Evaluation results

NordicWay 2

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Document Information

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Glossary

Term/Abbreviation	Definition
AWWD	Alert wrong-way driver
CAD	Connected and automated driving
CCN	Connected and cooperative navigation
CEF	Connecting Europe Facility
CIP	City innovation platform
C-ITS	Cooperative intelligent transport system
DENM	Decentralised environmental notification message
EBL	Emergency brake light
EU	European Union
EVA	Emergency vehicle warning
FEV	Fully electrical vehicle
GDPR	General Data Protection Regulation
GLOSA	Green light optimal speed advisory
GNSS	Global navigation satellite system
GPS	Global positioning system
GUI	Graphical user interface
HLN	Hazardous location notification
HMI	Human-machine interface
I2V	Infrastructure to vehicle
ICT	Information and communication technology
IPR	Intellectual property right
IS	Intersection safety
IT	Information technology
IVS	In-vehicle signage
IVSL	In-vehicle speed limit
KPI	Key performance indicator
Latency	Send/receive latency = time from timestamp sent to timestamp received of message at any node
Location accuracy	Relative precision of the referenced location for the published event at any node with respect to the actual location of the actual event
Message success rate	Percentage of sent messages received (on node level)
MoU	Memorandum of understanding
NAP	National access point
OBD	On-board diagnostics
OBU	On-board unit
OEM	Original equipment manufacturer
Physical coverage	Change in length of the network covered by C-ITS services
PoC	Proof of concept
PVD	Probe vehicle data
PoC	Proof of concept
R&D(&I)	Research & development (& innovation)

TERM/ABBREVIATION	DEFINITION
REST API	Representational state transfer application programming interface
RLC	Road or lane closure
RSMP	Roadside message protocol
RSU	Roadside unit
RWIS	Road weather information service
RWW	Road works warning
SI	Signalised intersections
SPaT / SPATEM	Signal phase and timing extended message
SRTI	Safety related traffic information
SUP	Scale up partner
TI	Traffic information
TMA	Truck mounted attenuator
TTG	Time to green
WG	Working group

Content

1 Introduction

The NordicWay 2 project, co-funded by the Connecting Europe Facility (CEF) programme, was set up to support the deployment of so-called Day-1 and Day-1.5 cooperative intelligent transport system (C-ITS) services in the Nordic countries (Denmark, Finland, Norway and Sweden). Another objective for NordicWay 2 was to extend the use of C-ITS in vital road-freight-transport routes subject to extreme weather conditions and in urban and interurban environments. The project also supported infrastructure readiness for connected and automated driving in the region and contributed to the harmonisation and interoperability of C-ITS services in Europe.

In addition to the above objectives, NordicWay 2 was set to assess the feasibility of C-ITS services in the Nordic countries. Specifically, this was done by evaluating whether the services can be technically implemented (i.e., the quality of service fulfils the requirements), whether the general public accepts the services and is willing to use them, whether viable ecosystems can be built for service provision, and whether socioeconomic benefits can be expected and under which conditions. This socioeconomic impact of the services was assessed addressing the impacts on safety, transport network efficiency, the environment and mobility.

This evaluation results report describes the methods used and the evaluation results and conclusions obtained.

Satu Innamaa (VTT) was responsible for compiling the report. Anna Schirokoff (Traficom) was responsible for coordinating the evaluation activities. Different teams under the NordicWay 2 Evaluation Group were responsible for planning and conducting the evaluation for different evaluation areas and reporting them. Namely,

- *Pilots description* (Chapter 2): Michaela Sannholm (Traficom) for the Finnish pilots, Magnus Hjälmdahl (Sweco) for the Swedish pilots and Per Einar Pedersli (NPRA) for the Norwegian pilots
- *Technical evaluation of the quality of service* (Chapters 3.3 and 4.1)*:* Mikko Tarkiainen (VTT), supported by Kimmo Kauvo (VTT), Risto Öörni (VTT), Per Einar Pedersli (NPRA), Vishal Baid (Sweco), Magnus Hjälmdahl (Sweco) and Daniel Bergqvist (Sweco)
- *Ecosystem evaluation* (Chapters 3.4 and 4.2): Petri Mononen (VTT), supported by Magnus Simons (VTT), Risto Kulmala (Traficon Oy), Felicia Hökars (Sweco) and Per Einar Pedersli (NPRA)
- *User acceptance evaluation* (Chapters 3.5 and 4.3): Merja Penttinen (VTT), supported by Pirkko Rämä (VTT), Satu Innamaa (VTT), Carlos Viktorsson (Sweco), Solveig Meland (SINTEF) and Lone Dörge (Genua), pre-work by Satu Kotituomi (Traficon Oy) and Risto Kulmala (Traficon Oy)
- *Socioeconomic evaluation* (Chapters 3.7 and 4.5): Risto Kulmala (Traficon Oy) and Fanny Malin (VTT), supported by Satu Innamaa (VTT), Lone Dörge (Genua), Solveig Meland (SINTEF), Per Einar Pedersli (NPRA), Martin Ström (Trafikverket), Anders Bak Sørensen (Vejdirektoratet), Felicia Hökars (Sweco), Carlos Viktorsson (Sweco) and Magnus Hjälmdahl (Sweco)

In addition to the evaluation work coordinated by the NordicWay 2 Evaluation Group, driver behaviour evaluation was planned and conducted locally under NordicWay 2 without direct contribution to or by the NordicWay 2 Evaluation Group. These two studies are referred to in this report as follows:

- *Driver behaviour evaluation* (Chapters 3.6 and 4.4)
  - Emergency vehicle approaching (warning): based on Lidestam et al. (2020)
  - Reindeer warning: based on Kotituomi et al. (2019)

2 Pilots

NordicWay 2 piloted and evaluated a multiplicity of Day-1 and Day-1.5 C-ITS services in Finland, Norway and Sweden. All C-ROADS services were piloted by at least one use case in at least one country under the NordicWay 2 project. However, none of the services was piloted in all three countries (Table 1).

Table 1. Piloted NordicWay 2 use cases and corresponding C-ROADS services. Abbreviations: IVS = in-vehicle signage, PVD = probe vehicle data, CAD = connected and automated driving, CCN = connected and cooperative navigation

	C-ROADS SERVICES	NORDICWAY 2 USE CASES	FI	NO	SE
Day-1 services	IVS	In-vehicle speed limit	x	x	-
	Hazardous location notifications (HLN)	Weather and road condition	x	x	-
		Slow or stationary vehicle	x	x	-
		Emergency vehicle approaching	-	-	x
		Traffic ahead warning	x	x	-
		Emergency brake light	-	x	-
		Cooperative collision warning	-	x	-
	Road works warning (RWW)	Road and lane closure	x	x	-
		Mobile roadworks	-	x	x
	Signalised intersections (SI)	Signal violation / intersection safety	-	x	-
		Time to green	-	-	x
		Green light optimal speed advisory (GLOSA)	-	x	x
		Traffic signal priority request	-	-	x
	PVD	Single vehicle data	x	x	-
Day-1.5 services	Traffic management	Traffic information & smart routing	x	x	-
		On-street parking information and management	-	x	-
		Information on alternative fuel vehicle fuelling & charging stations	-	x	-
	CAD	Data collection for mapping of infrastructure readiness	-	x	-
	CCN in and out of the city	Dynamic access control of designated infrastructure	-	-	x
	Dynamically controlled zones	Dynamic environmental zone	-	-	x

Service provision ecosystems and the aim of each pilot differed from one country to another and from one implementation to another.

In Finland, services were piloted with three ecosystems which all provided several services for real users for large, some even for whole, road networks in Finland with fleet sizes of up to several thousand users. Service providers shared information within the ecosystem in interchange nodes, and the pilot focused on feasibility of the ecosystem concept. In Finland, cellular communication was used for connectivity, and the services were provided for either mobile device or vehicle display.

In Norway, the piloting was done mainly on the E6 between Oslo and Svinesund and on the E8 between Skibotn and Kilpisjärvi. Some of the pilots did not have constraints on their geographical coverage. Piloting was mainly done with sensors or a few test vehicles in normal traffic. Tests focused on transfer of messages to the interchange node. In addition, proof of concept (PoC) trials were done with registered users. In Norway, the communication technology was mostly cellular communication. Selected roadside infrastructure and vehicles were equipped with ETSI ITS-G5 when needed to ensure interoperability. Services were provided for either mobile device or vehicle display.

In Sweden, the piloting took place (mostly) in Gothenburg, Uppsala and Stockholm. Tests were done with a few test vehicles with focus on PoC or technical evaluation. In Sweden, hybrid communication was used with cellular as the primary means of communication, supplemented by ITS-G5 for road works warnings.

In addition to these country-specific tests and pilots, NordicWay 2 tested the interoperability of the following C-ITS services throughout the NordicWay 2 network with the Nordic Tour experiment:

- Slow or stationary vehicle(s) & Traffic ahead warning
- Weather and road condition
- Traffic information & smart routing

This interoperability test run was conducted by the Norwegian Road Administration in collaboration with the other partners in NordicWay 2.

3 Evaluation methods

3.1 Evaluation areas covered

The NordicWay 2 evaluation covered all the impact areas addressed in the C-ROADS Evaluation and Assessment Plan (Table 2).

Table 2. C-ROADS evaluation areas and their coverage and priority in NordicWay 2

EVALUATION AREA	PRIORITY*
User Acceptance	++
Safety	++
Traffic efficiency	+
Environment	+
Organisational	++
Socio-economy	++
Quality of service	++

*Rating of priority:

- '++': Primary evaluation area for the pilot. It implies a major effort and involvement in the evaluation of the impact area.
- '+': Secondary evaluation area for the pilot. It implies a minor effort and involvement in the evaluation of the impact area.
- Empty cell: Impact area not investigated by the pilot.

Tables 3 and 4 give an overview of the evaluations in NordicWay2. They list high-level research questions and indicators, or key performance indicators (KPIs) related to them. The impact areas in Table 3 were assessed on a single implementation level. This included the quality of service and the impacts on driver behaviour. Service ecosystems, user acceptance, socioeconomic impacts and the feasibility of C-ITS service provision for the Nordic countries were assessed at project level as a joint effort by the evaluation partners of all the countries involved (Finland, Norway, Sweden and Denmark) (Table 4).

Table 3. Impact areas, high-level research questions and KPIs for those areas, which were evaluated on a single implementation level

IMPACT AREA	RESEARCH QUESTION	INDICATOR/KPI	UNIT	WHERE STUDIED		
				FI	NO	SE
Quality of service	What is the impact (of NordicWay2) on the coverage of the service?	Physical coverage	-	x	x	-
		Number of vehicles equipped with • fully functional C-ITS in-vehicle device • partially functional C-ITS in-vehicle device	Number	x x	x x	-
		Change in number of external data sources per C-ITS service	Number	-	x	-
		Number of C-ITS service vehicles or users	Number	x	-	-
	What is the performance of the service?	Number of C-ITS messages distributed per service and node	Number	x	-	-
		Location accuracy	-	x	-	-
		Latency • end-to-end • between federated interchange nodes	s ms	x x	x -	x x
		Message success rate	%	x	-	-
	Is the continuity of services achieved cross-border?	Cross-border continuity of services	Yes/no	x	x	x
		Cross-organisational/cross-brands data sharing	Yes/no	x	x	-
Driver behaviour	What is the effect of EVA messaging on the propensity of drivers to give way to an ambulance on an emergency call?	Distance from ambulance when giving way	m	-	-	x
		Lateral position when overtaken	m	-	-	x
		Mean speed when overtaken by ambulance	km/h	-	-	x
	What is the effect of reindeer warning on driving behaviour?	Focusing attention	% of users	x	-	-
		Discussing the alert	% of users	x	-	-
		Activities performed while driving	% of users	x	-	-
		Use of control devices	% of users	x	-	-
		Overtaking	% of users	x	-	-
		Distance to the vehicle ahead	% of users	x	-	-
		Driving speed	% of users	x	-	-

Table 4. Impact areas, high-level research questions and KPIs for those areas that will be evaluated at project level

IMPACT AREA	RESEARCH QUESTION	INDICATOR/KPI	UNIT
Service ecosystem	What should be taken into account in forming a service ecosystem? What defines an “ideal” ecosystem?	Acceptability / attractiveness of the Business case (to the ecosystem partners)	Description
		Feasibility of the ecosystem	Description
		Roles • for private actors • for public actors • what is/are the “must have player(s)” in the ecosystem(s)	Description
	What problems and challenges have been encountered?	Encountered problems and challenges in the ecosystem	Listing / table
	What is the business potential of the service?	Business potential	Description
	What are the most important things to be taken into account (and solved) in the service development and provision phases?	Issues in implementing the service	Listing / table
User acceptance	Are the Nordic drivers aware of C-ITS services?	Awareness of C-ITS services	%
	Which C-ITS services/messages are relevant in Nordic conditions?	Importance of information content	Likert scale
	What do Nordic drivers see as benefits and potential disadvantages of C-ITS services?	Perception of the stated benefits and potentially negative effects	Likert scale
	What is the driver’s willingness to share data with the service provider?	Willingness to share data or act as a source of warnings	Yes/maybe/no
	What is the willingness to use C-ITS services?	Willingness to use	%
	What is the importance of having the C-ITS service abroad?	Importance	Likert scale
Socio-economy	Mobility: Are the vehicle hours driven impacted?	Vehicle hours driven	Hour, %
	Safety: Is the number of fatal and injury accidents impacted?	Fatal, non-fatal injury and property damage-only accidents	Number, %
	Efficiency: Are vehicle hours lost due to congestion impacted?	Vehicle hours lost due to congestion	Hour, %
	Environment: Are CO_2 emissions impacted?	CO_2 emissions	Tonnes, %
	What is the socioeconomic impact of C-ITS service bundles?	Monetary value of benefits and costs	€
Feasibility	Is the use of connected and automated driving feasible on European road networks in the Nordic countries?	Feasibility • Technical • User acceptance • Business model and ecosystem • Socioeconomics	Description, conclusions

3.2 Overall approach to evaluation

The overall evaluation approach in NordicWay 2 followed the principles of the FESTA methodology (CARTRE & FOT-Net 2017), and the main steps of the process described in FESTA V (Figure 1) were followed. The NordicWay 2 Evaluation Plan was in line with the C-ROADS Evaluation and Assessment Plan (C-ROADS 2018) and European ITS Platform/EasyWay Evaluation Framework and Guidelines (Tarry, Turvey & Pyne 2012 and Tarry, Turvey & Kulmala 2012). It also utilised the methodological framework set in the NordicWay (1) project where appropriate (Innamaa et al. 2017, NordicWay 2017). Evaluation methods are described in detail for all evaluation areas in Chapters 3.3–3.8. They include updates to the NordicWay 2 Evaluation plan (Innamaa et al. 2018).

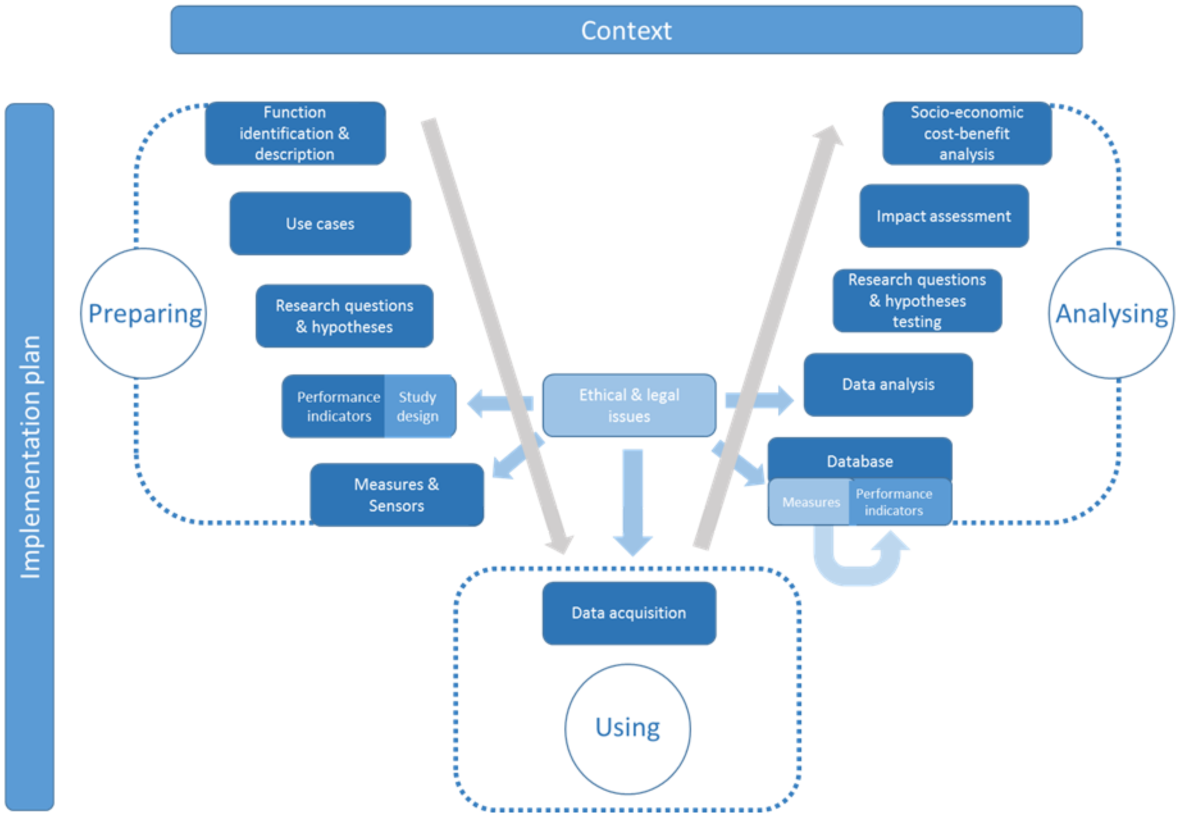


Figure 1. "FESTA V", i.e., the steps that typically have to be considered when conducting a field operational test (CARTRE & FOT-Net 2017)

3.3 Quality of service

3.3.1 Overall approach to quality-of-service evaluation

The quality-of-service aspect was studied in NordicWay 2 pilots in Finland, Norway and Sweden. The overall conclusions on the quality and potential challenges related to the quality of the piloted C-ITS services were made at NordicWay 2 level. The assessment of the quality of services complemented the tests done in a previous NordicWay (1) project (Innamaa et al. 2017).

The comparison at NordicWay 2 level was done only for C-ITS services with similar implementations across the Nordic countries. Key performance indicators (KPIs) were aligned as much as possible before the start of the pilots, but the differences in the services and pilots made it quite difficult to find fully comparable KPI results. Therefore, most of the C-ITS services and KPIs were studied and reported separately at national level. This was due specifically to e.g., the following reasons:

- Service implementation in one country differed from that in other countries.
- Scales of the service pilots varied significantly.
- KPI calculation methods were somewhat different from the other countries or KPIs were not measured at all in the other countries.

The KPI reporting or calculation was done with various methods. For example, the impact of NordicWay 2 on the coverage of the C-ITS services was collected directly from the service providers involved in the pilots. The performance of the services was calculated from the logs collected from the interchange nodes inside the federation (following the draft architecture for NordicWay 2 by Sundberg (2019)), supplemented by controlled tests. In addition, the cross-organisational and cross-border data sharing was studied in the pilots and during the Nordic Tour.

The following chapters summarise the methods used to collect information and calculate KPIs in each country. A detailed description is given in Annex 1. Most of the KPIs were the same but there are some variations, which are indicated in the KPI tables from each country (for details, see the KPI index and descriptions in Annex 1).

3.3.2 Evaluation methods in Finland

In Finland, the quality of services was studied by focusing on the overall functionality and performance of the services. The technical testing of the services was done by utilising the logs collected from the interchange nodes in Finland. In addition, controlled field tests were conducted to test the performance of the selected services in the real world.

Data logging from the nodes

The data logging was designed to meet the requirements of the selected Quality KPI calculations in Finland. The data logging was implemented to the backends of the three service providers in the Finnish NordicWay 2 network (INFOT, EEE, Vaisala). The logging is described in detail in Annex 1.

The logging was done in the node servers for all messages sent out and received from the interface to the respective interchange node. Data logging was active during the measurement session, which ran from 28 April 2020 to 31 May 2020.

Controlled field tests

The controlled field tests in Finland focused on verifying the main functionalities of the selected services, cross-organisational data sharing, and measuring end-to-end latencies. As a sample solution, two mobile (Android) applications, which operate under two different nodes, were selected for the field tests (ForeC from EEE Innovations and Louhi from Sitowise — connected to the INFOT backend). The web application RoadAI from Vaisala was also used. The mobile applications covered a variety of message types which could be launched manually by the user. This feature enabled simple field testing. The third node (Vaisala) did not implement similar mobile applications which could be used in the tests. The latency measurements focused on the two mobile applications and the cross-organisational data sharing verified from all nodes.

The controlled field tests were conducted on 27–29 April 2020 in Tampere, Finland, as both stationary and driving tests. The stationary tests were run in the back yard of the VTT vehicle labs at Niittyhaankatu, Tampere. The driving tests were run in the southern parts of Tampere on a route including suburban streets, rural roads and motorways. In the driving test, a test route of about 30 km was driven twice; the map in Annex 1 shows the approximate locations where the test events were launched while driving. See Annex 1 for further details on the tests.

KPIs measured in Finland

Annex 1 provides an overview of the KPIs measured in Finland. It includes tables with descriptions of the KPIs and the KPI calculation methods. The input for the KPIs was collected by various means, e.g., reported by the service providers, by calculating from the log files, and/or data collected in controlled tests.

The service provider reported KPIs related to service coverage and the number of C-ITS devices and users during the pilot in Finland. The number of C-ITS messages distributed per service node and the corresponding message success rate were calculated from the log files generated by the federated nodes. The calculation of latency (between federated nodes) utilised the same principles as the calculation of the two previous KPIs. Two KPIs were calculated based on the results of the controlled tests: location accuracy and latency end-to-end.

3.3.3 Evaluation methods in Norway

In Norway, the quality of services was studied by focusing on the overall functionality and documentation of the equipment used and deployed in the pilots. The data logging from the interchange node tests was done before the common design of documentation was developed and is therefore not reported in the same way as the Swedish and Finnish results for latency.

Data logging from the nodes

The test scenarios for the *Bouvet interchange node* were (1) sending 2000 messages as soon as possible, from one client to the interchange node, and (2) sending one message, receiving one message, 2000 times, from one client to the interchange node.

For the different scenarios, the configuration of the interchange was changed to see if the latency was affected. Memory size and number of validation processes were two important parameters. The test environment was a small ecosystem with one client sending DATEX II messages to the interchange node.

The company Aventi performed an end-to-end test, but the interchange node was not included. Instead, the messages ended up in the Norwegian DATEX II node (see Annex 1). This setup was interesting because it measured latency in an ITS-G5 short-range communication setup with both an onboard unit (OBU) and roadside unit (RSU). Log files were used to track the transfer of each DENM message. An android phone was used just to trigger a DENM message from the OBU and there was no logging in the Android.

See details of the data logging in Annex 1.

Controlled field tests

The controlled field tests in Norway focused on verifying the main functionalities of the selected services and cross-organisational data sharing. Most of the field tests were proof-of-concept tests (PoC).

The Bouvet test at Skjervøy tested signal violation and GLOSA (virtual lights). The aim of the field test on Skjervøy was to verify that the system can be used to take cars through bottlenecks on the FV866 section.

NPRA tests in Skibotndalen evaluated warnings on slow or stationary vehicle(s) and traffic ahead, as well as the interoperability of weather and road conditions services. The aim of these field tests was to verify the quality of the detection systems and to set up the service ecosystem.

NPRA tests at Jonsvatnet, Trondheim, tested the slow or stationary vehicle(s) warning and the traffic ahead warning. The aim of the field tests at Jonsvatnet were to verify the PoC of the services. The maintenance vehicle sent messages to the Norwegian interchange node which were then distributed to a mobile app in the vehicles approaching the maintenance vehicle.

The Nordic Tour was planned together with all of the partners in NordicWay 2. The route totalled 5 000 km of real-world roads in a comprehensive network with large variation in road geometry, traffic volume and topography, including both urban and rural areas. During the test there were moderate differences in weather conditions, and the follow-up logging was done in winter. The test route was Gothenburg-Kilpisjärvi-Gothenburg, passing through four countries and across five border crossings. The test equipment was always connected to the interchange.

The aim of the Nordic Tour was to collect data on vehicle perception of infrastructure and focus on:

- State-of-the-art ADAS (vehicles understand the surroundings, have a camera able to detect lane markings and signs along the entire route)
- Connectivity measurements (RSRP, RSRQ and ping times)
- Measurements on interference in LTE bands (data from spectrum analyser)
- GNSS logging (accuracy, signal quality, potential CW-jamming, AGC shifts)
- Cross-border testing of service functionality, logging of connectivity when crossing borders
- Logging of events available through the interchange when driving in all four countries.

These experiments are described in more detail in Annex 1. More information on the Nordic Tour is available in ‘Norwegian Pilot 2, Evaluation and final report’ by NordicWay 2 (2020a).

KPIs measured in Norway

Annex 1 provides an overview of the KPIs measured in Norway. It includes tables with descriptions of the KPIs and KPI calculation methods. Input for the KPIs was collected in various ways including reports by service providers, calculations based on the log files and/or data collected in controlled tests.

The service provider reported KPIs related to service coverage and the number of C-ITS devices during the pilots. Latency logging was done in an early phase of the development and was used to find an optimal configuration of the interchange node. No latency measurements were done during the field tests. Two KPIs were calculated based on the results of the controlled tests: physical coverage of communication technology and cross-border continuity of services in terms of cellular communication and handover situations.

3.3.4 Evaluation methods in Sweden

In Sweden, the quality-of-service evaluation focused on latencies. For the various pilots, a couple of different setups were used for transmission of messages from one end to the other through the common interchange node. The latency measurements were done separately for different C-ITS services.

For the *emergency vehicles approaching (EVA) warning*, the messages included the parts from the integration and connection with the SOS alarm until the EVA warning messages were finally received in the vehicles and a message was displayed on the vehicle HMI. End-to-end measurements were performed through Carmenta TrafficWatch and the interchange node to Volvo Cars' backend cloud, which sends messages to the cars. In total, there were 31 400 records of messages at Carmenta TrafficWatch from 251 different emergency missions.

In the case of *connected traffic lights*, for traffic signals the time between the change in the traffic signal phase (green, yellow or red) and what you see/sense in the vehicle was measured as latency. The time from the switch of signal at the infrastructure to the OEM Cloud was measured. The HMI was not involved in the process.

For *dynamic access control*, the messages were initiated at the traffic management centre, which contains systems from Technolution for exchange with the interchange node, interaction with the traffic operator, and the central databus for traffic data. The message then passed through the interchange node to the OEM's digital environment. Scania developed an interface making it possible to send request for access and receive messages for approved or denied access provided through the interchange node. The architecture included a set of future extensions whereby dynamic access control can be connected to C-ITS solutions, traffic network management systems and weather systems for additional information from external sources. The latency was measured using the stopwatch method. Two different latencies were measured: first, the latency between access request from within the truck to the operator and back again to the truck; and second, latency between transmission and reception in the application.

For *dynamic environmental zones*, the City of Gothenburg offered a test version of a city innovation platform (CIP), which was under development as part of the EU project IRIS. This CIP delivered a common means for data exchange and storage from a smart city perspective. Thus, exchange of controlled zone information, restrictions, status etc. was most suitable through this platform. The central data exchange was based on the Ericsson Interchange Node, which offers a common platform for information exchange between business and governmental systems. Technolution deployed an installation of their traffic management suite MobiMaestro for this purpose, and the existing central databus was extended with support for dynamic environmental zones information. MobiMaestro exchanges the dynamic environmental zone information with CIP through a standardised REST API. Finally, Volvo Cars extended the cloud, enabling the dynamic environmental zone information to be received and pushed to vehicles in the area. Test software in the vehicle ensured that the vehicle automatically ran on pure electric within the zone. The latency was measured using the stopwatch method. The measurement corresponded to the measure of latency between changing a geofence state in the GUI and the actual response of the vehicle.

The service and warning message for *road works warning* (RWW) was generated at the RWW unit mounted on the TMA vehicle. The message was received by the Kapsch unit, which transferred the RWW message in DENM and DATEX II format through the interchange node to the OEM cloud and finally to the vehicle. The OEM cloud also received road work information messages from Trafikverket in DATEX II. Latency was not measured for this service.

These experiments are described in more detail in Annex 1.

3.4 Service ecosystem

3.4.1 Overall approach

Ecosystems were studied in all the Nordic countries based on commonly agreed principles. The activities in the ecosystem evaluation were planned and organised jointly by the NordicWay 2 Evaluation Group (Activity 3) and the Interoperability & Technical Coordination Group (Activity 2).

The ecosystem evaluation work centred on two series of workshops in each country with NordicWay 2 pilots. The first set of workshops focused on the present state and scaling up of the ecosystem. The second set looked especially at innovative marketing strategies and other aspects, measures or requirements that could or should be implemented to achieve growth and scaling up of services after the pilot stage. See the script for the workshops in Annex 2.

Practical implementation of the ecosystem evaluation included workshops that invited C-ITS service providers to define, based on their own ecosystem, the ideal ecosystem that they saw as the most sensible and feasible for providing such services. This included the definition of roles (including the roles of public authorities) and the necessary agreements between the ecosystem partners (who pays whom — without going into actual monetary prices). C-ITS service providers were also invited to assess and express their views on the business potential of the various services, as well as on the key deployment issues that have arisen or are foreseen in the service build-up and in the short and medium term.

In short, the ecosystem evaluation work aimed at investigating the following:

I Service Ecosystem

- Partners
- Roles (data collection, data enrichment, quality control, service delivery, etc.) including the public sector
- Value network (including data sharing)

II Feasibility and viability of the ecosystem

- Business potential (short- to medium-term potential)
- Business case validation (how partners accept it and see its utilisation)
- Challenges within the value network
- Deployment issues

III Aspects of service contracting

- Requirements of the ITS Directive: SRTI
- GDPR, others

The main phases covered in the ecosystem evaluation were:

1. Preparing a manuscript or script for all national workshops to collect pilot ecosystem assessment data for each country, and providing guidance on the organisation of and reporting on national workshops
2. Organising the workshop series (autumn 2019 and spring 2020) and reporting on their results
3. Collecting and compiling national results from all the Nordic countries which have production pilots (i.e., Finland, Sweden and Norway)
4. Producing a synthesis of all national workshops, and
5. Providing and integrating a summary report as part of the NordicWay 2 Evaluation report.

Table 5 details the tasks in the service ecosystem evaluation.

Table 5. Task descriptions of the ecosystem evaluation

TASK	DESCRIPTION
Workshop script	Start-up. Discussions with the NordicWay 2 Evaluation Group and Nordic contact persons. Charting out the characteristics of national implementations, and the effects of these on evaluation. Workshop script compiled based on this and the work plan. Background, e.g., C-ITS Platform Business models group report, SRTI PoC MoU (Data for road safety), C-ITS Platform Horizontal Business model, Working Group draft final report, etc.
Organising workshops & reporting	Guidance for national organisers. Translations into national languages (if needed) by national organisers, as well as reporting back in English to the ecosystem evaluation group (VTT & Traficon).
1st workshops in Finland, Norway and Sweden	National organisers implement these in each country, autumn 2019.
Summary of 1st workshops	Short summary and lessons learned for enhancing 2nd workshops. Input to the NordicWay 2 Interim Evaluation Report. Script for the secondary set of workshops.
2nd workshops in Finland, Norway and Sweden	National organisers implement these in each country, spring 2020.
Synthesis report	Workshop results, data analysis, synthesis. Answers to the research questions. Analysis to be linked to other ongoing evaluation work — to the user acceptance study in particular.
Ecosystem evaluation report	To be integrated into the NordicWay 2 Evaluation Report

3.4.2 Research questions and methods

Table 6 lists the defined research questions, main indicators and the basic result format. The starting point for defining and assessing the feasibility of a service ecosystem was the development of a value network model, extended to public stakeholders. Modelling focused on structuring the roles needed to deliver the service. Assessment of the feasibility of a service ecosystem examines how ecosystem actors are able to meet the required roles, what technological and business changes are required (or were required) to implement new services, and assesses industry drivers and barriers.

Table 6. Research questions, indicators, format for ecosystem evaluation

RESEARCH QUESTIONS - THIS IS WHAT WE WANT TO EXTRACT	INDICATORS / KPIS	FORMAT
What should be taken into account in forming a service ecosystem? What defines an ”ideal” ecosystem?	Acceptability / attractiveness of the business case (to the ecosystem partners)	Description (qualitative)
	Feasibility of the ecosystem (build up phase and resilience)	Description (qualitative)
	Roles • for private actors • for public actors • what is/are the “must-have player(s)” in the ecosystem(s)	Description (qualitative)
What problems and challenges have been encountered? (either encountered thus far or foreseeable now)	Encountered problems and challenges in the ecosystem	Listing / table
What is the business potential of the service?	Business potential	Description (qualitative), if possible, some quantitative data included (expected/potential number of users, willingness to pay, etc.)
What are the most important things to be taken into account (and solved) in the service development and provision phases, in the short term and medium term?	Issues in implementing the service	Listing / table

Research questions:

- What problems or challenges have been or are expected to be encountered in the value network?
- What are the key issues that need to be considered and addressed in deployment in the short and medium term?

In assessing business potential, a simplified market segment model was created and, for key segments, user value models. To quantify the potential, user volumes and liquidity were assessed (if possible, by market segment) based on information available from ecosystem operators. In addition, the earnings models of operators in different areas of the value network were examined.

Research questions:

- What is the business potential of the service?
- How should the service ecosystem theme be defined?

To model the deployment of future new services, a phased growth model of ecosystem development was created. The starting point was the pilots of the NordicWay 2 project and their estimated results. In the process of structuring the process, it was essential to consider the interaction between supply and demand (network effect).

Research question:

- What are the key issues that need to be considered and addressed in deployment in the short and medium term?

3.4.3 Result reporting structure

Table 7 details the requirements for reporting from each service ecosystem. The Finnish ecosystem evaluation group provided all instructions and data to Sweden and Norway in English — and correspondingly received back all reported national data and results from the Norwegian and Swedish workshops also in English. If and when any translations to and from Norwegian or Swedish were needed or considered useful, they were to be handled by the Norwegian and Swedish actors and workshop organisers, during all stages of the ecosystem evaluation process.

Table 7. Reporting content

REPORTED ITEM	FORMAT, QUANTITY	DETAIL LEVEL, CONTENT, ETC.
Ecosystem description	Illustration. In editable format, e.g., PowerPoint. See an example in Annex 2 One per production pilot	• Different actor names visible • Main data sources visible • Data flows visible • Money flows visible • External actors visible
Service description	Table One per production pilot. *)	• Service provided • Data provided • Intended user groups • Estimate of user count
Role chart	Matrix / table One per production pilot. *)	For each actor, their involvement in the 24 stages of the service provision chain (with tick marks)
Challenges encountered	Table One per production pilot. *)	Challenges in: • Forming the ecosystem • The service formulation and provision phases • Access to data and right to use data for service provision purposes within the pilot (within the consortium, with public actors, with commercial actors) • Other issues / challenges
Lessons learned	Table One per production pilot. *)	Lessons learned in: • Forming the ecosystem • The service formulation and provision phases • Access to data and right to use data for service provision purposes within the pilot • Other issues / challenges
Pains, gains, commitment	Table One table, containing all involved pilot actors	For each actor: • pains • gains • commitment
Scaling up issues	Table One per production pilot. *)	For each pilot: • What is needed to scale up from pilot level • Possible level (national, Nordic, European) • New actors needed • Main investments or development needed • Moving to C-ITS (federation model or other) issues • Public sector's role (cities and other public actors clearly separated)

*) Or optionally, one single table where each different production pilot and/or service is clearly distinguishable.

