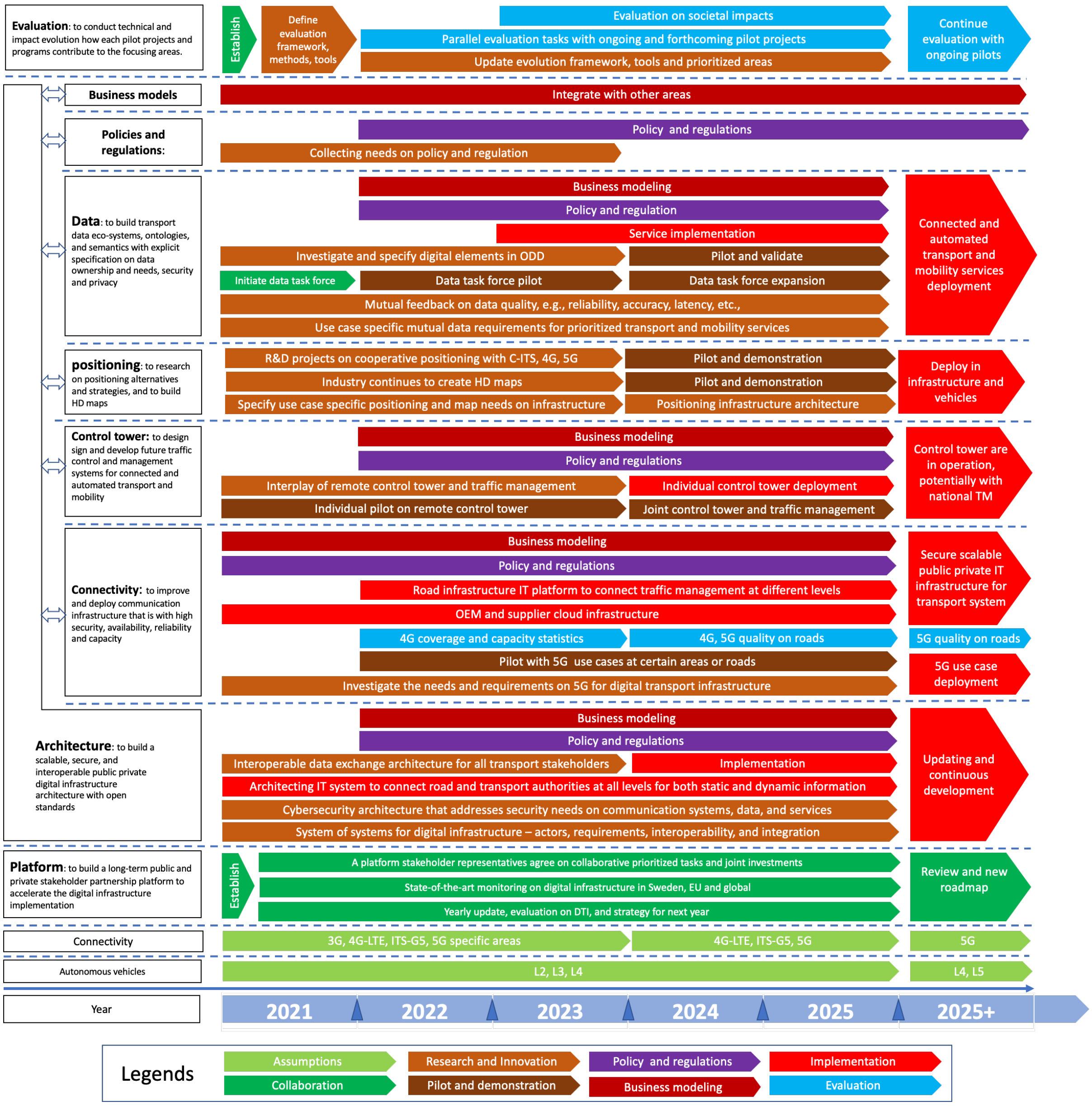
Develop collaborative business models together with all stakeholders to accelerate digital infrastructure implementation

Business models are a strong driving force to realize sustainable and long-lasting implementation.

Action points:
2021 – 2025:
- Integrate with other focus areas
- Build business models to facilitate public and private collaboration
- Public integrate requirements on digitalization in infrastructure procurement
- Industry stakeholders build business models to accelerate the implementation of digital infrastructure and to support the introduction of new transport and mobility services

Milestones:
- Business models

Appendix 1 – the full roadmap



Appendix 2 - Digital Transportation Infrastructure

Introduction

This appendix collects major activities in Sweden and at the EU level regarding digital and physical infrastructure for future connected and automated mobility. The aim is to pave a ground for analysis for mapping out the needs of digital infrastructure in Sweden.

In addition, global activities from major countries on policies and roadmaps of digital transport infrastructures are presented. Those countries are selected based on the ranking of KMPG autonomous driving readiness index regarding infrastructure and represent the leading efforts regarding different aspects including infrastructure.

The appendix is by no means an exhaustive collection of projects or activities so missing of projects of activities is expected. Furthermore, the document is not a formal report and a mixture of Swedish and English is present.

Activities and projects regarding digital transport infrastructure

1.1 Sweden

Tidigt projekt beskrev digital infrastruktur som och den har använts i rapporten.

"Digital infrastruktur för transportsystemet" - är den IT- och kommunikationsarkitektur som tillsammans med regelverk och standarder möjliggör interoperabilitet och digital samverkan mellan uppkopplade fordon, människor, infrastruktur och andra datakällor."

1.1.1 Trafikverket

Trafikverket jobbar aktivt inom digital infrastruktur med olika aktiviteter som beskrivits b.la, ITS handlingsplan [1], Geofence handlingsplan [2], samt senast färdplan för ett uppkopplat och automatiserat vägtransportsystem [3].

Trafikverket är ansvarig för implementeringar av National Access Point (NAP) i Sverige som regleras av EUs delegerad Act (DA) av ITS Direktiv (2010/40/EU). Inom NAP är följande information tillgängligt.

Information	Available
(a) Multimodal Travel Information DA 1926/2017	www.trafficdata.se
(b) Real-Time Traffic Information (RTTI) DA 962/2015	www.trafficdata.se
(c) (c) Safety-Related Traffic Information (SRTI) DA 886/2013	www.trafficdata.se
(d) (e) Safe and secure truck parking (SSTP) DA 885/2013	www.trafficdata.se

Med tankar om värdet på fordonsgivardata har trafikverket initierat olika projekt och studier om användningen av data för att förbättra vägunderhåll. Till exempel i program Digital vinterväglagsinformation[1], trafikverket jobbar med Volvo Cars för att samla in och bearbeta anonymiserade fordonsdata från uppkopplade personbilar.

I färdplan för ett uppkopplat och automatiserat vägtransportsystem föreslog trafikverket många konkreta åtgärder för att jobba proaktivt inom området där behovet av digital infrastruktur har diskuterats. I december 2019 anordnades Trafikverket en workshop som handlade om två åtgärder i färdplanen. Det ena handlade om åtgärd 1 - automatiserad buss mellan noder på landsväg och det andra handlade om åtgärd 3 - automatiserade fordon på statligt vägnät i dedikerat körfält. Infrastrukturstöd för automation har diskuterats i workshopen och nyckelinformation handlar om digital infrastruktur kan sammanfattas som följande.

åtgärd 1 - Automatiserad buss mellan noder på landsväg	
Digital infrastruktur • trafikledning, styrning & övervakning	Digital infrastruktur (sensorer, kameror, kommunikationslösningar V2V, V2I) anses inte vara nödvändigt men kan öka tryggheten och bekvämligheten. Bussoperatörernas fleet managementsystem bör användas för att övervaka och styra trafiken. Delade data från hela kedjan samt plattformar anses vara en komponent för genomförandet.
åtgärd 3 - Automatiserade fordon på statligt vägnät i dedikerat körfält	
Digital infrastruktur • ledning, styrning, övervakning • trafikcentral • kontrolltorn • kameror • data • digital tvilling, moln • karta • datahantering • v2v/v2i/v2x	Fordonen ska inte vara beroende av digital infrastruktur ur trafiksäkerhetssynpunkt men kan vara nödvändigt för en effektiv trafikering. Det nämndes att kommunikation mellan fordon och infrastruktur har potential att skapa nytta. Det anses vara viktigt att kombinera olika kommunikationslösningar och att det ska vara teknikneutralt, att utvecklingen går i linje med internationella standarder och att använda de lösningar som redan existerar. Avseende trafikledning nämndes det att samarbete är viktigt, att samverkande trafikledningscentral kommer behövas under försöket och att slot management kan vara nödvändigt i ett inledande skede. Kameror behövs främst som informationskälla för att utvärdera pilotprojektet och digital tvilling med detaljerad karta och realtidsinformation om fordonen som trafikerar sträckan för effektiv trafikering. Högkvalitativa data behövs men det är oklart vem som ansvarar för det. I nuläget hanterar varje fordonstillverkare sin data separat.

1.1.2 Nordic Way

Nordic Way is a cross-country C-ITS project with focus on demonstration and pilot of day 1 and day 1.5 C-ITS services. The current project Nordic Way 2 is ending in 2020, and a new project will follow. As a C-ITS project, the Nordic Way projects addresses the digital transport infrastructure including the communication infrastructure, communication standards, and data with the chosen services. A summary of the current Nordic Way 2 is shown below:

Services	
Dynamically Controlled Zones	The service is to distribute traffic policy protocols to road users in real-time which enable dynamically controlled zones and vehicles to adjust characteristics accordingly.
In Vehicle Signage	The service is to inform drivers about actual, static and dynamic road signs via in-vehicle systems. Road signs can be mandatory or advisory.
Signalized Intersections	The service is to provide information to road users to support safe and efficient crossing of signalized intersections. The implementation of the use cases should increase safety and traffic flow efficiency and reduce adverse environmental effects following from erratic and stop-and-go driving.
Probe Vehicle Data	The service is to provide vehicle-generated data about vehicles, road conditions and traffic situations to road users, and to road operators and other types of service providers.
Road Works Warning	The service is to warn road users about nearby road works (mobile, static, short-term, long-term).

[1] https://www.trafikverket.se/om-oss/nyheter/aktuellt-for-dig-i-branschen3/aktuellt-for-dig-i-branschen/2020-10/okad-sakerhet-och-framkomlighet-med-digital-vaglagsinformation/

Hazardous Location Notifications	The service is to warn road users about potentially hazardous situations or events on the road. Warnings include information about the location and type of a hazard, distance to the hazard, its expected duration, etc.
Communication infrastructure	
Radio access	• 4G public network: For all of the services • ITS-G5: For the service of Road Work Warning, warning information is sent through ITS-G5 radio in addition to the cellular network.
Networking infrastructure	The Nordic Way deploys the interchange network to enable a cloud to cloud communication for information exchange between different stakeholders. Interchange is built on standards and open solutions such as AMQP. It aims at a scalable, interoperable C-ITS infrastructure with embedded privacy, security and data governance.
Messages and data	Those follow the C-ITS messages with adaptations for the transmission over IP networks.

In addition to the pilot, the Noridic Way project has also analyzed the C-ITS eco-system and proposed different alternatives for implementations. The readers can refer to the Nordic Way project website[2] for further information.

1.1.3 AD Aware Traffic Control

AD Aware Traffic Control is a series of projects financed by Drive Sweden that investigates the information exchange between different stakeholders with the application on emergency vehicles, hazardous location warning, and sharing of vehicle sensor data. The Project approaches C-ITS services in a similar way as the Nordic Way project. Services and digital infrastructure can be summarized as follows:

Services	
Emergency vehicle warning	The service is to sharing emergency vehicle warning information to autonomous vehicles and connected vehicles so that they are able to react ahead of time.
Hazardous location warning	The service allow vehicles to warn each other in case of hazards such as hazard light warning.
Vehicle sensor data sharing	
Communication infrastructure	
Radio access	The project uses existing public 4G networks.
Networking infrastructure	The project uses similar interchange network as in Nordic Way.
Messages and data	The project uses DENM message from C-ITS standards with modification, and develops new messages based on the DATEX II standard.

1.1.4 Drive ME

Projektet drive me [4] har identifierat behoven på digital infrastruktur som beskrivs enligt följande:

kommunikationsinfrastruktur	• På sikt bör Trafikverkets och kommunernas alla anläggningar, utrustningar och skyltar vara uppkopplade och ha möjlighet att kommunicera med trafikanterna. • Utrustningarna bör på sikt kunna kommunicera och själva skicka ut digital information om tillstånd, via moln-lösning eller på lite längre sikt direkt till fordonen. • Kommunikationssätt till och från fordon skulle kunna ske m.h.a. ITS G5 eller C-V2X (korthållskommunikation baserad på 5G-teknologi, som standardiseras av 5GAA). Man kan också tänka sig att sätta upp specifika ITS-stationer vars syfte är att upprätthålla kommunikation mellan fordon och molntjänster. Även cellulär kommunikation (5G) kan upprätthålla sådan kommunikation, men för extremt högtrafikerade vägsträckor kanske dedikerade ITS-stationer kan vara ett alternativ. • Det är inte heller säkert att 5G klarar de realtidskrav som vissa applikationer ställer, speciellt vid hög belastning.

[2] https://www.nordicway.net/

	• Korthållskommunikation direkt mellan infrastruktur och fordon eller fordon till fordon innebär större säkerhetsrisker än kommunikation via respektive OEMs molnbaserade lösning.
Digital beskrivning av vägutrymme samt väganläggningar	• Högupplöst 3D-beskrivning av vägutrymmet krävs för att autonoma fordon ska kunna navigera sig fram optimalt efter vägen. I dagsläget är det fordonsleverantörerna i samarbete med underleverantörer som HERE och TomTom som tar fram den digitala beskrivningen av vägutrymmet. • Huruvida myndigheterna ska ta en roll i detta och i så fall på vilket sätt är i dagsläget oklart. • Ansvar för att kommunicera ut tillfälliga förändringar i vägutrymmet t.ex. vid vägarbeten ligger på väghållaren.
Digital beskrivning i form av realtidsinformation om vägutrymme och status i väganläggningar	• Digital beskrivning i form av realtidsinformation om vägutrymme och status i väganläggningar grönt) och en prognos om när det kommer att slå om. • SPAT/Map är en standard framtagen för just trafiksignalinformation. • Digital realtidsinformation från väganläggning underlättar för AD-fordon. I samband med att sådan information sprids till enskilda fordon är det också viktigt att se på hur det påverkar det totala trafikflödet.
Digital trafikinformation	• Trafikinformation kategoriseras normalt inte som en del i infrastrukturen, men icke desto mindre är tillgång till korrekt och uppdaterad trafikinformation i realtid en förutsättning för ett trafiksäkert framförande av autonoma fordon och för optimal kapacitet i vägnätet. • Autonoma fordon behöver, på ett standardiserat sätt, ha tillgång till realtidsinformation om vägarbeten, avstängda körfält och vägar, trafikolyckor/incidenter, väglag, tillfälliga evenemang mm. • Autonoma fordon behöver också i realtid ha god kunskap om alternativa vägar och framkomligheten på dessa. En dialog behövs mellan väghållare, fordonsleverantörer och tjänsteleverantörer för att hitta ett sätt att tillsammans optimera för det totala trafikflödet vid bl.a. omledningar.

1.2 International activities

1.2.1 VRA

In the EU project VRA - Support action for Vehicle and Road Automation network, digital infrastructure was defined as [5]:

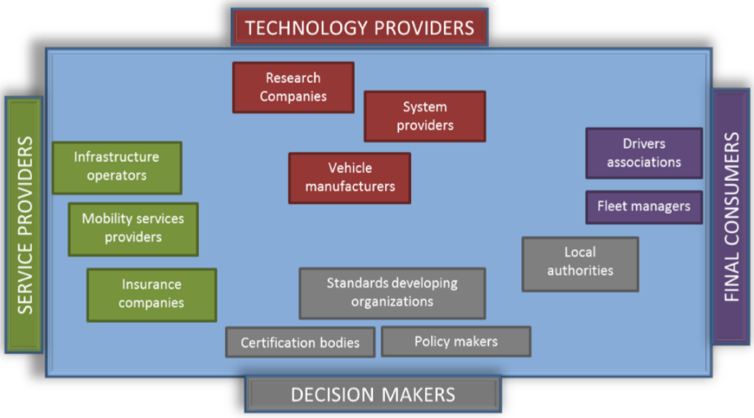
"static and dynamic digital representation of the physical world with which the automated vehicle will interact to operate. This includes sourcing, processing and information".

The roles of digital infrastructure and the challenges were summarized as follows.

Roles	Challenges

• Provide accurate map data (e.g. HD Maps)
• Provide apriori knowledge along the road (Electronic Horizon)
• Enable high relative position accuracy (landmarks)
• Reproduce human like driving (driving patterns)
• Allow or not automated functions on specific roads (e.g. managed lanes)
• Notify the vehicle about situations ahead that may require human attention or even intervention (L4->L3->L2…)
• Provide dynamic information around the vehicle (LDM)
	• HD maps: Accurate data/position, update frequency, diverse situations, cost
	  ▪ Need for more precise data with complete accuracy/accurate positions
	  ▪ Different driving situations
	  ▪ Levels of automated driving
	  ▪ Collab oration between public and private sector
	  ▪ Separation of static and dynamic data
	• How to best realize data integration
	  ▪ Sensor data and maps
	  ▪ One stop interface
	• Question of reliability and levels of automated driving
	• Liability
	  ▪ Roles of carmakers, map makers, and governments
	• Roles of static and dynamic data
	  ▪ Different conditions and scenarios
	  ▪ Sensor data at under 300 meters
	  ▪ Speed of updating types of data (dynamic, quasi dynamic, quasi static, static)
	  ▪ Infrastructure and coordinates for positions of pedestrians, etc. and liability
	  ▪ Separating dynamic data and maps, and different uses
	• Privacy
	  ▪ Question of how to send information
	  ▪ Updating software
	• Security and risk of terrorism attacks

Stakeholders were identified and illustrated in the following graph and described in detail in the following table.