3.4.4 Swedish and Norwegian adjustments to the workshop series

The workshop series kick-off took place in Espoo, Finland, on 7 September 2019. The remaining initial workshops (in Sweden and Norway) were arranged with a flexible schedule. In addition to the timing flexibility, the other Nordic actors in Sweden and Norway were given some other levels of freedom in their national implementations of workshops and were free to adjust the programme, timing, structure and working methods, as long as the given reporting instructions and requirements were being met. National organisers in Norway and Sweden, after first consulting the Finnish evaluation team on any major re-structuring ideas, were granted the liberty of e.g.:

- Having just one collective workshop (as in Finland) or several pilot or service-specific workshops
- Extending the proposed tentative duration of the workshop or its sections (e.g., to a full day or more if needed)
- Adding specific questions or items that are nationally interesting but not listed in the current script. In such cases, the instruction was that if possible, the additional findings would still be reported in a lighter format to the general ecosystem evaluation
- Proposing issues to be collected also in the other Nordic workshops
- Having some freedom to schedule the 1st set of workshops as most convenient

Regardless of this flexibility, however, apart from the timing no major adjustments were made and the original script was utilised — as well as the reporting template and content provided beforehand. Some minor adjustments were made, including the following:

- Due to the general timeline, the Swedish and Norwegian workshops were not able to comment on and propose new questions or modifications to the draft survey of the user acceptance study. (There was a commenting round in Sweden and Norway also; it just did not involve the pilot companies so directly.)
- In Sweden, separate workshops were arranged for all pilots instead of a single collective one. Therefore, the individual workshops were also slightly shorter. Altogether six workshops were planned, the topics being:
  - Emergency Vehicle Approaching
  - Connected Traffic Signals
  - Dynamic access control for designated infrastructure
  - Dynamic environmental zones
  - Road Works Warnings
  - Data sharing at national level
- In Norway, 15 services were piloted. Some were grouped together (as for the ecosystem that runs the services). Four services were selected, and the experience was used for the other services. According to the Norwegian plan, the ecosystem evaluation summary was sent out to the partners with a brief "Norwegian" guideline, and the initial discussions were based on this partner per partner, supplemented with a common Skype meeting with the partners.

These adjustments were duly discussed with the ecosystem evaluation group and in the NordicWay 2 Evaluation Group. The proposed adjustments were approved, since they did not have an impact on the overarching ecosystem evaluation goals, nor on the overall timeline, budget, results or final reporting of the ecosystem evaluation entity.

3.4.5 Final workshops

As explained above, the focus of the initial workshop series was on the present state and scaling up of the ecosystem. With regard to the following steps and the second set of workshops, the focus was especially on innovative marketing strategies and other aspects, measures or requirements that could or should be implemented to achieve growth and scale-up of services, both in the short term and beyond.

The detailed focus, content and timeline for the remainder of the evaluation, including the secondary set of workshops, was designed during Q1/2020. The pandemic breakout imposed some challenges on the evaluation during spring 2020 due to e.g., meeting and travel restrictions. However, the data was able to be collected (i) in a virtual workshop on the Finnish ecosystems, (ii) in several physical workshops on the Swedish ecosystems pre-pandemic, and additionally (iii) as written input from the Norwegian ecosystems.

3.5 User acceptance

User acceptance was one of the focal areas of the NordicWay 2 evaluation. All NordicWay 2 countries participated in the user acceptance evaluation work. The main responsibility for the content and coordination of the work, analysis of data and reporting of results was carried out by Finland.

The user acceptance of C-ITS services was evaluated via a common survey. The survey was designed for the general public, targeting 1 000 driver's licence holders per country. It was carried out independently in each country by a market research company in March-April 2020. Analysis and reporting were thereafter done centrally for the data, including the responses of over 4 000 drivers in all who responded to the survey in Finland, Denmark, Norway and Sweden. The main results were analysed for both 'all countries' and each country separately. Statistical analysis per background variable (age, gender, driving experience and technology adoption) were made for the entire data (all NordicWay 2 countries together), not for each individual country.

The common questionnaire used in the survey is in Annex 3 of this report. The NordicWay 2 Evaluation Group designed the survey questionnaire as a joint effort and translated it into the national languages. Driver sample selection and data collection were handled by a market research company in each country and the data was saved in a common data format, either SPSS or Excel, to enable common data analysis.

The questions addressed the relevance and acceptance of the services and willingness to use. The questions were the same for all the countries, enabling pooling of data and comparison of country-specific results. Specifically, the questions addressed:

- Awareness of the C-ITS services
- Importance of various information contents provided by C-ITS services, separately for trips on motorways or main roads and on urban streets
- Perception of the stated benefits and potentially negative effects
- Willingness to share data with the service provider or act as source of warnings
- Trips for which the respondent would use C-ITS services
- Importance of having the C-ITS service also abroad
- Background questions related to gender, age, driving, vehicle and technology adoption

Service definitions were made for the survey together with the NordicWay 2 Interoperability and Technical Coordination Group (Activity 2).

Willingness to use is an important input for the socioeconomic assessment, as use of service strongly affects the benefits that can be achieved with the service.

3.6 Driver behaviour

In NordicWay 2, driver behaviour evaluation was made only at national level for single implementations (i.e. service level). The studies here were not coordinated by the NordicWay 2 Evaluation Group.

3.6.1 Emergency vehicle approaching

[*This chapter provides a short summary of a Swedish simulator study on user reactions to EVA messages. Details are reported in Lidestam et al. (2020)*]

The study was designed to test the effect of EVA messaging on drivers' propensity do give way to an ambulance on an emergency call. In total 22 car drivers with valid driving licences for a private car (category B in Sweden) participated. They were aged 19–57 years, M = 29.3 years, SD = 12.3 years, 13 males and nine females, and had had their driving licences for 1–38 years, M = 10.1 years, SD = 12.3 years.

There were three experimental conditions of EVA Message: baseline with no EVA message (EVA 0), EVA message on the instrument cluster alone (EVA 1), and EVA message on the instrument cluster and on the infotainment display in the centre console (EVA 2). The design was 3 × 2 × 2 (EVA Message × Interface Order × Baseline Order) split-plot factorial, with EVA Message and Interface Order within groups, and Baseline Order between groups. EVA Message refers to the three experimental conditions (i.e., EVA 0, EVA 1, and EVA 2, respectively). In Interface Order 1, EVA 1 was presented first, whereas in Interface Order 2, EVA 2 was presented first. Baseline Order 1 had the EVA 0 baseline condition first and then either EVA 1 or EVA 2, whereas Baseline Order 2 had either EVA 1 or EVA 2 first and finished with EVA 0.

A proprietary small car simulator without motion cueing was used (Figure 2). The EVA message was presented as a yellow triangle with a blue warning light and a text message stating "*Emergency vehicle approaching! Pay attention!*" As the ambulance closed in, further instructions were displayed regarding yielding and slowing down. In EVA 2, the EVA message was additionally presented on the infotainment display in the centre console. See Figure 3 for the two versions of the EVA message. The EVA message was received 50 seconds before the ambulance was estimated to catch up with the participant's car, based on the relative speed difference.

Figure 2. Simulator used in the study

Figure 3. Two versions of EVA messages

The test scenario took about 30 minutes to complete and was about 20 km long. An ambulance on an emergency call, with blue lights and sirens engaged, caught up with and passed the participant's car three times during the session (at about 3 km, 6 km, and 11.5 km from the start of the scenario). The scenario ended after the participant was passed by the ambulance for the third time, at about 20 km.

3.6.2 Reindeer warning

[*This chapter provides a short summary of a Finnish survey study on the self-assessed driving behaviour effects of a reindeer warning system. Details are reported in Kotituomi et al. (2019).*]

Over the last decade there have been from 3 300 to 4 500 collisions with reindeer each year in Finland. They cause direct costs of repairs to vehicles damaged in a collision, but also additional problems for reindeer owners and they result in losses for transport companies for the time the vehicles cannot be used on the roads.

Preventing reindeer collisions has proved to be challenging. During 2013–2015, a reindeer alert service that combined location data and mobile phone technology was trialled for the first time. The professional drivers who took part in the experiment exchanged alerts using smartphones permanently mounted in their vehicles. In 2016, the service was expanded and given the name Porokello.

Initially, 1 000 phones were given to professional drivers who could give and receive alerts. In 2017, alerts could be sent to other road users in reindeer husbandry areas using the Porokello application. In

2018, the service was expanded with the addition of the Varottaja (Warner) application, which enabled people to send alerts using their own phone when on leisure trips.

A study on the Porokello application looked at its impact on traffic safety. In the same study, the effects on driving behaviour were assessed based on a survey. Those results are summarised in this report.

Internet surveys were prepared for persons issuing warnings and Porokello app users. Responses were received from 55 persons giving warnings. The number of persons actively issuing warnings on a daily basis was around 350. At the time of the study, 710 phones with the Porokello Pro app were in use and one phone might have been used by several persons to give warnings. The number of persons using the Varottaja app to give warnings was around 600.

The Internet survey was used to study (among other things) impacts on driving behaviour based on the drivers' subjective assessment. The survey also charted the advantages and disadvantages of the service, as well as ideas for developing it. The surveys contained about 50 questions. The survey questions on driving behaviour are in Annex 4.

3.7 Socio-economy

3.7.1 Overall approach

The assessment of socio-economic impacts was done as a joint effort by the NordicWay 2 Evaluation Group. The impacts were assessed for the Nordic Countries participating in the pilot deployments of the project. The assessment was carried country by country, and also for all four countries. Finland was responsible for the analyses and reporting, while every country was responsible for collecting the data needed for their respective country.

The assessment covered all services piloted in the NordicWay 2 project by at least one partner. As the pilot deployments did not generally fully represent the final deployment in terms of networks covered, user segments, HMI nor other service details, the analysis was carried out for hypothetical expected end-user services of the service type in question. This enabled the utilisation of results of other studies and pilot deployments of the same service types elsewhere.

The socioeconomic impact assessment included the impact areas seen as relevant from the point of view of the piloted services. The areas to be considered include mobility (travel behaviour), safety (accidents), traffic efficiency (travel time) and environment (emissions) (Innamaa et al. 2018). The socio-economic impact assessment done for Finland as part of NordicWay (1) (Innamaa et al. 2017) was used as a basis.

Each country will provide the basic data for their road networks, containing the following data for their networks in 2020 and 2030:

Length (km)

- Vehicle kilometres driven (million/year)
- Share of heavy vehicles (%)
- Average speed (km/h)
- Vehicle hours driven (million/year)
- Vehicle hours spent in congestion (million/year)
- Fatal accidents (number/year)
- Non-fatal injury accidents (number/year)
- Property damage-only accidents (number/year)
- CO_2 emissions (million tonnes/year)

The impacts were assessed for each service utilising the indicators above in determining the magnitude of the total effects in each network. The number of networks varied country by country. The impacts were scaled up to the national level according to the expected level of deployment in 2030 in each network service by service.

As the services were linked together, and largely utilised the same digital infrastructures, the socioeconomic assessment was carried out separately for each country by combining the whole service portfolio in the country in question and in the Nordic countries as a whole by:

- Selecting the cost elements related to the service provision and assessing the magnitude of costs

- Estimating the socioeconomic feasibility for the services in the Nordic countries selected for the assessment

The unit costs for travel time, emissions and road accidents may well change dramatically in the period of calculation, i.e., from 2020 to 2030, due to highly automated driving (de Looff et al. 2018), Vision Zero (EC 2016), and climate change mitigation policies. As these changes are very difficult to predict, the latest available unit costs were to be used in the assessments.

The expected levels of deployment were estimated by the NordicWay 2 Evaluation Group in terms of network coverage (length of network covered by the service), event coverage (percentage of events/incidents/etc. warned or informed about coverage by the service), vehicle penetration rate (percentage of vehicles in traffic flow equipped with the C-ITS communication device), and the use of services. These estimates can be found in Annex 5.

3.7.2 Mobility impacts

As with all impacts, mobility impacts were first assessed for the hypothetical case of full road network coverage and vehicle fleet penetration, and for each individual service separately. The impacts of a service were determined based on existing literature and expert assessment of the impacts on the NordicWay 2 network. After this, the impacts were scaled up to reflect the estimated coverage, penetration and use of the services in 2020 and 2030, and finally combined with the impacts of other services provided in the same service bundle to estimate the total effect.

The mobility impacts focused on the effects on the following indicators:

- Number of journeys
- Timing of journeys
- Choice of travel mode
- Route choice

3.7.3 Safety impacts

Based on earlier socioeconomic assessments (e.g., EC 2016, Kulmala et al. 2012), safety impacts form a key part in the socioeconomic assessment both directly in terms of fatalities, injuries and property damages reduced, but also indirectly by decreasing accident-related congestion resulting in savings in travel time and emissions.

The safety assessment was carried out according to the methodology described by Kulmala (2010). The assessment begins by selecting the relevant safety mechanisms of the service from the following list (originally from Draskoczy et al. 1998):

(1) Direct in-vehicle modification of the driving task

(2) Direct influence by roadside systems

(3) Indirect modification of user behaviour

(4) Indirect modification of non-user behaviour

(5) Modification of interaction between users and non-users

(6) Modification of exposure

(7) Modification of modal choice

(8) Modification of route choice

(9) Modification of accident consequences only

Table 8 shows the safety mechanisms relevant for each service. The safety assessment investigated first the direct, then indirect, effects of the NordicWay 2 C-ITS services selected. The rationale for the selection is explained by the program theory diagrams developed for each service included as Annex 6.

Table 8. Safety mechanisms deemed relevant for the C-ITS services assessed, The main safety mechanism for each service is marked as X and the other safety mechanisms considered in the assessment as x, **EBL = Emergency brake light, EVA = Emergency vehicle approaching, IVSL = In-vehicle speed limit, RWW = Road works warning, RLC = Road or lane closure, SV/IS = Signal violation / intersection safety, TTG = Time to green, GLOSA = Green light optimal speed advisory, TI = Traffic information, AWWD = Alert wrong-way driver**

SAFETY IMPACT MECHANISMS	SLOW VEHICLE	WEA-THER	EBL	EVA	OTHER HAZARD	IVSL	RWW-RLC	RWW-MOBILE
M1. Direct in-vehicle modification of the driving task	**X**	**X**	**X**	**X**	**X**	x	x	**X**
M2. Direct influence by roadside systems		x				**X**	**X**	
M3. Indirect modification of user behaviour	x	x	x	x	x	x	x	x
M4. Indirect modification of non-user behaviour	x	x	x	x	x	x	x	x
M5. Modification of interaction between road users	x	x		x	x	x	x	x
M6. Modification of exposure								
M7. Modification of modal choice		x						
M8. Modification of route choice		x						
M9. Modification of accident consequences only				x				

SAFETY IMPACT MECHANISMS	SV/IS	PRIOR-ITY REQ.	TTG	GLOSA	FUEL& CHARG-ING	ON-STREET PARKING	TI & ROUT.	AWWD
M1. Direct in-vehicle modification of the driving task	**X**	**X**	x	x	x	**X**	x	**X**
M2. Direct influence by roadside systems	x	x	**X**	**X**				
M3. Indirect modification of user behaviour	x	x	x	x				x
M4. Indirect modification of non-user behaviour	x	x	x	x				x
M5. Modification of interaction between road users	x	x	x	x			x	x
M6. Modification of exposure					x	x	x	
M7. Modification of modal choice		**X**			**X**	x	x	
M8. Modification of route choice					x	x	**X**	
M9. Modification of accident consequences only		x						

Concerning the direct impacts (mechanisms M1 and M2), it was necessary to determine the accident types affected by the direct effects. The results of this are shown in Table 9. After this, the target accidents affected by each selected mechanism were determined. For this purpose, the following accident type distribution was used for both normal and adverse weather conditions:

- Collision on the road with pedestrian
- Collision on the road with all other obstacles
- Collision not on the road with pedestrian or obstacle or other single vehicle accidents
- Frontal collision
- Side-by-side collision
- Angle collision

- Rear-end collision
- Other accidents with two vehicles
- Other accidents

The choice and percentual shares of target accidents are described in detail in Annex 7. These apply to all NordicWay2 countries, although the accident distributions mentioned above were requested from each country.

Table 9. Accident types affected by the C-ITS services assessed, marked in grey

ACCIDENT TYPE	SLOW VEHICLE	WEATHER	EBL	EVA	OTHER HAZARD	IVSL	RWW-RLC	RWW-MOBILE
Collision on the road with pedestrian		Accidents in adverse weather conditions					Accidents at fixed road works	Accidents at mobile road works
Collision on the road with all other obstacles								
Collision not on the road with pedestrian or obstacle or other single vehicle accidents								
Frontal collision								
Side-by-side collision								
Angle collision								
Rear collision								
Other accidents with two vehicles								
Other								

ACCIDENT TYPE	SV/IS	PRIORITY REQ.	TTG	GLOSA	FUEL& CHARGING	ON-STREET PARKING	TI & ROUTING	AWWD
Collision on the road with pedestrian						Accidents involving vehicle looking for parking place		
Collision on the road with all other obstacles								
Collision not on the road with pedestrian or obstacle or other single vehicle accidents								
Frontal collision								
Side-by-side collision								
Angle collision								
Rear collision								
Other accidents with two vehicles								
Other								

In order to estimate the direct safety effects, we needed to determine the effectiveness of the services with regard to the target accidents. The effectiveness of a service was expressed as the percentage (%) of prevented target accidents due to the driver being informed/warned by the C-ITS service. It can also be regarded as the proportion of target accidents that would have occurred if the driver had not received the C-ITS warning/information.

Actual empirical evidence was only found for the in-vehicle speed limits, which according to Elvik & Høye (2015) reduce injury crashes by 3–5%. Other effectiveness figures were based on the earlier NordicWay (1) evaluation report (Innamaa et al. 2017) and NordicWay 2 Evaluation Group expert assessment based on knowledge about the impacts of similar, non-C-ITS services.

The effectiveness of the service also depends on whether the service user had previously used a similar non-C-ITS service or no service at all. The effectiveness of services is likely much lower for the people who already use a similar C-ITS service. The estimation of the effectiveness of different services is described in detail in Annex 7.

With the estimates provided above it was possible to calculate the direct safety effects of the services if all networks, vehicles and events were covered by the service and all were using the services, i.e., a 100% use situation. This was done independently for each service and each network by multiplying the following figures:

- Overall effectiveness of the service with regard to target accidents
- Proportion of target accidents out of the relevant accident type
- Percentage of relevant accident type out of all road accidents

3.7.4 Efficiency impacts

C-ITS services likely affect the reliability of travel times, which is a key objective especially for goods transport. So far, the available data does not allow the use of travel time reliability as an indicator in a socioeconomic assessment. Hence, the assessment focused on the impact on average travel times. The travel times can be affected via the following mechanisms:

- Traffic flow is harmonised through speed advice locally, improving the throughput of a road section or intersection
- Warnings of problems ahead prepare drivers to slow down, reducing the emergence of shock waves which would cause congestion
- Traffic is diverted from roads suffering an event or incident to an alternative route
- Traffic is distributed smartly on the road network to maximise the throughput of the network
- Safety improvement due to the service is reducing accident-related congestion

In the impact assessment, the travel time impacts needed to be estimated for the whole transport system as, for instance, at signalised intersections reductions in travel time on one street can be associated with an increase on the crossing street, and rerouting to an alternative route can be longer than the originally chosen route and result in increased travel time.

3.7.5 Environmental impacts

The environmental impact assessment will focus on CO_2 emissions, which are closely linked to the fuel consumption of the vehicles, which are in turn related to changes in amount of travel (vehicle kilometres driven), as well as changes in speed level and congestion. Hence, the main inputs to the environmental assessment come from the mobility and efficiency impacts.

The fuel efficiency of vehicles will likely improve during the period 2020–2040. Electrification of vehicle fleets will also affect the CO_2 emissions from an average vehicle. Therefore, the assessment will take these trends into account.

3.7.6 Scaling up

In order to assess the socio-economic feasibility of the C-ITS service deployment and operation, the effects above need to be scaled up to the road networks in each country. All countries provided information of their main road networks, including the Trans-European Road Network, but some had disaggregated the data into various sub-networks. Denmark provided information for one, Finland for six, Norway for three, and Sweden for four networks.

The effects were scaled up by multiplying the effects estimated for full coverage and use with the following factors:

- Network coverage – share of network covered by C-ITS service provision
- Event coverage – share of “events” covered by the C-ITS service
- Vehicle flow penetration – share of vehicles on the network with C-ITS communications
- Use of service during travel – share of drivers using the service

The values used in scaling up the results for the different networks are presented in Annex 5.

3.8 Feasibility

Assessment of the feasibility of the C-ITS service provision in the Nordic countries was carried out as a joint effort of the NordicWay 2 Evaluation Group. The conclusions on feasibility were based on all the evaluation results obtained from the assessments described above, including discussion on the pros and cons for feasibility of C-ITS service provision in the Nordic countries. Specifically, the feasibility was assessed based on answers to the following questions:

- Is it technically feasible to set up C-ITS services for the Nordic countries? (i.e., Is the quality of C-ITS services sufficient?)
- Do users accept the services and are they willing to use and pay for them? Are users willing to share information with the C-ITS service providers?
- Can we find feasible business models and ecosystems to provide the services?
- Can we expect socioeconomic benefits from the services?

More specifically, the feasibility of C-ITS service provision addressed the following questions shown in Table 10:

Table 10. Research questions for feasibility assessment

EVALUATION AREA	HIGH LEVEL RESEARCH QUESTION	DETAILED RESEARCH QUESTION
Technical	Is it technically feasible to set up C-ITS services for the Nordic countries? (i.e., Is the quality of C-ITS services sufficient?)	Can data be shared across organisations?
		Can C-ITS services achieve interoperability between different countries?
		Are latencies low enough for successful implementation of C-ITS services?
		Is the architecture with the federated network of interchange nodes a feasible solution?
User acceptance	Do users accept the services and are they willing to use and pay for them? Are users willing to share information with the C-ITS service providers?	Do people know C-ITS services?
		Are users willing to use C-ITS services?
		Are users willing to pay for C-ITS services?
		Are users willing to share information with the C-ITS service providers?
Business model and ecosystem	Can we find feasible business models and ecosystems to provide the services?	Can we find feasible business models for service provision?
		Can we find feasible ecosystems for service provision?
Socio-economics	Can we expect socioeconomic benefits from the services?	Can we expect mobility benefits from the services?
		Can we expect safety benefits from the services?
		Can we expect efficiency benefits from the services?
		Can we expect environmental benefits from the services?
		Do socioeconomic benefits outweigh the costs?

4 Evaluation results

4.1 Quality of service

4.1.1 Results in Finland

The functionality of the services, which was studied in the Finnish technical evaluation, was verified and found to operate as expected. The data sharing between three nodes was successfully verified. The following subchapters provide the results of the KPI measurements and discussion of the findings.

The measurement session was affected by the Covid-19 pandemic, which certainly limited the traffic volume during the pilot period in spring 2020. Therefore, the use of traffic-related mobile application, traffic disturbances and events was also limited in Finland during this period.

4.1.1.1 Coverage of service KPIs

Coverage of the service KPIs was collected from the Service Providers. The results are summarised in Table 11.

Physical coverage – KPI_Q01

The services piloted in Finland were based on the cellular networks. Therefore, the physical coverage of almost all services reached the entire road network in Finland. However, one service provider collected (weather) data only from ring roads and major incoming roads in the Helsinki region and from the E18 between Helsinki and Turku.

Number of vehicles equipped (new mobile applications) – KPI_Q02a

In Finland, the vehicles were not equipped with in-vehicle devices, but ‘fully functional C-ITS’ mobile applications were used, which were able to send out and receive messages. New installations of mobile applications during the pilot (January–May 2020) in Finland varied between 40 and 662 installations depending on the application. The total number was around 860 mobile application installations.

Number of vehicles equipped (partially functional C-ITS in-vehicle device) – KPI_Q02b

Some vehicle equipment was used to collect data only. The number of vehicles fitted with ‘partially functional C-ITS’ to collect data during the pilot (January–May 2020) in Finland varied across the service providers from 20 to 60 in-vehicle devices, mostly in trucks. The total number of new in-vehicle device installations was 120. In addition, around 800 buses provided data at the end of the pilot in the Helsinki Region.

In addition, some mobile applications were only used to show warnings. An Android mobile app, ‘Telkkä’, already had 3900 installs before the NordicWay 2 pilot. In addition, the ‘Liikennetilanne’ app from Traffic Management Finland had over 10 000 installs before the NordicWay 2 pilot. It provided warnings, including the road works detected by Vaisala.

Number of C-ITS service vehicles or users – KPI_Q04

The number of active C-ITS users was estimated by the service providers. In the case of mobile applications, the number of active users was available from e.g., Google Play Console or Firebase. For example, Firebase defines an active user as follows: “An active user has engaged with an app in the device foreground”. The number of active users of [fully functional C-ITS; ref KPI_Q02] mobile applications during the pilot in Finland varied between applications. The number of active users were between 30 and 300 users per month, the total number around 465 mobile users per month (reported in May 2020). The total number of limited mobile application (Telkkä & Liikennetilanne) users was unknown.

If we sum up the total number of active mobile users (per month) and the number of new in-vehicle device installations together, we could estimate the total number of active test users/vehicles (both in-vehicle information providers and fully functional mobile apps). The total number of test users was close to 600 participants per month. This number does not include limited mobile applications and the Helsinki buses.

Table 11. Summary of results on the coverage of service KPIs.

QUALITY KPI	KPI	DESCRIPTION	UNIT	RESULTS
KPI_Q01	Physical coverage	Change in length of the network covered by C-ITS services	-	All roads in Finland
KPI_Q02a	Number of vehicles equipped	Change in number of vehicles equipped with fully functional C-ITS new mobile applications	Number	860 – number of new mobile installations (during Jan–May 2020)
KPI_Q02b	Number of vehicles equipped (partially functional C-ITS in-vehicle-device)	Change in number of vehicles equipped with partially functional (only receiving or sending messages) C-ITS in-vehicle device	Number	120 new in-vehicle devices (during Jan–May 2020)
KPI_Q04	Number of C-ITS service vehicles or users	Change in number of vehicles receiving C-ITS service(s), e.g., number of users per day	Number	465 – number of active mobile users (per month)

4.1.1.2 Service performance KPIs

The service performance was analysed from the data logs from the node servers, as well as in the controlled tests. For Infotripla and EEE nodes, the clocks of the servers could be synchronised with NTP and obtaining accurate timestamps for message transmission and reception was possible. Therefore, only messages sent and received by Infotripla and EEE were included in the analysis.

Number of C-ITS messages distributed per service and node – KPI_Q03a

The number of messages distributed per service and node was calculated from the node server logs during the data collection period (all messages during 28 April–31 May 2020). The number of C-ITS messages sent by EEE and Infotripla nodes is presented in Table 12. The largest number of messages sent was related to weather conditions. In total, 362 526 such messages were sent from EEE to Infotripla. The most common message type sent from Infotripla to EEE was related to abnormal traffic, with 2 766 messages.

Table 12. Number of C-ITS messages distributed per service and node (KPI_Q03a).

MESSAGE TYPE	MESSAGES SENT [N]	
	FROM EEE TO INFOTRIPLA	FROM INFOTRIPLA TO EEE
WeatherRelatedRoadConditions	362 526	-
PoorEnvironmentConditions	4	30
GeneralObstruction	34	36
AbnormalTraffic	95	2 766
VehicleObstruction	7	114
SpeedManagement	20	-
NonWeatherRelatedRoadConditions	-	121
MaintenanceWorks	-	1
Total	362 686	3 068

Location accuracy – KPI_Q07

Location accuracy was inspected in controlled tests. The positioning of mobile applications was based on the Global Navigation Satellite System (GNSS) of the mobile phone. The logfile received from the Vaisala server was imported to the QGIS application and plotted on a map. The results are presented in Figures 4 and 5 superimposed on OpenStreetMap and Digiroad layers (purple mesh). All points (N=20) inspected manually and those matched to the road network were within 9 metres of lateral difference compared to the Digiroad road data. The maximum longitudinal difference was 55 metres.

Figure 4. Location accuracy observations on the northern part of the test route in the Tampere area.

Figure 5. Location accuracy observations on the southern part of the test route in the Tampere area.

In the worst case, a location error can lead to dislocation of an event to the wrong road if there are two roads close to each other. Figure 6 presents detailed analysis of two pairs of sent (brown) and received (black) messages during the controlled test. The coordinates of the sent message were noted from the recorded video, and the received ones from the Vaisala logfile. Brown shows the location where the test vehicle was when the message was sent. After receiving the mobile reported coordinates, the backend system performs map matching, and therefore in some cases the location could be on a different road segment (in this case, Kannistonpolku vs. Kannistontie). However, the exact reported location of the sending mobile phone was unknown. The location error of the mobile phone (GPS) could be tens of meters in the worst case, especially since during the controlled tests the mobile phones were on the back seat of the car and the metal roof of the car blocked some of the GPS signals. This kind of error occurred only once during the controlled test, and it is not known if it was a positioning or a map matching feature or an error in the mobile phone location. The distance between the points in this case was 22.4 metres.

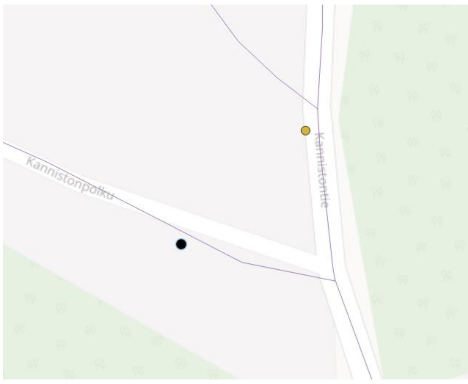


Figure 6. Map matching on Kannistontie.

Latency (end-to-end) – KPI_Q08

The end-to-end latency was measured between three mobile devices in the controlled field tests. The analysis of the annotated video recordings showed quite a large variation of the end-to-end latencies. Latency measurements for the interchange loop from Louhi to the ForeC application (median 6.2 sec; N=21) and the other way round from ForeC to the Louhi application (median 5.3 sec; N=25) were much larger than for the node loop from ForeC to another ForeC application (median 1.2 sec; N=25). This difference does not represent the delay or latencies of the federated interchange system (median delay between interchange nodes in the controlled tests was around 0.3 sec, see Figure 7). The reason can be explained by the different implementations of the mobile applications and the node and other backend systems. The Louhi application sent the message to the Infotripla node, where some delay occurred before the message was transmitted to the federated interchange system. Infotripla polled data from some subsystems instead of receiving data asynchronously. Additionally, Infotripla performed integration and validation for incoming subsystem events before they were approved as valid publishable events. These actions included:

- Validating the event location and mapping the event to the road network
- Checking if there was/were already similar active event(s) in system, and possibly combining these similar events with the latest event by calculating the new event location and new duration for the event

NOTE! The service implementations in this Finnish NordicWay 2 pilot were not optimised for minimising end-to-end latency. Service providers' applications used in the testing were integrated to the NordicWay 2 federated interchange network as a part of the pilot in Finland. Optimising the message transfer implementations could provide an increase in service performance.

The controlled field test included measurements done in the stationary vehicle and during the driving tests. The results from both tests were similar, as the commercial cellular network coverage was good or very good in the testing area. The end-to-end latencies were measured from Louhi to the ForeC application (median 6.2 sec, N=21) in stationary vehicle tests and from Louhi to the ForeC application (median 4.2 sec, N=20) in driving tests. Figure 7 shows the division of median latencies calculated from the controlled tests. It can be seen that the median latency between interchange nodes (0.3 sec) was quite small.

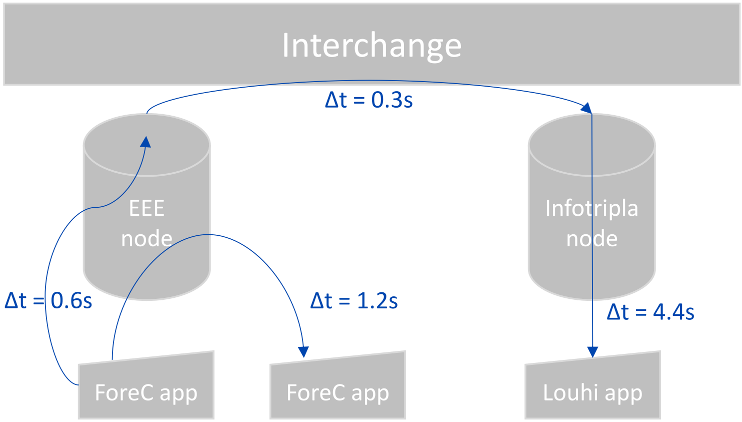


Figure 7. Division of median latencies in the controlled tests in node and interchange loops.

Latency (Interchange; node-to-node) – KPI_Q08b

The interchange latency between the Finnish nodes was calculated from the node server logs during the data collection period. The latency was measured between two service providers (Infotripla and EEE), which had their server clocks synchronised. Key figures for the latency between interchange nodes (from EEE to Infotripla and Infotripla to EEE) are presented in Table 13.

Table 13. Latency (Interchange; node-to-node) – KPI_Q08b, in terms of characteristics of latency (interchange, node to node), for messages sent during the observation period (09:00 28 April 2020 – 23:50 31 May 2020)

	Transmitting node	
Receiving node	**EEE**	**Infotripla**
EEE		N = 2741 mean: 9635 ms median: 219 ms std. deviation: 290975.67 ms 95th percentile point: 1128 ms
Infotripla	N = 358126 mean: 269 ms median: 85 ms std. deviation: 7734.07 ms 95th percentile point: 124 ms	

Message success rate – KPI_Q10

The message success rate was calculated from the node server logs during the data collection period. The numbers of transmitted and received messages are summarised in Tables 14 and 15. In total, 365 754 messages with unique message ID were sent from Infotripla to EEE or EEE to Infotripla. Of these messages, 364 576 were successfully received, which implies a message success rate of 99.68% when calculated over both combinations of sender and recipient.

Table 14. Message success rate, messages from EEE to Infotripla (KPI_Q10) in terms of sent and received messages by message type, from EEE to Infotripla, during 28 April 2020 – 31 May 2020

Message type	Messages sent [N]	Messages received [N]	Success rate [%]
WeatherRelatedRoadConditions	362 526	361 596	99.74
PoorEnvironmentConditions	4	4	100.00
GeneralObstruction	34	34	100.00
AbnormalTraffic	95	91	95.79
VehicleObstruction	7	7	100.00
SpeedManagement	20	20	100.00
Total	362 686	361 762	99.75

Table 15. Message success rate, messages from Infotripla to EEE (KPI_Q10) in terms of sent and received messages by message type, from Infotripla to EEE, during 28 April 2020 – 31 May 2020

Message type	Messages sent [N]	Messages received [N]	Success rate [%]
AbnormalTraffic	2 766	2 555	92.37
GeneralObstruction	36	22	61.11
VehicleObstruction	114	107	93.86
NonWeatherRelatedRoadConditions	121	103	85.12
PoorEnvironmentConditions	30	26	86.67
MaintenanceWorks	1	1	100.00
Total	3 068	2 814	91.72

The results indicate that not all C-ITS messages sent during the trial were successfully received. No detailed investigation was carried out to identify the causes of unsuccessful transmissions. Analysing and reproducing the failed message transmissions would have required additional tests and probably also collaboration with the owners of the communicating nodes. However, at least two potential causes of unsuccessful message transmissions can be identified. First, DATEX II messages are typically validated by the recipient. If the message does not pass this validation, it may be recorded as successfully transmitted but not received. Second, it is also possible that some messages have in fact been received at the destination node but not received as such. This is possible if the receiving node starts receiving messages before data logging is started or if the software generating the log file fails.

Table 16 summarises the service performance KPI results presented above.

Table 16. Summary of the results of the service performance KPIs

Quality KPI	KPI	Description	Unit	Results	Comment
KPI_Q03a	Number of C-ITS messages distributed per service and node	Number of C-ITS messages distributed per service and node	Number	Median: EEE → Infotripla: 362686 Infotripla → EEE: 3068	Messages logged during 28 Apr – 31 May 2020 Number of messages per message type, see Table 12
KPI_Q07	Location accuracy	Relative precision of the referenced location for the published event at any node with respect to the actual location of the actual event		Lateral difference < 9 m Longitudinal diff. < 55 m	N=20 This result corresponds to quality level *** (Advanced) defined in the EU EIP quality package (Kulmala et al. 2019) for RTTI (event information) and SRTI (except wrong-way driver).
KPI_Q08	Latency (end-to-end)	Send/receive latency – time from timestamp sent to timestamp received of message between two end-user devices	s	Median: Interchange loop: Louhi → ForeC 6.2 s ForeC → Louhi 5.3 s (Node loop: ForeC → ForeC 1.2 s)	N = 21 (from Louhi) N = 25 (from ForeC) (Service implementations were not optimised for minimising end-to-end latency)
KPI_Q08b	Latency (between federated interchange nodes)	Time difference between receive time and send time measured between two Interchange nodes	ms	Mean: Infotripla → EEE: 9635 ms EEE → Infotripla: 269 ms 95%: Infotripla → EEE: 1128 ms EEE → Infotripla: 124 ms Median: Infotripla → EEE: 219 ms EEE → Infotripla: 85 ms	N=2741 (from Infotripla) N=358126 (from EEE) (Service implementations were not optimised for minimising end-to-end latency)
KPI_Q10	Message success rate	Percentage of sent messages received (on node level)	%	Median: EEE → Infotripla: 99.75% Infotripla → EEE: 91.72% Combined: 99.68%	N=362686 (from EEE) N=3068 (from Infotripla)

4.1.1.3 Other KPIs

Other KPIs in Finland included only the cross-organisational/cross-brands data sharing (KPI_Q13, Table 17). The data sharing between all three nodes in Finland was verified from the data logs from the servers, as well as visually in the controlled field tests. In the controlled field test, the message was sent from one mobile application and successfully received by another under another node, and the message was also received by a third node, which was verified from the node map user interface.