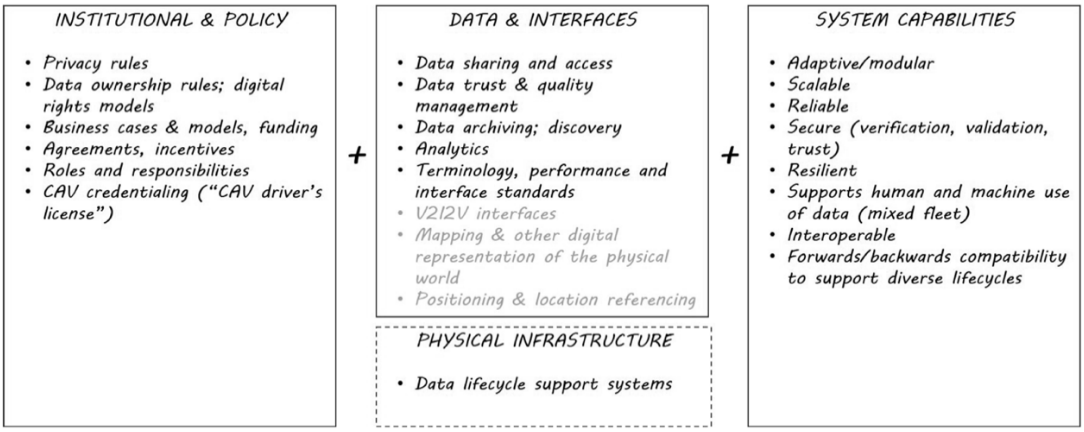
Stakeholder	Function	Digital Infrastructure aspects
Policy makers and legislative bodies	Produce regulations and ensures compliance	• Cost benefit analysis for PA • Clear definition of the role of • the public and private sectors (governance, responsibility, etc…) role and regulations, • ownership (privacy issues)
Vehicle manufacturers	Manufacture and sell vehicles with a level of automation	• Requirements of the DI • applications using accurate mapping and precise localization
System providers	Offer VRA related systems and applications for vehicles and infrastructures	• Cloud based spatial data infrastructure for highly automated driving
Research companies	Provide new paradigms and application solutions. Part of the technology providers chain	• Identify requirements (precise/lane-level positioning, human-like behaviour, landmarks, etc) • definition of requirements for digital infrastructure (content and quality)
Service providers	Make business providing services based on vehicle and road automation	
Infrastructure operators	Management of roads and highways.	
Certification bodies	Homologation of vehicles, equipment and drivers for automation	• Certification & minimum standardisation of map representation
Insurance companies	Provide Insurance for automated vehicles. Safe mobility and responsibilities	• Tort liability standards automated vehicle
Standards Developing Organizations	Primary activities in developing, coordinating, promulgating, revising, amending, reissuing, interpreting, or otherwise producing technical standards that are intended to address the needs of some relatively wide base of affected adopters	• Needed for reliability and keeping a good level of safety • Standardisations of map contents for automation • Standardize interfaces with Cloud

1.2.2 AVS 2018

In the 2018 Autonomous Vehicle Symposium (AVS) [6], a breakout session was organized. Though the definition of digital infrastructure is broad, it was summarized as

“A digital infrastructure is a transportation data ecosystem governed by a set of institutional policies and technical standards”.

An illustration was provided as follows.



1.2.3 CARTRE

In the EU project CARTRE - Coordination of Automated Road Transport Deployment for Europe, it was described as

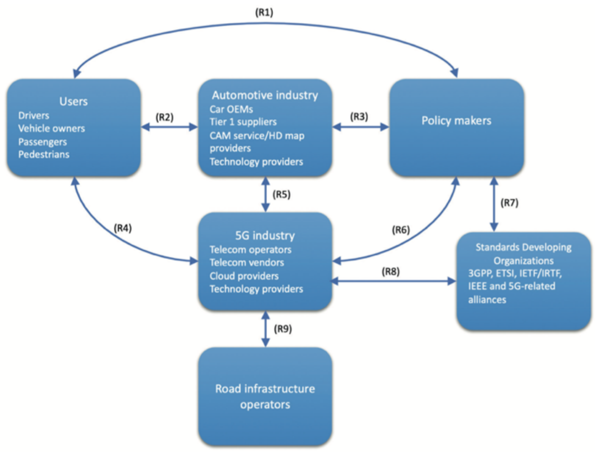
The "Digital Road infrastructure" may be defined as "the digital representation of road environment required by Automated Driving Systems, C-ITS and Advanced Road/Traffic Management System".

In more detail, CARTRE described that the digital road infrastructure can be understood as the integration of multiple geo-located information layers and described the challenges and recommendations. Major points are summarized as follows.

Digital infrastructure components
• Static - Basic Map Database (e.g. Digital cartographic data, Topological data, Road Facilities) • Semi-static - Planned activities and forecast (e.g. traffic regulations, road works, weather forecast) • Semi-dynamic - Traffic Information (e.g. accidents, congestion, local weather) • Dynamic - Information through Vehicle to X communication (e.g. surrounding vehicles, VRU, traffic signals) • Dynamic driving recommendations (e.g. lane change, distance gap, speed) • Positioning, communication and back-office infrastructure
Recommendations
• Large scale FOTs and RDI activities are needed to assess especially the physical (road and roadside) infrastructure needs for, and consequences of, higher levels of automation. • Defining Operational Design Domains can further improve the understanding of required updates for PDI. • The transition phases between different levels of automation need to be addressed specifically. • The communication between road infrastructure and connected automated vehicles needs to facilitate functional safety in distributed functions for automated road transport. • In urban environments new infrastructural sensing methods could overcome blind spots. • Vehicle fleet data could be used for collective perception, where an integrated efficient and dependable computing platforms and control strategies will be required, together with standardized data interfaces.

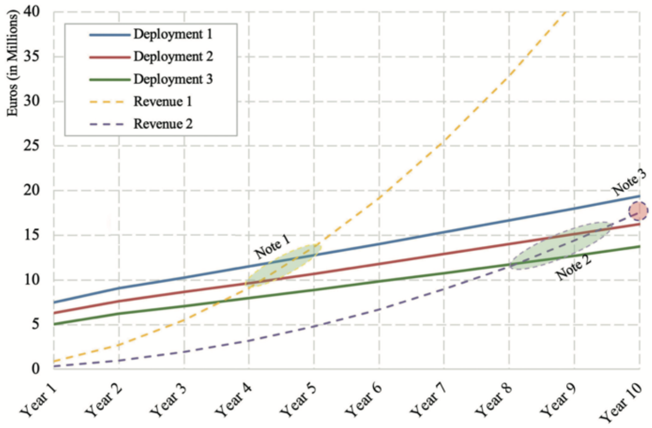
1.2.4 5GPPP

In [7], 5G PPP has investigate the V2X infrastructure for connected and automated driving from a business perspective. The report identified the following stakeholder relations with also detailed descriptions of their roles. The report focuses on the V2X infrastructure from the telecom industries' perspective; therefore, it can be considered as only part of the whole digital infrastructure ecosystem.



In the report, 5G infrastructure deployment scenarios were also proposed with cost benefits analysis, as summarized in the following table and figure.

	Revenue 1	Revenue 2
Deployment 1	A single network operator makes a full deployment and provides connectivity to all vehicles on the highway. This can be interpreted as the case where all vehicles are served by the same network, using **national roaming**.	More than one network operator makes a full deployment, each provides connectivity only to its subscribers on the highway. In a realistic interpretation, this could be the case of parallel network deployments with **no investment nor network sharing**.
Deployment 2	A single network operator makes a deployment, sharing road infrastructure; it provides connectivity to all vehicles on the highway. This can be the case where all vehicles are served by the same network by using **national roaming and passive sharing** with the road operator.	More than one network operator makes a deployment, sharing road infrastructure; each provides connectivity only to its subscribers on the highway. In a realistic interpretation, this could be the case of parallel network deployment; with **passive sharing** of elements with the road operator.
Deployment 3		More than one network operator makes a deployment, sharing network and road infrastructure; each provides connectivity only to its subscribers on the highway. In a realistic interpretation, this could be the case of **active network sharing**.



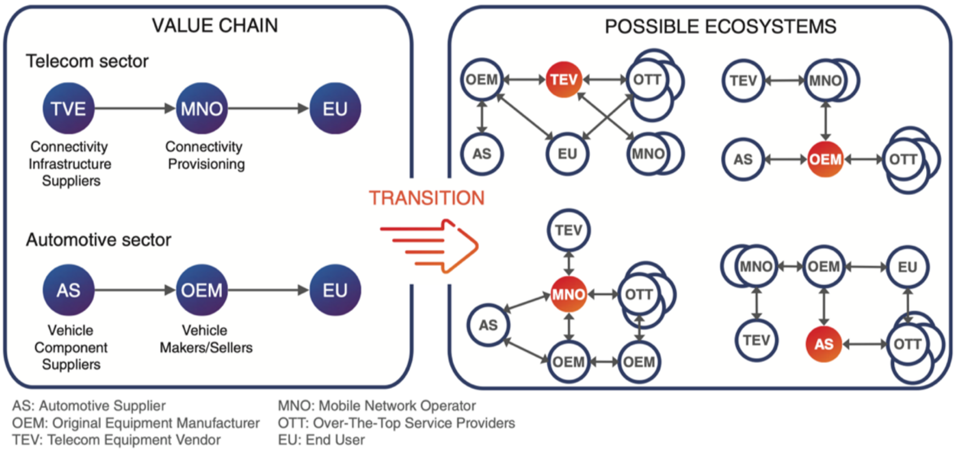
Note 1: if a single network operator is able to capitalize on all vehicles in the highway segment (revenue model 1), all deployment options break-even within the first 5 years of service.

Note 2: if there is more than one network operator and the vehicle subscriptions are split, the deployment options allowing network sharing break-even after 8 to 10 years of service.

Note 3: if no network sharing is allowed and the number of subscribed vehicles is divided among different network operators, there is no profit reached within 10 years.

1.2.5 5GCAR

In the EU project 5GCar, potential business models are proposed for the digital transformation of connected and automated driving. The model showcased different transformation possibilities as well as the new role for each of the stakeholders. One of the significant challenges remain from the telecom sector is that V2X might not be interesting for operators because the possibilities for usage-based billing are limited.



	New activity	Example	Main advantage for OEM
OEM	Service/connectivity platform	Tesla uses an in-house cloud platform to build own services on top of it and partners directly with MNOs.	No sharing revenue streams. Higher data control.
AS	Service platform providers	Bosch IoT Cloud Suite, partnered with TomTom, has ready-to-use cloud services.	Trust have been partnered with OEM before.
TEV	Service or/and connectivity platform providers	Ericsson has solutions for enabling connectivity and services such as the connected vehicles cloud and a specific vehicle marketplace for building applications on top.	Partners with many MNOs, good position for connectivity platform providers if multiple MNOs (eSIM).
MNO	Service or/and connectivity platform and device.	Cadillac platform OnStar work through AT&T connectivity. Other MNOs are also providing service platforms such as Telia Sense, partnering directly with EasyPark.	Connectivity providers already partners for info-tainment applications.
New-Comers	Service or/and connectivity platform providers	Cubic Telecom partners with MNOs and handles Audi's eSIM connectivity. Otonomo car data exchange platform for new applications.	Flexible to adapt and tailored to the marked.

Automotive supplier (AS); Telecom Equipment Vendor (TEV)

1.2.6 Inframix

In the EU project inframix, infrastructure has been classified with similar scale to SAE autonomous driving level, the so-called Infrastructure Support Levels for Automated Driving (ISAD). It is a mixed physical and digital infrastructure category for CAV at different automation levels.

The ISAD levels start with the conventional infrastructure without any support for automation (Level E). The availability of a digital map with static regulatory information (e.g. speed limits) is assigned to Level D. At Level C begins the full digitalization of infrastructure elements and thus the availability of all relevant digital information in digital form, esp. VMS, traffic lights, which can be extended by further environment information. Level B describes infrastructures that are able to perceive complete traffic situations on a microscopic basis by specialized sensors (e.g. fixed infrastructure radars). This sensor data could be augmented by data coming from vehicles such as probe vehicle data, and more advanced cooperative perception messages. However, using this data alone does not provide microscopic traffic perception capability as it relies on the equipment of vehicles. At Level A the infrastructure uses its traffic perception capabilities for microscopic traffic management. Microscopic traffic management goes beyond dynamic speed limits (currently displayed on VMS) and provides optimal speed advice, lane usage and lane change recommendations, advice on inter-vehicle gaps etc. to automated and connected vehicles.

	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Digital infrastructure	A	Cooperative driving	Based on the real-time information on vehicles movements, he infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow	X	X	X	X
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time	X	X	X	
	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs	X	X		
Conventional infrastructure	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs	X			
	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs				

1.2.7 US FHA Federal Highway Administration

In 2018, FHA organized national dialog on digital infrastructure and data, respectively. A general summary is as follows, and can be found in [8].

Different Types of Data Will Be Important for Enabling Safe and Efficient AV Operations	• Operational data, such as real-time data on work zones, road weather, special events, signal phase and timing (SPaT), and lane closures were identified as potentially important for supporting AV operations. • Data regarding vehicle operating regulations or local rules of the road, such as speed limits and school zones, were also identified as useful for AVs. • Public agencies desire access to data that could help them understand the impacts of AVs on the broader transportation system.
Data Providers, Public Agencies, and Third-Party Aggregators Have Unique Roles	• Data ownership • Third party access to vehicle data • Authorities may govern the data usage
Public Agencies Have Differing Levels of Resources and Capability to Address AV Data	• Public agents have different level of resources • identifying different tiers of organizational readiness, along with the expected level of support from each type of stakeholder
The Digital Infrastructure Definition Is Emerging, Incomplete and Includes Multiple Components	• a digital infrastructure represents the connected and interoperable components needed to gather and process data for AVs. • A digital infrastructure includes data capture, transmission, storage, information delivery and analysis. The parts of a digital infrastructure could include hardware, software, and protocols and policies (including standards) • Digital infrastructure exists to different degrees at different places
Digital Maps Are a Key Part of the Digital Infrastructure	• HD maps are provided by private sector, but might be improved with real-time roadway conditions and characteristics • it would be valuable for the public sector to produce nationwide maps of infrastructure characteristics (e.g., bridge heights, lane widths, and right-of-way widths) and rules of the road, including dynamic elements such as signal phasing and timing.
A National Transportation Digital Infrastructure Framework Could Be Valuable	• Data interfaces • Intellectual property, confidential business information, and licensing • Liability • Data quality and trust in data sources • Privacy protections • Coordination of resources to support the development of digital infrastructure • Prioritization of data sets and digital infrastructure elements

1.2.8 EU STRIA roadmap

In the EU STRIA Roadmap 2019 on connected and automated transport [9], Physical digital infrastructure together with other digital traffic related areas are described with action points and recommendations.

Action points	**Physical / Digital Infrastructure:** To develop an EU strategy for physical and digital Infrastructure (PDI) development for CAD, a close cooperation of OEMs, traffic managers, road operators and users is required.

	Therefore, a European Forum on CAD should be established in the short term. In parallel, the requirements of the PDI ecosystem should be determined in a structural dialogue with industry, road operators and authorities. Among others, ISAD levels have to be defined, and afterwards, real-world performances should be assessed for different use cases in a living lab. Finally, the provision and use of traffic-relevant information should be studied. • Discuss strategy with OEMs, traffic managers, road operators and users, • Shape PDI ecosystem for cooperative, connected, automated driving • Develop how CAV will impact PDI • Design and management • Advance infrastructure-based sensing methods • Assess real world performance of PDI for different use cases • Optimize the provision and use of traffic relevant information
	Traffic Management System: Starting from research to understand the changes from human to software-based control of vehicles, the requirements for traffic management systems to integrate CAD have to be defined, and integrated traffic, network and incident management systems need to be simulated and tested. In the medium and long term, traffic management systems for CAD need to be integrated and implemented in real-world testing settings. This can be done in pilots, FOTs and living labs. • Understand changes from human to software-based control • Define requirements for integrated CAD traffic management systems • Simulate and test integrated traffic network and incident management • Integrate traffic management for CAD in real world test setting • Implement CAD specific traffic management systems
	Adequate Connectivity: The fail-safe operation, appropriate degradation, privacy protection and end- to-end security provision of network coverage to support, facilitate and improve CAD by increased contextual awareness should be the matter of publicly funded research. In parallel, the connectivity performance needed for safe and secure operation, also across borders, has to be standardized on the medium term. • Ensure CAD fail-operation, degradation for limited network coverage • Standardize connectivity performance needed for safe secure CAD • Prepare regulation of privacy and liability related issues of CAD • Design validate mechanisms for cross-effective end to end security
	Cyber Security of Data: Research on cyber security of data for CAD in the short term should cover security requirements in a hybrid communication environment as well as potentials for breaking security mechanism. In the medium term, cost- effective mechanisms for cyber security could be validated in a pilot, and finally, test beds need to be adapted to cyber security of CAD, and procedures for cyber security testing and certification have to be developed. • Assess security requirements in a hybrid communication environment • Analyse potentials for breaking security mechanism of CAD • Establish and validate cost effective mechanism for cyber security • Create and run international testbeds • Develop procedures for CAD cyber security testing, validation, certification
	Data Storage & Sharing: A 'standard' model for data sharing based on open and interoperable programming interfaces (APIs) and access control by defined user rights has to be developed. It shall focus on the data value chains, and data storage needs, and the related standards supported by appropriate analytical tools and infrastructure. Probe vehicle, traffic and operation data of CAD can be simulated and tested in a pilot on routing of automated vehicles also in mixed traffic. • Develop standard model for data sharing focused on data value chain • Standardize data storage and enable it by providing reliable infrastructure • Simulate and test the use of probe CAD vehicle, traffic operation data
	Artificial Intelligence: Besides a further development of deep neural network-based algorithms for CAD, procedures for training and testing complex AI vehicle control need to be developed, and an ethical, moral framework for the responsible use of AI in CAD has to be established in the short term, and transparency of the algorithms is to be ensured. This shall help to further develop the concepts, techniques and models of AI for CAD. • Evaluate deep NN based algorithms • Develop procedures for training and testing complex AI vehicle control • Develop ethical moral framework for the use of AI in CAD • Develop AI concepts techniques models to fulfill challenges of CAD
Recommendations	• Establish a European CAD Stakeholder Forum to discuss the strategy on physical and digital infrastructure (PDI) roles and needs for CAD with OEMs, traffic managers, road operators, and users and

	to identify opportunities for harmonization – e.g. in an expert group comparable to the Sustainable Transport Forum or the C-ITS platform. • Fund research to prepare the PDI ecosystem for cooperative, connected and automated driving, covering e.g. infrastructure needs for different automation levels, definition of ISAD levels, street design elements, maintenance, redundancy as well as infrastructure-based sensing, and provision of traffic data. Also, business and financing models shall be included. • Foster research collaboration between traffic management centers in Europe to explore changes from human to software-based control, and to study, test and simulate integration of connected and automated driving into traffic, networks and incident management systems. • Prepare regulation on liability and privacy issues of connected and automated driving by ensuring the interoperability of methods and messages that indicate connectivity performance and degradation of functions in case of limited network coverage, as well as changes at borders and launch standardization mandates. • Fund collaborative research on data storage and sharing for CAD, aiming at a 'standard model' of data sharing (or the interoperability of coexistent models in view of competition) focused on the data value chain, to be tested with probe vehicle and infrastructure sensing data, and to be standardized.