Table 17. Summary of the results of other KPIs

Quality KPI	KPI	Description	Unit	Results
KPI_Q13	Cross-organisational/ cross-brands data sharing	Data sharing between organisation within a country or cross-border	Yes / No	Yes

4.1.1.4 Summary of Finnish results

In Finland, large numbers of messages were sent during the NordicWay 2 trial. Except for relatively small samples taken of all messages, the analysis required either the use of existing software packages or software tools developed for the purpose. The use of automated tools was more or less dependent on data sets conforming to agreed specifications, and the conformance of data sets might facilitate or hamper the analysis of the log files.

During the study, some challenges with conformance of data sets were encountered. For example, the message ID of an individual C-ITS message was expected to remain stable when the message was communicated between federated nodes. Two of the service providers followed this practice, while one of them appended additional characters to the message ID when the message was received and recorded to a log file. Therefore, special processing of the message ID field had to be implemented for one of the nodes.

The possibility to analyse message latencies was dependent on the possibility to synchronise the clocks of transmitting and receiving nodes to a time reference. This was successfully implemented and verified with two nodes. For this reason, message latency could be finally analysed only for messages exchanged between EEE and Infotripla.

The results for end-to-end latency and latency between federated interchange nodes were consistent with each other. According to the results of the controlled test, message latency between EEE and Infotripla nodes was about 0.3 s. This is about 200 ms more than the median (85 ms) value and quite close to the mean (269 ms) obtained by analysing the log files.

The results on message success rates indicate that at least some messages were transmitted but not successfully received. The results also showed that the message success rate was clearly better for messages transmitted from EEE to Infotripla (99.75%) than for messages from Infotripla to EEE (91.72%), although no statistical analysis was made. Some potential causes for unsuccessful message transmissions were identified such as messages transmitted but not successfully validated at the destination node and limitations in the implementation of the data logging. More detailed analysis of message success rate and unsuccessful messages was considered to be outside the scope of the study.

Finally, the cross-organisational data sharing in the NordicWay 2 Finnish pilot and the data sharing across the interchange system was confirmed with all three nodes. Messages were distributed and received by all consortiums and their end-users. The end-to-end latencies measured (median < 6.2 sec) in the controlled tests showed that the cellular (4G-LTE) implementation of the selected C-ITS services and the NordicWay 2 interchange system was able to provide fully functional services. However, the service implementations in this Finnish pilot were not optimised for minimising end-to-end latency.

4.1.2 Results in Norway

4.1.2.1 Coverage of service KPIs

Coverage of the service KPIs was collected from the service providers.

Physical coverage - KPI_Q01

The services piloted in Norway were based on hybrid communication, both cellular and short range. For cellular solutions the physical coverage is the whole road network, and there are also some back-office services that are accessible from websites and will be distributed mainly by cellular technology. For short range services the coverage will be of small areas (spots).

As we have some “cellular services” located on special road segments, this will not have relevance all over the country; thus it is not the default that cellular solutions cover the whole country. Table 18 shows an estimate of the coverage for all services and pilots.

Table 18. Physical coverage estimations for Norway.

C-ITS SERVICE	NETWORK COVERAGE PER PILOT
IMMEDIATE COLLISION RISK WARNINGS	
Slow or stationary vehicle(s) & traffic ahead warning	Skibotndalen=80km Jonsvatnet=45 km
Signal violation / intersection safety	Skjervøy
Cooperative collision risk warning	Petterø
INCREASED RISK WARNINGS	
Roadworks warning, mobile roads work	Skibotndalen=80km Jonsvatnet=45 km
Weather and road condition warning	Skibotndalen=80km
IMPROVING TRAFFIC FLOW	
Time to green	Skjervøy
Green light optimal speed advisory (GLOSA)	Skjervøy
Traffic information & smart routing	Skjervøy-Grense=140km Tromsø-Grense=150 km County of Troms
BEING INFORMED	
On-street parking information and management	Ranheim= Spot Børsa= Spot
Information on alternative fuel vehicle fuelling & charging stations	All of Norway
OTHER	
Collection of data mapping of infrastructure readiness for connected and automated driving	E8-E6=1850km

Number of vehicles equipped – KPI_Q02

In Norway, we had about 40 OBU (ITS-G5) to collect, send and receive messages. The testing was done at Patterø junction and at a test lab in Oslo, conducted by the company Aventi. The plan was also to test the ITS-G5 technology installed in a next generation Volkswagen Golf, but the technology is currently not operating in Norway due to special implementation from Volkswagen. The G5 technology testing at Patterø includes 40 OBU, four permanent RSU and two mobile RSU ITS stations from the company Aventi (Figure 8).

Figure 8. Aventi RSU (mobile ITS station).

Number of vehicles equipped with partially functional C-ITS in-vehicle-device - KPI_Q02b

Some vehicle equipment (cellular phones) was used to collect only data in the test vehicles. The number of vehicles fitted with 'partially functional C-ITS' to collect data during the pilot was limited to three or four. In addition, around 10 users had access to a mobile app from OneTraffic that collected messages from the Aventi back-office system.

Change in number of external data sources per service – KPI_Q03

Before NordicWay 2, any mobile service used only data from the DATEX II node, for which Vegvær (the Norwegian RWIS) and the traffic data counting system (point measurements) were the main data sources. With NordicWay 2, several external data sources have been established. This was demonstrated at the two main test sites on the E8 in the Skibotn Valley and the E6 at the Patterød junction. The new data sources are coupled to the instrumentation established at the test sites. The data includes:

- Travel time
- In-vehicle speed limits
- Speed (slow moving vehicles)
- Stopped vehicles

Table 19 summarises the results related to the coverage of services in Norway.

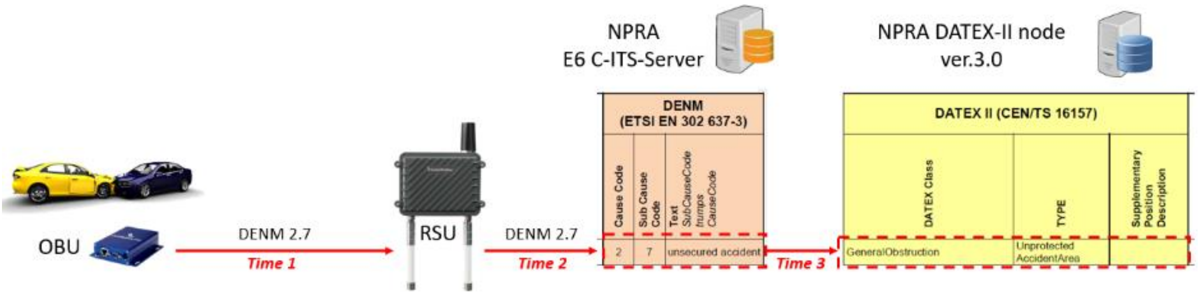
Table 19. Summary of results on the coverage of service KPIs in Norway.

Quality KPI	KPI	Description	Unit	Results	Comment
KPI_Q01	Physical coverage	Change in length of the network covered by C-ITS services	%	See Table 18	All roads for some services Local roads for some services Spots for some services
KPI_Q02	Number of vehicles equipped	Change in number of vehicles equipped with fully functional C-ITS in-vehicle device	Number	40 vehicles with OBU	Test vehicles
KPI_Q02b	Number of vehicles equipped with partially functional C-ITS in-vehicle device	Change in number of vehicles equipped with partially functional (only receiving or sending messages) C-ITS in-vehicle device	Number	10 vehicles with cellular applications	Test vehicles
KPI_Q03	Change in number of external data sources per service	Change in number of external data sources per service (via federated/interchange nodes) (comparing the situation before and after NW2)	Number	Different types of services with different numbers of external sources, varying from 1 to 4	

4.1.2.2 Service performance KPIs

Latency (end-to-end) – KPI_Q08

Aventi did a limited test (Aventi "interchange node": Send 1 message, receive 1 message) by manually generating a DENM message in the OBU and measuring the latency between the different nodes, designated time1, time2 and time3. However, the clocks of the OBU, RSU and C-ITS servers were not synchronised accurately.



Test #	DENM sent from OBU	DENM received by RSU	Time 1(ms)	Message received to CITS	Time 2(ms)	Successfully written to Datex Node	Time 3(ms)
1	1600842046699	1600842046704	5	1600842046758	54	1600842047293	535
2	1600843060908	1600843060918	10	1600843060973	55	1600843061546	573
3	1600843337358	1600843337361	3	1600843337435	74	1600843337910	475
4	1600843592745	1600843592750	5	1600843592807	57	1600843593388	581
5	1600844005569	1600844005573	4	1600844005623	50	1600844006164	541

Aventi

Figure 9. Aventi setup and test results for latency.

Cross-border continuity of services – KPI_Q12

A logging setup was established to verify the continuity of connection when crossing a border. There were still some issues, typically a loss of reception before re-establishing the connection. However, the same equipment may behave differently during a handover; two similar Samsung S9 phones were used in the test but behaved quite differently.

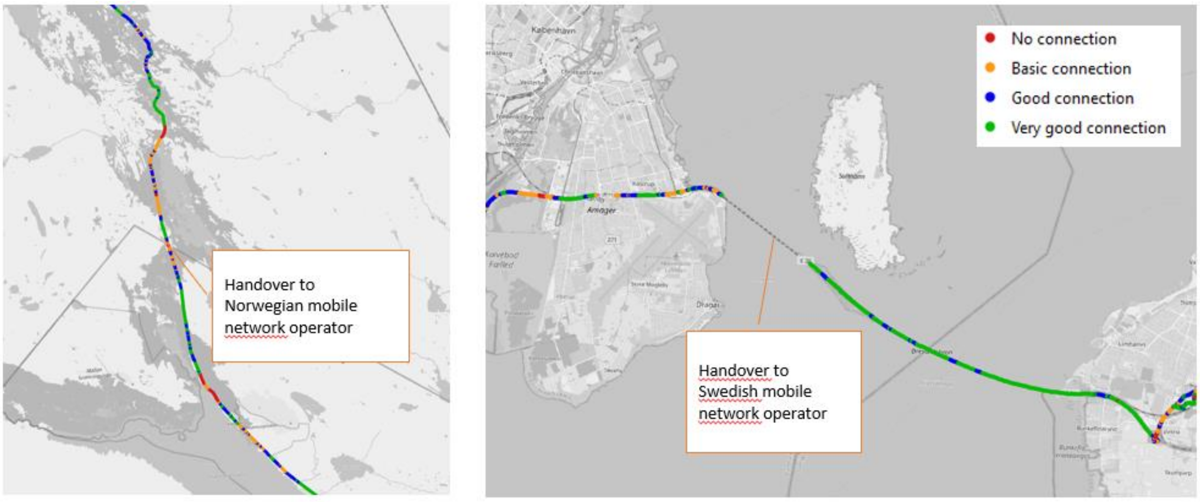


Figure 10. Quality of connection when border crossing

Cross-border testing of the services also included the interchange node testing. This important test was done in order to verify that the interchange received events and messages from all countries and service providers and that the service applications were able to consume these messages. Logging of messages and visual observations from a map view of a mobile application verified that the ecosystem was working well in all four countries. When driving along the Nordic Tour route, an application on the phone continuously presented messages from the interchange federation nodes, see Figure 11. This confirmed that the cross-border continuity of services worked.

Figure 11. Messages shown on map during Nordic Tour

From this test, it is quite clear that the interchange and delivery of messages works, but one needs to take great care when filtering the messages. There were some issues with road works; ghost road works appear in the digital world but there is no trace of them in real life. Conversely, there were missing road works which exist in the real world but do not appear in the digital world. These issues were encountered in all countries, for details see NordicWay 2 (2020a).

Cross-organisational/cross-brands data sharing – KPI_Q13

Figure 12 shows one example of the ecosystem in which different organisations (actors) were involved and represented different brands. The cross-organisational data sharing in the Norwegian pilot and the data sharing across the interchange system was confirmed. Messages were distributed and received by all actors and their end-users.

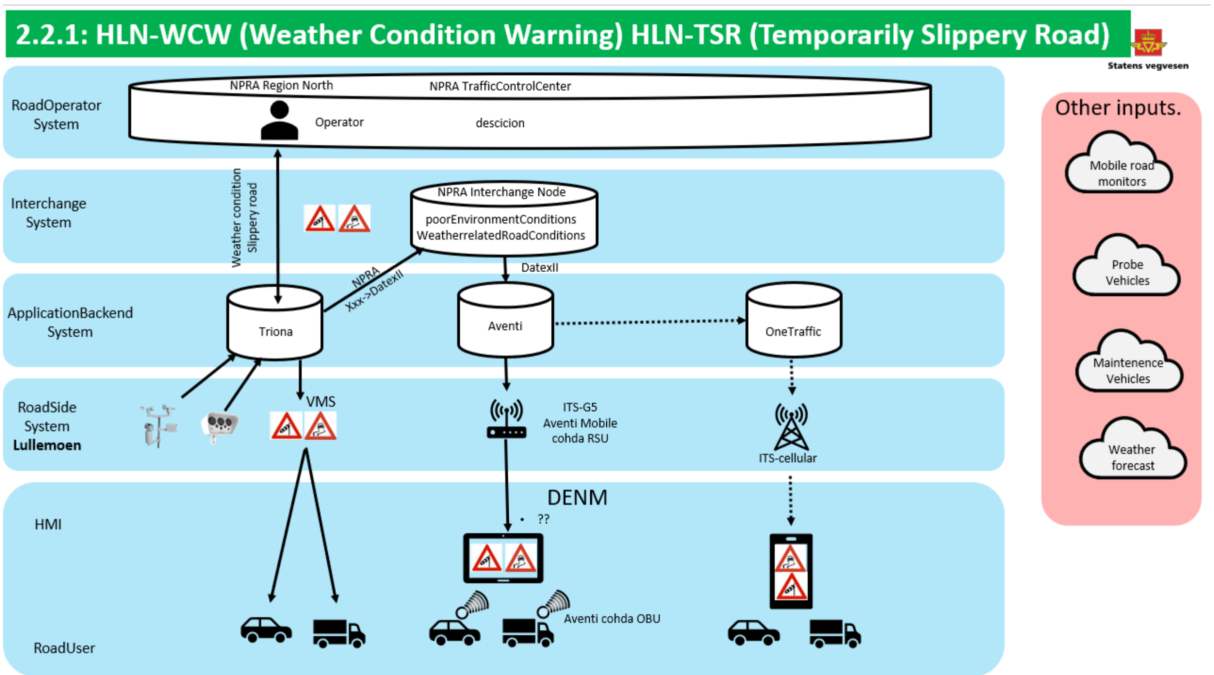


Figure 12. Example of a service ecosystem in Norway.

Table 20 summarises the results related to service performance.

Table 20. Summary of results of the service performance KPIs

QUALITY KPI	KPI	DESCRIPTION	UNIT	RESULTS	COMMENT
KPI_Q08	Latency (end-to-end)	Send/receive latency – time from timestamp sent to timestamp received of message	s	Median Aventi 0.6 s	N = 5 from OBU to Datex node Clocks not synchronised
KPI_Q12	Cross-border continuity of services	Cross-border continuity of services	Yes / No	Yes	Reported in Nordic Tour results
KPI_Q13	Cross-organisational/ cross-brands data sharing	Data sharing between organisations within a country or cross-border	Yes / No	Yes	

4.1.2.3 Other test results

Nordic Tour tests

Main results from Nordic Tour:

- The Norwegian Road Administration (NRA) needs to look at the processes, as automation requires coherence between the digital and physical worlds. This could be an extra use case for C-ITS with cellular connection.
- GNSS shows that location services are subject to global affairs and care should be taken in that respect.
- GNSS issues with entering and exiting tunnels. On average not bad for consumer-grade GPS, but this is only the internal error estimate. The real absolute error will be a challenge without correction data.
- GPS jammers were observed, and C-ITS services are susceptible to GNSS interference; there is a need for cooperation with experts in the field.
- Cellular coverage: There are differences related to the equipment used; the cellular network seems to be quite complex and different user equipment seems to be supported differently.
- There also seem to be some priority schemes related to roaming and different types of subscriptions / sim cards. The NRA should be aware of sim card/subscription priorities.
- Border crossing still has some issues; there is typically a loss of reception before re-establishing the connection when crossing the border.

Interchange node testing

The interchange node testing was done in Norway. The testing was done internally using the same hardware and two different apps. It was therefore not similar to other tests for service latencies, as it did not measure the communication aspect at all. However, this was a valuable test of how the system (interchange node) received and processed incoming messages.

Bouvet interchange node: 2000 messages, sent continuously (as soon as possible)

When messages were sent continuously, the growth of latency as the number of messages increases indicated that there was a bottleneck somewhere where messages were piling up, see Figure 13. One possible bottleneck was the interchange app (which includes validation). It is possible that the interchange app could not read messages fast enough. To test this, we tried a different number of interchange apps, from one to 20, to see if this would lower the latency. In theory, having several interchange apps to read from the queue would mean that one could process a number of messages simultaneously. The results gave no significant results for finding the best configuration. As shown in the graph, with a higher number of interchange apps in use there was greater variation in the order the messages arrived in, causing more noise in the graph.

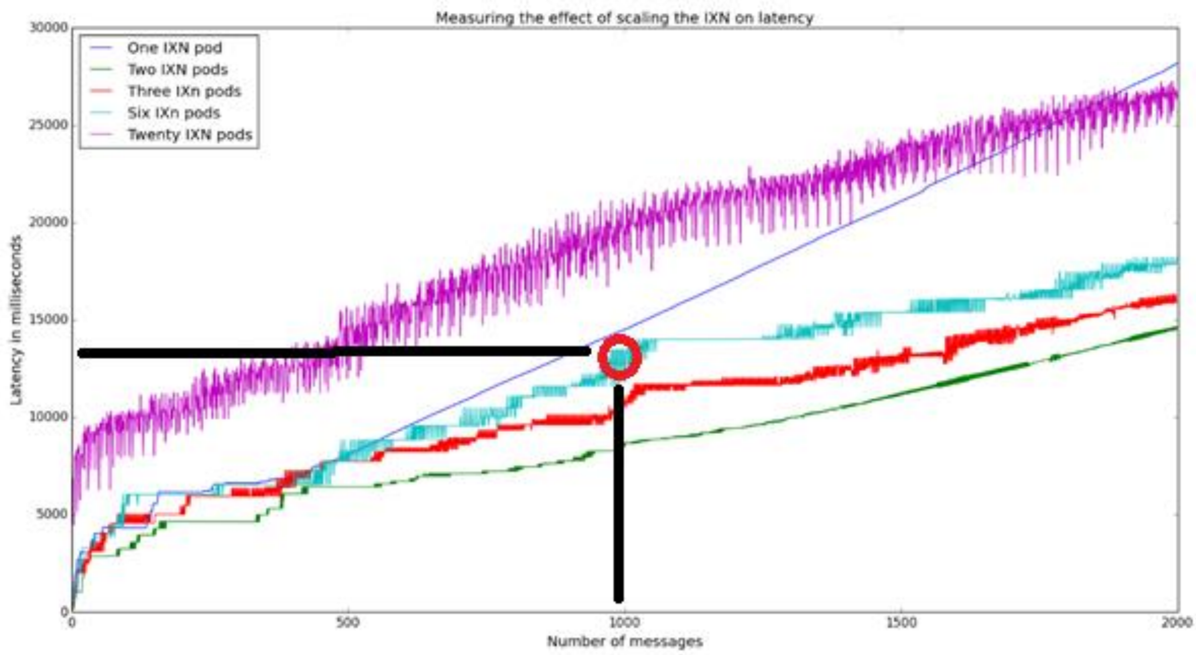


Figure 13. Data logging latency of service app - interchange node, 2000 messages as soon as possible.

The test showed the processing time when continuously pushing messages into the interchange node. At the red circle in Figure 13 the system had processed 1 000 messages within 13 500 ms from the starting point. We also see that the processing time (latency) per message is the highest at the beginning, which is consistent with the tests on sending one message (60 ms latency).

Bouvet interchange node: Send 1 message, receive 1 message, 2000 times

In this test, one DATEX II message was sent after the previous message was received. Running this scenario with one client did not reveal any performance issues, hence the tuning does not give a notable effect. The median latency lies between 59 and 60 milliseconds when running with different tuning options, see Table 21.

Table 21. Data logging latency service application-Interchange node, 1 message 2000 times.

VARIABLES	AVERAGE OF 5 RUNS
1 app	min: 50 ms max: 806 ms avg: 61.0794 ms median: 59.0 ms message loss: 0
3 app	min: 50 ms max: 814 ms avg: 65.2151 ms median: 60.0 ms message loss: 0

4.1.3 Results in Sweden

This chapter summarises the results of the technical evaluation focusing on the quality of services in Sweden. More detailed information is available in the NordicWay 2 'Activity 9 – Swedish pilot' report (NordicWay 2, 2020b).

4.1.3.1 Latency results

Emergency Vehicles Approaching (EVA) warning

For EVA, the average latency round-trip time between Carmenta TrafficWatch and Volvo Cars Cloud was 203 ms (see Figure 14 and Table 22).

	rttCtc2Vcc (in ms)
count	1813.000000
mean	202.570916
std	70.777248
min	31.252861
25%	156.244755
50%	187.510252
75%	234.375238
max	1031.264067

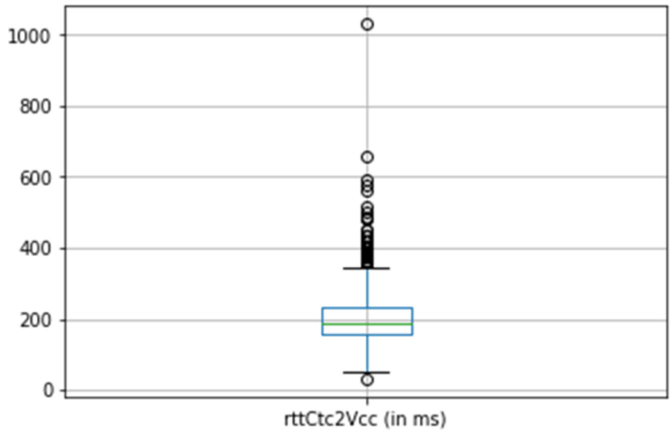


Figure 14. Results from measurements of messages sent between Carmenta TrafficWatch and Volvo Cars Cloud.

Table 22. Summary of the results on latency between federated interchange nodes

QUALITY KPI	KPI	DESCRIPTION	UNIT	RESULTS	COMMENT
KPI_Q08b	Latency (between Federated interchange nodes)	Delay between the first (validated if necessary) detection of the event and the moment the information is provided by the content access point	ms	203 (average) (N = 1813)	Round-trip time between Carmenta TrafficWatch and Volvo Cars Cloud

From a standardisation point of view, it is important to make sure that the information content in EVA messages fulfils the needs in order to create a driver-centric presentation of warning messages in vehicles. There are concerns when displaying warning messages to drivers, for example the risk of slowing down emergency vehicles or in the worst case creating new incidents and accidents. Further work is recommended to investigate this topic.

Connected traffic signals

For connected traffic signals, several tests were conducted within the project at several locations.

City of Gothenburg

The results from May 2018 show a latency mainly under 200 ms (Figure 15) and from June 2020 a latency of 200–500 ms (Figure 16).

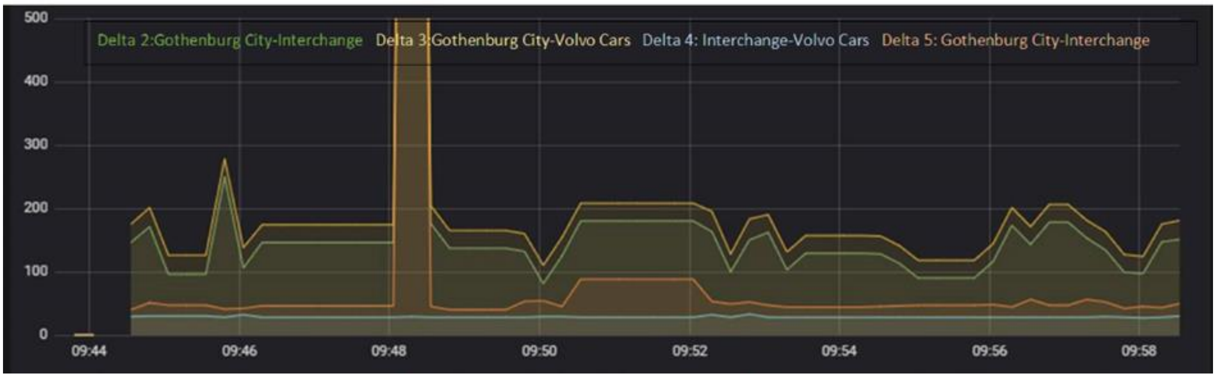


Figure 15. Latency measurements in the Gothenburg test area, May 2018.

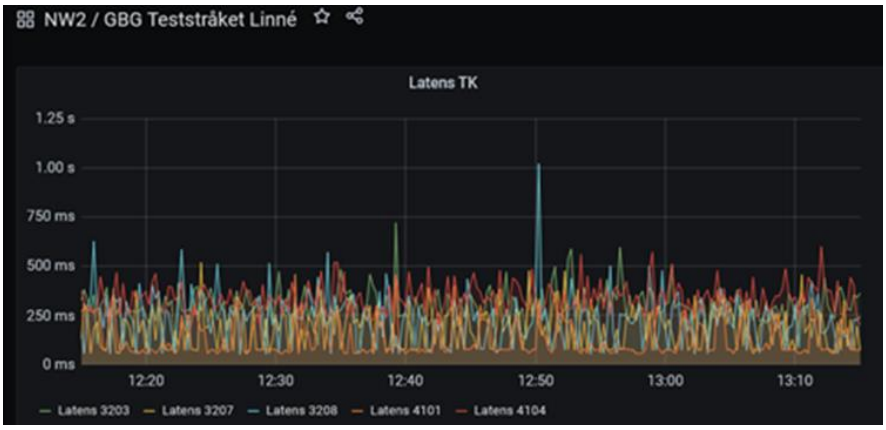


Figure 16. Latency measurements in the Gothenburg test area, June 2020.

City of Uppsala

The results from May 2020 show a latency at intersections 304 and 305 of 800–1000 ms. The latency at intersection 303 was roughly 1600 ms (see Figure 17). The results from June 2020 show a latency at intersections 303 and 304 of 700–900 ms. The latency at intersection 305 was mainly 400–500 ms. Average latency at intersection 303 was 1200ms, at intersection 304 850ms, and at intersection 305 675ms (see Figure 18).

Figure 17. Latency measurements at Luthagsesplanaden in Uppsala, 20 May 2020.

Figure 18. Latency measurements at intersections 303, 304 and 305 in Uppsala.

Swedish Transport Administration

At one of the Swedish Transport Administration's intersections in the Gothenburg area, where traffic signal "6830" is the starting point and Volvo Car Cloud the end/receiver point, the latency was found to be mainly less than 50 ms for SPATEM messages.

The difference in latency at different intersections might be due to the full chain of hardware and software, including the communication link type, not being exactly the same at all intersections. The value of low latency depends on the application. For safety-critical and/or vehicle control related applications, a low latency might be needed. However, as in the case of signal phase change prediction, when data is recreated and updated many times before reaching a final value, the usefulness of having a low latency diminishes. For a phase change prediction more than a few seconds into the future, it is not worth getting it within a very short time as it will change many times anyway.

In addition, the variations in latency over time show how different factors and conditions in IT infrastructure can impact latency both short and long term. This highlights the need for designing solutions that are robust and scalable over time. It also shows the importance of constant monitoring of the KPIs of the complete system to ensure that the data is usable by end-consumers.

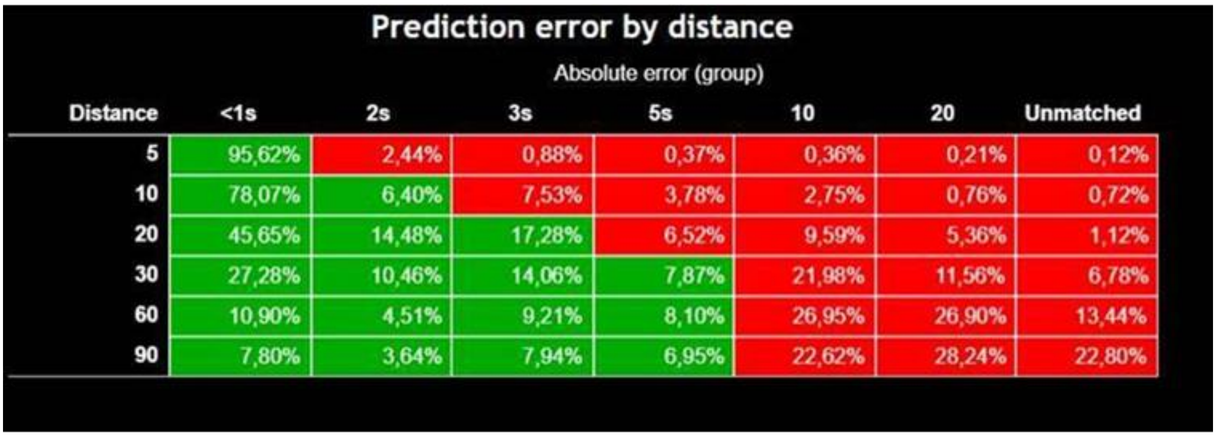
Table 23 summarises the Swedish results on latency for EVA.

Table 23. Summary of the Swedish results on latency for EVA

QUALITY KPI	KPI	DESCRIPTION	UNIT	RESULTS	COMMENT
KPI_Q08b	Latency (between federated interchange nodes)	Delay between the first (validated if necessary) detection of the event and the moment the information is provided by the content access point	ms	1. City of Gothenburg: < 500ms (max) 2. City of Uppsala (average): intersection 303 = 1200ms, intersection 304 = 850ms, intersection 305 = 675ms. 3. Traffic signal 6830 in Gothenburg: < 50ms (max)	The variations in latency over time show how different factors and conditions in IT infrastructure can impact latency both short and long term.

Figure 19 is a screenshot of the prediction quality dashboard. As a traffic light controller operates in time intervals and not by distance, the distance is measured in seconds, and thus the real distance is implied by the local speed regulation. The table is interpreted as follows:

- 5 seconds before the actual signal phase change, 95.62% of the predictions had an error of less than 1 second
- 5 seconds before the actual signal phase change, 95.62+2.44% = 98.06% of the predictions had an error of less than 2 seconds
- 10 seconds before the actual signal phase change, 78.07% of the predictions had an error of less than 1 second
- 10 seconds before the actual signal phase change, 78.07+6.4% = 84.47% of the predictions had an error less than 2 seconds



Prediction error by distance

Distance	<1s	2s	3s	5s	10	20	Unmatched
	Absolute error (group)						
5	95,62%	2,44%	0,88%	0,37%	0,36%	0,21%	0,12%
10	78,07%	6,40%	7,53%	3,78%	2,75%	0,76%	0,72%
20	45,65%	14,48%	17,28%	6,52%	9,59%	5,36%	1,12%
30	27,28%	10,46%	14,06%	7,87%	21,98%	11,56%	6,78%
60	10,90%	4,51%	9,21%	8,10%	26,95%	26,90%	13,44%
90	7,80%	3,64%	7,94%	6,95%	22,62%	28,24%	22,80%

Figure 19. Prediction quality dashboard SWARCO.

This means that the predictions were increasingly accurate the closer in time and space the road user got to the intersection. It also emphasises the reasoning around the low/no value of low latency in this case: there is no use getting in under a second a prediction that is only relevant 20 or 30 seconds into the future.

Conclusions

- Lack of accuracy with respect to predictions: The experiences so far have been that short-time predictions for sharing real-time SPaT messages are crucial for smooth driving when passing through signalised intersections. This is true for vehicles approaching a traffic light on green or red or when a vehicle is standing at a red light. It is essential in vehicle-actuated mode, i.e., when there is any form of traffic actuation (ordinary vehicles/cyclists and/or prioritised vehicles) or influence on the length of green/red intervals — it is also valid for most coordinated signals, as for all isolated traffic signal control in operation in Sweden. In other forms of control, such as fixed time control (coordinated or isolated) or adaptive signal control, this need is taken into account and is built into this type of signal control.
- From a technical point of view, the whole data handling chain works from traffic signal to OEM Cloud with acceptable latency with all different actors and variable technical solutions and versions included.
- Short time predictions, which are part of the SPaT message, need to be improved for all vehicle-actuated signalised intersections in order to get as correct data as possible for the effectiveness of the traffic flow. Poor timing affects most Swedish signalised intersections.

Dynamic access control

For dynamic access control, using the stopwatch method, a latency of 20 seconds was measured from the driver's request to the response from the traffic operator (Table 24). Most of the delay was due to human interaction from the traffic control centre and the driver response. An average latency of 300 ms between transmission and reception in the application was also measured.

Table 24. Summary of the results for dynamic access control

Quality KPI	KPI	Description	Unit	Results	Comment
KPI_Q08	Latency (end-to-end)	Send/receive latency – time from timestamp sent to timestamp received of message	s	20 (average)	Most of the delay was due to human interaction from the traffic control centre and the driver response
KPI_Q08b	Latency (between federated interchange nodes)	Delay between the first (validated if necessary) detection of the event and the moment the information is provided by the content access point	ms	300 (average) (N=299)	Latency between transmission and reception in the application

Dynamic Environmental Zones

For dynamic environmental zones, using the stopwatch method, a maximum latency of 10 seconds was measured from the GUI change to the actual response in the car.

Table 25. Summary of the results for dynamic environmental zones

QUALITY KPI	KPI	DESCRIPTION	UNIT	RESULTS	COMMENT
KPI_Q08	Latency (end-to-end)	Send/receive latency – time from timestamp sent to timestamp received of message	s	10 (average)	Latency between GUI change and actual response in the car

4.1.4 Summary and conclusions at NordicWay 2 level

In this summary chapter, a comparison at NordicWay 2 level was done for selected C-ITS services for latency-related KPIs for which the reporting or calculation was aligned. In addition, some significant national results are highlighted. Finally, the overall conclusions and lessons learnt from the technical evaluations and challenges related to the quality of service are summarised based on the input from the national results.

NordicWay 2 architecture and implementation

The NordicWay 2 architecture (Sundberg 2019) was designed to allow the exchange of C-ITS messages between the backends of different service providers, and between service providers and Traffic Data Providers. The architecture included aspects of multiple federated interchange nodes. The information exchange was based on two protocols: the Basic Interface protocol, acting as a data interface between different actors, and the Improved Interface protocol allowing for automatic detection, onboarding and queue generation. In the NordicWay 2 project, backends in different countries were linked to each other, including the road authorities of Norway, Sweden and Denmark and a network of service providers in Finland, connected to three local interchange nodes.

The NordicWay approach was developed to support service interoperability in a C-ITS/ITS environment, where cloud services and entities are part of end-to-end solutions, and connectivity is achieved using cellular and other communication links (Flensholt 2020b). The environment is open, scalable and flexible, allowing different entities to connect and collaborate as required for the purpose of C-ITS service provision. The service and use case specifications are aligned with the existing C-ROADS specifications of services and use cases at the functional level. They include additional types of entities, such as the interchange entities, and include additional user scenarios, such as user- and vehicle-initiated scenarios.

Most of the services in NordicWay were deployed using DATEX II (Flensholt 2020a), instead of the standardised ETSI messages used by the C-ROADS specifications (C-ROADS 2020). Migration of DATEX II from v2.3 to v3.0 was done during the project. The new version of DATEX II v3.0, which is not backwards compatible, was used in NordicWay 2 by Finland, whereas other countries still used the older version.

Latencies

Latencies were measured as technical performance KPIs in the Finnish, Norwegian and Swedish pilots. Both end-to-end latencies and the latency between two interchange nodes were measured. The services were not exactly equal, C-ITS services were not the same, and the service implementations were different. The Finnish technical evaluation measured the latencies of (hazardous location notification) messages transmitted from a mobile application through federated interchange nodes to another mobile application. In Sweden there were various C-ITS services in the tests, including Emergency Vehicle Approaching, Traffic signals, Dynamic environmental control, etc. Table 26 summarises the results of end-to-end latency tests and Table 27 latency tests between two interchange nodes. In Norway the measurements of latencies were done in only part of the ecosystem and are not comparable to the Swedish and Finnish results, as they were not done with the interchange node, see Table 28.

Table 26. Summary of end-to-end latencies in NordicWay 2.

COUNTRY	MEASUREMENT DESCRIPTION	LATENCY	COMMENTS
Finland	Louhi app -> Interchange -> ForeC app	6.2 sec (median)	Controlled test, N=21
	ForeC app -> Interchange -> Louhi app	5.3 sec (median)	Controlled test, N=25
Sweden	Changing a geofence state in the GUI -> response in the vehicle	10 sec (average)	Dynamic controlled zone (Task 8), controlled test, measured using the stopwatch method

Table 27. Summary of latency (between federated interchange nodes) in NordicWay 2.

COUNTRY	MEASUREMENT DESCRIPTION	LATENCY	COMMENTS
Finland	Infotripla node -> Interchange -> EEE node	219 ms (median)	N=2741
	EEE node -> Interchange -> Infotripla node	85 ms (median)	N=358126
Sweden	Round trip time: Carmenta TrafficWatch -> Interchange node -> Volvo Cars Cloud	203 ms (average)	EVA warning, N=1813
	Traffic Light Controller -> Interchange node -> OEM clouds	Gothenburg: < 500ms (max) Uppsala (average): intersection 303 = 1200ms, intersection 304 = 850ms, intersection 305 = 675ms. Traffic signal 6830 in Gothenburg: < 50ms (max)	Connected traffic signals, SPAT and MAP data
	Dynamic access control transmission -> reception in the application	300 ms (average)	Dynamic environmental zone, N=299

Table 28. Summary of latency tests in Norway.

COUNTRY	MEASUREMENT DESCRIPTION	LATENCY	COMMENTS
Norway	OBU -> RSU – Aventi Application-> DATEX II node	0.6 s (median)	OBU and RSU use ITS-G5 short range technology N= 5 DENM messages

The latency results varied a lot. It should be noted that the service implementations in the Finnish and Swedish pilots were not optimised for minimising latency. As could be seen from the results in Sweden, variations in latency over time show how different factors and conditions in IT infrastructure can impact latency both short and long term. This highlights the need for designing solutions that are robust and scalable. It also shows the importance of constant monitoring of the KPIs of the complete system to make sure that data is usable for end-consumers. For the purpose of the pilots, the latencies did not hinder the piloted services. These latency measurements and results are elaborated in the national result chapters.

Message success rate

The message success rate was calculated from the node server logs during the data collection period (28 Apr – 31 May 2020) in Finland. In total, 365 754 messages with unique message ID were sent from Infotripla to EEE or vice versa. Overall, the message success rate was high. It proved to be difficult to estimate why some messages were not delivered. Potential causes for unsuccessful message transmissions were that messages were transmitted but not successfully validated at the destination node, and there were limitations in the implementation of data logging. In addition, some interchange node tests were done in Norway, see 4.1.2.3.

Table 29. Message success rate results from Finland.

COUNTRY	MEASUREMENT DESCRIPTION	MEDIAN	COMMENTS
Finland	Infotripla node -> Interchange -> EEE node EEE node -> Interchange -> Infotripla node	Combined: 99.68%	N=365 754

Conclusions and lessons learnt

The technical evaluations in NordicWay 2 provided some lessons related to the organisation and implementation of the technical testing of the piloted services. The conformance of log files, data logging practices and message processing has to follow common specifications (including a stable and unique message ID), which enables successful analysis of the results from the log files. In addition, the possibility to analyse message latencies from the log files is dependent on the possibility to synchronise the clocks of transmitting and receiving nodes to a time reference. This needs to be verified constantly during the trials. When there are multiple partners or actors involved with the service value chain, the implementation of these testing requirements needs clear communication early enough and follow-up during the trials. The same methods also enable monitoring of the C-ITS services after deployment to provide reassurance as to their proper functionality.

The cross-organisational data sharing in the national NordicWay 2 pilots and data sharing across the interchange system was confirmed. Interoperability between the different countries was tested during the Nordic Tour, and events reported were visible across the Nordic countries. During the Nordic Tour it was discovered that there are issues with GNSS (e.g., consumer grade devices in poor reception areas, GPS jammers and global affairs) and cellular coverage/networks in cross-border situations (e.g., roaming agreements/sim cards, loss of / re-establishing reception, etc.). These technical issues need to be taken into account when deploying the C-ITS services. The (4G) cellular coverage will develop further and can be expected to cover the whole road network soon, as this is required from the mobile network operators (at least in Finland).

The end-to-end latency analyses showed that cellular (4G-LTE) implementation of the piloted C-ITS services and the NordicWay 2 interchange system is able to provide fully functional services, although the implementations in the pilots were not optimised for minimising latency. The median values of end-to-end latency measured in controlled tests allow successful implementation of many Day-1 C-ITS services such as different types of hazardous location notification. The medians of latency measured between federated nodes are consistent with this outcome. However, the number of events in the controlled test was relatively small, and the measurements were carried out over a short time period. A more detailed analysis of the end-to-end latency, including its distribution, characteristics and contributing factors, would be a relevant topic for future research. In addition, as the technologies evolve, presumably the latency will decrease.

Variability of the latency results in the pilot implementations highlights the need for designing robust solutions during the deployment of services that are also scalable. It also shows the importance of constant monitoring of the KPIs of the complete system to make sure data is usable for end-consumers. The quality of the services depends highly on the quality of the data. During the pilots, it was realised that the quality of data from detection systems needs to be confirmed before implementing the services. There is a risk of sending a false message if the incoming data is not correct or accurate. Other service providers, like traffic network management systems and weather service providers, should be able to be integrated in the NordicWay2 interchange system.

The design of the HMI and the interaction of C-ITS services used while driving needs special attention. In addition, the information content in C-ITS messages needs to support a driver-centric presentation of warning messages in vehicles. There are concerns that displaying a message (for example the emergency vehicle warning) to the driver could, in the worst-case scenario, create a new incident and accident. This topic was not included in the technical evaluation of the services, and further research is recommended.

The cellular networks can support ITS services on top of all other communication use cases, delivering excellent economy of scale and nationwide road network coverage from the start. Combined with a neutral data sharing platform, such as a federated network of interchange nodes, Nordic and European service continuity can be assured for all NordicWay 2 Day-1 cases.

4.2 Service ecosystem

4.2.1 Roles of ecosystem actors (service provision chains and value network diagrams)

During the workshops and from documents material was collected on the services, their data provision chains and data providers, current user groups and number of users in 2019 (where applicable and where the ecosystem was willing to share this data). The role of each ecosystem player within the service provision chain was presented with an end-to-end content provision and service provision matrices. For each ecosystem also a value network diagram was created representing two scenarios, namely,

1) Current status, i.e., the status of the ecosystem as-is, during the NordicWay 2 pilot stage, and
2) Perceived status after the NordicWay 2 pilot stage, in the possible scaled-up state in the short- or medium-term future.

The types of actor-to-actor flows presented in the network maps include data, information (processed data), monetary resources (money from service revenue, purchases or funding), legislation/regulation, physical goods (such as data loggers etc.) and finally, the provision and delivery of the complete service. Some examples of the value networks are presented below.

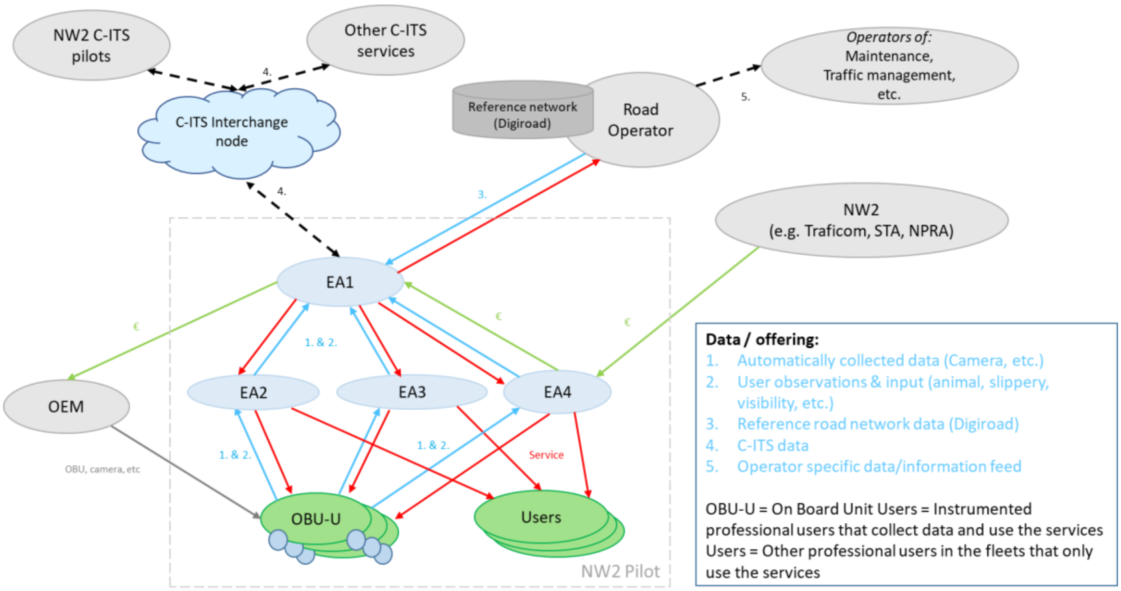


Figure 20. Pilot ecosystem – Current status (Example from Finland)

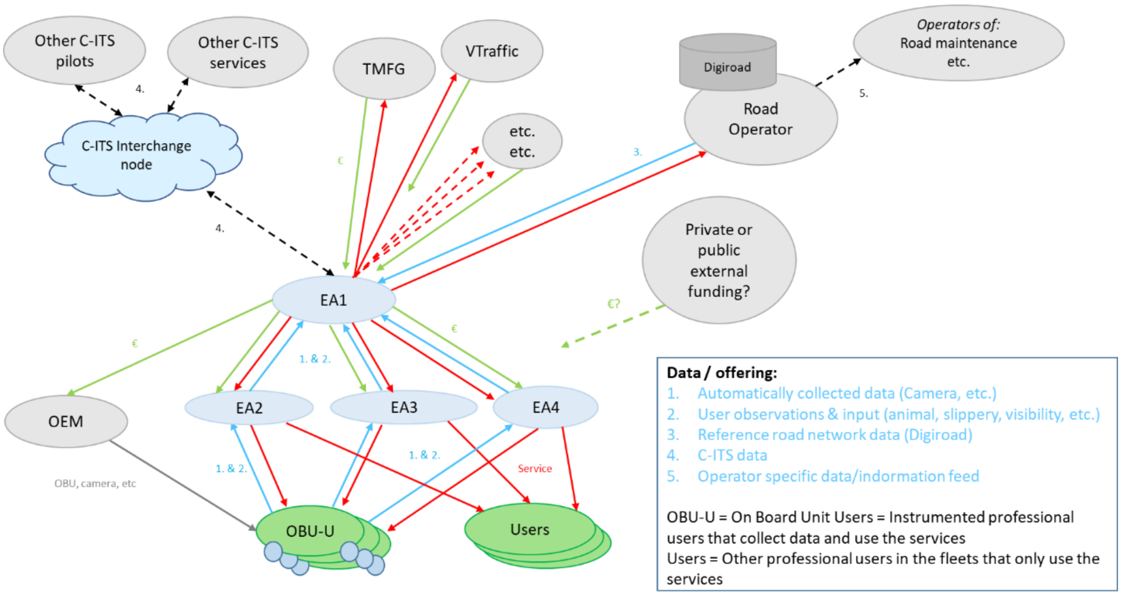


Figure 21. Pilot ecosystem – Post-NordicWay 2 status or scaled-up status (short/medium term future, an example from Finland)

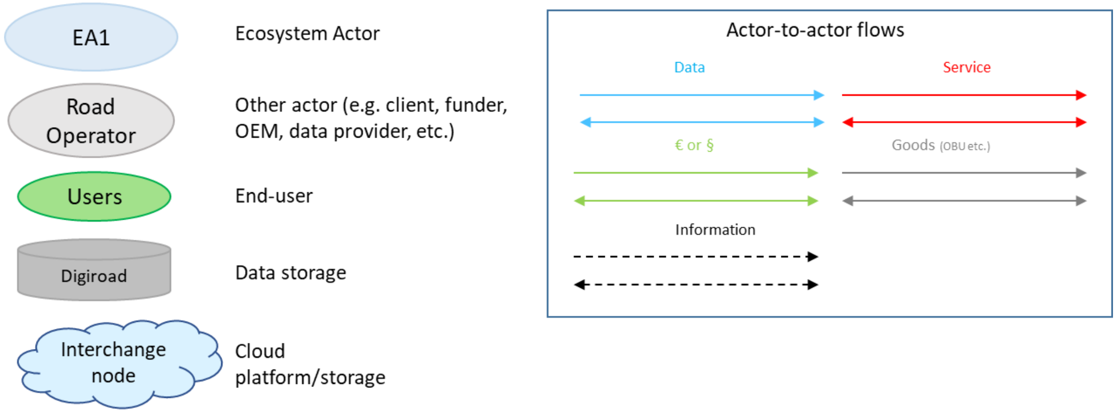


Figure 22. Items used in Value Network Diagrams

4.2.2 Encountered challenges and lessons learned

This chapter covers the findings from early-stage issues and potential challenges that had come up during the early stages of forming the ecosystem and service provision. These findings may be helpful to future C-ITS deployment cases as earlier lessons to be considered in forming a service ecosystem. The following is not an exhaustive account from the collected data and company perceptions, but rather a compilation of the most frequently reported ramp-up challenges.

"Contracts (especially GDPR personal data implications for data access and agility)": Personal data handling and worries relating to how to secure contractually that every pilot action is in line with existing legislation seemed to recur a lot. The issue is very sensitive and potentially has notable legal and even monetary implications if not handled properly and thoroughly. In consequence, such proper and thorough handling typically takes some time and often requires some costly professional legal counsel. Agreements should be considered to include sanction clauses to ensure that e.g., all data needed by the ecosystem is received on time. In addition, subcontracting chains (as is the case in some NordicWay 2 ecosystems) must ensure that the terms and key words used in contracts are explained openly and explicitly to avoid misunderstandings. Also, some companies felt that delays in contracting pilots may lead to the conclusion that C-ITS as a whole is not a mature or predictable business area yet. That could have a negative effect by reducing the willingness to invest, within both clients and potential C-ITS companies.

"Data quality assurance across the ecosystem": The data quality assurance challenge is at least two-fold: (i) the data collected from outside the ecosystem, e.g., weather or infrastructure data, needs to be of consistent quality, and (ii) the understanding of and practices in collecting data from within the ecosystem need to be uniform. With regard to (i), a wish was to have in place a feedback channel or platform, to be able to easily report any inconsistencies and flaws in the received data to the data source owner. The latter of the two, that is (ii), is more in the hands of the ecosystem to manage and solve by themselves. The ecosystems have proven that the technical solution works in general, but they also need to "fine tune" the concept and the quality of the detection and data when going large-scale.

"Service coverage (geographical and temporal)": This concern seems often to recur among businesses. A large enough data collection fleet is needed with comprehensive enough and frequent enough rotation and driving across the region intended to be covered. For example, in the case of postal services, this can be secured to some extent with regular postal deliveries (i.e., letters, invoices, magazines etc.) all across the nation's addresses, and hence all across the entire road network except for some private roads and all forestry roads. Service coverage is something that depends on traffic flow, but it is also dependant on connected devices along the roads/streets generating data from different infrastructure actors and from typically road infrastructure owners.

"Interchange node limitations": Some services collect and contain richer data than the node is catering for (e.g., pictures, video). Therefore, if this data is to be shared with a wider audience, different parallel platforms need to be in place. The responsibility for putting them in place most likely falls to such actors that aim to gain added value from sharing this kind of additional data.

"Datex version discrepancies etc.": As could be observed, challenges of a more technical nature started to emerge in the ecosystem evaluation process, regardless of the clear instructions not to focus on these here. However, these issues undeniably also have a bearing on many aspects of the ecosystem and

service viability, feasibility, business, etc., so they are reported also, for future reference and especially for cross-checking with the technical evaluation.

Additionally, in some ecosystems there had initially been some confusion about responsibilities among consortium members: On what level can each actor provide solutions? How to handle smaller changes during the project? Who is responsible for what? etc. However, these issues were generally solved early on with ecosystem internal daily communication.

4.2.3 Companies' motivational aspects and expectations (pains, gains & commitments)

The following reports the observations from ecosystem actors' pains, gains and commitments. As part of investigating the ecosystem actors' motivation to join the deployments, an analysis of their 'pains, gains and commitment' was performed. *Pain* relates to the actor's so-to-say sacrifice, i.e., input, changes in ways of thinking, changes in processes, investment, challenging priority choices etc. needed prior to or during joining. *Gain* means the expected business outcome or other expected benefit of being involved in these pilots and in C-ITS provision in general. *Commitment* aims to chart out the main reasons and motivations for joining — and also the reasoning for staying onboard, potentially over a longer term exceeding the pilot's duration. An account of the expressed pains, gains and commitments is presented below.

Pains

The word cloud (all word clouds in this chapter were made with the word cloud generator at jasondavies.com/wordcloud) in Figure 23 illustrates the most commonly reported pains for the companies in joining a C-ITS ecosystem. The most frequently reported pains or discomforts included many types of extra work and costs connected to the development of new services, service concepts, software and hardware. Some of the pains related to getting hold of all of the needed data and attracting a wide enough initial (and hopefully continually expanding) clientele base. Also defining sensible business cases, business models, sales channels/methods and finally a meaningful revenue stream — all of these required some extra effort as well.

Figure 23. Word cloud for the most commonly reported pains for companies in joining a C-ITS ecosystem

C-ITS is a market characterised by rapid changes and strong competition. Much of the competition is furthermore characterised by large international players with ample resources. In order to maintain services offered to national and Nordic customers, companies may be dependent on being able to involve themselves in R&D processes where there are risk-relieving measures from national, Nordic and European institutions. However, typically the companies' daily business operations are characterised by many short-term assignments — and some long-term ones. The companies' perception is that it creates greater value for them if the R&D processes have a long-term framework. This helps them generally plan R&D activities with lower risk, try out different types of service and business models, realise synergies between their own commitments and those of others in the ecosystem, develop cutting edge expertise and follow the relevant market activities. Companies would therefore gladly see a continuation of these kinds of pilots be realised over an even longer time frame with a larger volume if possible.

Constantly renewing itself and adapting to new market situations through participation in R&D&I activities has frequently been recognised as one of the main added values in participating in these kinds of pilots, however painful such renewal processes sometimes may be. Testing and introducing cutting edge technology as well as working together, drawing out the good results and solving the challenges together, is important to both the ecosystem actors and to a customer that contributes to road-proving new business models in technology pilots. Notably, C-ITS is still a fairly new concept and the learning curve is steep. However, companies do not see this only as a negative phenomenon, since current employees are given exciting tasks which makes them generally more content in their workplace. The ITS field is undergoing rapid development, and the companies see challenges related to the standards to be used and that different solutions choose different variants or implementations of these. The area of expertise requires employees to keep up to date with developments. Participation in courses and seminars are therefore important activities. In terms of recruiting a new work force, it was recognised that it is generally not possible or at least not easy to hire people with already obtained C-ITS knowledge and experience in the Nordic countries, and the same situation is probably dominant elsewhere in Europe as well. Lack of investments (not always clear as to investments by whom and to which purpose, but mostly public investment in data and the infrastructure needed to manage and move it) was also highlighted by many and this included a risk of making the existence of mature commercial market potential less obvious. To summarise, here some highlights and analysis of some of the frequently observed (or otherwise noteworthy) Pains:

"Integrator pain": Being the integrator, i.e., the organisation responsible for integrating and quality-checking all the data and information, inevitably adds some extra pressures.

"Attracting users": The ecosystems felt that attracting a wide and large enough paying user base is or will be one of the key pains in setting up a new C-ITS service. This pain especially intensifies when the targeted clients are private car owners and drivers (as opposed to public or business-to-business clientele). This issue also strongly connects to the business model-related observation mentioned below on revenue streams from individual private users being thin.

"Revenue streams from individual private users may be thin": Related to aforementioned pain of attracting users, several ecosystems expressed worry with regard to accumulating meaningful turnover from individual private users. The ecosystems are already trying to think of ways to get around or over this issue. One solution, at least for some types of services and/or ecosystems, could be a "grouping synergy", meaning a setup where businesses such as insurance companies or large employers are the primary clients and payers for the services. Provided that data security and privacy issues permit it (there might be some challenging issues here in terms of data handed over like this), they could then cater these services to their customers or employees, with e.g., a "safe-driving index" and an associated insurance premium discount incentive, or, based on the operational gains that an industry expects to benefit due to safer, more resilient and more fluent material flows. See more on this issue later in the scaling-up strategy discussion.

"Product development investment, data costs, etc.": Direct incurred costs of setting up and operating a service — whether those costs manifest as human capital, time or money — inevitably are one central consideration in determining the overall profitability of a new commercial activity.

"Lack of a skilled workforce (capabilities, knowledge, experience)": The well founded and understandable observation of generally having great difficulties in hiring people with previous C-ITS expertise is to be taken seriously if and when a wide take-up and provision of C-ITS services is the vision. Some of this expertise gap will be filled with company internal learning, training and learning-by-doing but hopefully the curricula in the academia will also mirror these developments and the associated skills needs sometime soon.

Gains

The adjacent word cloud in Figure 24 depicts the most commonly reported expected gains for the companies from joining a C-ITS ecosystem. Especially highlighted were new business opportunities, access to new data, revenue growth and the new national and international networks/networking coming from the cooperation in the ecosystem in itself.

Figure 24. Word cloud for the most commonly reported expected gains for companies from joining a C-ITS ecosystem

Some companies foresee that there will be a huge demand for integrators that can employ these systems for cities and highway operators. It is therefore useful to be a part of the consortiums and work together with relevant partners, while at the same time creating market recognition, increasing interest and traction generally, and building a good reputation. To sum up, some highlights and analysis of some of the frequently observed or otherwise notable gains are presented below.

"Revenue, clientele growth, product portfolio, etc.": Clearly and quite understandably, a large portion of the anticipated gains for businesses is new or growing business. In the end, by far the most meaningful performance metric for the commercial players is and will continue to be the turnover, or more precisely the overall net financial profitability of activity and the hence forthcoming capability to produce capital for the owners. (See also commitment "Participation supports strategic objectives / supports the corporate strategy" below.)

"International partnerships": New networks and especially the international aspects of some deployments were seen as a clear added value of the participation, from the perspective of the companies.

"Operational gains": This observation or claimed gain stems from the fact that in some service deployments, the current users and also the primarily foreseen users of the C-ITS services can be within the service ecosystem. Namely, in some of the deployments, the services are particularly directed to professional fleet drivers, e.g., in postal services and in material transports to the forestry industry as a whole. For example, an umbrella organisation for national timber transporting companies, large and small, and postal services are also partners in the associated NordicWay 2 ecosystem. Therefore, a stated gain was "safe and fluent material flows", which as such is an operational gain, but one that also has obvious and inherent financial implications within the production cycle. Notably in such cases, the primary customer (i.e., the entity that actually pays for the service) is e.g., the post delivery company, the forestry company or the logistics company (i.e., the employer), even though the actual end-users are professional drivers (i.e., the employees).

Commitment

The word cloud in Figure 25 illustrates the most commonly reported commitments for the companies resulting in them joining a C-ITS ecosystem. Most prominently highlighted was the aspiration to be an active actor in this market while creating new business. The most frequently reported motivation statements included also the will to be involved at the forefront of the latest R&D&I activities and the fact that being involved in these kinds of endeavours strongly supports the company's strategic choices and objectives.

Figure 25. Word cloud for the most commonly reported commitments for companies resulting in them joining a C-ITS ecosystem

Participation in this type of projects may enable the companies to profile themselves to the outside world. The companies have developed several new products and services and are already seeing some results. The solutions seem to have gained more prominent visibility profiles. The companies have implemented integrations with variants of sensors and data that have brought new products/solutions. They have tested several variants of hardware that have proven useful in putting other solutions into production. They have gained several new customers related to the management of integrations with the road traffic centres. The ITS initiative has led to competitive products and the companies' ITS efforts have contributed to being first on the market with products and services. This gives the companies increased competitiveness. Finally, some examples of the perceived commitment issues include:

"Active actor in the market, heavily involved in R&D&I": Typically, the involved actors feel that they want to stay ahead in the competition and that this can be partially achieved by being active in new and upcoming services and in novel research, development and innovation activities.

"Participation supports strategic objectives / supports the corporate strategy": This observation may be quite self-explanatory and as such not very surprising: if the corporate strategy states that the company should proactively take part in such piloting activities, the organisation tends to seek such opportunities and join them. This relates to the performance management systems where "What you measure is what you get" acts as a well-suiting statement for private organisations — and notably for public actors alike, albeit that the performance management metrics and vertical accountability might differ, as presented by e.g., Mononen (2017) and Mononen & Leviäkangas (2016).

4.2.4 Scalability and long-term economic sustainability of the businesses and services

The data gathering next went out to investigate the ecosystem actors' views on scaling up from local to national level, from national to Nordic level, and up to European or Global level. In focus were e.g., the business potential and scaling up issues beyond the pilot implementation phase. This section covers the following questions:

1) What do you expect the service and/or the ecosystem to look like five years from now?
2) What new actors or data sources are needed in various scaling-up levels? Are any of the current ones becoming marginal?
3) Where is investment and/or development needed?
4) What are the implications (pros & cons) of the federation model?
5) What ought to be the public sector's role?

The Covid-19 pandemic breakout imposed some challenges on the evaluation during the spring of 2020, due to meeting and travel restrictions and other limitations. However, some data could be collected (i) in a virtual workshop organised for the Finnish ecosystems, (ii) in several physical workshops organised for the Swedish ecosystems pre-pandemic, and additionally (iii) as written input from the Norwegian ecosystems. Some insight into the ecosystems' aspirations for scale-up were also acquired from the value network analysis. Based on the outcomes, it has emerged that the ecosystems´ and individual actors' ideas for sooner-or-later scaling up the services, or otherwise commercially capitalising on the pilot participation, are already there and brewing, but are generally not yet that concrete. On the other hand, and notably, amongst the assessed ecosystems there were exceptions to this generalisation, and some ecosystems were progressing with their scaling-up strategies pragmatically. Partly due to this, the ecosystem evaluation and its final workshop continued from this aspect, once the piloted C-ITS services themselves and the actors' ideas on capitalising on them were in a more advanced state of maturity. The focus then was on e.g., various marketing strategies and other forms of involving and committing the potential clientele, regardless of whether it is about individual users or business-to-business clients.

The 2nd round scalability workshop

In the second-round workshop, based on e.g., the authors' earlier work and literature, the ecosystems were (among other things) presented in some general-scaling up strategies as precursors and examples. According to Parker et al. [4], in the platform economy eight distinctive strategies can be recognised for scaling up and for beating the chicken-or-egg dilemma. (See Figure 26.)

Follow that rabbit strategy Use a non-platform demonstration project to model success.	**The piggyback strategy** Connect with an existing user base from a different platform and stage the creation of value units to recruit those users.	**The seeding strategy** The platform company acts as first producer, borrows value units or simulates platform activities creating value units that will be relevant to at least one set of potential users. Others will follow.	**The marquee strategy** Provide incentives to attract members of a key user set onto your platform. This is a single group of users who are so important that their participation can make or break the success of the platform.
The single-side strategy Create a business around product or services that benefit a single set o users, later attract a second set of users who want to engage in interaction with the first set.	**The producer evangelism strategy** Design your platform to attract producers, who can induce their customers to become users of the platform.	**The big-bang adoption strategy** Use one or more traditional push marketing strategies to attract a high volume of interest and attention to your platform.	**The micromarket strategy** Start by targeting a tiny market of members already engaging in interactions, in order to provide matchmaking characteristics of a large market.

Figure 26. Eight distinctive strategies for beating the chicken-or-egg dilemma (modified from Parker et al. (2016))

In the pilot phase, typically services are tested within professional networks or as limited consumer group tests. Scale-up of businesses requires access to larger markets and clear earnings models. Finding and co-operating with a Scale-Up Partner (SUP, Figure 27) can speed up business growth. SUP is an actor who already has access to a larger market or who can help reach out to a market. According to Parker et al. (2016), network effects refer to the impact that the number of users of a platform has on the value created for each user. Positive network effect refers to the ability of a large, well-managed platform community to produce significant value for each user of the platform.

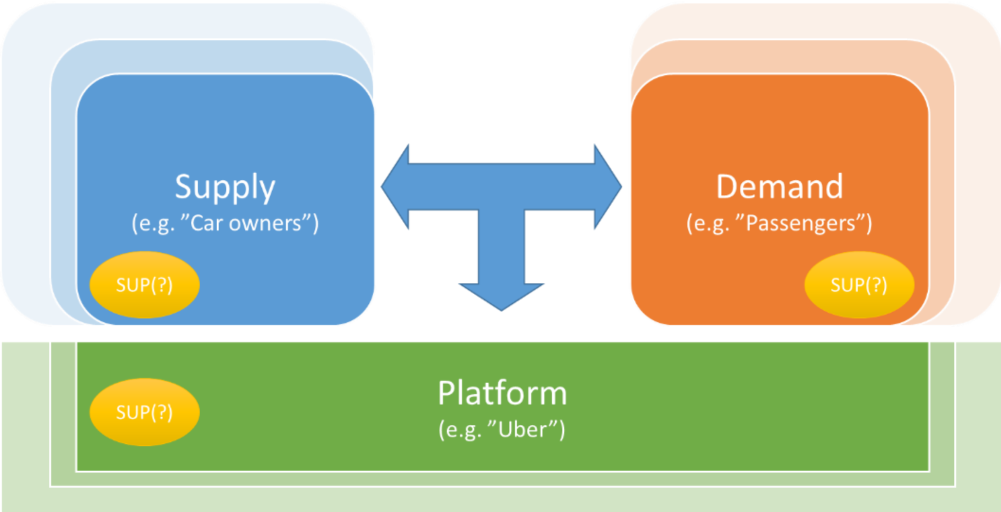


Figure 27. SUP thinking

These above strategies, along with SUP thinking, worked as the basis for the ecosystems to self-evaluate which of these (either none, one or more) best represent the desired avenue of progress, and with which kinds of adjustments or improvements. Notably, only Day-1 pilots were captured in the spring 2020 workshop, so the very few Day-1.5 pilots remain excluded from the evaluation. The data and results from these evaluations are presented below to provide insight into different approaches across the C-ITS deployment environments.

Single side strategy: As the most concrete and prominent example, this strategy has been very successfully applied in the scaling-up efforts of at least one ecosystem. The adaptation in this case has gone through first creating the business for public clients in the road maintenance sector, then attracting a secondary set of users. The primary business secured the production of a valid data set (i.e., timely traffic related information with good coverage both geographically and temporally) that is partly used to serve the primary client but secondarily has opened up new market segments. This is to say that while collecting the data needed for the primary client´s service, additional data can be collected at the same time, data which then opens up other opportunities. The companies stated that without the original public opening it would never have been possible to come up with a large enough fleet of vehicles to collect the data, to end up with an economically sustainable and growing C-ITS service portfolio. Additionally, single-side strategy was picked and addressed by several other ecosystems. For example, national and international travel and tourism are seen as viable market segments to be targeted (in connection to information for route planning, traffic fluency, travel times, weather, car rental, etc.).

Follow that rabbit: Discussions have been ongoing with the insurance sector. One of the challenges there is the transfer of personal data, such as location, to insurance companies. An easy fix would be user consent. (One potential issue with consent is that it is possible for the data subject to withdraw their consent whenever, after which the data cannot be used. This could be avoided in situations where there are some other grounds for processing personal data in addition to the consent.) Also, the retail sector is seen as an attractive prospect, especially for its advertising potential.

Piggyback strategy: National data platforms could operate as distribution channels. Global cartographic service providers have the automotive sector as one major market sector, and that sector is also very interesting to SMEs; however, they might be too big to co-operate with. This could be overcome by approaching them via intermediate (larger) market actors in the ecosystem. As a kind of a by-product of discussing this strategy, one notion came up relating to automotive OEMs and more specifically to the data quality from vehicles: as a surprise to many of the companies, the quality of data fetched from e.g. OBD is far lower that one might assume. It often requires multiple and sometimes rather laborious layers of validations, crosschecks, enhancements and clean-ups before being actually usable in C-ITS provision. (This comment was brought up by one company and agreed with by many. However, with regard to any metrics or specific detail on what exactly the quality issues had been, none were collected in the course of the ecosystem evaluation.)

Big bang strategy: This could be (and has in fact proven to be) applicable to addressing very tangible and well-recognised safety concerns (for example in northern Finland a warning about reindeers on the road) targeted to enthusiastic user groups (such as, in the mentioned reindeer case, professional logistics fleets and drivers).

Potential SUPs: As potential SUPs, the ecosystem partners recognised the following types of actors: navigation device manufacturers, large fleet owners (e.g., petrochemical industries, taxi companies and logistics operators), insurance sector companies and to some extent also telecommunication operators. The latter is perceived as slightly problematic or limited. Telecommunications operators have, at least in the Nordic countries, lately actively widened their offerings from the traditional data transfer provision to various kinds of other commodities, such as devices and media services (television, streaming, audio books, games, etc.); for example, one of the major media houses in Finland was recently purchased by a major telecommunications operator. Nevertheless, the leap to find sufficient attractiveness and business from road safety related services is perceived as somewhat far-fetched, at least in the current business climate. Overall, for C-ITS information production, it seems rather challenging to find a profitable business model without clearly realising the uses of the information by the “big market” actors, i.e., the automotive and non-life insurer axis. In addition, the information needs of national transport and road infrastructure should be covered by the same solution in order to yield a “single ecosystem platform” that could carry as a business. Thus, looking to the future, it would be beneficial to be able to identify information needs that generate added value from the roadside for the trio of automotive insurers-road infrastructure.

Other findings on scaling-up issues

When asked how the service will or could look five years from now, and what is required to reach these visions, the ecosystems reported the following testimonials:

> *Case 1*: Services may be feasible if they are implemented over a bigger geographical area and not just some cities and regions. Several countries should decide on implementing the service for OEMs to be able to invest time and money in it. Administrations could implement solutions from where static and dynamic traffic regulations can be provided in a secure way. The entity in direct contact with the administrations' solutions could be an OEM backend, a service provider, an aggregator, or an interchange node provider. Companies would like to see agencies in the centre of the services, because when scaling up, OEMs would like to connect to a single point of entry. Therefore, a centralised concept hosted by an administration can offer this single point of entry and every city/region uses their systems to feed the central platform.
>
> *Case 2* (Case about geofencing and more specifically about dynamic environmental zones): Within five years it would be possible to use the service without changing the actual regulation. Within 10 years we might be able to actually change the regulation, and then we would have had five years of testing. It is important to distinguish whether it is an incentive-based or regulation-based service. The public sector might not be involved if it is incentive based, but it could be. In terms of the regulatory implementation scheme, there is a challenge to have an international standard. From an OEM perspective it would be good to have a more global software solution than this local use case, but of course it can be introduced in steps. In order to reach this vision, it is important to have more end-users, public transport stakeholders, heavy vehicle transport operators, etc. that can include the functionalities into their systems. There will also be a need for more data such as trusted sensor data on current air quality, etc. If the system is to be efficient in the future, it needs to be coordinated with other services. There will also have to be an entity that coordinates these services. Regarding the business model, if the service is used as a prerequisite for procurement, this would give a push/pull to the technology. It could then be interesting for the transport fleet to invest in the technology.
>
> *Case 3*: The geographical coverage should be the whole of Europe, which is what is being developed in C-ROADS. The service should cover all vehicles with drivers that have signed the GDPR consent. Maybe the RWW service is not a business case in itself. In order to be valuable for the user, other forms of works along the road, such as service work (e.g., change of tires) or accident zones are also important to inform the driver about. Other obligations for public transport actors, such as increasing the safety for road workers, may have implications here, such as potentially being an enabler for scaling up the RWW and similar services. To increase the number of users, the information needs to be accessible on smartphones as well, not only integrated into the vehicle's HMI. Therefore, app providers are a new group of actors needed. OEMs could also create their own apps, like a "Safety app" which they provide to their customers.
>
> *Case 4*: Most likely the actors involved in traffic signals today will also be the ones providing this service in the future. In different cities there might be some new suppliers present. The city needs a software provider who can use the RSMP standard efficiently with their solutions. In terms of geographical coverage of TTG and GLOSA, in five years from now there will probably be smaller scale installations such as certain spots, corridors or intersections where you can find these services. It is impossible to predict the number of users; it will depend on where the service is implemented. Fleets can use the services, and commercial traffic will probably benefit the most from this service. In order to scale up, more cities need to be interested in investing in this service, and in order for that to happen, cities/municipalities need to see the socioeconomic value of the service. There are also some negative discussions surrounding these services where they are considered as technological solutions only for cars. The benefits of the services, such as less emissions and smoother traffic, need to be highlighted. Some paying customers are needed, but who that should be is unclear. Probably, it will be public actors who make the decision on implementing the technology. New data sources might also be needed; possibly the road users could be able to put in their data somehow. Today, a lot of data is provided from I2V but not so much the other way round, V2I. Perhaps we should allow the public sector to do business in order to get the revenue streams in place. Further, there will have to be new investments both in roadside and in backend. Standards for protocols etc. on European level both for OEMs but also for local road authorities are needed. It is much easier for OEMs and local road authorities to get instructions than them investigating everything by themselves. Furthermore, new investments to handle and process big amounts of data are needed. Perhaps there will be new service providers

that provide a new service/connection layer, doing the map data work, and selling this data to subscribers such as OEMs. How to manage a platform for data sharing also needs to be answered before implementation. The cities are quite dependent on this. The rules for the cities' data are quite different from those regulating data from a private organisation. The city will need to open up their data a lot, and it could be a challenge to share these different types of data on a common platform.