1.2.9 ITIF

In [10], the Information technology & innovation foundation (ITIF) summarizes the main barriers for digital infrastructure and gives recommendations as follows:

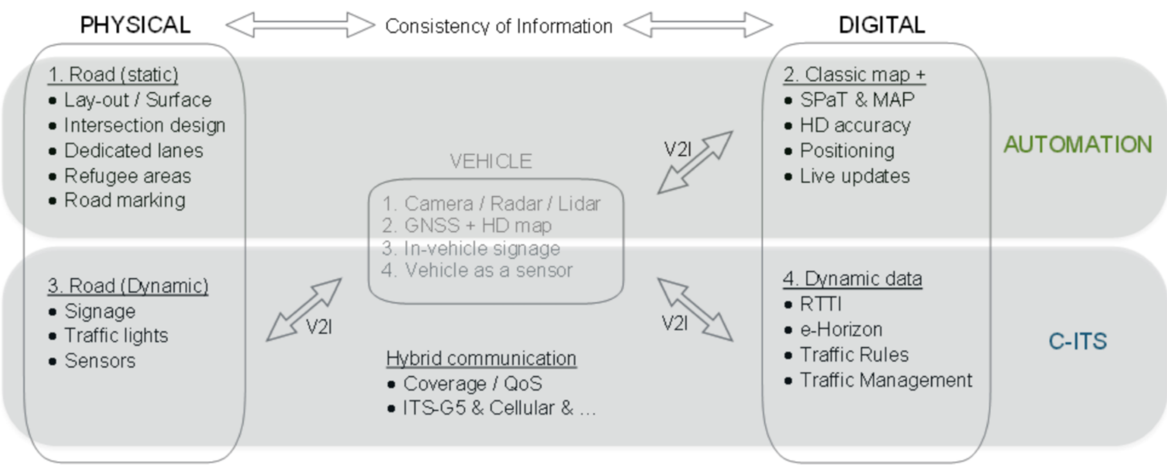
Barriers	Recommendations
• Risk aversion of new technologies especially for governments • Lacking digital technology experiences of operator, particularly government • lack of patient up-front capital available for investments • Coordination with many stakeholders • Chicken-or-egg issue • Pressure from privacy advocates on the infrastructure organizations • Difficulties on common standards	• Create "Digital-Friendly" Regulatory Policies • Agencies Should Develop Strategies for How They Can Support Digital Infrastructure in the Areas They Influence • Increase Funding for Digital Infrastructures • Don't Let Privacy and Security Concerns Slow Deployment

1.2.10 C-ITS Platform

In C-ITS platform[11], the working group on PDI described the digital infrastructure as follows, together with detailed descriptions.

"The digital infrastructure is composed of data bases and geographical data as well as the related back-office functions. It contains both static and dynamic data and connects and interacts with vehicles through hybrid communication equipment incorporating at least short-range and long-range communication systems. Continuous improvement of cellular coverage for long range communication and deployment of short range communication infrastructure along motorways and urban environments supports tactical and strategic information exchange (e.g. safety and automation related applications).

An illustration was given as follows:



Information to be exchanged can be roughly categorized into two groups, and examples were given as follows.

Data categories:
• Local, dynamically generated (tactical) data which is mainly used for safety purposes. Messages for this type of information (SPAT/MAP, IVI, CAM, DENM, LDM etc.) is already standardised and well tested in pilots, though updates of these standards may still be needed. • The other group is strategic data which reflects the more static traffic environment: Road network topology, circulation plans, static signage, rules and restrictions. In short these are traffic regulations. Some of the data sets are partly standardised for broadcast purposes, but most of this at best exist as proprietary databases within the different Member States.
Data examples
• Two-way real-time exchange of traffic safety or traffic efficiency related warnings (hazardous situations such as end of traffic jam, dangerous weather conditions, etc.) between vehicles and infrastructure (meaning detection of the hazardous situation and generation of the warning message can come from both). • Infrastructure-based sensors to detect the different traffic participants and traffic influencing objects, e.g. detecting pedestrians and cyclists at critical intersections and transmitting such information to vehicles. • Standardised transmission of short-term road construction or accident situations (position, lane/location concerned, time, speed limit, existing lane markings, passing lanes, etc.) supported by Local Dynamic Map (LDM) and high-definition maps (HDMAPs) concepts. • Transmission of definitive and binding duration of traffic light status and timing (SPAT) for change to the next signal phase and intersection topology (MAP) information. • Transmission of right of way rules (traffic light signal, stop, give way, etc.). • Transmission of (dynamic) speed limits, entrance to urban environments, etc. • Transmission (forwarding) of the position and operation mode of emergency vehicles and other priority vehicles with right of way permission to ensure traffic prioritisation at intersections, road segments and traffic lights. Transmission of lane closure and traffic light information to influence traffic flow such that prioritized vehicles can benefit from the optimized flow.

At the time the report was written, the exact path for digital infrastructure was mentioned to be unclear. The report gave the following recommendations regarding different topics.

Physical and digital infrastructure support for automated mobility	While vehicles will gradually become more connected and smarter in the future, it is accepted that infrastructure will continue to play a role. As detailed local infrastructure support – physical and/or digital – may never cover the entire road network (including unpaved roads etc.), there are doubts whether full level 5 scenarios will truly materialise (implying drive anywhere anytime without any human back-up plan). Therefore, it is recommended that public and private stakeholders jointly look for scenarios where infrastructure investment and deployment of automated mobility makes most sense, creating "level 4 islands" which can gradually grow and merge into larger interoperable areas in support of new (automated and driverless) mobility services.
Roads for automation	• Road operators to identify, in close collaboration with OEMs and digital map providers, key attributes of roads relevant for automated driving, with the aim of adding predictability on what to expect on the road ahead and enlarging the decision base for using automatic mode. Where needed, possible or desirable define values for these attributes. • Once identified these attributes will need to be moved into formal standards in Management of Electronic Traffic Regulations (METR) and merged into road and traffic regulation for international harmonization. • To investigate the (regulatory) consequences of Quality of Service and Functional Safety needs with respect to information sharing and the resulting infrastructure requirements.
Connectivity for automation	• To enable efficient data exchange between vehicles and with road, regional, local and other authorities and fully exploit the support from digital road infrastructure (for example by adding predictability through standardised road attributes in support of automated driving) automated vehicles shall be cooperative and connected vehicles.
Position support	• Road operators, OEMs and suppliers should jointly investigate how physical and digital infrastructure can contribute to redundancy and safety in accurate positioning. This includes investigating the needs for landmarks along the roads considered for higher level automated driving, and to consider providing them where socioeconomically feasible, in particular for temporary work zones and higher risk road sections (e.g. tunnels, urban canyons). • To stimulate the standardisation of the information exchange required for these improvements and support the implementation of interoperable European Geolocation Referencing services.
Handling complex traffic situations / Intersections	• To support handling complex traffic situations, vehicle industry, road operators, supplier industry and academia need to work together to define common operational environments for collective perception. Based on those results a new set of technology agnostic C-ITS messages for collective perception needs to be standardised.

	• all actors (OEMs, suppliers, authorities) must work together to create standardised C-ITS messages for traffic regulations, complementing existing “sensor-type” CITS messages, both of which are needed for the vehicle to take the correct action. • Specific standards on the context and the interpretation boundaries at receiving side (including the quality assumptions to quantify trustworthiness, precision, timeliness and reliability of information) need to be developed and implemented in all C-ITS equipment.
Consistency between physical and digital	• All actors that possess, control or own data need to work on the accelerated and joint implementation – by public and private stakeholders – of existing and future Delegated Acts under the ITS directive. All actors are encouraged to jointly define fair conditions for sharing data, taking into account the costs related to transforming raw data into useful (traffic) information.
Legal aspects of digital infrastructure	• Similar to vehicles, also infrastructure will continue to evolve by introducing new technologies, generating new data and new information flows. A clear legal framework – including traffic regulation – will be essential to avoid (new) conflicts between information coming from physical and digital infrastructure, and establish precedence regarding information.

1.2.11 C-Roads Platform

1.2.11.1 ITS-G5

C-Roads oversees the implementation of C-ITS in different European countries. Most of the services are based on C-ITS standards [12], and harmonization with cellular based communications is also under investigation. The C-ROADS platform publishes Roadside ITS-G5 System profile CSP [13] and defines a common base for the ITS-G5 based communications between the roadside unit and vehicles, e.g., I2V. This is to ensure interoperability between the roadside ITS station (R-ITS-S) and vehicle ITS station (V-ITS-S). The CSP considers all layers of the C-ITS architecture. CSP follows closely the C2C CC Basic System Profile [14]. In addition to support mobile ITS stations, mobile roadside ITS G5 System profile (MSP) is also specified in [15]. CSP and MSP define detailed requirements with a format of RS_CSP/MSP_(*number*).

It is notified that C-ROADS specification mostly regards the infrastructure side based on ITS-G5, while since vehicle ITS-Station shares the same architecture, it is essentially the same sending/receiving processes at the vehicle side. Generating, processing the information and reacting to certain events should follow the service specification described in [16]. A more general description of the broad C-ITS services can be found in [17] and their functional requirements can be found in [18].

The following table summarizes the implemented services within C-Roads, use cases, the C-ITS messages having been used, together with references on standards. All specification of data elements can be found in the C-ITS dictionary ETSI TS 102 894-2 [19].