Case 5: To move from the pilot stage to real-life large-scale deployments, we need road operators, regional governments and cities with a willingness to invest in smart technologies like C-ITS for the public good. Alternatively, we can build a privatised C-ITS platform for basic services and charge for add-on services required by public actors and private businesses alike. Companies are exploring both options, the latter potentially being far more profitable than the former but also much harder to achieve, going up against established international actors such as Here, TomTom, Garmin, Inrix, Waze and Google protecting their proprietary traffic alert and management solutions. We need larger national C-ITS implementations that serve a purpose, and not just pilots. With a future need for both a C-ITS platform and solution such as dynamic/satellite-based road pricing, companies will need to work to influence decision makers to make the pricing part of C-ITS, avoiding a situation where we end up with two large ICT solutions for road traffic. Other road services should also be part of a national, Nordic and European C-ITS platform, deriving trust from the EU C-ITS Security Credential Management System. Investments are also needed in efficient backend systems, hybrid communication, and useful traffic services beyond the Day-1 services. The best way to embed other traffic services into the C-ITS platform is to use Service Announcement Messages. There is a hope that national authorities will continue to support the technology and facilitate the players who invest significant amounts of money in development and roll-out both nationally and globally.

4.2.5 Observations and comments on the federation model / interchange node

This chapter reports the findings from when the ecosystem actors were asked about their views on the implications (e.g,. pros & cons) of the federation / interchange model.

Positive:

- "All data structured through one source would be very helpful."
- "Cooperation with other actors will become more important in the future. Size becomes important to get into market position. Collaboration via a common platform also helps to increase the product range."
- "Our platform is built to collect data from multiple sites, so all interchange of data is good for us."
- "The opportunity provided by the federation model is that actors in different countries can produce and consume messages, and thereby have the possibility to establish new services."
- "Enables cross-border exchange and services."

Neutral:

- "We will end up with one of these C-ITS models in Europe: (1) A federation of compatible C-ITS platforms (tied together by the EU CCMS and the C-Roads specifications) where a vehicle can be handed over from one road operator's platform to another as it travels safely through different regions and countries, or (2) Half a dozen competing and privatised C-ITS companies, but proprietary platforms performing the traffic management (we can already see the beginning of this). Travellers who can afford the subscriptions will be provided with safe, pleasant and efficient road trips similar to the different classes when travelling with different airlines."
- "The role of the interchange node might remain marginal in this particular pilot. The data format is limited and does not allow transferring images, for example."

Negative:

- "The interchange model does not scale. Regional and local policies and governances are needed. Open protocols and common security systems will allow more scalable and distributed architectures."
- "A challenge is that the actors have to agree on the use of standards. It is also a challenge that some actors are not open-minded regarding the sharing of information."
- "A bottleneck for innovation?"

To recap: generally, the federation model was perceived as more of an opportunity and a benefit than otherwise — but opposing views, challenges and worries were brought up as well.

4.2.6 Position and roles of the public sector / public actors

The ecosystem actors acknowledge that the public sector has had a significant role in the early stages of C-ITS development, but they estimate that active participation is needed in the long run as well. Public sector actors and public funding have been integral to the development steps by e.g.

1) Helping to populate the network and providing valuable real-time data;
2) Increasing the value of the network for all by helping to have more organisations and people to join and share data and messages;
3) Creating a network effect that will be a great benefit to the ecosystems; and
4) Being demanding customers who describe the needs and specs, and provide input e.g., into business and payment models, regulation needs and contractual obligations (incl. GDPR).

Also useful have been the development funding opportunities and large-scale pilot contracts along with the support in regulation, policy, governance, and full-scale deployment issues. Relating to this, the public sector is often seen by the companies as a crucial facilitator that supports development and business, offers an operating environment for business without any stakeholder priorities, ensures technology neutrality, and participates in offering digital infrastructure to services in the form of open data and communications. Many solutions are largely based on participation from the public sector as well as the public. As such, the societal benefits could be substantial, while the willingness to pay for the solution (for most citizens) is probably going to be low, according to the companies' estimate. A clear division of roles between public and private activities is needed. The use of such traffic services improves traffic safety and environmental friendliness, which generally are among the performance targets and responsibilities of authorities; should they therefore pay for the services to some extent? A recurring comment was that regardless of the service, some public intervention or investment is going to be needed in the longer term also. One of the reasonings of the companies is also that their direct revenue collection pipeline stops the moment the publication of data happens. In short, the companies feel that "If there is public data, there needs to be public co-funding." Inversely, the data-producing and processing actors may feel a need to avoid data publication as long as the data may still contain some untapped revenue for them.

According to the companies, one public role could be to include standardised requirements on what type of data needs to be delivered to their sub-contractors as procurements. This could be the C-ROADS specification, for instance. If the sub-contractors know that this comes up in every procurement, they will know how to price it. Administrations could also lend support with standards on procedures for other operators, such as municipalities, to make it easier for them to connect to the ecosystem. Another important role for the public sector could be to help secure the quality of the data.

At the most wishful end of the spectrum, in terms of state presence and involvement, some companies also aspire to e.g., the establishment of publicly funded fixed test arenas for continuous R&D&I and testing, long-term programmes, and regular R&D&I projects with procurements. However, considering e.g., the ever-present pressures to control public expenditure, the realistic chances of this happening, at least widely and on a large scale, are not likely to be very high. An idea was also expressed that the public sector should in certain instances consider procuring compliant data and information from companies as services, instead of acquiring software and hardware (including IPR) for public sector ownership. Service procurement (not referring to consulting here) often contributes to the emergence of innovations and therefore to a favourable development of the international competitiveness and export capabilities of the industry.

Overall, the conclusion within practically all observed ecosystems was that from their perspective, the public sector is and most probably will remain an important, if not *the* most important, facilitator, client and market driver for C-ITS. The ecosystem actors went as far as claiming that the public sector may in some cases end up as the only client, especially wherever the data and information is fully opened up, i.e., made public. One of the Nordic ecosystems stated that the ideal situation for the general public would be that e.g., different national road authorities end up in charge of the C-ITS platforms. However, in their view a more likely scenario is one where most things are privatised and run by large international corporations while regulated by federal or national governments. Relating to this, from the national and EU interest perspectives, the ecosystem actors found it crucial that a certain level of local sourcing and control would be retained in C-ITS services and in the data needed for them, since the globally dominant platform businesses are generally from outside the EU. Becoming reliant on such actors only, some risks and less than ideal setups may be invoked, in terms of national and European self-sufficiency and competitiveness.

4.2.7 Summary of ecosystem evaluation key findings

C-ITS services are being deployed at increasing rates, but many initiatives have been characterised by a technology push, where things are developed with a focus on the concepts and technology from the very start, and with limited attention to the value and for actual business viability at the end.

During the ramp-up phase, the main challenges include contracting (especially GDPR) issues, data quality issues and service coverage issues. The initial pains relate to attracting a user base in the harshly competitive climate, thin revenue streams from private users, product development investments, and lack of an experienced workforce. Expected gains from being involved in such ecosystems include revenue, clientele growth, product portfolio expansion, international partnerships, and operational gains. The companies are committed to such piloting endeavours due to wanting to be at the forefront in the R&D&I field and due to such activities strongly supporting the company strategic choices and performance objectives.

As viable or potential scaling-up strategies, the most prominent was the “single side strategy” and the others highlighted were “follow that rabbit”, “big bang” and “piggyback”. The most prominent and promising scale-up partner candidates were the automotive sector, navigation device manufacturers and large fleet owners.

Business model (feasibility, scalability, long-term sustainability, profit) issues and concerns include a recurring comment that regardless of the service, some public involvement, intervention, funding or investment is going to be needed in the longer term also, if a wide and large-scale roll-out and adoption of C-ITS is aspired to. For C-ITS, it holds true that if there is no data, there will be no services either. To extend from that, the businesses feel that if there is no investment from e.g., road authorities, there will be no data and hence no services. It is, in other words, an interaction between different actors which gives the end-user and society beneficial services.

4.3 User acceptance

4.3.1 Objective and method

The main KPIs selected for user acceptance were relevance, feasibility and barriers, acceptance and willingness to use (Table 4). In addition, willingness to pay was of interest, especially for the cost-benefit analysis.

In total, over 4 000 drivers responded to the survey in Finland, Denmark, Norway and Sweden. The main results were analysed for both “all countries” and each country separately. Statistical analysis per background variable (age, gender, driving experience and technology adoption) were made for the entire data (all NordicWay 2 countries together), not for each individual country. The main results are presented in this chapter. Note that differences between driver groups (age, gender, driving experience and technology adoption) are mentioned only if those were statistically significant ($p<0.05$). Further results, including the full distribution of responses per country further utilised in the socioeconomic impact assessment, are presented in Annex 8.

In all, the driver sample was quite similar in all participating countries; there were slightly more male (55–58%) than female (42–45%) drivers, the largest age groups overall were 26–50 years (Finland & Sweden) or 51–65 years (Norway). In Denmark, the oldest group, 66 years and older, was the largest group in the sample (Figure 28).

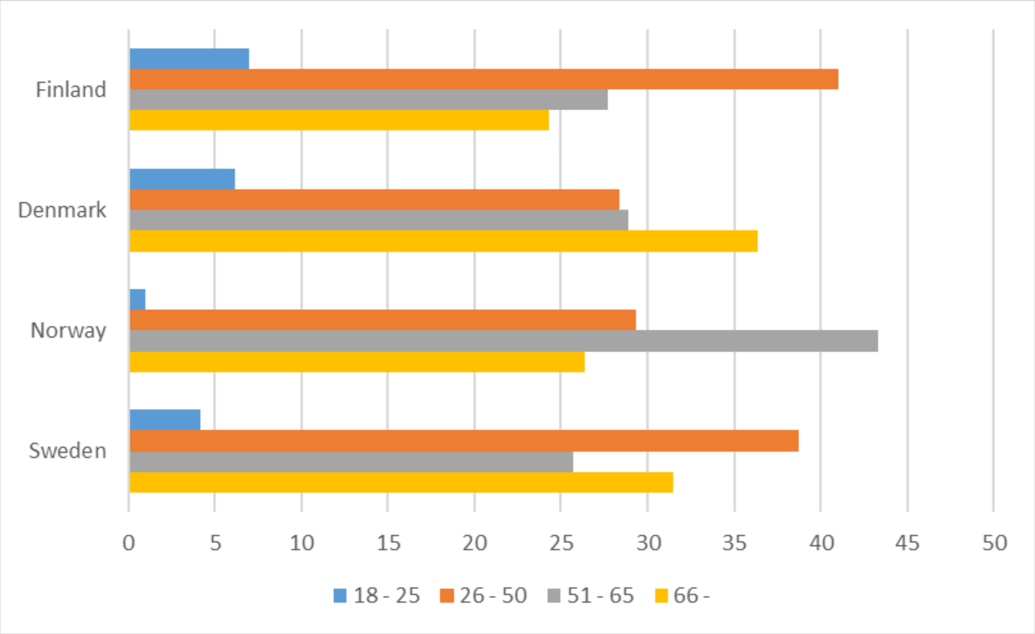


Figure 28. Respondents' age distribution

Most of the respondents reported their annual kilometres driven to be under 20 000 km. In Denmark, the largest group was in the category 1 501–10 000 km, whereas in all the other countries the largest share of respondents was in the category 10 001–20 000 km.

Most of the respondents (63–72%) considered themselves to be average in technology adoption. The share of late adopters varied between 28% (Denmark) and 14% (Norway).

4.3.2 Awareness of C-ITS services

In all, 34–45% of respondents were at least somewhat familiar with the C-ITS services (Figure 29). Their own experience with the systems was, however, still quite limited, as only 3–6% of respondents had used them by themselves. It is also notable that over half (54–65%) of the respondents had not heard about C-ITS before this survey.

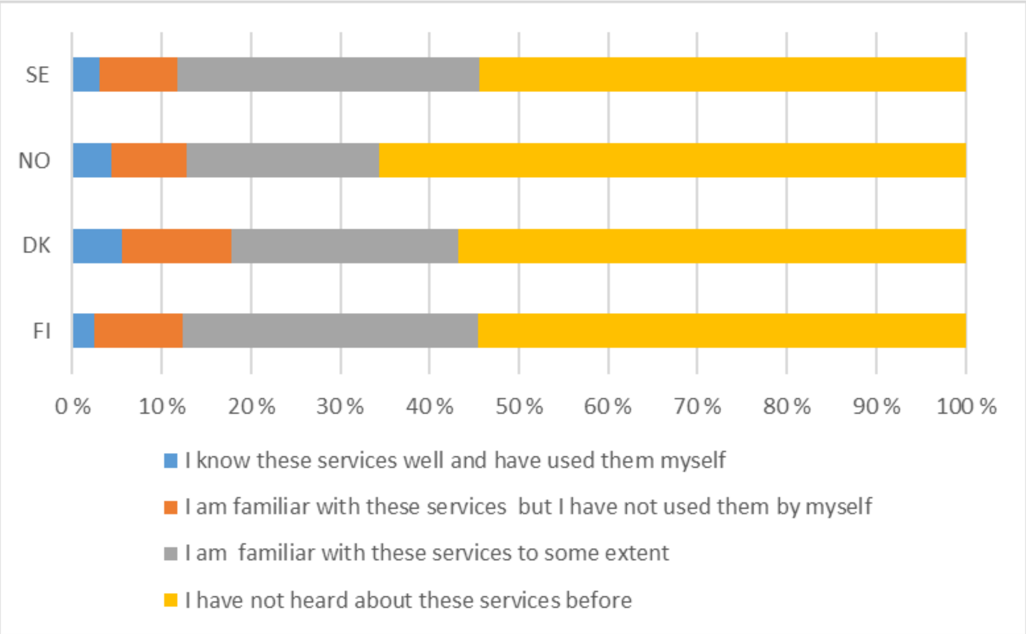


Figure 29. Awareness and actual usage of C-ITS services.

Overall, male drivers were more aware of the services than female drivers. Awareness decreased with age and increased with annual mileage. Awareness was overall highest among early technology adopters. These results are well aligned with earlier studies related to ITS or C-ITS (e.g., Penttinen et. al. 2019, Penttinen & Luoma 2020)

4.3.3 Importance of information content

The most important information contents for trips made on motorways or main roads were all types of information contents indicating some kind of road blockage — either an accident, obstacle, closure or large animals on the road (Figure 30). All these scored on average 6 or above on a scale of 1–7, where 7 was 'very important' and 1 'not at all important'. When taking into account all responses, the location of alternative fuel/charging was not scoring as high as other pieces of information. However, for those drivers who selected 'petrol, 'electricity' or 'other' as energy source(s) of their vehicle, the average was higher, over 5. If analysing only those drivers (147 in the whole sample) with fully electrical vehicles (FEV), then the average is ever higher, 5.5.

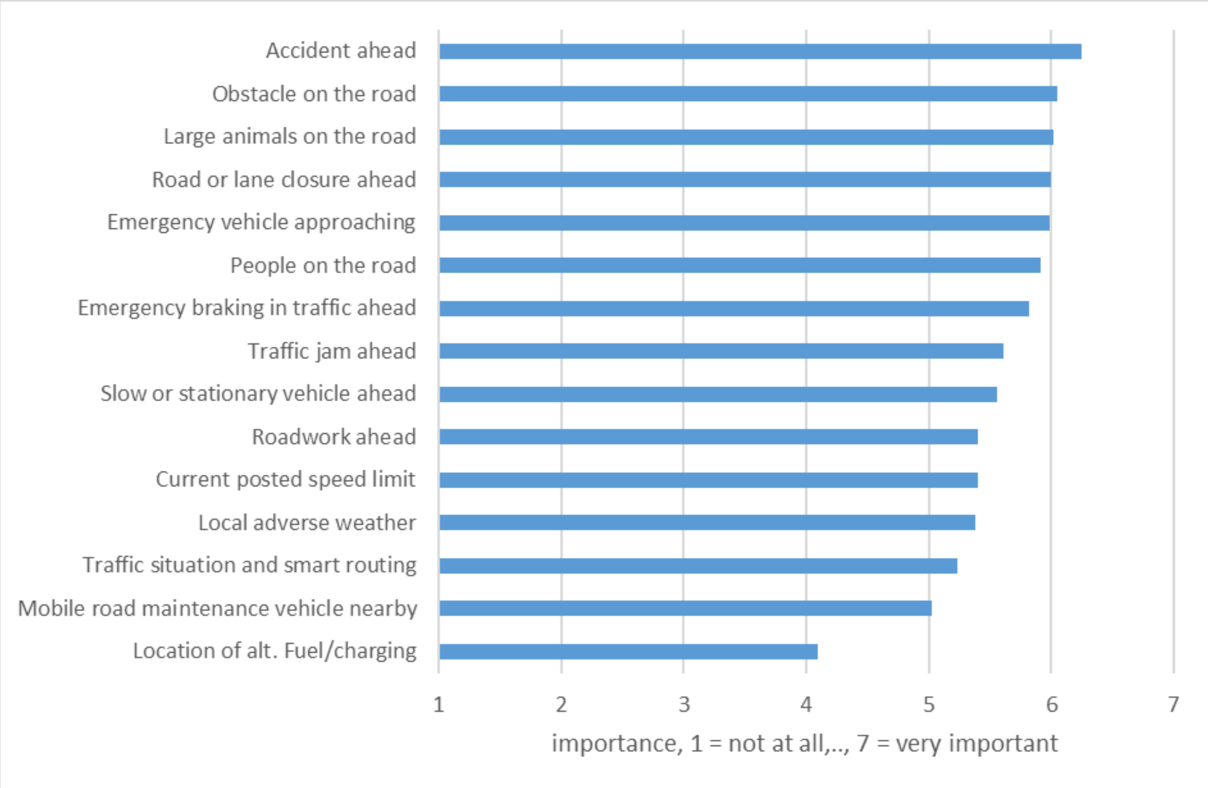


Figure 30. Importance of information content for trips made on motorways or main roads.

For trips made on urban streets (Figure 31), slightly different information contents turned out to be more important than for motorways or main roads (Figure 30). Three contents — emergency vehicle approaching, accident ahead and road or lane closure — all scored over 5.5 on a scale of 1–7 (Figure 31). Warning about potential red-light running was also considered important in both cases: warning the driver if they are about to run a red light or if someone else is about to do it. It is worth noting that overall, the information was seen as slightly more important when driving on motorways or main roads than when driving in an urban environment. Concerning information about alternative fuel or charging stations, the same applies in urban environments as on main roads or motorways: information is more important for those who have alternative fuel or electricity as the only energy source for their vehicle. The score for all of these was 4.5, and for those with a fully electric vehicle it was higher, at 5.0.

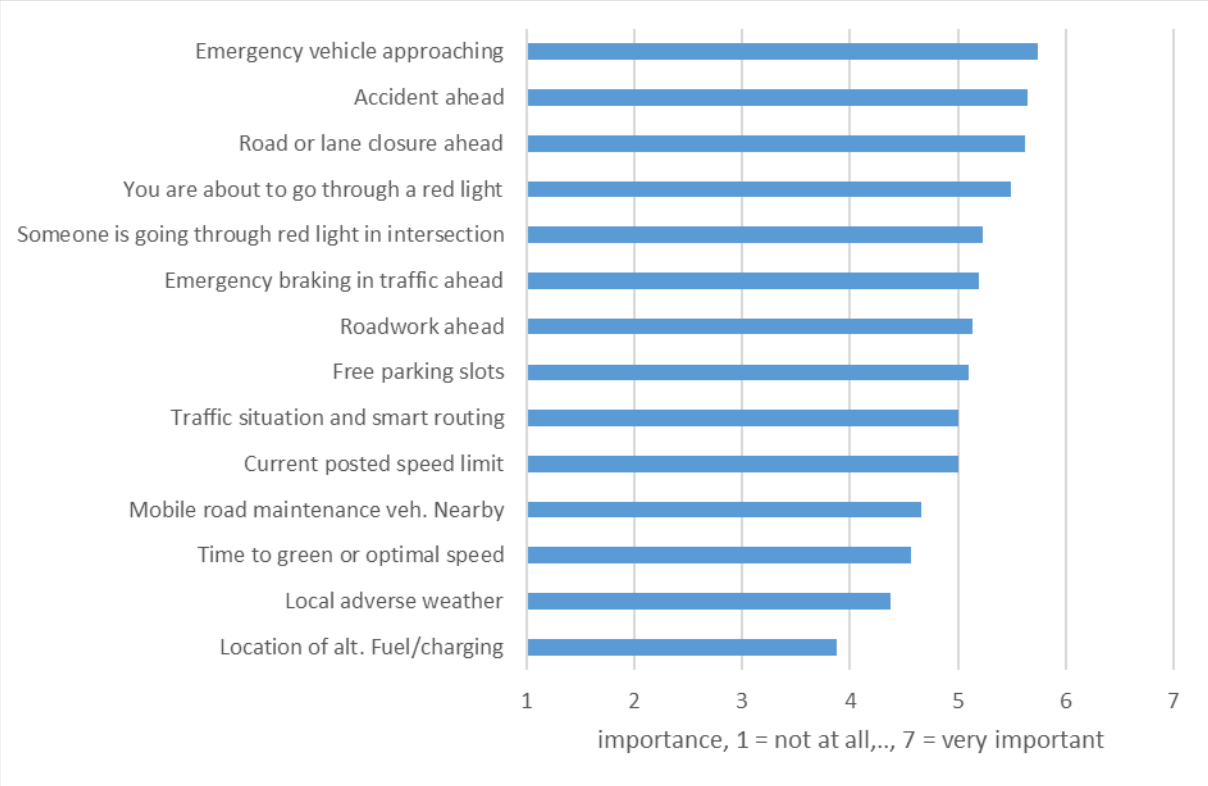


Figure 31. Importance of information content for trips made on urban streets.

4.3.4 Benefits and potential disadvantages of C-ITS services

Drivers were asked how much they agree with various statements concerning the potential benefits or potential disadvantages of C-ITS services (Figure 32). In all, C-ITS services were seen most often as improving fluency (5.7 on a scale of 1–7 where 1 = 'fully disagree' and 7 = 'fully agree') or safety (5.6). Drivers were more willing to use the services on main roads and motorways (5.6) than on urban streets (4.9). This aligns well with the earlier stated importance of information content, where the listed information contents were seen overall as more important on motorways and main roads (Figure 30) than in urban environments (Figure 31). In both environments, early adopters of technology were more willing to use the services than people considering themselves late adopters. The same is true of all the statements concerning potential benefits and willingness to use and pay for; early adopters are more willing to use and pay for the services, and they consider those more useful than late adopters. In contrast, late adopters report more often that the services would distract them and that the services are useless.

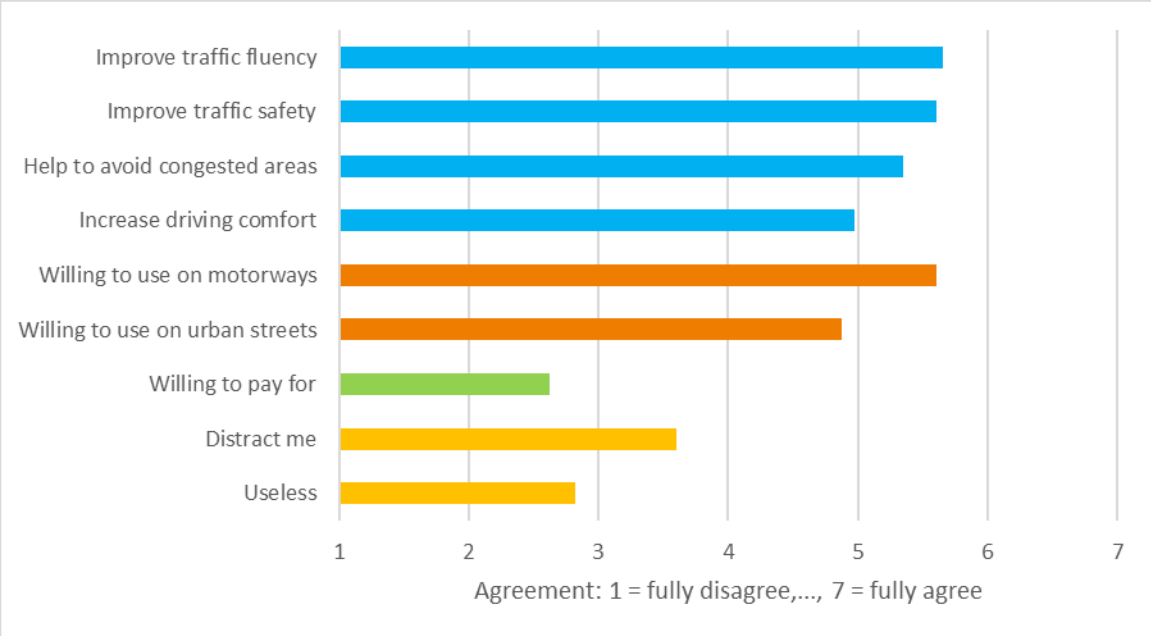


Figure 32. Benefits and potential disadvantages of C-ITS services.

When analysing the opinions per age group, it seems that older drivers would be more willing overall to use the services, and consider them more beneficial than young drivers do. Young drivers also reported more often that the services are useless and would distract them. Overall, drivers were not too concerned about distraction (3.6) and found the services generally rather useful (disagreement with an average score of 2.8 for the service being useless). However, the willingness to pay is still quite low (2.6). The share of respondents willing to pay (selected 5 or higher on the 7-point scale) was 15% and an additional 15% were unsure (selected 4, the neutral alternative, on the 7-point scale).

4.3.5 Willingness to share data

Drivers were most willing to share data related to weather or road conditions collected by their vehicle (Figure 33); 47% of them were willing to share the data and an additional 30% were considering it. The speed and location of one's own vehicle raised the most concerns (with only 40–41% 'yes', 35–36% 'maybe' and 18% 'no'), whereas willingness to send manual warnings got the most unsure reactions (10% compared to 6–8%). Nevertheless, 75–82% of respondents considered for all data types that they would be willing or might be willing to share these data with the service provider.

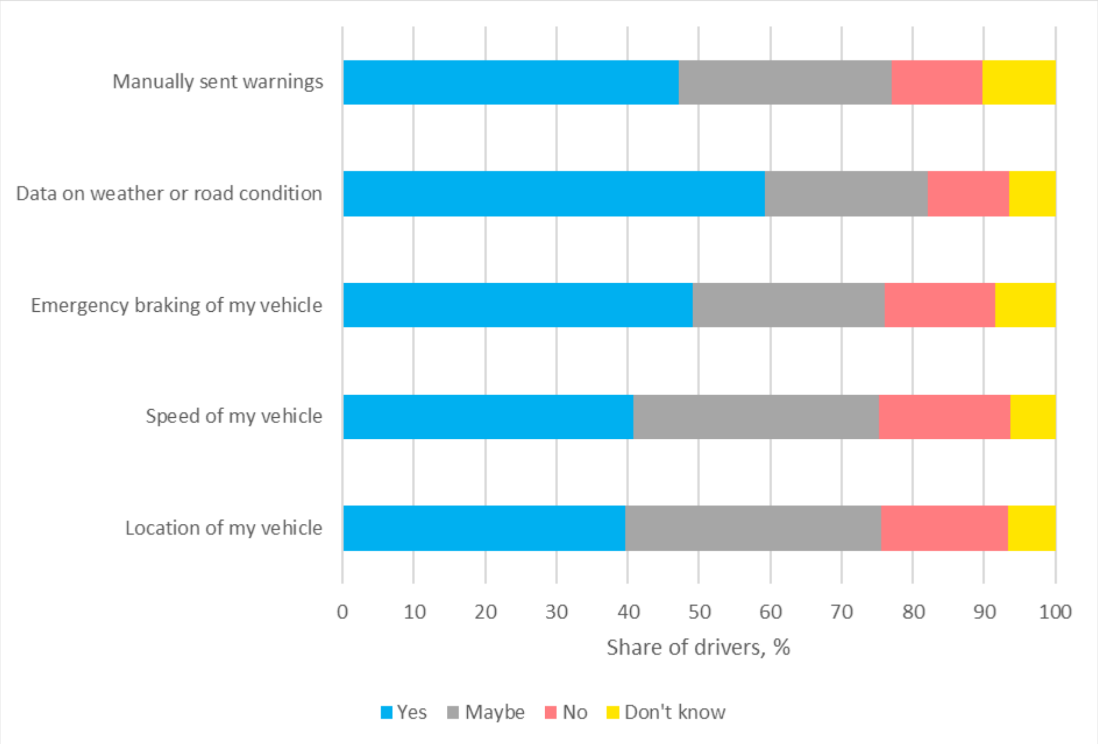


Figure 33. Willingness to share data.

When analysing the willingness of the respondent groups to share data, the following trends were observed: men were more willing than women, younger drivers than older ones, and early adopters of technology than late adopters. Additionally, female drivers, the oldest drivers and late technology adopters responded more often "not sure" for willingness to share the data. One interesting finding is the effect of age; even if younger drivers found the services useless and potentially distracting, they were nonetheless more willing to share data needed for the services than were older drivers.

4.3.6 Willingness to use in various contexts

In all, 44% of the drivers stated that they would be willing to use C-ITS services always or on most of their trips. Almost the same share, 40%, stated that they would use the services on selected trips. Of drivers who selected the option 'on selected trips' (N = 1633), most of them said they would be willing to use the services on longer trips (73%) and on unfamiliar routes (64%) (Figure 34).

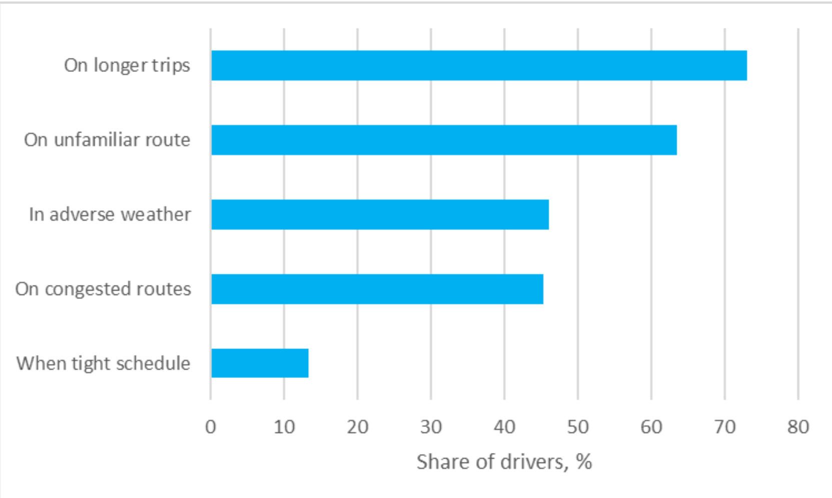


Figure 34. Willingness to use C-ITS services on various contexts.

On average 45% of Nordic drivers drive abroad. This varies from 28% of Finnish drivers to 60% of Norwegian drivers. The average score for the importance of having the C-ITS service available also abroad was 5.4 on a scale of 1–7 for drivers who indicated driving abroad. The countries where this use abroad would be relevant included the other Nordic counties (73–95% depending on the country) and Central Europe (45–64%) for all countries. Also, Southern Europe was considered important by relatively many (34–44%). However, the Baltic countries and Russia were considered more important by Finnish drivers (58% and 16% respectively) than by drivers of other countries (1–5%).

4.3.7 Summary

Four high-level research questions (Table 30) summarise the more detailed research questions set for the user acceptance study in NordicWay 2 (Table 4). Based on the survey results, all of the C-ITS service contents were considered important or relevant in Nordic conditions. The most important information contents for trips made on motorways or main roads were all of the type indicating some kind of road blockage — either accident, obstacle, closure or large animals on the road. For trips made on urban streets, emergency vehicle approaching, accident ahead, road or lane closure and warning about potential red-light running were considered the most important.

Table 30. High-level research questions set for the user acceptance study

RESEARCH QUESTION	INDICATOR
Which C-ITS services/messages are relevant in Nordic conditions?	Relevance
Which C-ITS services/messages are feasible to deploy in Nordic conditions? (User viewpoint)	Feasibility & barriers
What is the willingness to use?	Willingness to use
What is the acceptance of the systems?	Acceptance

Feasibility of deployments in Nordic conditions was addressed in the user study by willingness to share data with the data provider and willingness to pay. Willingness to share data was quite high, and 75–82% of respondents considered for all data types (manually sent warnings and weather or road conditions, emergency braking, speed and location of the vehicle) that they would be willing or might be willing to share these data with the service provider. Willingness to pay for C-ITS services may become a barrier to deployment, as the share of respondents willing to pay (selected 5 or higher on the 7-point scale) was only 15% and an additional 15% were unsure (selected 4, the neutral alternative, on the 7-point scale).

Respondents considered the information content important for both motorways and main roads, as well as for urban environments. They also perceived the services to have safety, fluency and comfort benefits and did not expect the services to distract them.

Willingness to use was high for the C-ITS services. In total, 84% of respondents considered that they would use these services either on all trips or on selected trips, especially on long trips or on unfamiliar routes. Having the C-ITS services available also in other Nordic counties and in Central Europe was considered important by those who drive abroad.

In conclusion, C-ITS services were considered relevant and the acceptance was high. It must be borne in mind, though, that most of the drivers (54–66%) had never heard of C-ITS services and only 3–6% had used these services themselves. Thus, even if there is acceptance for those who know or are informed about these services, the overall awareness is still rather low. In addition to lack of awareness, also lack of willingness to pay may become a barrier to deployment of the services. It is also important to note that since so few drivers had personal experience of the services, the results should be considered indicative, and later when the services become more widely known and used, issues such as HMI may become more relevant for acceptance and willingness to use.

4.4 Driver behaviour

4.4.1 Emergency vehicle approaching

[*Chapter 4.4.1 summarises the results published originally in Lidestam et al. (2020).*]

The EVA message affected the distance to the ambulance when giving way such that the two versions of EVA 1 and EVA 2 caused the driver to give way earlier (i.e., at a greater distance before the ambulance caught up). There was also an interaction effect between the EVA message and the baseline order, such that when EVA 0 (no EVA) was the first condition, and EVA 1 [EVA message on the instrument cluster alone] and EVA 2 [EVA message on the instrument cluster and on the infotainment display of the centre console] followed, drivers did not give way as early when there was no EVA message, but then gave way much earlier. However, when EVA 1 and EVA 2 initialised the test and EVA 0 finished it, the drivers gave way roughly as early, even when there was no EVA message, which implies a learning effect. See Figure 35 for a summary of these results.

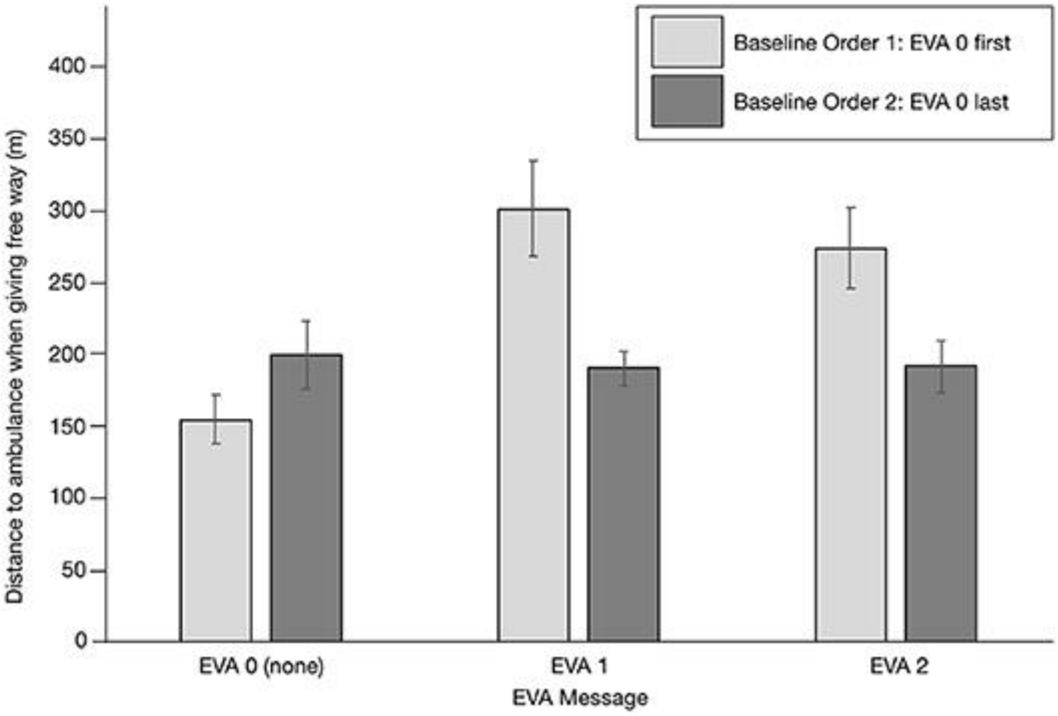


Figure 35. Mean distance (± SE) to ambulance when giving way by exceeding 3 m lateral position from the road centreline, by Baseline Order and EVA Message.

For lateral position when the ambulance was alongside the participant and speed when the ambulance was alongside the participant, no effects were found.

In conclusion, the EVA message had a significant effect on how early the drivers gave way, such that the EVA message made the drivers give way at much greater distances to the ambulance than when there was no EVA message. There was also a learning effect such that after receiving the EVA message, the drivers gave way early even though there was no EVA message. The EVA message thus improved the driver's propensity to give way early.

4.4.2 Reindeer warning

[*This chapter provides a short summary of a Finnish survey study on the self-assessed driving behaviour effects of a reindeer warning system. Details are reported in Kotituomi et al. (2019).*]

The Porokello survey results regarding self-assessed driver behaviour impacts of the reindeer warning, both for persons giving warnings and users, are shown in Figure 36. The percentages have been calculated assuming that if the respondent did not say “no effect”, “cannot say”, or “only had an impact when I saw a reindeer”, the alert had had an effect on the factor in question. As the respondents were able to select several detailed impacts under each factor, the totals of the percentages for different impacts could not be calculated.

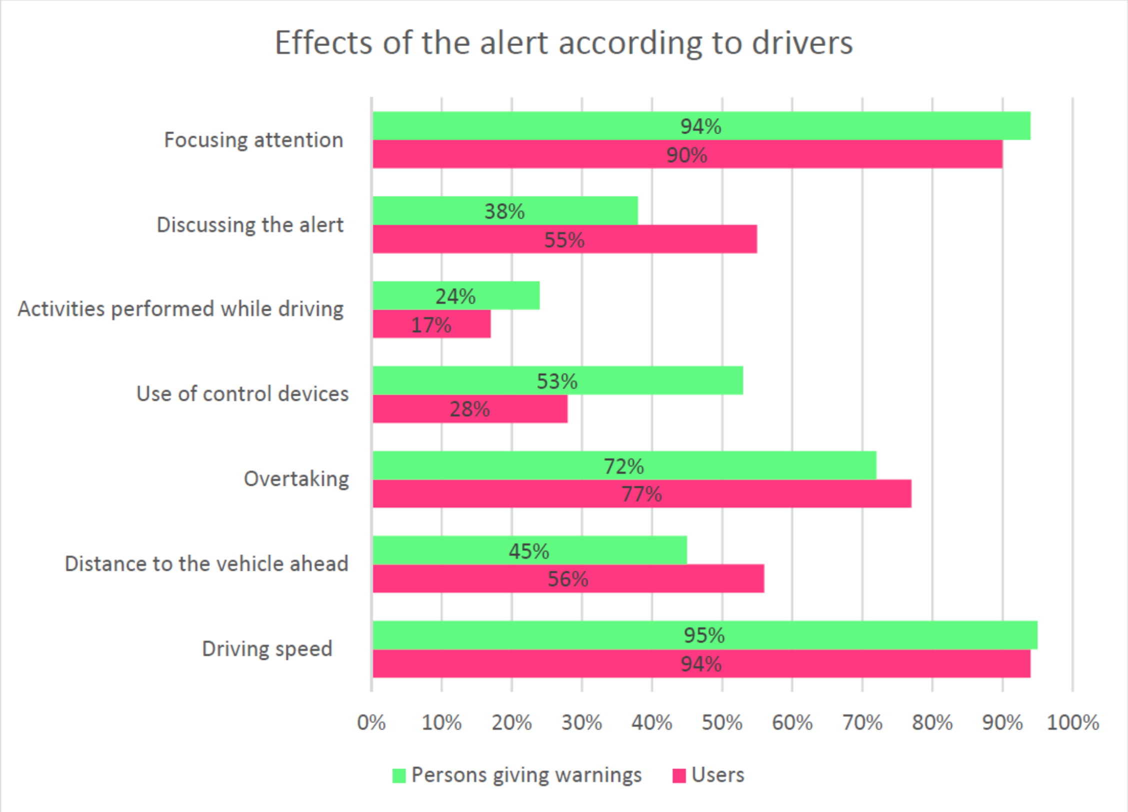


Figure 36. Effects of the alert on driving behaviour according to the Porokello survey (persons giving warnings: n = 55; users: n = 126)

Effects on focusing the driver's attention came up as the most important impacts. During the Porokello trial, impacts on driving speeds and overtaking behaviour were significantly greater than in the previous trial of a reindeer alert service (Aittoniemi et al. 2015). Talking about the alert was also more common during the Porokello trial. Part of the reason for this probably is that in the previous study, the service was only trialled by professional drivers, who mostly were driving alone.

According to the Porokello survey, in the selected incidents the alert had the greatest impact on focusing the driver's attention and the driving speed. In focusing the driver's attention, key impacts on identified factors were cited as keeping a lookout for possible reindeer and other animals on road margins; this was mentioned by 87% of the persons giving warnings and 82% of the users. For other identified impacts associated with alertness and their proportions in the responses, see Figure 37. The number of options the respondents could choose was not limited. In the freely worded text field (question: in other ways, how?), looking for animal tracks in the snow was also mentioned.

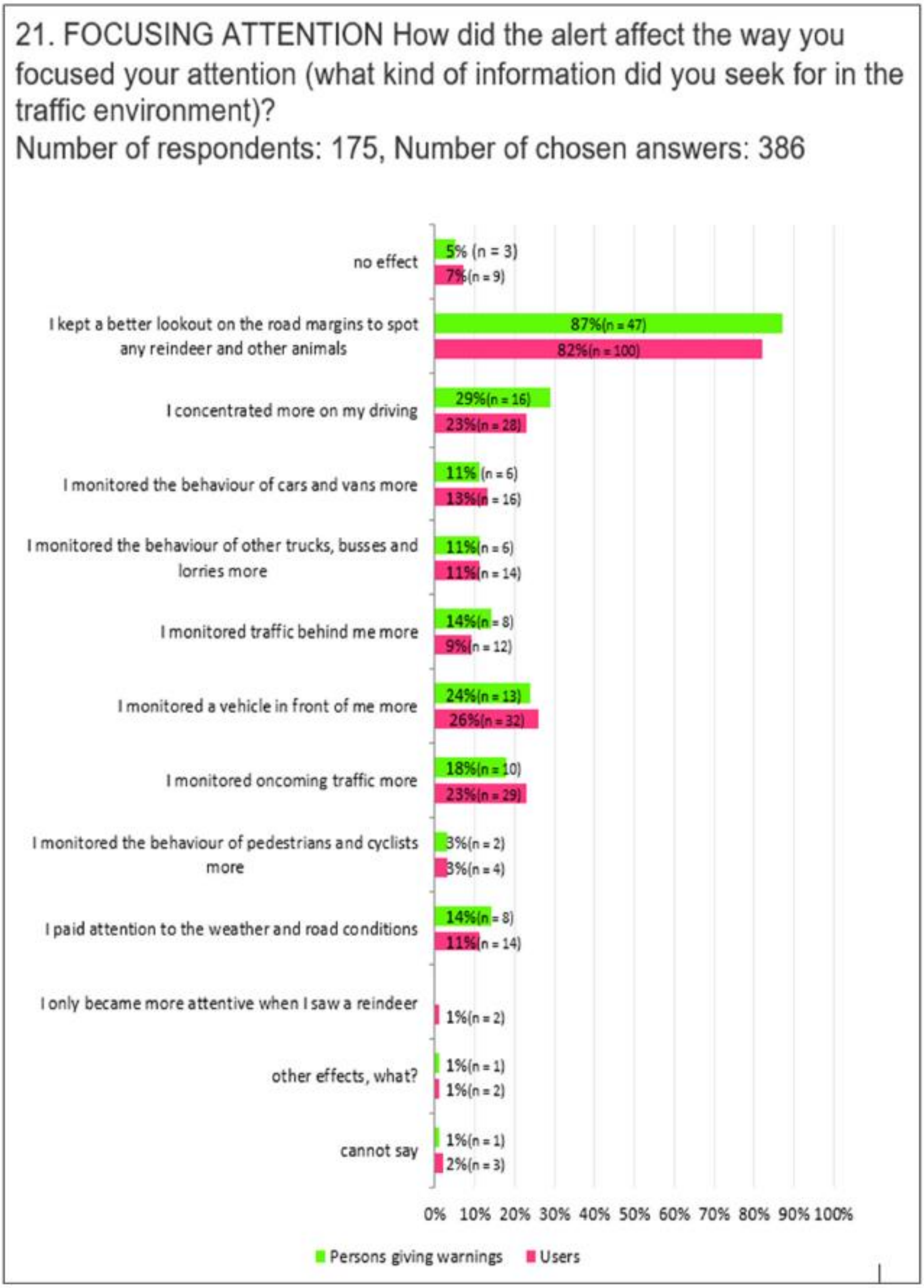


Figure 37. Impact of an alert on focusing the driver's attention based on Porokello survey

The alert had an almost equal impact on the driving speed as on alertness: 87% of the persons giving warnings and 81% of the users said they had slowed down after receiving an alert. For other identified impacts associated with driving speed and their proportions in the responses, see Figure 33. The number of options the respondents could choose was not limited. In the freely worded response fields, such aspects as increased general alertness were mentioned.

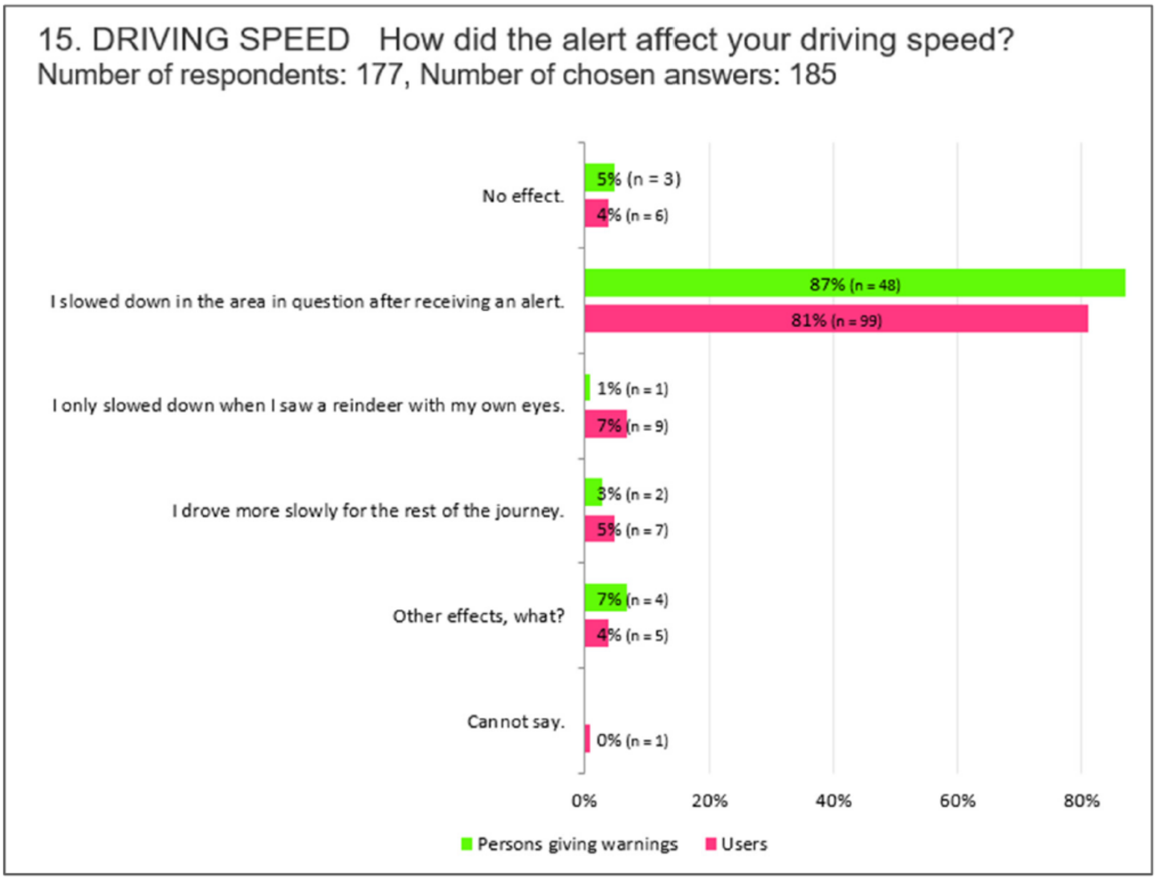


Figure 38. Impact of the alert on driving speed based on Porokello survey

Other significant impacts on driving behaviour mentioned by the respondents were:

- Overtaking: I attempted to avoid all overtaking (persons giving warnings 51%, users 54%)
- Distance to the vehicle in front of you: I maintained a longer distance to the vehicle in front of me (persons giving warnings 45%, users 55%)
- Talking about the alert: I talked about the purpose of the alert with a passenger (persons giving warnings 31%, users 51%).

4.5 Socio-economy

[*In this chapter, official statistics are used when available. Reference is given to the estimates that are based on earlier studies. If no reference is given with an estimate, it is based on expert assessment verified in NordicWay 2 Evaluation group.*]

4.5.1 Mobility

As a specific response to the service, the amount of travel is likely affected by the route guidance type of services, i.e., fuel & charging information, on-street parking information, and traffic information and smart routing. These services will have little to no impact when the driver is familiar with the route to the destination or already has a certain parking establishment or location in mind.

On average, a Finnish person makes 22 long journeys annually, often to an unfamiliar destination (FTA 2018). This means about 2% of the annual number of journeys but as much as 15% of the total kilometres driven. Dynamic navigation systems have been found to shorten journeys by about 6% in highly motorised countries (van Rooijen et al. 2008). In Finland, with less dense road networks than most highly motorised countries, there are fewer alternative routes and the effect could be about 0.7–1.0% on average. This would mean a roughly 0.10–0.15% reduction of annual distance driven for these longer journeys. Naturally, the service will also affect some other journeys to unknown destinations, and the total effect could be a 0.15–0.20% reduction in annual vehicle kilometres. Concerning fuel and charging stations and on-street parking spaces, the annual effect will be clearly smaller — perhaps 0.007–0.010%.

Public transport priorities have an impact on mobility by making the use of public transport more attractive via improved punctuality and reduced travel time. Public transport signal priorities and public transport information at stops have been shown to increase the number of public transport passengers by 11% on tram and bus lines (Lehtonen & Kulmala 2002). The effect due to priorities alone would today and in 2030 be lower, perhaps 8%. This 8% is the magnitude of the effect of having all signals service along public transport lines equipped with signal priorities, compared with no priorities at all. The effect is due to more public transport journeys by experienced public transport users but also to having new users. Some new public transport users have been users of cars or bicycles and some pedestrians. In the larger Finnish cities, cars, vans and trucks correspond to 80% of the average daily journey kilometres, the corresponding share for public transport is 15% and active modes 5% (FTA 2018). The assumption is that 10% of the increasing journeys are due to a shift from former car users, 45% from active transport users, and 45% due to more journeys by public transport users. This impact is only relevant for urban areas.

The C-ITS services for car drivers in total may also influence mobility by making one's own car a more attractive travel option due to increased awareness and a feeling of being more informed. Some of the warning services may also increase distances driven, as some service users may utilise alternative routes to evade the problem warned about. This effect is quite small, and a reliable estimate of its magnitude could not be made. The effects of a small 0.05–0.10% increase in the annual vehicle kilometres were, however, checked in the sensitivity analysis.

4.5.2 Safety

Direct safety effects

The safety effects were calculated as low and high estimates taking into account the low and high effectiveness estimates. The low and high estimates of direct safety effects in the 100% use situation are presented in Table 31. The in-vehicle speed limits, emergency brake lights and slow/stationary vehicle and traffic ahead warnings (Slow Vehicle) would be most efficient in the 100% use situation.

Table 31. Effectiveness in terms of percentages of injury crash reductions due to direct safety effects of the C-ITS services selected in 100% use situations on different road networks in Finland. EBL = Emergency brake light, EVA = Emergency vehicle approaching, IVSL = In-vehicle speed limit, RWW = Road works warning, RLC = Road closure, SV/IS = Signal violation / intersection safety, TTG = Time to green, GLOSA = Green light optimal speed advisory, TI = Traffic information, AWWD = Alert wrong way driver

Finnish network	Slow vehicle	Weather	EBL	EVA	Other hazard	IVSL	RWW-RLC	RWW-Mobile
Low effectiveness								
1: Long and/or heavily trafficked tunnels	0.97	-	2.89	0.02	-	2.25	0.27	0.19
2: "Full telematics network" – E18 including Ring III	0.87	0.14	2.57	0.02	0.74	2.25	0.27	0.19
3: Heavy traffic peri-urban motorways and roads	0.90	0.10	2.66	0.03	0.49	2.25	0.27	0.19
4: "TEN-T main network" excluding the above	0.39	0.01	0.42	0.02	0.78	2.25	0.12	0.19
5: Other main public roads network	0.36	0.01	0.39	0.02	0.73	2.25	0.12	0.19
6: Main streets in the biggest cities	-	0.00	0.11	0.01	0.04	2.25	0.11	0.10
High effectiveness								
1: Long and/or heavily trafficked tunnels	1.49	-	3.85	0.03	-	4.00	0.81	0.26
2: "Full telematics network" – E18 including Ring III	1.33	0.24	3.43	0.03	1.23	4.00	0.81	0.26
3: Heavy traffic peri-urban motorways and roads	1.37	0.17	3.55	0.04	0.82	4.00	0.81	0.26
4: "TEN-T main network" excluding the above	0.66	0.02	0.59	0.03	1.31	4.00	0.36	0.26
5: Other main public roads network	0.60	0.02	0.54	0.03	1.22	4.00	0.36	0.26
6: Main streets in the biggest cities	0.17	0.01	0.22	0.03	0.08	4.00	0.21	0.16

Finnish network	SV/IS	Priority request	TTG	GLOSA	Fuel & charg.	On-str. park	TI & routing	AWWD
Percentage of relevant accident type for direct safety effect of the service								
1: Long and/or heavily trafficked tunnels	-	-	-	-	-	-	-	0.04
2: “Full telematics network” – E18 including Ring III	-	-	-	-	-	-	-	0.05
3: Heavy traffic peri-urban motorways and roads	-	-	-	-	-	-	-	0.06
4: "TEN-T main network" excluding the above	-	-	-	-	-	-	-	-
5: Other main public roads network	-	-	-	-	-	-	-	-
6: Main streets in the biggest cities	0.40	0.00	0.12	0.24	0.00	0.00	0.00	0.03
Percentage of target accidents out of the crashes of the accident type above								
1: Long and/or heavily trafficked tunnels	-	-	-	-	-	-	-	0.05
2: “Full telematics network” – E18 including Ring III	-	-	-	-	-	-	-	0.06
3: Heavy traffic peri-urban motorways and roads	-	-	-	-	-	-	-	0.08
4: "TEN-T main network" excluding the above	-	-	-	-	-	-	-	-
5: Other main public roads network	-	-	-	-	-	-	-	-
6: Main streets in the biggest cities	0.53	0.00	0.24	0.48	0.00	0.00	0.00	0.05

Indirect safety effects

Concerning the impact mechanisms M3–M9, the assessments are listed below.

‘Indirect modification of user behaviour’ (M3) was assessed to be relevant for all services providing warnings and similar types of information due to over-reliance on the coverage and reliability of the system. For some warnings, the situations are so rare and exceptional that the effect is negligible; examples include wrong-way driver and driver running a red light. For signal priorities, the drivers of emergency vehicles may approach signals at higher speeds. With regard to time-to-green and GLOSA, the effect is expected to be negligible.

The magnitude of this impact is not easy to estimate and was left at zero in the basic calculations. In the sensitivity analysis this effect was included. Calculated for the whole bundle of services, this over-reliance could mean a slight increase in speed (0.3–0.5%) for the equipped free-driving vehicles (i.e., for those not following another vehicle) on the networks studied. This means an injury accident increase of about 0.6–1.0%, and a fatal accident increase of about 1.2–2.0% according to Nilsson (2004). As not all vehicles are free, the effects are reduced by 5% on low-volume roads, 15% on high-volume roads, and 50% on urban networks, assuming that the percentages of vehicle kilometrage driven in platoons are of such magnitude.

‘Indirect modification of non-user behaviour’ (M4) was also assessed to be relevant for all services where the vehicle behind the user needs to slow down due to the user’s (stronger or earlier) speed reaction to the warning. M4 may also be observed in overly short headways or risky overtaking if the following non-user does not understand the reason for the reaction of the user. Hence, the effects of this impact mechanism were assessed to be negligible in the calculations and left at zero for all other services than in-vehicle speed limits. For that service, the service also affects the speeds of all vehicles in platoons following the equipped ones. As the service lowers the speeds of the vehicles to reduce their fatal crash risk by 8–10 % (Elvik & Høye 2015), this would mean a reduction of crash risk of 4–5% according to Nilsson (2004) if the effect is solely due to speed change. If a vehicle is assumed to drive in a platoon, 5% of the vehicle km driven on networks with low volumes and 15% on networks with high volumes, the effect of M4 could be an injury crash risk reduction of 0.20–0.25% on low-volume networks and 0.60–0.75% on high-volume networks. The corresponding numbers for fatality risk would be 0.4–0.5 % and 1.2–1.5 % reductions. On streets, with 50% platooning the impact would be 2.0–2.5% injury crash and 4–5% fatal crash reductions.

‘Modification of interaction between users and non-users’ (M5) was assessed to be relevant for most services. The effect could be positive for the warnings for low or stationary vehicle ahead, other hazardous location notification, signal violation warning, and alert wrong-way driver when the danger is visible and the risk highest. On motorways, some users might even hog the left lane to prevent others driving too fast to the incident site, but this can be misunderstood by non-users and cause hazardous behaviour such as risky overtaking (Innamaa et al. 2017). M5 was assessed to be relevant for all services in terms of somewhat less attention being paid to other road users in favour of the object of the warning or information provided by the service. In conclusion, as the potential mechanisms in M5 may include both positive and negative reactions, it was left at zero in the calculations.

‘Modification of road user exposure’ (M6) has already been detailed in the mobility effects. This is relevant for the route guidance type of services i.e., fuel & charging information, on-street parking information, and traffic information and smart routing. Traffic information and smart routing is estimated to reduce the annual distance driven by about 0.15–0.20%. Fuel and charging station and on-street parking space information would reduce travel by 0.007–0.010%. The exposure is also estimated to increase by 0.05–0.10% due to more comfortable driving due to C-ITS and increased use of detours in incident cases.

‘Modification of modal choice’ (M7) was assessed to be relevant for a small proportion of users of a weather warning service in adverse road weather conditions (long journeys), in cases where they felt safer if they trusted the system to pinpoint dangerous locations (Innamaa et al. 2017). In practice, this impact mechanism was left at zero in the calculations. The mobility effects of public transport priorities described earlier have a safety impact. The fatality rates in active transport and car travel are higher than for public transport users (Peltola & Aittoniemi 2008) — for car users twice as high and for active transport users 10 times as high as for public transport users. The mobility changes result of a 0.12 percentage point reduction in car travel, 0.54 percentage point reduction in active transport use, and 1.2 percentage point increase would result in a fatality rate drop of 2%. This could correspond to an injury accident risk decrease of perhaps 1%.

The use of personal cars could be made more popular with fuel and charging information, on-street parking information, and traffic information and smart routing services. As this could attract travellers from both safer (public transport) and less safe modes (walking and cycling), this effect is left at zero for these services.

‘Modification of route choice’ (M8) was assessed to be relevant for weather warning, fuel and charging information, on-street parking information, and traffic information and smart routing services. For weather warning services, the effects could occur in instances of adverse weather when the driver assumes that another route has less adverse conditions due to e.g., better winter maintenance. In such cases, the new route will likely be longer than the one originally planned, compensating for the improved safety due to less adverse conditions. Hence, the effect is likely negligible. For traffic information and smart routing, the route choices would likely be to roads of a lower road hierarchy, i.e., to lower-class roads with higher accident rates than the original route intended (van Rooijen et al. 2008). In essence, this would eliminate the safety benefits due to less exposure from M6. For fuel and charging station information and on-street parking information, the route changes may not lead to more traffic on less safe roads. Hence, the impact of M8 for these services is regarded as negligible.

Concerning M9 ‘Modification of accident consequences only’, signal priorities for emergency vehicles lead to quicker access to accident injury treatment by emergency vehicles. The priorities are estimated to reduce emergency vehicle journey times in cities by 10% (Ramboll 2018). This would likely have reduced the fatalities occurring on urban networks by a similar amount as eCall, which according to Virtanen et al. (2005) would have reduced fatalities by 4.6%. This percentage applies when all relevant signals are equipped with priorities compared to none being equipped. The impact on fatalities on other road networks were estimated to be negligible.

4.5.3 Efficiency

Important efficiency effects are due to the reduction of crash-related congestion resulting from the decrease of road crashes.

Li et al. (2006) point out that almost 60% of congestion in the U.S. is caused by incidents including also poor weather, road works, and other traffic events. Unforeseen traffic incidents, including crashes, are responsible for only about 25% of cases of road congestion (Cambridge Systematics 2005). Crash-related congestion is more severe than that caused by other traffic incidents due to considerably higher clearance times for crash related incidents, especially for fatal and injury accidents (Wang et al, 2008).

The proportion of incident-related congestion cases out of all congestion cases is higher the lower the road's average daily traffic volume is in relation to the road's capacity. At the same time, the consequences of incident-related congestion are more severe the higher the traffic volumes are. Crashes can be estimated to account for 30–40% of vehicle hours lost due to congestion in the vicinity of metropolitan areas in the U.S. on the basis of the results of Cambridge Systematics (2005).

On the Finnish networks, the share of incident-related congestion is much lower than in the U.S. on city streets and high-volume networks. In Finland, events such as road works cause much more congestion than incidents on these networks. The share of incident-related congestion is, however, considerably higher than in the U.S. on low-volume networks. (Lindholm 2020).

Thus, on high-volume networks in the NordicWay 2 area, the share of incident-related congestion of congestion-related travel time delays is estimated to be 10–15%. The shares on low-volume networks is estimated to be 60–70% and on city streets 5–10%.

In addition, positive efficiency effects arise from the decreased distance driven due to the aforementioned mobility effects of traffic information and smart routing, fuel and charging information, and on-street parking information, as well as increased driving speeds due to behavioural modification reported under the safety effects. Efficiency is affected negatively by the increase in vehicle hours driven due to increased use of private cars and (2.0–2.5 %) lower speeds due to in-vehicle speed limits. The effects of other changes are assumed to be negligible.

4.5.4 Environment

In the environmental impact assessment, we focus on CO_2 emissions. The impacts will be caused primarily by two main mechanisms. First, changes in mobility in terms of modal choice and especially vehicle kilometres driven are proportional to the changes in CO_2 emissions. However, for these networks this effect of estimated changes in modal choice would be relevant only for the urban network defined for Finland, and the magnitude of the impact was very small. Therefore, it was omitted from the overall environmental impact assessment. Second, changes in vehicle speeds will affect the amount of CO_2 emissions. The largest speed-related effects are due to the decrease of congestion described in the efficiency impacts, as less vehicles will use the low congested flow speeds with highest CO_2 emissions.

The first mechanism is easy to calculate by using the percentual change in CO_2 emissions as in vehicle kilometres, but for the second we need to make some assumptions. These assumptions and the calculations based on them are the following:

- CO_2 emissions are, according to FTIA (2020b), 50–60% higher at congestion speeds of around 20 km/h than at the average speeds on the networks. We used 55% for all networks assessed.
- For the selected network the number of vehicle hours spent in congestion is *vh-c.*
- The speed during the hours of congestion is 20 km/h and thereby the distance driven on congestion is '20 *vh-c'* vehicle km.
- If the total number of vehicle km driven on the network is VKM, the CO_2 emissions on the network are $CO_2(network) = 20\ vh\text{-}c \cdot 1.55\ A + (VKM - 20\ vh\text{-}c) \cdot A$.
- *A* is the average CO_2 emission per km driven in fluent traffic for the network in question, determined from the equation above, as we know the total amount of CO_2 emissions on the network.
- The reduction of congestion by a proportion of *b* thereby reduces the CO_2 emissions by '$b \cdot 20\ vh\text{-}c \cdot 0.55\ A$' on average.

4.5.5 Benefit and costs

In the socioeconomic assessment, all calculations were based on the 2030 deployment scenarios in different countries.

4.5.5.1 Benefits

The safety, efficiency and environmental benefits were calculated for all networks studied for 2030 for the low and high effectiveness values concerning the impacts. The calculation included all of the impacts of the various services with one exception. Concerning the benefits of in-vehicle speed limit information, the speed reduction impacts were assumed to be primarily due to reduction of speeding. According to DfT (2000), the disbenefit of increasing journey times of illegal, speeding drivers by reducing their speed should not be taken into account. Hence, these disbenefits are not considered in the assessment. However, they were taken on board in the sensitivity analysis.

National unit values were used to give the impacts monetary values. Table 32 gives the monetary value for the different impact types. The value of a prevented property damage-only accident was estimated to be 5 000 €.

Table 32. Unit values of benefits for the NordicWay 2 countries in 2030 in 2020 currency values

VALUES IN EURO, YEAR 2030	DENMARK	FINLAND	NORWAY	SWEDEN
TIME VALUES, EUR PER VEHICLE HOURS				
Travel time (passenger transport)	23.9	12.6	26.5	23.9
Delay time (passenger transport)	35.8	12.6	39.8	35.8
Travel time (freight transport)	75.8	51.8	75.4	75.8
Delay time (freight transport)	106.2	51.8	113.2	106.2
ACCIDENT VALUES, EUR PER ACCIDENT				
Fatality (one fatality)	5 134 243	3 601 561	3 622 404	5 134 243
Non-fatal injury accident	1 103 699	490 921	360 275	1 103 699
EMISSION VALUES, EUR PER TON				
CO_2 emissions	56.4	92.1	209.6	56.4

Table 33 shows the benefits in the high and low effectiveness scenarios in percentages for the different countries. Road safety is improved with fatal accidents dropping by 1.2–4.8% in the low and 1.7–6.3 % in the high scenario. The corresponding changes for less severe accidents are 0.9–2.0 % and 1.5–3.5%, respectively. The effects are lowest in Finland, where a large part of the networks consists of rural main roads with low levels of service and event coverage. Travel times are reduced by 0.01–0.04% in the low and 0.02–0.10% in the high scenario. Again, the average effect is lowest in Finland for the same reason as above. The changes in CO_2 emissions range from 0.01% to 0.07% in the low and from 0.03% to 0.10% in the high scenario.

Table 33. Percentual changes due to the deployment of C-ITS services in 2030 in the *low* and *high effectiveness* scenarios

LOW EFFECTIVENESS SCENARIO	DENMARK	FINLAND	NORWAY	SWEDEN
Vehicle hours driven (million/year)	-0.04%	-0.01%	-0.04%	-0.02%
Vehicle hours spent in congestion (M/year)	-0.004%	-0.002%	-0.003%	-0.0002%
Fatal accidents (number/year)	-3.3%	-1.2%	-4.8%	-3.9%
Non-fatal injury accidents (number/year)	-1.6%	-0.9%	-2.0%	-1.7%
Property damage only accidents (number/year)	-1.6%	-1.0%	-2.0%	-1.7%
CO_2 emissions (million tonnes/year)	-0.05%	-0.01%	-0.07%	-0.02%
HIGH EFFECTIVENESS SCENARIO	**DENMARK**	**FINLAND**	**NORWAY**	**SWEDEN**
Vehicle hours driven (million/year)	-0.10%	-0.02%	-0.10%	-0.02%
Vehicle hours spent in congestion (M/year)	-0.9%	-0.02%	-0.5%	-1.8%
Fatal accidents (number/year)	-4.5%	-1.7%	-6.3%	-5.2%
Non-fatal injury accidents (number/year)	-2.7%	-1.5%	-3.5%	-2.9%
Property damage-only accidents (number/year)	-2.7%	-1.6%	-3.5%	-2.9%
CO_2 emissions (million tonnes/year)	-0.07%	-0.07%	-0.10%	-0.03%

Table 34 and Table 35 show the quantitative benefits of the C-ITS services in 2030 on the networks of the NordicWay countries for the low and high effectiveness scenarios. The benefits are shown as changes in user-related costs. Negative numbers are a reduction in user costs and thereby real benefits. Positive changes indicate higher user costs and thereby disbenefits. The results for the different networks are shown in Annex 9.

Table 34. Benefits or user-cost changes due to the deployment of C-ITS services in 2030 in the *low effectiveness* scenario

BENEFITS IN NUMBER	DENMARK	FINLAND	NORWAY	SWEDEN
Vehicle hours driven (million/year)	-0.17	-0.05	-0.35	-0.09
Vehicle hours spent in congestion (M/year)	-0.0008	-0.0002	-0.0009	0.00
Fatal accidents (number/year)	-1.86	-1.02	-3.46	-2.48
Non-fatal injury accidents (number/year)	-7.6	-11.6	-47.2	-46.0
Property damage-only accidents (number/year)	-26.6	-51.3	-236.2	-334.7
CO_2 emissions (million tonnes/year)	-0.0024	-0.0005	-0.0032	-0.0018
VALUE IN MILLION €				
Vehicle hours driven	-4.58	-0.77	-9.63	-2.92
Vehicle hours spent in congestion	-0.032	-0.004	-0.038	-0.001
Fatal accidents	-9.52	-3.68	-12.55	-12.73
Non-fatal injury accidents	-8.34	-5.71	-17.02	-50.82
Property damage-only accidents	-0.13	-0.26	-1.18	-1.67
CO2 emissions	-0.135	-0.049	-0.662	-0.102
TOTAL VALUE OF CHANGES IN USER COSTS	**-22.7**	**-10.5**	**-41.1**	**-68.2**

Table 35. Benefits or user-cost changes due to the deployment of C-ITS services in 2030 in the *high effectiveness* scenario

BENEFITS IN NUMBER	DENMARK	FINLAND	NORWAY	SWEDEN
Vehicle hours driven (million/year)	-0.37	-0.06	-0.47	-0.12
Vehicle hours spent in congestion (M/year)	-0.17	-0.003	-0.16	-0.23
Fatal accidents (number/year)	-2.48	-1.40	-4.55	-3.29
Non-fatal injury accidents (number/year)	-13.03	-19.26	-82.21	-80.60
Property damage only accidents (number/year)	-45.94	-84.92	-411.06	-586.19
Co2 emissions (million tonnes/year)	-0.0034	-0.0044	-0.0046	-0.0026
VALUE IN MILLION €				
Vehicle hours driven	-10.221	-0.960	-12.872	-3.895
Vehicle hours spent in congestion	-7.046	-0.044	-6.374	-10.855
Fatal accidents	-12.74	-5.03	-16.49	-16.88
Non-fatal injury accidents	-14.38	-9.45	-29.62	-88.96
Property damage only accidents	-0.23	-0.42	-2.06	-2.93
Co2 emissions	-0.193	-0.404	-0.964	-0.145
TOTAL VALUE OF CHANGES IN USER COSTS	**-44.8**	**-16.3**	**-68.4**	**-123.7**

The results indicate considerable benefits from the services — most especially from better road safety. Travel time benefits also play a major role in the monetary benefits of other countries than Finland, where the primary part of the road network included in the assessment has very little congestion as well as low network and event coverages of the C-ITS services. CO_2 emissions have very little role in the monetary benefits of the services.