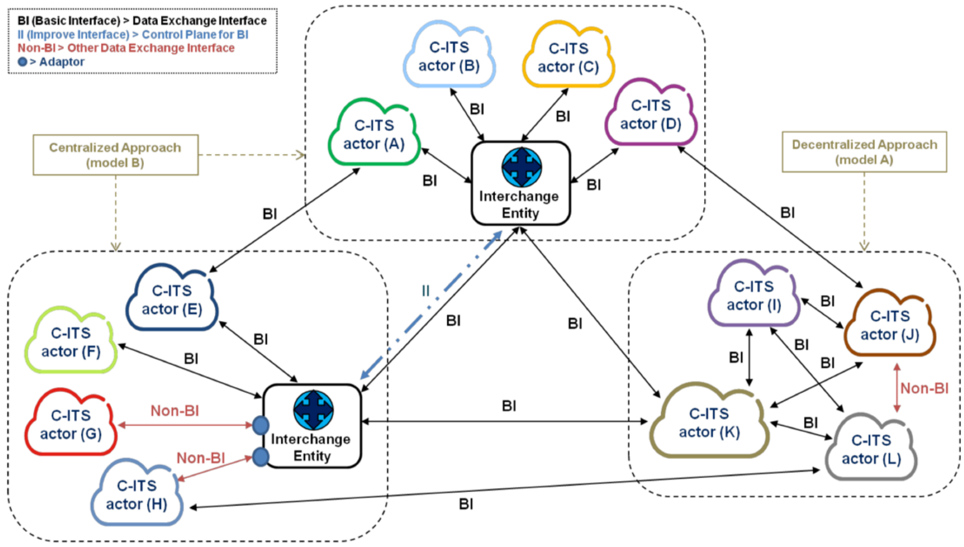
Services	Use cases	Messages	References
In-Vehicle Signage	• Dynamic Speed Limit Information (IVS-DSLI) • Embedded VMS “Free Text” (IVS-EVFT) • Dynamic Lane Management (IVS-DLM) • Shock Wave Damping (IVS-SWD) • Other Signage Information (IVS-OSI)	IVIM	IVI service: ETSI TS 103 301 [20] IVIM payload definition: CEN ISO/TS 19321 [21] IVI general payload: Table 10 in [22] IVIM for IVS: Table 11 in [22]
Hazardous Location Notification	• Accident Zone (HLN-AZ) • Traffic Jam Ahead (HLN-TJA) • Stationary vehicle (HLN-SV) • Weather Condition Warning (HLN-WCW) • Temporarily slippery road (HLN-TSR) • Animal or person on the road (HLN-APR) • Obstacle on the road (HLN-OR)	DENM	DEN service: ETSI EN 302 637-3 [23] DEN PDU header: ETSI TS 102 894-2 [17] DENM general payload specification: Table 3 in [22] DENM for HLN: Table 8 in [22] Service parameter: Table 9 in [22]

	• Emergency Vehicle Approaching (HLN-EVA) • Emergency Vehicle in Intervention (HLN-EVI) 1.6 Railway Level Crossing (HLN-RLX) • Unsecured Blockage of a Road (HLN-UBR) • Alert Wrong Way Driving (HLN-AWWD) • Public Transport Vehicle Crossing (HLN-PTVC) • Public Transport Vehicle at a Stop (HLN-PTVS)		
Road Works Warning	• Lane Closure (RWW – LC) • Road Closure (RWW – RC) • Road Works – Mobile (RWW-RM) • Winter Maintenance (RWW-WM) • Road Operator Vehicle in Intervention (RWW-ROVI) • Road Operator Vehicle Approaching (RWW-ROVA)	DENM	DEN service: ETSI EN 302 637-3 [23] DEN PDU header: ETSI TS 102 894-2 [17] DENM general payload specification: Table 3 in [22] DENM for RWW: Table 6 in [22] Service parameters: Table 7 in [22]
Signalized Intersections	• Signal Phase and Timing Information (SI-SPTI) • Green Light Optimal Speed Advisory (SI-GLOSA) • Imminent Signal Violation Warning (SI-ISVW)	MAP (topology) Extended Message (MAPEM), Signal Phase And Timing Extended Message (SPATEM)	MAPEM/SPATEM header: ETSI TS 102 894-2 [17] MAPEM/SPATEM data elements: Table 12, 13 in [22]
	• Traffic Light Prioritization (SI-TLP) • Emergency Vehicle Priority (SI-EVP)	Signal Request Extended Message (SREM), Signal request Status Extended Message (SSEM)	Traffic light control (TRC) service: ETSI TS 103 301 [20] , ISO TS19091 [24], SAE J2735 [25] SREM/SSEM header: ETSI TS 102 894-2 [17] SREM/SSEM data elements: Table 14, 15 in [22]
Probe Vehicle Data	• Vehicle Data Collection (PVD-VDC) • Event Data Collection (PVD-EDC)	CAM DENM	CAM: ETSI EN 302 637-2 [26] DENM: ETSI EN 302 637-3 [23] Specification (wished): Annex in [16]

1.2.11.2 Hybrid communication

In addition to ITS-G5, hybrid communication profile has been specified to enable sending/receiving C-ITS messages through IP-based networks. A **BI (Basic Interface)** is introduced between each C-ITS actor/third party for message exchange based on the Advanced Message Queuing Protocol (AMQP). For backend communication between countries/regions, an **II (improved interface)** introduced for BI control.

An illustration is shown as follows:



A general summary from C-Roads is that at the service and functional level, everything is generally standardized. The requirements on communication basically means that infrastructure and vehicles should be able to send and receive messages needed for different services. In other words, the ITS-Station should be available at the control center, the roadside, and within the vehicles. Down to the communication level and stand at a technical neutral point, it is up to each country and OEM to decide which technologies they will implement, provided they can satisfy the service requirements. C-ITS itself is digital infrastructure for connected vehicles. The information exchanged through C-ITS based on ITS-G5 is limited and are mostly for location-based services. Expanding C-ITS to IP-based networks introduces richer information that could be used to support advanced driving support and autonomous driving. Those are under investigation through C-ITS day 2 services, and 3GPP 5G-V2X.

1.2.12 CCAM Single platform

On 3 June 2019, the European Commission presented its EU-wide platform - The Cooperative, Connected, Automated and Autonomous Mobility (CCAM) Single Platform, which consists of an informal group of both private and public stakeholders. Two working groups (WGs) are connected to digital infrastructure, they are WG3 - Physical and digital road infrastructure, and WG6 - Connectivity and digital infrastructure for CCAM.

WG3 - Physical and digital road infrastructure: There are efforts to develop a single list of road attributes relevant for CCAM in order to have different stakeholder "speak the same language". This is to prepare for defining the building blocks of an ISAD approach, understanding the interplay of ISAD and ODD, providing a basis for project leaders to point out where lie the needs/possibilities in terms of research and innovation activities to prepare infrastructure for CCAM, and above all, reaching a better understanding of how infrastructure supports CCAM.

WG6 - Connectivity and digital infrastructure for CCAM: This group has activities to support the coordination of activities that focus on telecommunication infrastructure; identify how satellite navigation can support the predeployment of automated vehicles; gather and exchange experiences, best practices and knowledge on how spectrum can be efficiently allocated to various technologies; promote collaboration regarding communication technology, both long-range and short-range; coordinate testing and pre-deployment activities; address technical and legal issues that are relevant to data storage and cloud access; and carry out an assessment of the state-of-play how online platforms influence communication technologies.

1.2.13 MANTRA

In the project MANTRA [27]: Making full use of Automation for National Transport and Road Authorities, infrastructure needs have been analyzed for future vehicle and road automation. Digital infrastructure generally followed the same definition as in C-ITS platform while more detailed discussion was described with relation to a selected list of automation functions, and their Operational Design Domain (ODD) attributes.

Following the ODD attributes description, the digital infrastructure was further detailed into four groups as shown below.

HD map	• Geometric Map is composed of raw sensor data collected by raw sensor data from lidar, various cameras, GPS, and IMUs. The output is a dense 3D point cloud, and this data is postprocessed to produce derived map objects that are stored in the geometric map. • Semantic Map Layer is built upon the geometric map layer, by adding semantic objects. Semantic objects can be either 2D or 3D such as lane boundaries, intersections, parking spots, stop signs, traffic lights, etc. that are used for driving safely. These objects contain rich information such as traffic speeds, lane change restrictions etc. • Map priors layer contains dynamic information and human behaviour data. Examples such as the order in which traffic lights change, the average wait times in a typical day at the lights, the probability of a vehicle at a parking spot, the average speeds of vehicles at parking spots etc. Autonomy algorithms commonly consume these priors in models as inputs or features and combined with other real-time information. • Real-time knowledge layer is the top-most layer in the map that is dynamically updated contains real-time traffic information. This data can also be shared in real time between the fleet of autonomous vehicles.
Satellite positioning	• The need is the network of the RTK land stations enhancing the accuracy of satellite positioning.
Communication	• The basic communication types will most likely still be vehicle to vehicle short range (V2V SR), vehicle to infrastructure short range (V2I SR), and vehicle to infrastructure medium/long range (V2I LR). The last mentioned will likely be provided via cellular networks, but the short range V2I communications will need communication beacons beside or over the road, connected to different servers (road operators, vehicle manufacturers, service providers, fleet managers, etc.) via trunk communications such as fibre optic cabling. V2V SR is essential for highway convoy, truck platooning, and road work safety trailer use cases.
Information system	• Some systems need real-time information on incidents, roadworks, events, congestion and other disturbances on the route ahead as preview information of problems ahead outside the range of the vehicle sensors. • The automated vehicle systems usually also need information of the rules and regulations of any restrictions concerning automated driving, including real time traffic management information, and geofencing information in order to avoid routing through forbidden areas.

For each of the selected automation functions, ODD attributes have been specified. The part regarding digital infrastructure are summarized as follows.