A sensitivity analysis was carried out by calculating the effects of five other scenarios:

1. Taking on board speeding-related disbenefits
2. Assuming 0.5% higher speeds due to behaviour adaptation and 0.1% more car use due to improved comfort
3. Taking away the most safety effective service in-vehicle speed limit
4. Assuming full vehicle penetration (20% ITS-G5, 60% cellular, 20% hybrid)
5. Assuming full use of all services available to the user

The results of the sensitivity analysis were similar in all countries. Table 36 shows the results for Finland's high effectiveness scenario.

Table 36. Benefits or user-cost changes due to the deployment of C-ITS services on the Finnish road networks in 2030 in the *high effectiveness* scenario for the basic case and three alternative calculation cases for a sensitivity analysis.

FINLAND 2030 – HIGH EFFECTIVENESS SCENARIO	0	1	2	3	4	5
BENEFITS IN NUMBER	BASIC	SPEEDING DIS-BENEFITS INCLUDED	SCEN. 1 + M3 & M6	SCEN. 2 WITHOUT IVSL SERVICE	SCEN. 0 + 100% VEHICLE PENE-TRATION	SCEN. 0 + FULL USE
Vehicle hours driven (million/year)	-0.06	1.49	0.93	-0.55	-0.13	-0.09
Vehicle hours spent in congestion (M/year)	-0.003	-0.003	-0.04	0.005	-0.011	-0.002
Fatal accidents (number/year)	-1.40	-1.40	-0.79	0.35	-3.10	-1.40
Non-fatal injury accidents (number/year)	-19.26	-19.26	-14.97	0.02	-46.0	-20.2
Property damage-only accidents (number/year)	-84.92	-84.92	-66.48	-0.51	-202.4	-89.2
Co2 emissions (million tonnes/year)	-0.0044	-0.0044	-0.0002	0.0011	-0.0105	-0.0060
BENEFITS IN MILLION €						
Vehicle hours driven	-0.960	24.6	15.4	-9.120	-2.133	-1.411
Vehicle hours spent in congestion	-0.044	-0.044	-0.72	0.076	-0.180	-0.037
Fatal accidents	-5.03	-5.03	-2.85	1.26	-11.05	-5.03
Non-fatal injury accidents	-9.45	-9.45	-7.35	0.011	-22.57	-9.93
Property damage-only accidents	-0.42	-0.42	-0.33	-0.0026	-1.01	-0.45
CO_2 emissions	-0.404	-0.404	-0.022	0.104	-0.970	-0.557
TOTAL VALUE OF CHANGES IN USER COSTS	**-16.3**	**9.2**	**4.1**	**-7.7**	**-38.0**	**-17.4**

Including the speeding-related disbenefits in terms of increased travel times due to in-vehicle speed limits would make the change in vehicle hours driven transform from a minor reduction to a clear increase, reducing the benefits in 2030 by €25 million, and resulting in a negative benefit in total. Assuming slightly increased vehicle speeds and car use would result in a negative total benefit, although the disbenefits in vehicle hours and the benefits in road safety would be lower due to higher speeds. If the most safety effective service in-vehicle speed limits were not included in the service bundle, the total benefit would be positive. This would be due to reduced vehicle hours driven, as the other effects would increase user costs to some extent via e.g., slightly reduced safety.

The benefits would increase greatly, if all vehicles or their drivers had a C-ITS device during travel. The more than double vehicle penetration would lead to more than twice as high benefits. The full use of the services would also increase the benefits but not very much due to the quite high use percentages of the most effective services.

Separate sensitivity analyses were not made for the network or event coverages. Basically their impact is proportional to the various effects. As the event coverages are already quite high for many services, i.e. the improvement of event coverages will not have a major impact on the overall results. For many countries, the network coverages of many services are quite low especially on the low-volume networks. There the improvement of network coverages would have considerable impacts, but on the higher volume networks the impacts would be quite moderate.

4.5.5.2 Costs

The costs of roadside units and vehicle units have been discussed in several reports (e.g., Asselin-Miller et al. 2016, Degrande et al. 2020, Nokes et al. 2020). We have utilised the results of Asselin-Milller et al. (2016), as they focused on European data and were the foundation for the benefit-cost analysis carried out in the C-ITS Platform's Phase I. The other two studies provided quite similar results to those of Asselin Miller et al. (2016). The cost differences between ITS-G5 and cellular direct communications C-V2X-based roadside units are small and expected to narrow in time (ABI Research 2018). Hence, the roadside and vehicle unit costs are assumed to be the same for both ITS-G5 and C-V2X technologies.

A vehicle unit's cost is estimated to be €180. Such a vehicle unit is capable of hybrid communications including both ITS-G5 V2X and cellular V2I connectivity. The cost of a vehicle unit providing only V2V

ITS-G5 is only slightly lower at €172. The annual operation and maintenance costs are estimated to be €16 per unit. (Asselin-Miller et al. 2016)

The equipment costs of a new hybrid roadside station are estimated to be €6 000 with installation costs of €7 500, totalling €13 500. The annual operation and maintenance costs are estimated to be €580. The equipment and installation costs of updating an existing roadside station such as traffic signals are estimated to be €4 500, with annual operation and maintenance costs of about €400. (Asselin-Miller et al. 2016)

The equipment and installation costs of a mobile C-ITS station to be installed in road-works vehicles and trailers is assumed to be similar to those of the updated roadside station. The operation and maintenance costs are assumed to be twice as high as for updated roadside stations.

The costs for operating the service were estimated only with regard to the costs carried by the road operators in adapting their traffic management centres (TMC) and data management systems as well as the personnel, equipment, telecommunications and service purchase costs. The latter costs apply if the road operator plans to support service provision by purchasing the provision of selected services on its network(s).

The costs for establishing and operating C-ITS services in 2030 are shown in Table 37 for the different countries. The costs are dominated by the vehicle unit costs as in earlier socioeconomic evaluations such as the one carried out by Asselin-Miller et al. (2016). Denmark has no plans to invest in the service provision, although the other countries do. In Norway and Sweden, the road operator is to participate in the service provision, whereas in Finland and Sweden, the road operators will likely outsource and purchase the service provision. Norway and Sweden plan to invest considerably more in traffic management centre upgrading due to C-ITS services than Denmark and Finland.

Table 37. The costs for C-ITS service deployment and provision in the NordicWay 2 countries

DENMARK Cost elements	Number	Investment cost €	O&M cost/year €
C-ITS units			
In-vehicle units	656 040	118 087 200	10 496 640
Roadside units, new	200	2 700 000	116 000
Roadside units, upgraded	0	0	0
Mobile V2I stations	25	112 500	20 000
Back-office			
TMC		2 000 000	200 000
Data management		500 000	150 000
Service provision			
Personnel incl. Procurement			0
Equipment (HW+SW)			0
Telecommunications			0
Service purchase			0
Total			
Sum of the costs above		123 399 700	10 982 640
Sum of costs excl. In-veh.		5 312 500	486 000

FINLAND Cost elements	Number	Investment cost €	O&M cost/year €
C-ITS units			
In-vehicle units	785 450	141 381 000	12 567 200
Roadside units, new	12	162 000	6 960
Roadside units, upgraded	120	540 000	48 000
Mobile V2I stations	110	495 000	88 000
Back-office			
TMC		1 850 000	160 000
Data management		625 000	170 000
Service provision			
Personnel incl. Procurement			10 000
Equipment (HW+SW)			0
Telecom.			0
Service purchase			1 580 000
Total			
Sum of the costs above		145 053 000	14 630 160
Sum of costs excl. In-veh.		3 672 000	2 062 960

NORWAY Cost elements	Number	Investment cost €	O&M cost/year €
C-ITS units			
In-vehicle units	740 697	133 325 533	11 851 158
Roadside units, new	1 850	24 975 000	1 073 000
Roadside units, upgraded	0	0	0
Mobile V2I stations	600	2 700 000	480 000
Back-office			
TMC		6 000 000	200 000
Data management		1 000 000	200 000
Service provision			
Personnel incl. Procurement			300 000
Equipment (HW+SW)			200 000
Telecommunications			200 000
Service purchase			0
Total			
Sum of the costs above		168 000 533	14 504 158
Sum of costs excl. In-veh.		34 675 000	2 653 000

SWEDEN Cost elements	Number	Investment cost €	O&M cost/year €
C-ITS units			
In-vehicle units	1 960 800	352 944 000	31 372 800
Roadside units, new	5 000	67 500 000	2 900 000
Roadside units, upgraded	0	0	0
Mobile V2I stations	0	0	0
Back-office			
TMC		5 000 000	200 000
Data management		1 000 000	200 000
Service provision			
Personnel incl. Procurement			200 000
Equipment (HW+SW)			200 000
Telecom.			200 000
Service purchase			2 000 000
Total			
Sum of the costs above		426 444 000	37 272 800
Sum of costs excl. In-veh.		73 500 000	5 900 000

4.5.5.3 Benefits vs costs

The merit of carrying out a benefit-cost assessment is doubtful, as there is no definite timing for the investments yet, and the sensitivity analysis showed large variations due to different development scenarios. However, comparison of the benefits in 2030 and the costs is possible. This is done in Table 38.

Table 38. Costs and benefits for C-ITS service deployment and provision in the NordicWay 2 countries

Costs and benefits (€)	Denmark	Finland	Norway	Sweden
Vehicle unit costs				
Investment 2021–2030	118 087 200	141 381 000	133 325 533	352 944 000
Operation & maintenance 2030	10 496 640	12 567 200	11 851 158	31 372 800
Road operator costs				
Investment 2021–2030	5 312 500	3 672 000	34 675 000	73 500 000
Operation & maintenance 2030	486 000	2 062 960	2 653 000	5 900 000
Benefits				
Low effectiveness scenario 2030	22 741 967	10 475 197	41 087 119	68 239 294
High effectiveness scenario 2030	44 806 980	16 318 268	68 377 214	123 663 528

The comparison of costs and benefits shows that from the road operator perspective, the benefits even in the low effectiveness scenario in 2030 exceed the sum of the annual operating and maintenance costs that year and the investment costs up to that year in all countries. In the high effectiveness scenario, the benefits would cover also the operation and maintenance costs of the in-vehicle units in other countries than Finland.

Concerning the stronger efficiency, safety and CO_2 impacts on high traffic volume and congested roads than on lower volume roads, it is beneficial to focus the operation of C-ITS services on roads with high traffic volumes. Service provision on low traffic volume roads may also be socioeconomically profitable, but this depends on how the service users adapt their speeds and car use to the C-ITS services in the long run.

4.6 Feasibility

Feasibility for C-ITS service provision in the Nordic countries was assessed in terms of technical feasibility of the services, feasibility of business models and ecosystems for their provision, user acceptance and socioeconomic benefits. Specifically, feasibility was addressed with the following questions:

4.6.1 Technical feasibility of C-ITS services

The NordicWay 2 architecture was designed to allow the exchange of C-ITS messages between the backends of different service providers, and between service providers and traffic data providers. Data sharing cross-organisationally in the national NordicWay 2 pilots and across the interchange system was validated. Interoperability between the different countries was tested during the NordicWay Tour, and events reported were visible across the Nordic countries. During the Nordic Tour it was discovered that there are some issues with cellular networks in cross-border situations and GNSS reception with consumer grade devices. These technical issues need to be taken into account when deploying C-ITS services.

The end-to-end latency analyses showed that the cellular (4G-LTE) implementation of the piloted C-ITS services and the NordicWay 2 interchange system was able to provide fully functional services, although the implementations in the pilots were not optimised for minimising latency. The median values of end-to-end latency measured in (small-scale) controlled tests and the latency measured between federated nodes allow successful implementation of many Day-1 C-ITS services.

Variability of the latency results in the pilot implementations highlights the need for designing robust solutions during deployment of the services that are also scalable. It also shows the importance of constant monitoring of KPIs of the complete system to make sure that the data is usable for end-consumers. The quality of the services depends highly on the quality of the data, and incoming data should be accurate. Other service providers, like traffic network management systems and weather service providers, should be integrable into the NordicWay2 interchange system.

The design of the HMI and the interaction with C-ITS services used while driving need special attention. In addition, the information content of C-ITS messages needs to support a driver-centric presentation of warning messages in vehicles. This topic was not included in the technical evaluation of the services and further research is recommended.

Cellular networks can support C-ITS services on top of all other communication use cases, delivering excellent economy of scale and nationwide road network coverage from the start. It is recommended to be combined with a NAP (National Access Point), so that with a federated network of interchange nodes, Nordic and European service continuity can be achieved for all NordicWay Day-1 use cases.

4.6.2 User acceptance

User acceptance evaluation concluded that the overall acceptance of C-ITS services was high. Respondents considered the information content important both for motorways and main roads, as well as for the urban environment. Willingness to use was high for the C-ITS services. In total, 84% of respondents considered that they would use these services either on all trips or on selected trips, especially on long trips or unfamiliar routes. Willingness to share data with C-ITS service providers was quite high. Specifically, 75–82% of respondents considered, for all data types (manually sent warnings and weather or road condition, emergency braking, speed and location of their own vehicle), that they would be willing or might be willing to share these data with the service provider.

Willingness to pay for C-ITS services may become a barrier to deployment, as the share of respondents willing to pay (selected 5 or higher on the 7-point scale) was only 15% and an additional 15% were unsure (selected 4, the neutral alternative, on the 7-point scale).

It must also be borne in mind that most of the drivers (54–66%) had never heard of C-ITS services and that only 3–6% of them had used these services themselves. Thus, even if there is acceptance among those who know or are informed about the services, the overall awareness is still somewhat low. Thus, also lack of awareness may become a barrier to deployment of the services.

4.6.3 Feasibility of business models and ecosystems

During the ramp-up phase of starting the provision of a C-ITS service, the main challenges include contracting (especially GDPR) issues, data quality issues and service coverage issues. The initial pains relate to attracting a user base in the harshly competitive climate, thin revenue streams from private users, product development investments and lack of an experienced workforce. Expected gains from being involved in such ecosystems include revenue, clientele growth, product portfolio expansion, international partnerships and operational gains. The companies are committed to such piloting endeavours due to wanting to be at the forefront in the R&D&I field and due to such activities strongly supporting company-strategic choices and performance objectives.

Among viable or potential scaling-up strategies, the most prominent was the “single side strategy”. The others highlighted were “follow that rabbit”, “big bang” and “piggyback”. The most prominent and promising scale-up partner candidates were the automotive sector, navigation device manufacturers and large fleet owners.

Business model (feasibility, scalability, long-term sustainability, profit) issues and concerns include a recurring comment that regardless of the service, some public involvement, intervention, funding or investment is going to be needed in the longer term also if a wide and large-scale roll-out and adoption of C-ITS is aspired to. For C-ITS, it holds true that if there is no data, there will be no services either. To extend from that, businesses feel that if there is no investment from e.g., road authorities, there will be no data and hence no services. It is, in other words, the interaction between different actors that brings beneficial services to the end-user and society as a whole.

4.6.4 Socio-economic benefits

Mobility impacts

As a specific response to the service, the amount of travel is likely affected by the route-guidance type of services i.e., fuel & charging information, on-street parking information, and traffic information and smart routing. These services will have little or no impact when the driver is familiar with the route to the destination or already has a certain parking establishment or location in mind. For traffic information and smart routing, the total effect could be a 0.15–0.20% reduction in annual vehicle kilometres. Concerning fuel and charging stations and on-street parking spaces, the annual effect will be clearly smaller — perhaps 0.007–0.010%.

Public transport priorities have an impact on mobility by making the use of public transport more attractive via improved punctuality and reduced travel time. The effect of priorities alone would today and in 2030 perhaps be 8% in urban areas.

C-ITS services for car drivers in general may also influence mobility by making one’s own car a more attractive travel option due to increased awareness and a feeling of being better informed. Some of the warning services may also increase distances driven, as some users may choose alternative routes to evade the problem warned about. These effects are quite small, and reliable estimates of magnitude could not be made.

Safety impacts

The in-vehicle speed limits (IVSL), emergency brake lights (EBL) and slow/stationary vehicle and traffic ahead warnings (Slow Vehicle) were assessed to be the most efficient. In the 100% use situation, their effectiveness was estimated to be e.g., in Finland 2.3–4.0% for IVSL, 0.1–3.9% for EBL and 0.4–1.5% for Slow Vehicle using low and high estimates on different networks.

In addition to these direct effects on safety, C-ITS services are expected to have also indirect effects. The most relevant impact mechanisms included ‘Indirect modification of user behaviour’ (M3), ‘Indirect modification of non-user behaviour’ (M4) and ‘Modification of road user exposure’ (M6). Other mechanisms may also cause some effects, but as potential mechanisms either included both positive and negative reactions or the size of the effect was considered negligible, they were left at zero in the impact calculations.

Road safety was assessed to be improved, with fatal accidents dropping by 1.2–4.8% in the low and 1.7–6.3 % in the high effectiveness scenario depending on the country. The corresponding changes for less severe accidents were 0.9–2.0 % and 1.5–3.5%, respectively. The effects were the lowest in Finland, where a large part of the networks consist of rural main roads with low levels of service and event coverage.

Efficiency

Important efficiency effects were expected to result from a reduction in crash-related congestion due to fewer road crashes. On high traffic volume networks in the NordicWay 2 area, the share of incident-related congestion of all congestion-related travel time delays is estimated to be 10–15%. The shares on low-volume networks are estimated to be 60–70% and on city streets 5–10%.

In addition, positive efficiency effects arise from the decreased distance driven due to the above mobility effects, as well as to increased driving speeds due to behavioural modification. Efficiency is affected negatively by the increase in vehicle hours driven, due to increased use of private cars and lower speeds because of better compliance with speed limits among those with in-vehicle speed limit information.

Travel times were assessed to be reduced by 0.01–0.04% in the low and 0.02–0.10% in the high effectiveness scenario depending on the country. The average effect is lowest in Finland, where a large part of the networks consists of rural main roads with low levels of service and event coverage.

Environment

In the environmental impact assessment, we focused on CO_2 emissions. The impacts were expected to be caused primarily by two main mechanisms: (1) changes in mobility in terms of modal choice and especially vehicle kilometres driven, and (2) changes in vehicle speeds. The largest speed-related effects are due to the decrease of congestion described in the efficiency impacts, as less vehicles will use the low congested flow speeds with highest CO_2 emissions.

The reductions in CO_2 emissions were assessed to range from 0.01% to 0.07% in the low and from 0.03% to 0.10% in the high effectiveness scenario depending on the country.

Benefits vs. costs

The merit of carrying out a benefit-cost assessment is doubtful as there is as yet no definite timing for the investments, and the sensitivity analysis showed wide variations due to different development scenarios. However, comparison of both the benefits and costs in 2030 is still possible.

Comparison of the costs and benefits showed that from the road operator perspective, even in the low effectiveness scenario in 2030, the benefits exceed the sum of annual operating and maintenance costs that year and the investment costs up to that year in all countries. In the high effectiveness scenario, the benefits would cover also the operation and maintenance costs of the in-vehicle units in other countries than Finland.

Concerning the stronger efficiency, safety and CO_2 impacts on high traffic volume and congested roads than on lower volume ones, it is beneficial to focus the operation of C-ITS services on roads with high traffic volumes. Service provision on low traffic volume roads may also be socioeconomically profitable, but this depends on how the service users adapt their speeds and car use to the C-ITS services in the long run.

4.6.5 Conclusions on feasibility

Table 39 below summarises the evaluation of the feasibility of C-ITS provision in the Nordic countries. Based on the results of the technical evaluation in NordicWay 2, we conclude that:

- It is technically feasible to set up C-ITS services in the Nordic countries; i.e., the quality of C-ITS service seems sufficient for service provision.
- Challenges for service provision include most potential users never having heard of C-ITS services and their willingness to pay for them being low. However, they were willing to use these services and share data with the service providers.
- Feasible business models and ecosystems still require a solution with some public involvement, intervention, funding or investment in the longer term and, thus, definition of the public actors in the ecosystems.
- Socioeconomic benefits can be expected by 2030 if service provision follows the future scenarios defined for impact assessment. These benefits are related to mobility, safety,

efficiency and the environment. From the road operator perspective, in 2030 the benefits are expected to outweigh, even in the low effectiveness scenario, the sum of annual operating and maintenance costs that year and the investment costs up to that year in all countries. It is beneficial to focus the operation of C-ITS services on roads with high traffic volumes.

Table 39. Feasibility of different aspects for C-ITS service provision in the Nordic countries

	RESEARCH QUESTION	RESULT	CONCLUSION
Technical	Can data be shared across organisations?	The data sharing between organisations and over the interchange node was confirmed in the national pilots	Yes
	Can C-ITS services achieve interoperability between different countries?	The interoperability between Nordic countries was confirmed, as the events were visible across the Nordic countries during the Nordic Tour	Yes
	Are latencies low enough for successful implementation of C-ITS services?	End-to-end latency measurements proved that cellular (4G-LTE) implementation of the piloted Day-1 C-ITS services distributed over the NordicWay 2 interchange node enables fully functional services	Yes
	Is the architecture with the federated network of interchange nodes a feasible solution?	With the federated network of interchange nodes, Nordic and European service continuity can be deployed for NordicWay 2 Day-1 use cases	Yes
User acceptance	Do people know C-ITS services?	54–66% of respondents had never heard of C-ITS services; only 3–6% had used them	No
	Are users willing to use C-ITS services?	84% of respondents would use the service on all or selected trips	Yes
	Are users willing to pay for C-ITS services?	15% of respondents were willing to pay for the service and an additional 15% were unsure	No
	Are users willing to share information with the C-ITS service providers?	75–82% of respondents would or might be willing to share data with the service provider	Yes
Business model and ecosystem	Can we find feasible business models for service provision?	Some public involvement, intervention, funding or investment is going to be needed in the longer term	Maybe
	Can we find feasible ecosystems for service provision?	Solutions have been found for ecosystems providing C-ITS services The role of authorities must still be defined Lack of an experienced workforce is a challenge	Maybe
Socioeconomics	Can we expect mobility benefits from the services?	Small impacts on vehicle km driven and on mode choice	Yes
	Can we expect safety benefits from the services?	Fatal accidents to drop by 1.2–4.8% in the low and 1.7–6.3 % in the high effectiveness scenario depending on the country, less severe accidents by 0.9–2.0 % and 1.5–3.5%, respectively	Yes
	Can we expect efficiency benefits from the services?	Travel time reduction by 0.01–0.04% in the low and 0.02–0.10% in the high effectiveness scenario depending on the country	Yes
	Can we expect environmental benefits from the services?	Reductions in the CO_2 emissions to range from 0.01% to 0.07% in the low and from 0.03% to 0.10% in the high effectiveness scenario depending on the country	Yes
	Do socioeconomic benefits outweigh the costs?	From the road operator perspective, the benefits even in the low effectiveness scenario in 2030 exceed the sum of the annual operating and maintenance costs that year and the investment costs up to that year in all countries. In the high effectiveness scenario, the benefits would cover also the operation and maintenance costs of the in-vehicle units in other countries than Finland. It is beneficial to focus the operation of C-ITS services on roads with high traffic volumes.	Yes

5 Discussion and conclusions

5.1 Key findings

Among other objectives, NordicWay 2 was set to assess the feasibility of C-ITS services in the Nordic countries. Specifically, this was done by evaluating whether the services can be technically implemented (i.e., the quality of service fulfils the requirements), whether the general public accepts the services and is willing to use them, whether viable ecosystems can be built for service provision, and whether socioeconomic benefits can be expected and under which conditions. This socioeconomic impact of the services was assessed by addressing the impacts on safety, transport network efficiency, the environment and mobility.

The NordicWay approach was developed to support service interoperability in a C-ITS/ITS environment, where cloud services and entities are part of end-to-end solutions and connectivity is achieved using cellular and other communication links. The technical evaluation highlighted the need for designing solutions that are robust and scalable. They showed the importance of constant monitoring of KPIs of the entire system to make sure that data is usable for end-consumers. The conformance of log files, data logging practices and message processing have to be done according to common specifications (including a stable and unique message ID) which enables successful analysis of the results from the log files. A key finding of technical performance included that for the purpose of the pilots, the measured latencies did not hinder the piloted services. The cross-organisational data sharing in the national NordicWay 2 pilots and the data sharing across the interchange system was confirmed. Interoperability between the different countries was tested during the Nordic tour, and events reported were visible across the Nordic countries, but there were some issues in cross-border situations with GNSS (e.g., consumer grade devices in poor reception areas, GPS jammers and global affairs) and cellular coverage/networks (e.g., roaming agreements/sim cards, loss of / re-establishing reception, etc.). The cellular networks can support C-ITS services, delivering excellent economy of scale and nationwide road network coverage from the start for all NordicWay 2 Day-1 use cases.

Ecosystem evaluation showed that ramp-up phase challenges included contracts and especially GDPR personal data implications for data access and agility; geographical and temporal service coverage and technical issues like assurance of data quality across the ecosystem; interchange node limitations in sharing pictures or video data (some services collected and contained richer data than the node was catering); and DATEX version discrepancies. Their pains included also challenges in attracting users and thin revenue streams from individual private users, but also investment challenges and lack of a skilled workforce. The gains that the ecosystems expected were related to e.g., revenue, clientele growth, product portfolio and international partnerships. Different strategies for scaling up were discussed in the workshops. The ecosystem actors acknowledged that the public sector has had a significant role in the early stages of C-ITS development, and that active participation will also be needed in the long run.

User acceptance evaluation showed that over half of Nordic drivers have never heard of C-ITS services and that very few have used them (3–6%). The most important information contents for trips made on motorways or main roads were all types of information content indicating some kind of road blockage, either accident, obstacle, closure or large animals on the road. For urban environment, the top three contents were emergency vehicle approaching, accident ahead and road or lane closure. C-ITS services were seen most often as improving fluency or safety. Drivers were most willing to share data related to weather or road conditions collected by their vehicle with the C-ITS service providers. Speed and location of one's own vehicle raised the most concerns. In all, 44% of the drivers stated that they would be willing to use C-ITS services always or on most of their trips, especially on longer trips and on unfamiliar routes. The possibility to use the same C-ITS on other Nordic countries and in Central Europe was considered important by those who drive abroad.

The socioeconomic impact assessment indicated that as a specific response to the service, the amount of travel is likely affected by the route guidance type of services on unfamiliar routes. Public transport priorities have an impact on mobility by making the use of public transport more attractive via improved punctuality and reduced travel time. C-ITS services for car drivers in general may also influence mobility by making one's own car a more attractive travel option due to increased awareness and a feeling of being better informed. The estimates of direct safety effects were largest for in-vehicle speed limits, emergency brake lights, and slow/stationary vehicle and traffic ahead warnings. Indirect safety impacts were also expected, but in many cases their magnitude was hard to estimate. Important efficiency effects were expected to result from a reduction of crash-related congestion due to fewer road crashes. In addition, positive efficiency effects arise from the decreased distance driven due to the above mobility effects. In the environmental impact assessment, we focused on CO_2 emissions. The impacts are expected to be caused primarily by two main mechanisms: changes in mobility in terms of modal choice and especially vehicle kilometres driven are proportional to the changes in CO_2 emissions and changes in vehicle speeds. The largest speed-related effects are due to the decrease in congestion described in the efficiency impacts, as fewer vehicles will use low-congested flow speeds with the highest CO_2 emissions. The comparison of costs and benefits indicates that from the road operator perspective, in 2030 the benefits even in the low effectiveness scenario will exceed the sum of annual operating and maintenance costs that year and the investment costs up to that year in all countries. Yet, sensitivity analysis showed that the outcome of socioeconomic impact assessment depended highly on the made assumptions on the coverage, use and effectiveness of the services.

5.2 Transferability of results

The results from the Nordic countries may best be transferred to regions with good cellular network coverage and whose inhabitants mostly have experience using different applications. The road network in the Nordic countries is mostly sparse (few alternative routes) with little traffic (except in Denmark) and, therefore, incidents are more often related to adverse weather conditions or accidents than congestion caused by over-demand. Thus, exceptional situations are of interest to road users, even though none of the information content was considered unimportant on any network.

5.3 Conclusions

The following conclusions were made on feasibility: It is technically feasible to set up C-ITS services in the Nordic countries. Challenges for service provision include most potential users never having heard of C-ITS services and their willingness to pay for them being low. However, they were willing to use these services and share data with the service providers. In addition, feasible business models and ecosystems still require a solution with some public involvement, intervention, funding or investment in the longer term and, thus, definition of the public actors in the ecosystems. If these challenges are solved and a sufficient user base and good coverage of services are achieved for the C-ITS services, socioeconomic benefits can be expected. The monetary value of these benefits is expected to outweigh the sum of the annual operating and maintenance costs in 2030 and the investment costs up until then in all countries from the road operator perspective. It was recommended to focus the operation of C-ITS services on roads with high traffic volumes.

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Annex 1. Experiments and KPIs for quality of service evaluation

Data logging in Finland

The data logging was designed to meet the requirements of the selected Quality KPI calculations in Finland. The data logging included the following information for each message:

- **node_provider** – name of the company which is the node provider
- **who** – identifier for the message distributer obtained from the nationalIdentifier identifier section of the DATEX II document
- **what** – high-level information on what the payload is carrying, for DATEX II message, list of the situation record types in the message
- **id** – unique ID for the message, situationRecord id
- **how** – type of data contained in the body of this message, e.g. DATEX II
- **version** – version of the situationRecord, starting with 1
- **lon** – longitude of the message
- **lat** – latitude of the message
- **observation_time** – timestamp when the message arrives at the NordicWay 2 service provider for the first time from a mobile device
- **where1** – code for the country that the incident occurred in
- **send_time** – exact time at which the publication was compiled at the sender's system, AMQP send time, publicationTime
- **receive_time** – time at which this event was stored into the systems, AMQP receive time

The data logging was implemented to the backends of the three service providers in the Finnish NordicWay 2 network (INFOT, EEE, Vaisala), Figure 1-1. The service providers exchange DATEX II 3.0 messages over the AMQP1.0 protocol, using the specifications from the previous NordicWay (1) project. The C-ROADS BI (Basic Interface) protocol, described in C-ROADS (2020), is based on the NordicWay protocol, with some changes to accommodate for ETSI C-ITS messages. The NordicWay 2 project implemented the BI protocol at the beginning of 2020, when the Finnish pilot had already started, and the Finnish partners decided to continue with the original selected protocol. The communication uses the federated approach instead of making bilateral connections. The federated approach is a basis for the C-ROADS II (Improved Interface) protocol (C-ROADS 2020).

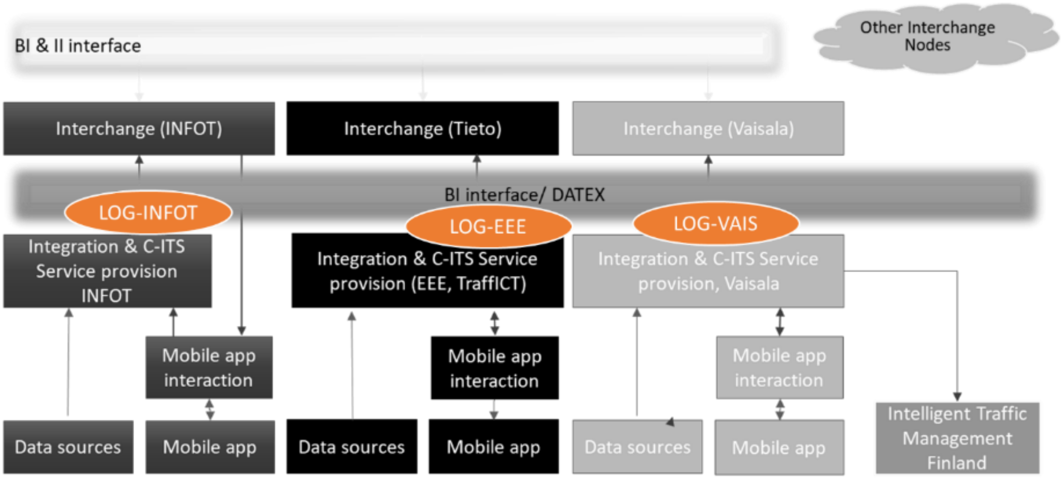

Figure 1-1. Data logging for technical testing of the three nodes in Finland.

The logging was done in the node servers for all messages that were sent out and received from the interface to the respective interchange node. The data logging was active during the measurement session from 28 April 2020 to 31 May 2020.

Controlled experiments in Finland

The controlled field tests in Finland focused on verifying the main functionalities of the selected services, cross-organisational data sharing and measuring end-to-end latencies. As a sample solution, two mobile (Android) applications, which operate under two different nodes, were selected for the field tests. (ForeC version 1.130 from EEE Innovations and Louhi version 1.13.0 from Sitowise — connected to INFOT backend, Figure 1-2). The ForeC application was available as a free beta-testing application from Google Play. The Louhi application was installed from an Android Package (APK) file. The web application RoadAI from Vaisala was also used and was accessible through a normal web browser. The mobile applications covered a variety of message types, which could be launched manually by the user. This feature enabled simple field testing. The third node (Vaisala) did not implement similar mobile applications that could be used in the tests. The latency measurements focused on the two mobile applications and the cross-organisational data sharing verified from all nodes.

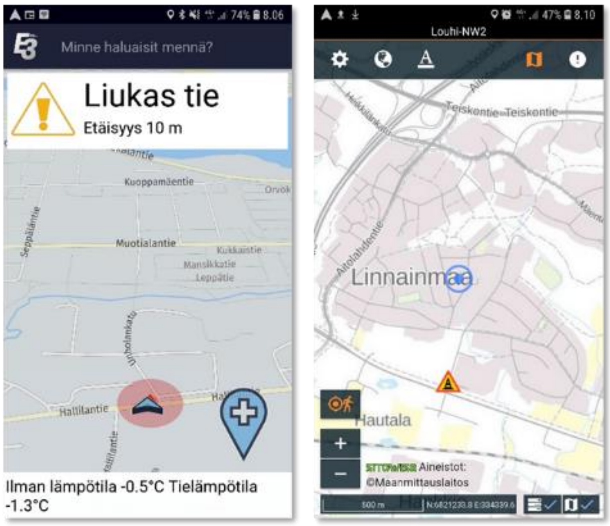

Figure 1-2. Screenshots from the ForeC and Louhi mobile applications used in the controlled tests in Finland.

The controlled field tests were conducted on 27–29 April 2020 in Tampere, Finland and involved stationary and driving tests. The stationary tests were done in the back yard of the VTT vehicle labs in Niittyhaankatu, Tampere. The driving tests were done in the southern parts of Tampere on a route that included suburban streets, rural roads and motorways. In the driving test, a test route of about 30 km was driven twice; the map below shows the approximate locations where the test events were launched while driving, see Figure 1-3.

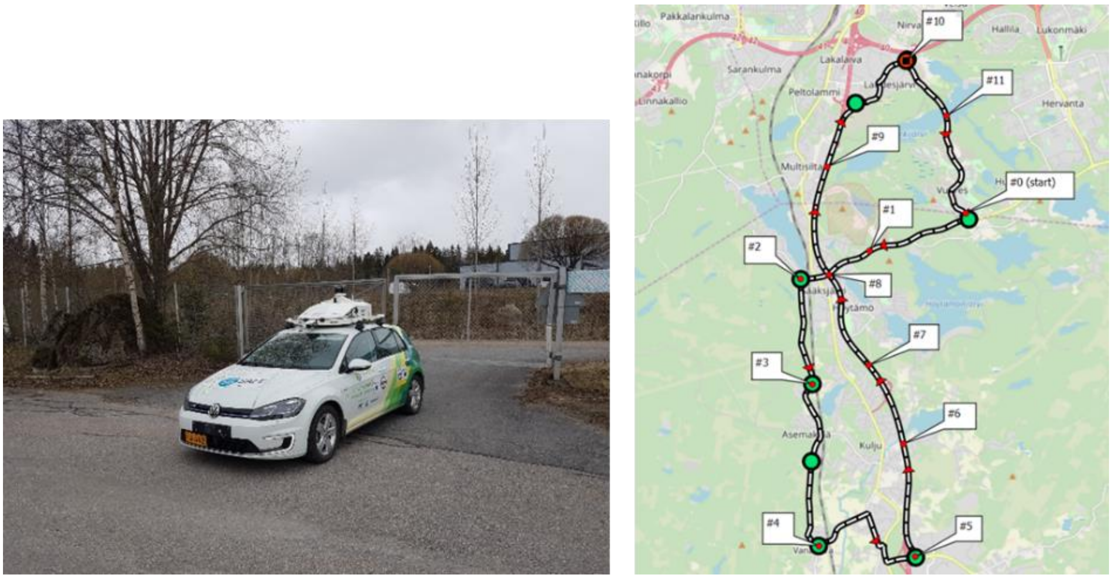

Figure 1-3. Test vehicle used in stationary tests, and the driving test route in Tampere.