Automation functions	ODD attributes - digital infrastructure	
Highway autopilot incl highway convoy (L4): the highway autopilot including highway convoy provides automated driving up to 130 km/h on motorways or roads similar to motorway from entrance to exit, on all lanes, including overtaking and lane change. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can at non-critical times override or switch off the system.	HD map	HD Map of minimum quality needed if the lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching.
	Satellite positioning	Needed if the road position, lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations (e.g. RTK) and possibly also by landmarks on problem sections (tunnels, forests, ...) and conditions (weather).
	Communication	Needed for end of queue, lane change, and merge situations for negotiations among vehicles and for maintaining a local dynamic map. Short latency V2V communication is a necessity for highway convoy. V2I communication can be used to receive traffic management information in addition to real-time information.
	Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances (SRTI) on the road ahead are needed for tactical decisions on route choice, lane selection and safe speed choice. Digital rules and regulations as well as a geofencing database are also needed.
Highly automated (freight) vehicles on open roads (L4)	HD map	Needed if the lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching.

	Satellite positioning	Needed if the road position, lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations and possibly also by landmarks.
	Communication	V2V and V2I communication needed for vehicles to communicate for safety and to access the dedicated lane or road.
	Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances on the road for tactical decisions. Currently CACCs would not recognize safety trailers if they are placed diagonally to the lane. Appropriate information/communication could provide a workaround.
Commercial driverless vehicles (L4) as taxi services: The automated taxi service operates without a human driver transporting passengers from their origin to their destination within the boundaries of a specific geographical area.	HD map	Needed as the lane identification and accurate lateral lane positioning solution is based on vision sensors (especially laser scanners) and satellite positioning with 3D HD map matching.
	Satellite positioning	Needed to complement the vision sensor system supported by satellite positioning with 3D HD map matching.
	Communication	At least 3G needed for V2I communications with operations centre, 4G or higher for remote control of vehicle. Possible short-range communication for communication in smart intersections.
	Information system	Digital traffic rules and regulations, geofenced restrictions
Driverless maintenance and road works vehicles (L4) Safety Trailer: A protective vehicle that is used to protect temporary or slow-moving mobile road works as well as clearing works after accidents from moving traffic.	HD map	No specific requirements
	Satellite positioning	Initial deployment on road shoulder: no satellite positioning required. Advanced version: enabling communication about its position required with land station (e.g. RTK) support accompanying the vision sensor system with 3D HD map matching to provide information to traffic management centre and in turn to road users through variable message signs/in-car navigational systems.
	Communication	CACC can provide information about position to traffic management centre for further information to road users. V2V communication with other maintenance vehicles, mobile road signs.
	Information system	Real-time information of the location and operation of the vehicle to be disseminated to traffic centres and service providers, and finally to other road users; Digital rules and regulations
Driverless maintenance and road works vehicles (L4) - Winter maintenance truck with regular operating speed: Winter maintenance works on highways are generally divided into preventive salting works performed at speeds of up to 60 km/h independent of snowfall and snow ploughing works performed at speeds of up to 45 km/h during and after snowfall.	HD map	Needed for full use - lane identification and accurate lateral lane positioning based on satellite positioning with 3D HD map matching.
	Satellite positioning	Needed for full use - road position, lane identification and accurate lateral lane positioning based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations (e.g. RTK) and possibly also by landmarks.
	Communication	V2I communication to be used to receive traffic management information in addition to real-time information.
	Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances on the road ahead are needed for tactical decisions on route choice, lane selection and coordinated take over procedure to operator.

1.2.14 5G strategic deployment agenda for CAM

In October 2020 a 5G Strategic Deployment Agenda for Connected and Automated Mobility (CAM)in Europe [28] is published with joint efforts from different organizations including ACEA, CEDR, GSMA and 5GAA. The following key areas are identified.

- Need for appropriate cooperation models to enable the initial deployment of 5G highways corridors
- Stabilizing the technology roadmap
- Cybersecurity
- Regulatory Innovation
- Data Access and Data Sharing

- Spectrum
- Coordination of Deployment

The agenda focuses on the 5G infrastructure deployment and discusses the way forward of 5G for CAM in Europe. The agenda comes after our study and we see many shared points with our pr

Digital infrastructure policies and roadmaps in major countries

Every year, KMPG publishes an on autonomous vehicle readiness index that ranks the countries based on different criteria. The following part presents information of the countries that are ranked high regarding the digital transport infrastructure.

1.3 The Netherlands

In 2018, Ministry of Infrastructure and Water Management sent a letter to the Parliament on smart mobility. Two of the key points are **future-ready infrastructure and road management** and **Careful utilisation of data exchange and connectivity**. The major action plan can be summarized as follows.

- Work with local and regional authorities to make location-based traffic rules available in digital version
- Further development of public data infrastructure
- Intelligent traffic lights to a national level
- New data sources such as from vehicles to be gradually combined with data from the public sector (loops, cameras)
- The ministry to take the leading role to coordinate road managers
- Accelerate the modernization of main roads with smart traffic signaling equipment, cameras, and processes to integrate the vehicle data
- Technical neutrality over C-ITS access technologies, and focus on services running over available telecommunication networks
- Using sensor data from vehicles such as Data Task Force
- Work with Ministry of Economic Affairs and Climate Policy (EZK) on access to vehicle data
- Work with EZK, the Radiocommunications Agency Netherlands and the telecoms industry on 5G services
- generic frameworks for competition, data sharing, data protection and cyber security

The Netherlands is active in many of the EU and national projects, especially regarding platooning and C-ITS. The Netherlands has one of the best 4G connectivity. The Ministry of Infrastructure and Water Management is taking a leading and coordinating role in digital infrastructure.

1.4 JAPAN

Aiming at a major demonstration of connected and automated driving functionalities in the context of the 2020 Summer Olympics, Japan is focusing on the accelerated provision and installation of the required infrastructure for connected and automated vehicles, cars, buses and trucks by a comprehensive strategic innovation program (SIP ADUS[3]).

Japan is one of the early countries which has implemented C-ITS infrastructure. In Japan, intersections have been equipped with communication equipment at 700MHz. The concept of dynamic map is one of the major research areas in Japans SIP-Adus program. Another key area is the infrastructure radar system aiming at an 79GHz radar system for detecting e.g., pedestrian at intersections.

[3] http://www.sip-adus.go.jp/

In addition to many of the AV trials, the Japanese government has partnered Innovation Network Corporation of Japan, Dynamic Map Platform Co., and Zenrin Co.[4] with Dynamic Map Planning to create 3D maps of the nation's roadways, and build the digital infrastructure needed for AVs to circulate in Tokyo. The high-definition 3D maps will include road signs, traffic lights, and pedestrian crossings, which, combined with information from the vehicle's sensors,—will enable vehicles to operate with greater precision, and could help in cases where, for example, a sign happens to be blocked by a tree or a pedestrian. The initial 3D-mapping effort will cover 300 km of expressways.

The Japanese government is playing a key role for pushing forward digital infrastructure by defining strategic programs, providing funding, and working closely with industries. C-ITS has long been implemented, and HD mapping is under development for CAV.

1.5 South Korea

In 2017, South Korea's Ministry of Land, Infrastructure, and Transport devoted $24.5 million to building AV infrastructure. Later in 2018, KT and the Korea Transportation Safety Authority (TS) completed construction of the nation's first experimental city K-City, based on the high-end fifth generation (5G) networks, to test autonomous vehicles. K-City is a test bed for the level-3 self-driving system, in which a vehicle detects and avoids obstructions on the road on its own, but returns control of driving to drivers in emergencies. The experimental city, which was set up in the 360,000 square meters of land with support from the Ministry of Land, Infrastructure and Transport, is aimed at commercializing level-3 self-driving cars at the earliest possible date. KT deployed C-ITS infrastructure and 5G based traffic control systems for real-time video and road information.

In 2019, South Korean President Moon Jae-in announced plans to commercialize fully automated vehicles by 2027[5], and become the first country in the world to have entirely self-driving cars on its roads. Prior to Moon's announcement, Trade, Industry and Energy Minister Sung Yun-mo mentioned that the government will revise regulations and set up traffic infrastructure for fully autonomous vehicles, as well as come up with insurance rules and drivers' responsibilities, by 2024. Meanwhile, a law that will aid the commercialization of self-driving cars will come into effect in May 2020. Alongside the government's initiatives, Hyundai said it will roll out semi-autonomous vehicles that can drive on highways on their own in 2021. By 2024, the automaker will begin selling vehicles capable of self-driving in cities.

The Korea government is taking a leading role in investigating the digital infrastructure for CAV and mobility. This is driven also by the 5G industry (telecom operator KT) and vehicle industry (Hyundai).

1.6 Australia

In 2017, Infrastructure Partnership Australia published a report [29] on autonomous driving with the identification on the support of communication infrastructure. The main elements are identified as follows.

- Sensors
- Traffic light and intersection communication
- Live traffic data

[4] https://thenewswheel.com/japan-will-soon-start-implementing-3d-maps-with-self-driving-vehicles/

[5] https://www.insurancebusinessmag.com/asia/news/breaking-news/korea-aims-for-fully-autonomous-vehicles-by-2027-180592.aspx

- Signage
- Incident and roadwork communication
- Pedestrian and cyclist interaction
- Internet connectivity
- Data storage

In view of the value of AV data, the report also recommended that governments, coordinated through Austroads to

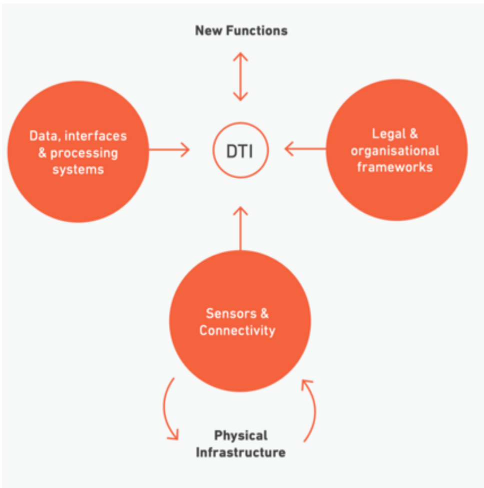
- Begin recording and annually reporting the number, type, usage and safety performance of AVs over time across each state, collating this information into a national database; and
- Implement standardized data recording and communication methods to reinforce cyber resilience.

1.7 Austria

In 2016, The Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT) released Action plan Automated Driving [30] where the thematic working group on digital infrastructure was established with the goal to 1) Definition of digital infrastructure 2) Implementation plan based on current projects 3) Focus connectivity, data security

Digital infrastructure was identified with the following foundations.

- Connected Vehicle Infrastructure
- Communication technologies & protocols
- Information management
- Traffic management
- Positioning (Galileo)
- HD maps
- Sensors, sensor networks and monitoring systems
- IT hardware and software



Concrete measure was also identified with clear tasks, roles and timelines.

Concrete measures
• Equipping of test environments with a digital infrastructure • Rollout of the C-ITS Basic Functions • Roadmap Digital Infrastructure • Integration of the Digital Infrastructure in the ITS Action Plan • How: Digital infrastructure as a basis for testing and deployment scenarios for automated driving; bmvit C-ITS Deployment Strategy, calls for tender for the ITS Action Plan with a focus on DTI • Who: ASFINAG, bmvit, provinces and municipalities, telecom operators, industry • When: Test environments & C-ITS deployment starting Q3/2016 Roadmap DTI Q3/2017 ITS Action Plan Measures Catalogue 2017 Tender for ITS Action Plan 2018

In November 2018, the BMVIT published the new action package “Automated Mobility (2019-2022)” summarizing the on-going efforts and specifying action plans. It was mentioned that Austria has been involved in major EU initiatives on CAD and has a strong position in digital infrastructure, especially C-ITS. Major points can be summarized as follows.

Infrastructure needs	
• Digital infrastructure is highly important when ensuring connectivity, information transfer ensuring connectivity, information transfer and sensor optimisation. • Data and information systems will become more and more important for interaction between digital and physical infrastructure. • Vehicles will transmit data on the condition of the physical infrastructure and a suitable traffic management process and improved is needed. • The infrastructural requirements presented by mixed traffic comprising automated, partially automated and non-automated vehicles must be taken into account and analysed appropriately with what, who, and when. • The functional description of design and layout parameters needs to communicate where, when and under which conditions connected and automated vehicles (and their users) are authorized to travel on road infrastrucsures.	
Tasks	Stakeholders
Survey of the influence that automated vehicles have on network availability and definition of the necessary modifications in regard to physical and digital infrastructure, as well as the traffic management processes.	ASFINAG
Development and implementation of a digital repository (static, d namic data) to identify the needs in regard to physical and digital infrastructures, operationalisation of control necessities and classification of Operational Design Domains so as to be able to define the matching technological (functionality and relevant issues such as safety and security), as well as legal and organisational frameworks for the (downstream) regular operation of automated vehicles on the public road network.	BMVIT, ASFINAG, federal government, states
Analyses of requirements of potentially connected, automated v hicle functionalities regarding the digital infrastructure, in particular C-ITS Day 1, Day 1.5 and Day 2 Services. Definition and articulation of a requirements catalogue and the corresponding framework conditions for infrastructure operators (highways and urban road networks).	AustriaTech with selected stakeholders (including ITS Austria, C-Roads, TM2.0, ASFINAG)
Further development and deployment of C-ITS services for the s port and integration of CCAD (adopted service definitions and message formats) on highways and urban road transport infrastructures including the necessary framework conditions for quality assurance.	BMVIT,ASFINAG, AustriaTech, Cities
Definition of infrastructure support levels. The highway infrastructure can be divided into a number of categories based on physical and informational facilities. This map of Infrastructure Support Levels for Automated Driving (ISAD) can be used as an additional source of information to define and distinguish the operational environments for automated vehicles in the mixed traffic phase.	ASFINAG

Austria involved in EU C-ITS and leads many developments through e.g., EcoAT, C-Roads, and have many national testing infrastructures for autonomous vehicles. Asfinag under BMVIT takes the major role in infrastructure digitalization and from 2020, ITS-G5 will be implemented in Austria.

1.8 Germany

The Germany effort on digital infrastructure for connected and automated vehicle is led by the Federal Ministry of Transport and Digital Infrastructure (BMVI) with close interaction with other governments and industry partners. In its report "Strategy automated and connected driving: Remain a lead provider, become a lead market, introduce regular operations" [31] which was published in September 2015, digital infrastructure was discussed with following major points.

Basic connectivity	• basic universal coverage at a speed of at least 50MBit/s by 2018 • motorways are connected with a bitrate of at least 50 MBit/s per antenna sector by 2018
Interlinking traffic signs	• intelligent interlinking of road signs, signals such as traffic lights, and telematics systems can optimize the flow of traffic
High-precision map systems	• development of appropriate data sets is primarily the responsibility of the market. • Supporting companies through financing assistance e.g., at the digital motorway testbed
Data	• make available traffic-related mobility and spatial data in an open-source approach and consolidate them on a data cloud • Using the “DAB+” digital radio standard, vehicles are to be provided with detailed real-time traffic information for their current location

	• a digital application is to be provided that collects mobility and spatial data and makes them available – and acts as an interface for other services
Cybersecurity	• developing guidelines for protection against non-authorized external access

The digital motorway testbed on A9 is one major investment for real-life testing of autonomous vehicles, as well as to identifying infrastructure needs. It is a 589 kilometer stretch of federal motorway in Bavaria that allows all stakeholders from the automotive industry to trial, assess and evolve AV related technologies. BMVI wants to, through the test and innovation, develop **standards for the digitalization of the federal trunk road network** and implement them within the scope of future structural maintenance, upgrading and construction projects.

Germany is active in C-ITS through projects such as SimTD, CONVERGE, C-ITS corridor. The strong automotive industry has joined hands with telecom for testing cellular communications for connected vehicles. The federal government works with stakholders for defining standardized intelligent roads. HD maps is believed to be the tasks of the industry.

1.9 Spain

The Spanish Ministry of Public Works and Transport has launched a Transport & Infrastructure Innovation Plan (2017) that develops the innovation strategy covering CADs. Major points regarding digital infrastructure can be summarized as follows. Each point has allocated budget for investigation.

Open data
• Promotion of new projects using open data • Definition of the catalogue of open transport data • Development of the open transport data multimodal portal
New data sources
• Partnerships with companies that generate mobility data • Application of social media data to mobility and transport • Use of mobile telephony data to determine transport demand • Integration of Galileo into the Fomento Group[6]'s applications
Road digitalization
• Standardisation of V2I and V2V communications • Introduction of a predictive maintenance of transport infrastructures • Positioning towards 5G networks

Spain is a core member in C-Roads with five test pilots

- DGT 3.0, overall road network, approximately 12,270 Km. cellular-based communication technologies (3G and 4G/LTE).
- SISCOGA Extended, the city of Vigo and its metropolitan area, 150 Km, ITS-G5.
- Madrid Calle 30, along the road "Calle 30" in Madrid, approximately 32 km. hybrid communication technologies.
- Cantabrian pilot, North spain, approximately 75 km, hybrid communications.
- Mediterranean pilot, Catalonia and Andalusia, approximately 125 km, hybrid technologies.

Spain (CTTC) also leads 5G project 5GCroCo which will test 5G technologies in the cross-border corridor along France, Germany and Luxembourg.

[6] Fomento group includes stakeholders for the plan: Adif, Renfe, Aena, Enaire, Crida, Puertos del Estado, Ineco, Cedex and Sasemar

1.10 China

In February 2020, 11 government authorities jointly published a new strategy – innovation and development strategy for intelligent vehicles. The strategy aims at scalable production of conditional autonomous vehicles, and commercial application of highly autonomous vehicles in certain scenarios by 2025. Regarding digital infrastructure, the strategy also mentions that by 2025, vehicular communication such as LTE-V2X should cover regions, the new generation 5G-V2X should be available in certain cities and highway, high precision positioning should be available.

More specifically, the following tasks are described under the key investment areas regarding digital infrastructure.

Intelligent road infrastructure	• Construct intelligent road and national traffic network • Driving digitalization, intelligence and standardization of road infrastructure • Combining 5G commercialize for vehicular communication • Standardize interfaces and protocol for road infrastructure, intelligent vehicles, transport operators, traffic management, etc.
high coverage vehicular network	• Accelerating vehicular communication with spectrum permits • Coordinates with public communicating network to construct new generation vehicular network at key roads and regions that can provide ultra-low latency, high reliability, high bandwidth, and mobile edge computing • Building narrow-band IoT network at bridges, tunnels, parks, etc., for information database and monitoring facilities
National high precision positioning service for vehicles	• Based on Beidou, building national high precision positioning service • Combining navigation and communication networks for multi-source navigation • Driving interoperability between Beidou and mobile communications • Building vehicle emergency response system
National road traffic GIS system	• Standardized base map for intelligent vehicles • Providing real-time dynamic data services • Data sharing between vehicle base map and satellite image data • Building fast updating and online service framework for road GIS
National intelligent vehicle data cloud control platform	• Based on existing infrastructure, building intelligent vehicle cloud control platform • Building coordinated, distributed cloud computing center • Building standardized, open and shared data center • Building secure and reliable cloud control software • Fusion infrastructure for data from vehicles, infrastructure, environment, etc.

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