In stationary tests, the total number of test events launched was 46 (Louhi -> ForeC: 21 + ForeC-Louhi: 25) and in the driving tests 20 (Louhi -> ForeC). The number of test events was limited, because one of the tested nodes had implemented an event aggregation function that checked whether there was already was a similar active event (or events) in the system, and was possibly combining these messages by location. Therefore, it was necessary to wait for the validation time of the previous message to expire.

The field test was conducted by launching events from one mobile application and receiving the message to another mobile device, with the same application, as well as a third mobile device with another application. As visualised in Figure 1-4, the message from the originating mobile device (P1) went through the application backend system (node loop) to the second mobile device (P2) and through the federated interchange interface (interchange loop) to the third mobile device (P3).

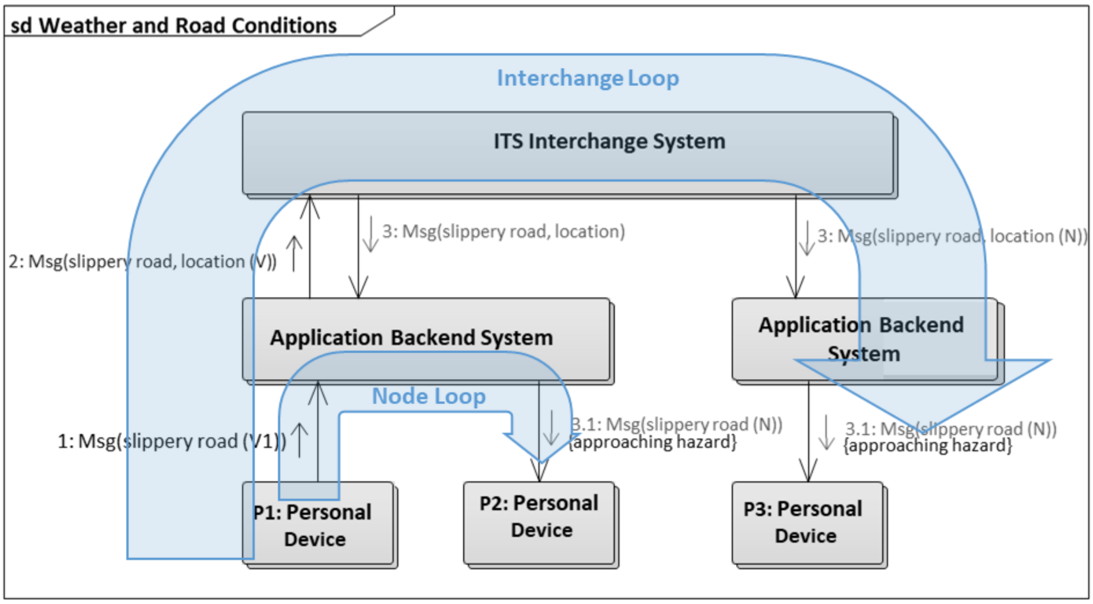

Figure 1-4. Visualisation of message transfer loops in the field test (image modified from NordicWay 2 Service Definitions report, NordicWay 2 (2019)).

The test setup in the backseat of the test vehicle is shown in Figure 1-5. The three mobile phones were side by side, and an additional mobile phone was used to show the real-time cellular signal meter. All mobile devices used in the test were Android phones with prepaid sim cards from a commercial mobile network operator (Telia Finland Oyj). The user interfaces of the test devices were video-recorded for the annotation analysis.

Figure 1-5. Test setup in the stationary and driving tests.

In the driving tests, the test setup included the reference VBOX video data acquisition system by RACELOGIC. It recorded the GPS location, timestamp, speed and video both inside and through the front view of the vehicle. The video recording of the field tests was used to measure the end-to-end latencies of the message transfer between devices as well as the location of the sent messages. The video recording and timestamps are shown in Figure 1-6. Timestamp A is the time at which a test event was sent out from the mobile application (on P1), timestamp B is the time at which the message/warning was visually shown on the second mobile applications (on P2), and timestamp C is the time at which the message/warning was visually shown on the third mobile applications (on P3).

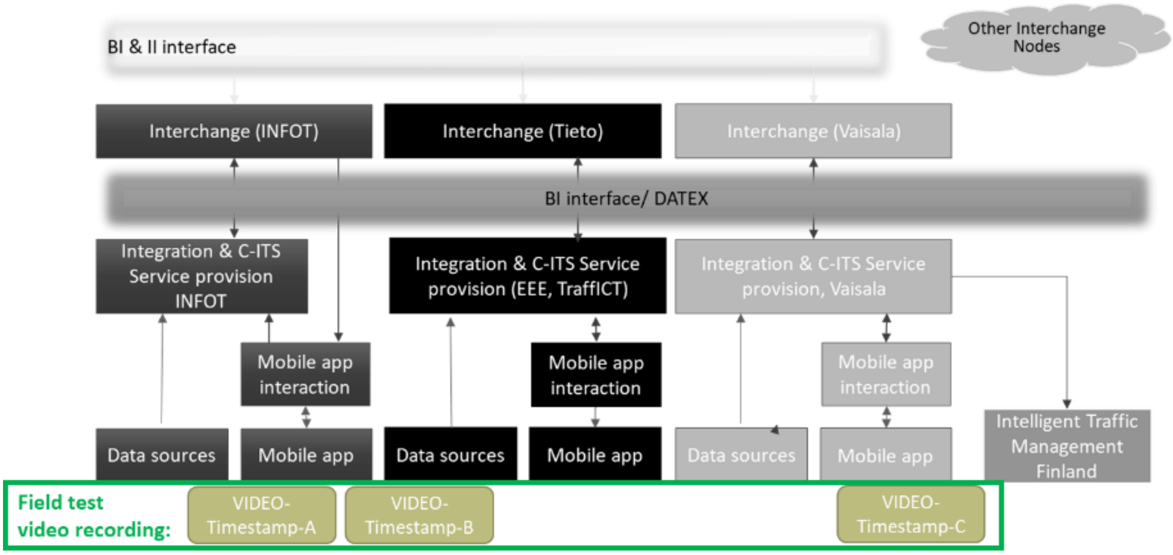

Figure 1-6. Video recording of test devices, and timestamps in the field tests.

KPIs in Finland

Service provider reported KPIs

Information for several KPIs were collected from service providers that had implemented the C-ITS services in the Finnish pilot. The service provider reported KPIs related to service coverage and the number of C-ITS devices and users during the pilot in Finland.

KPI calculation from the logs

The number of C-ITS messages distributed per service node (KPI_Q03a) and the corresponding message success rate (KPI_Q10) were calculated from the log files generated by the federated nodes, and the calculation of the KPIs was carried out with software written in Java for the purpose of analysing the log files. Each node included in the test generated two log files every day during the test period: log files of C-ITS messages received and transmitted during the day. The message ID included in each message served as a unique identifier for received and transmitted C-ITS messages.

All messages written in the log files of the transmitting and receiving node were first extracted from the text files, and indexes of transmitted and received messages were generated. In practice, a message with the same message ID was often transmitted and received multiple times from one node to another. If the same message had been transmitted or received multiple times, only the first transmission or the first reception of a message with the same message ID was included on the list of transmitted or received messages. It was then possible to count by message type how many of the messages on the list of messages sent (with a unique message ID) appeared on the list of messages received and how many messages of each message type had been sent with a unique message ID.

The calculation of latency (between federated nodes, KPI_Q08) utilised the same principles as the calculation of the two previous KPIs. First, indexes of all transmitted and received messages were created based on the log files of the transmitting and receiving nodes. Then, chronologically ordered lists of transmitted and received messages with unique message IDs were generated. It was then possible to calculate the latency between the first message transmission from the originating node (send_time in the log file of the transmitting node) and the first message reception at the destination node (receive_time in the log file of the receiving node).

For calculating the latency, it was possible to select only messages sent during a defined time window (with send time during the analysis period) for analysis. The calculation of the number of messages distributed per service node (KPI_Q03a) and related message success rate (KPI_Q10) was carried out for all messages in the log files of the calendar days covered by the analysis period.

KPI measurements in the controlled tests

Two KPIs were calculated based on the results of the controlled tests: location accuracy (KPI_Q07) and latency end-to-end (KPI_Q08). The location accuracy was determined based on the controlled driving tests as a combination of the video recordings and a server log file. The coordinates of the vehicle were noted down when the message was sent out and the coordinates of the same message were read from the Vaisala log file. These coordinate log files were then imported to the QGIS software on top of the DIGIROAD and OpenStreetMap data. The maximum lateral and longitudinal differences were measured with the tools of the QGIS software.

Latency end-to-end was determined based on the controlled standstill tests. Inspecting the video recordings, the message sent time and message receive time was noted down for every mobile device. The needed statistical values were calculated after that.

Table 1-1. KPIs for coverage of service in Finland. The information source for all these KPIs was the service provider.

Quality KPI	KPI	Description	Unit	KPI calculation method / Comment
KPI_Q01	Physical coverage	Change in length of the network covered by C-ITS services	-	Service coverage in Finland
KPI_Q02	Number of vehicles equipped	Change in number of vehicles equipped with a fully functional C-ITS in-vehicle device, e.g., number of app downloads	Number	In Finland, number of vehicles equipped with fully functional C-ITS new commercial mobile apps which send out AND show information
KPI_Q02b	Number of vehicles equipped with a partially functional C-ITS in-vehicle device	Change in number of vehicles equipped with a partially functional C-ITS in-vehicle device	Number	Number of vehicles equipped with a partially functional C-ITS in-vehicle device which ONLY sends out OR shows information
KPI_Q04	Number of C-ITS service vehicles or users	Change in number of vehicles receiving C-ITS service(s), e.g., number of users	Number	Number of active (C-ITS mobile app) users

Table 1-2. KPIs for service performance in Finland.

Quality KPI	KPI	Description	Unit	Information source: Calc. from logs	Information source: Controlled tests	Comment
KPI_Q03a	Number of C-ITS messages distributed per service and node	Number of C-ITS messages distributed per service and node	Number	x		Individual messages identified by their unique message IDs
KPI_Q07	Location accuracy	Relative precision of the referenced location for the published event at any node with respect to the actual location of the actual event	-		x	Video recording of the field tests: Visually inspect the received location compared to the sent event location
KPI_Q08	Latency (end-to-end)	Send/receive latency – time from timestamp sent to timestamp received of message between two end-user devices	s		x	Calculated from the video timestamps: Time difference between receive time and send time
KPI_Q08b	Latency (between federated interchange nodes)	Time difference between receive time and send time measured between two interchange nodes	ms	x		Calculated as the time difference between receive time and send time
KPI_Q10	Message success rate	Percentage of sent messages received (on node level)	%	x		Share of messages sent with a unique message ID (according to originating node) received by destination node

Table 1-3. Other KPIs in Finland.

Quality KPI	KPI	Description	Unit	Information source: Calc. from logs	Information source: Controlled tests	Comment
KPI_Q13	Cross-organisational / cross-brands data sharing	Data sharing between organisations within a country or cross-border	Yes / No	X	X	Data sharing of messages between three nodes in Finland

Data logging in Norway

Bouvet Interchange node

The test scenarios were:

- Sending 2000 messages as soon as possible, from one client to the interchange node
- Send 1 message, receive 1 message, 2000 times, from one client to the interchange node

For the different scenarios, the configuration of the interchange was changed to see if the latency were affected. Memory size and number of validation processes were two important parameters. The test environment was a small ecosystem with one client sending DATEX II messages to the interchange node, see Figure 1-7.

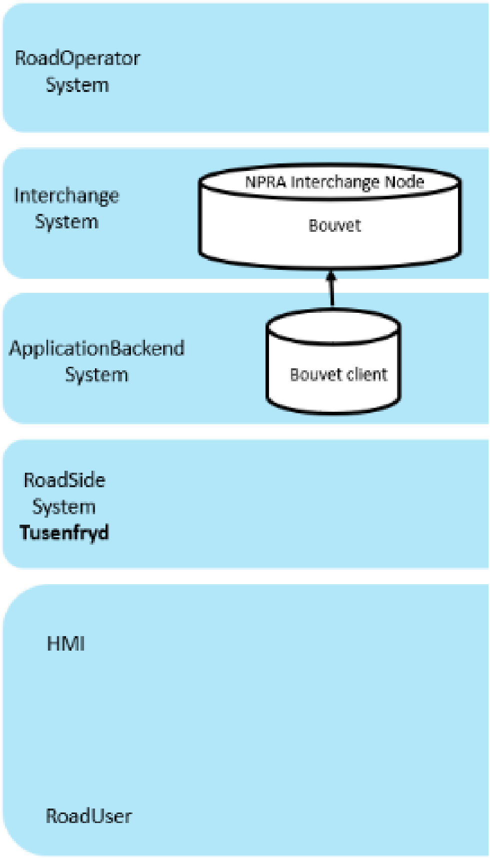

Figure 1-7. Bouvet interchange node test setup.

Aventi "interchange" node

The company Aventi did an end-to-end test but did not include the interchange node; instead, the messages ended up in the Norwegian DATEX II node (Figure 39). This setup is interesting because it measures latency in an ITS-G5 short-range communication setup with both an onboard unit (OBU) and roadside unit (RSU). Log files were used to track the transfer of each DENM message. An Android phone was used just to trigger a DENM message from the OBU and there was no logging by the Android. Time 1 is the time difference between the time the OBU transmitted the DENM and the RSU received it. Time 2 represents the time it takes from the RSU to the C-ITS-S (C-ITS station/server). Time 3 is the time it takes to transfer and write the DENM to the DATEX II node. No additional steps were taken to synchronise the clocks of the OBU, RSU and C-ITS-S while performing the test. All records were logged in universal timestamp.

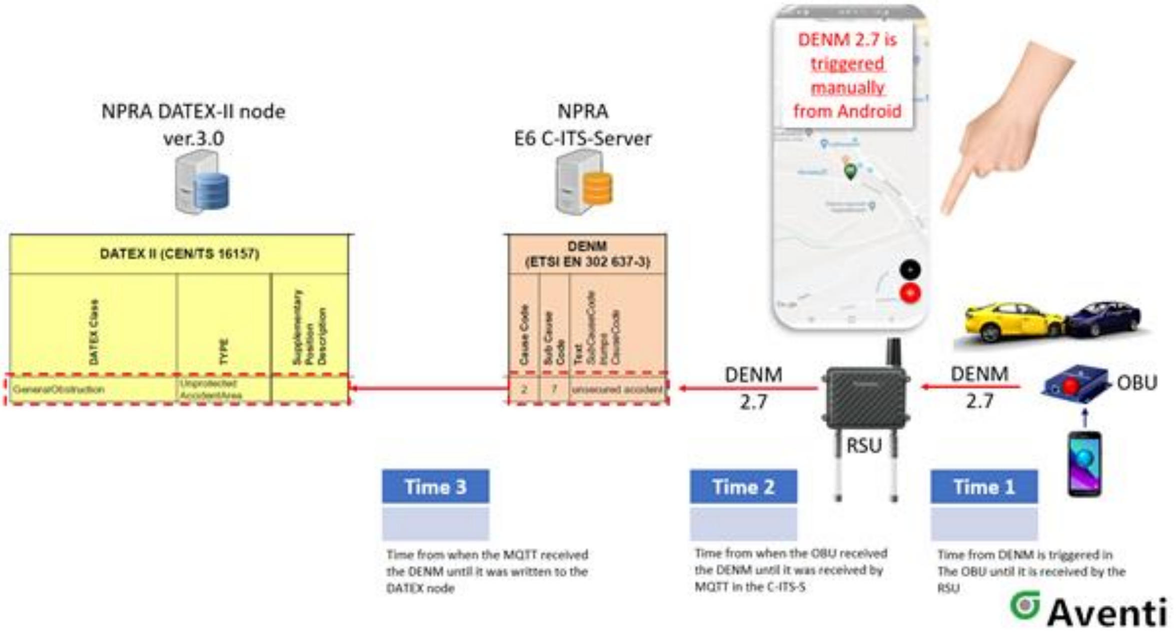

Figure 39. Aventi “interchange” node test setup.

Controlled experiments in Norway

Bouvet test at Skjervøy

The following services were tested

- Signal violation
- Green light optimal speed advisory (virtual lights)

The aim of the field test on Skjervøy was to verify that the system can be used to take cars through bottlenecks on the FV866 section (Figure 1-8).

Figure 1-8. Test area at Skjervøy, Norway.

NPRA tests in Skibotndalen

The following services were tested

- Weather and road conditions (interoperability)
- Slow or stationary vehicle(s) and Traffic ahead warning

The aim of the field tests in Skibotndalen (Figure 1-9) was to verify the quality of the detection systems and to set up the service ecosystem. There were plans for more testing and logging during spring/summer 2020, but the tests were cancelled due to the Covid-19 pandemic.

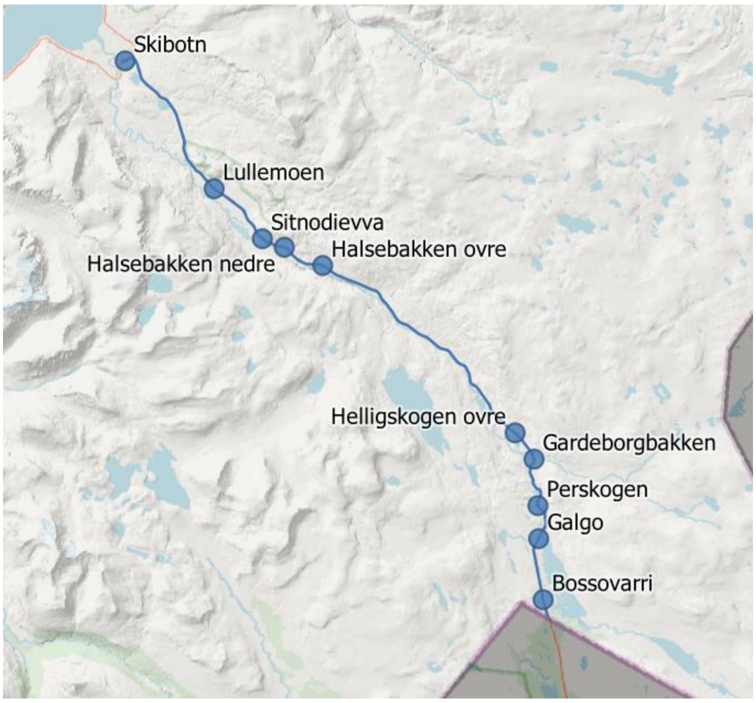

Figure 1-9. Main test sites in Skibotndalen

The service shown in Figure 1-10 was tested at the site Garderborgbakken and information was distributed on VMS signs and a mobile app, see Figures 1-11 and 1-12.

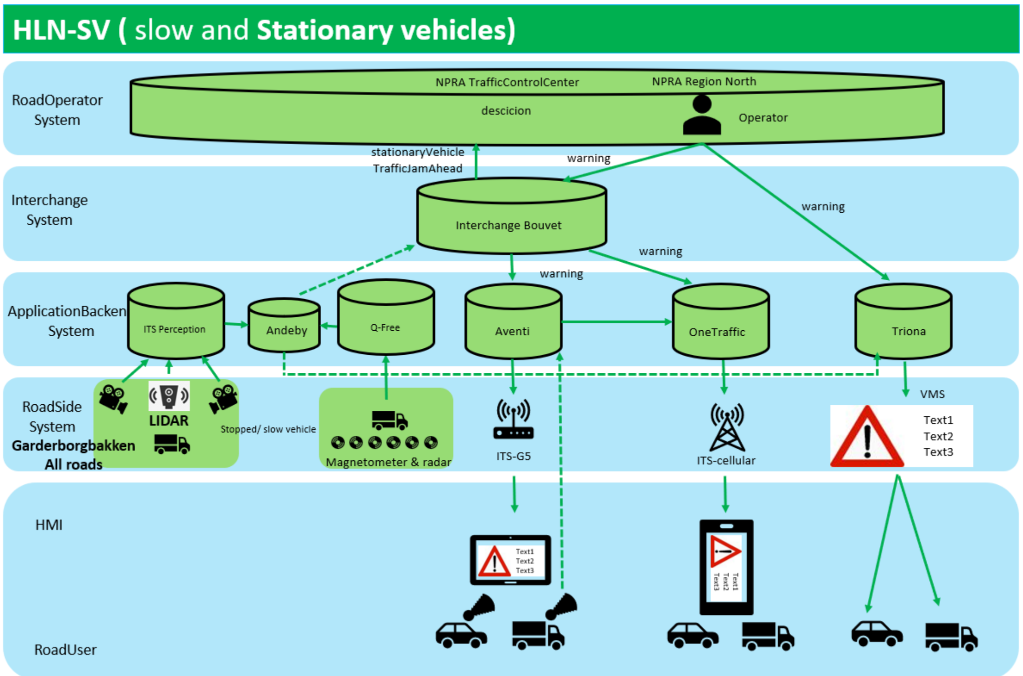

Figure 1-10. Technical ecosystem of the service Slow and stationary vehicle

Figure 1-11. VMS sign at Lullemoen

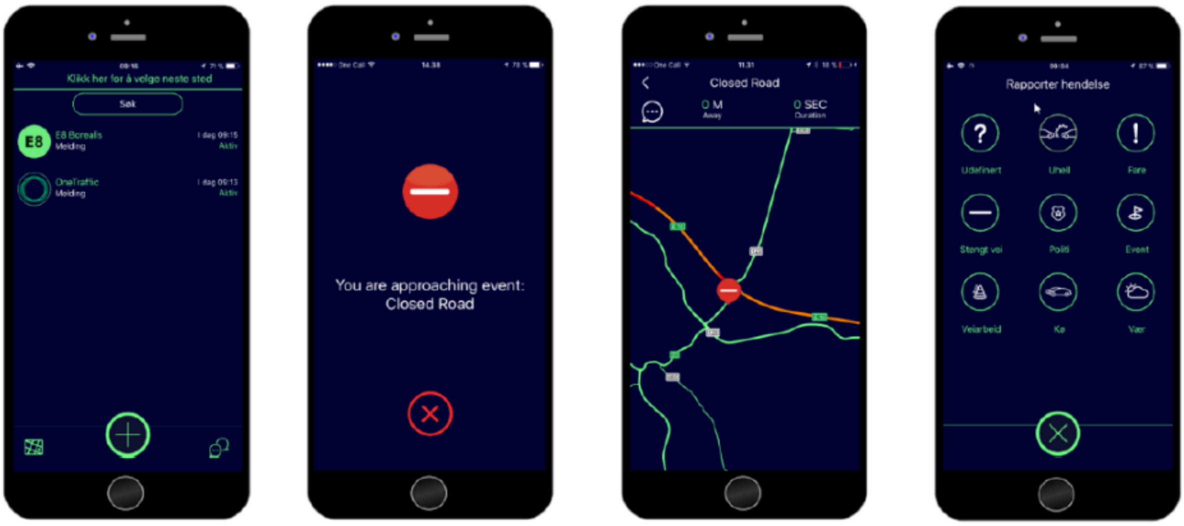

Figure 1-12. Screenshots from the OneTraffic service app

NPRA tests at Jonsvatnet, Trondheim

The following services were tested

- Slow or stationary vehicle(s) and Traffic ahead warning
- Road works warning

The aim of the field tests at Jonsvatnet were to verify the PoC of the services. The maintenance vehicle sent messages to the Norwegian interchange node, which were then distributed to a mobile app in vehicles approaching the maintenance vehicle (Figure 1-13).

Figure 1-13. Test driving at Jonsvatnet

Nordic Tour

The Nordic Tour was planned together with all of the partners in NordicWay 2. The route totalled 5 000 km of real-world roads in a comprehensive network with large variation in road geometry, traffic volume and topography, including both urban and rural areas. During the test there were moderate differences in weather conditions and the follow-up logging was done in winter. The test route was Gothenburg–Kilpisjärvi–Gothenburg, passing through four countries and five border crossings (two by ferry, three road-based), see Figure 1-14. The test equipment was always connected to the interchange.

The aim of the Nordic Tour was to collect data on

- Vehicle perception of infrastructure, focus on state-of-the-art ADAS
    - To what extent can the vehicle understand the surroundings?
    - Camera with detection of lane markings and signs along the entire route
- Connectivity measurement – RSRP, RSRQ and Ping times
    - On roof
    - In vehicle, worst-case (logging device in front passenger footwell, on the left)
    - In vehicle, not worst-case (in boot/trunk of the vehicle)
- Interference in LTE bands (data from spectrum analyser)
- GNSS logging – accuracy, signal quality, potential CW-jamming, AGC shifts
- Cross border testing of service functionality, logging of connectivity when border crossing and logging of events available through the interchange when driving in all four countries.

More information about the Nordic Tour is available in 'Norwegian Pilot 2, Evaluation and final report' by NordicWay 2 (2020a).

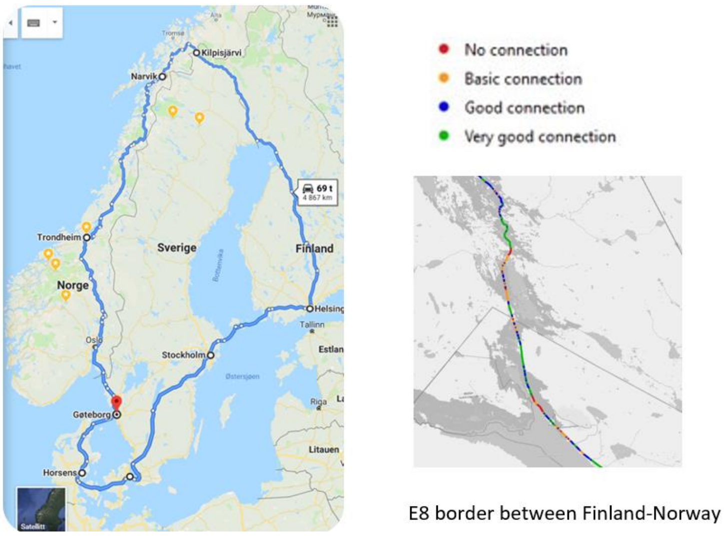

Figure 1-14. Nordic Tour route and cross-border communication quality

KPIs measured in Norway

Tables 1-4 and 1-5 provide an overview of the KPIs measured in Norway and the KPI calculation methods. The input for the KPIs was collected by various means, e.g., reported by the service providers, by calculating from the log files, and/or data collected in controlled tests.

Service-provider-reported KPIs

Information for several KPIs were collected from service providers which took part in the POC and had implemented the C-ITS services the Norwegian pilots. The service-provider-reported KPIs related to service coverage and the number of C-ITS devices during the pilots.

KPI calculation from the logs

Due to the cancellation of several test weeks, we have a limited number of data logs. The latency logging was done in an early phase of the development and was used to find an optimal configuration for the interchange node. No latency measurements were done during the field tests.

KPI measurements in the controlled tests

Two KPIs were calculated based on the results of the controlled tests.

Physical coverage is dependent on communication technology. If implemented with cellular technology, the coverage is not limited to a restricted area. If short-range (e.g., ITS-G5) communication is used, the coverage is typically about 500–800m and this technology is useful for services such as Wrong-way driver and the Green Light Optimal Speed Advisory (GLOSA).

Cross-border continuity of services was tested on the Nordic Tour with focus on cellular communication and handover situations.

Table 1-4. KPIs for coverage of services in Norway.

Quality KPI	KPI	Description	Unit	Information source		KPI calculation method / comment
				Serv.Prov. reported	Controlled tests	
KPI_Q01	Physical coverage	Change in length of the network covered by C-ITS services	-		x	
KPI_Q02	Number of vehicles equipped	Change in number of vehicles equipped with a fully functional C-ITS in-vehicle device, e.g., number of app downloads	Number	x		Limited number of test OBUs and RSUs
KPI_Q02b	Number of vehicles equipped with a partially functional C-ITS in-vehicle device	Change in number of vehicles equipped with a partially functional C-ITS in-vehicle device	Number	x		Limited number of test OBUs and RSUs
KPI_Q03	Change in number of external data sources per service	Change in number of external data sources per service (via federation/interchange nodes) (comparing the situation before and after NW2)	Number	x		
KPI_Q12	Cross-border continuity of services		Yes / No		x	Nordic Tour

Table 1-5. KPIs for service performance in Norway

Quality KPI	KPI	Description	Unit	Information source		KPI calculation method / comment
				Serv.Prov. reported	Calc. from logs	
KPI_Q08	Latency (end-to-end)	Send/receive latency – time from timestamp sent to timestamp received of message between two end-user devices	s		x	Special test with simulations
KPI_Q13	Cross-organisational / Cross-brands data sharing	Data sharing between organisations within a country or cross-border	Yes / No	x		Tested functionality through entire ecosystem

Controlled experiments in Sweden

Emergency Vehicles Approaching (EVA) warning

In the case of EVA, the messages included the parts from the integration and connection with SOS Alarm until the EVA warning messages were finally received in the vehicles and a message was displayed on the vehicle HMI (Figure 1-15).

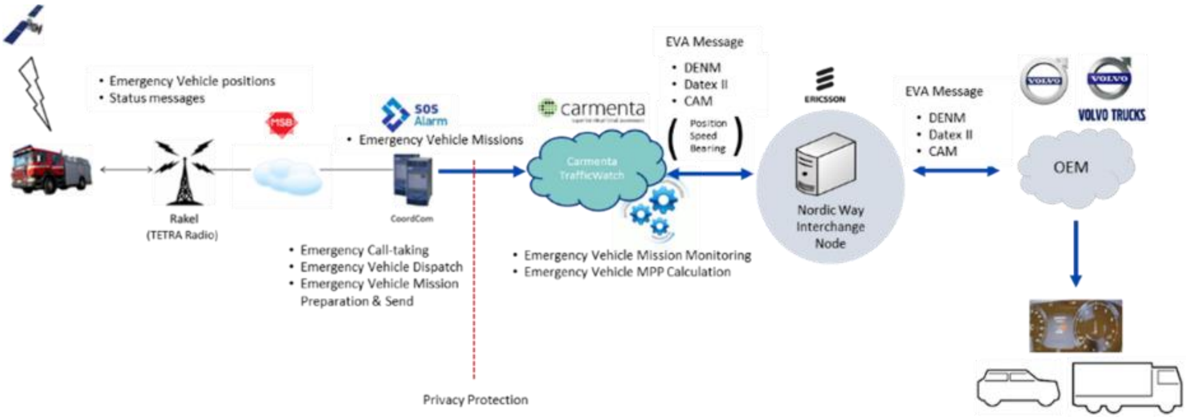

Figure 1-15. Description of components used for Emergency Vehicle Approaching warning messages.

For EVA, end-to-end measurements have been performed for the Emergency Vehicle Warnings from the Emergency Response system at SOS Alarm, through Carmenta TrafficWatch and the interchange node to the Volvo Cars backend cloud that sends the messages to the cars. In total, there were 31 400 records of messages at Carmenta TrafficWatch from 251 different emergency missions.

Connected traffic signals

In Figure 1-16, the architecture for connected traffic signals shows how timings (SPAT and MAP data), from Traffic Light Controller were generated and passed the interchange node towards the goal, the OEMs´ different clouds. The services Time-To-Green and Green-Light-Optimal-Speed-Advisory etc. were generated at the OEM side.

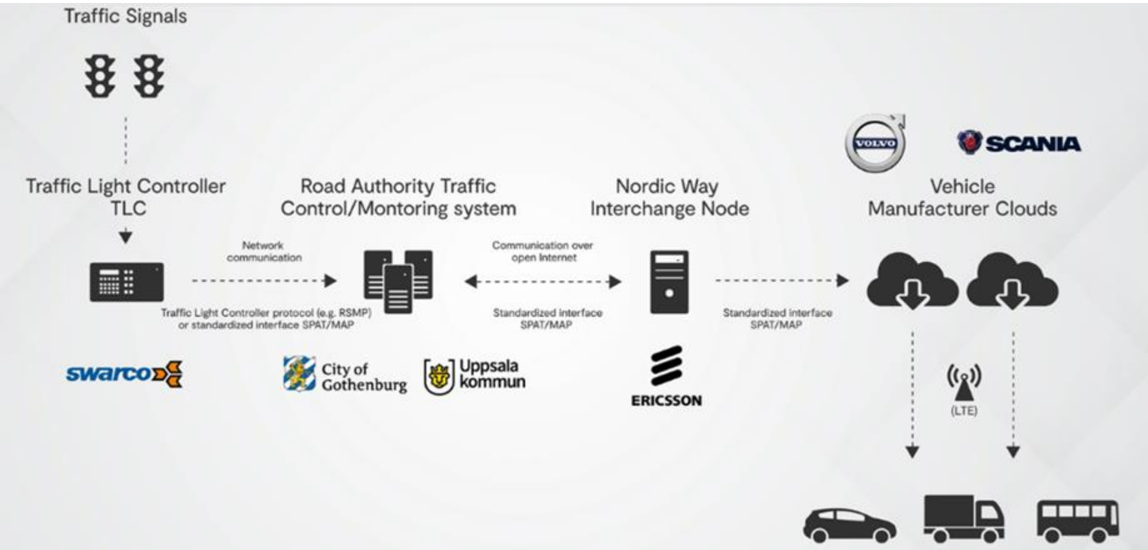

Figure 1-16. Architecture for TTG/TTR and GLOSA (one-way communication).

For traffic signals, the time between the change in the traffic signal phase (green, yellow or red) and what you see/sense in the vehicle was measured as latency. The time was measured from the switch of the signal at the infrastructure to the OEM cloud (Figure 1-17). The HMI was not involved in the process.

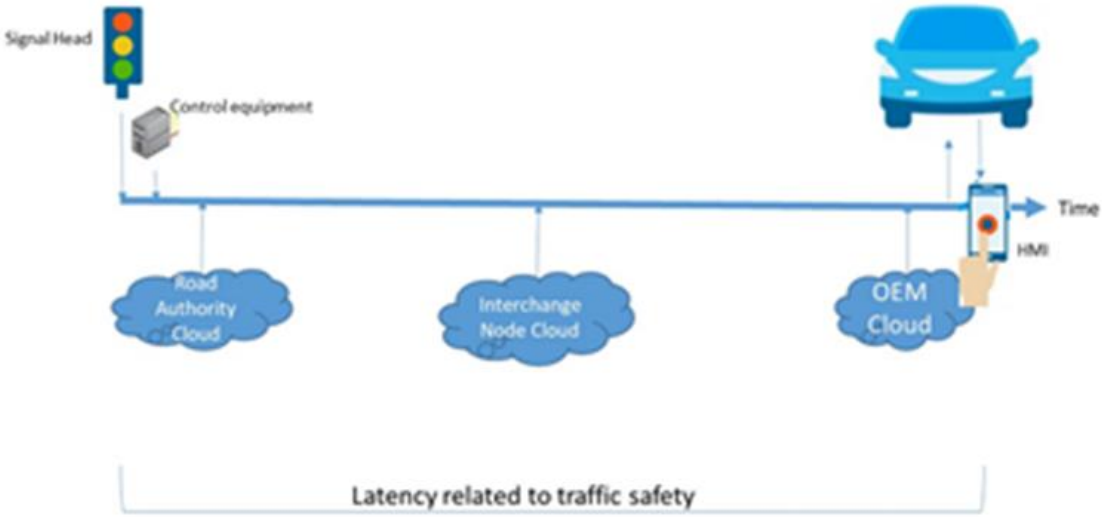

Figure 1-17. Latency measurement for TTG/TTR and GLOSA

Dynamic access control

For Dynamic access control, the architecture contained three main sub-systems (Figure 1-18): the traffic management centre (TMC), the interchange node, and the OEM digital environment. The messages was initiated at the TMC, which contained systems from Technolution for exchange with the interchange node, interaction with the traffic operator and the central databus for traffic data. The message then passed through the interchange node to the OEM's digital environment. Scania developed an interface making it possible to send request for access and receive messages for approved or denied access through the interchange node.

The architecture included a set of future extensions whereby dynamic access control can be connected to C-ITS solutions, traffic network management systems and weather systems for additional information from external sources.

The latency was measured by the stopwatch method. Two different latencies were measured: First, the latency between the access request from within the truck to the operator and back again to the truck, and second, the latency between transmission and reception in the application.

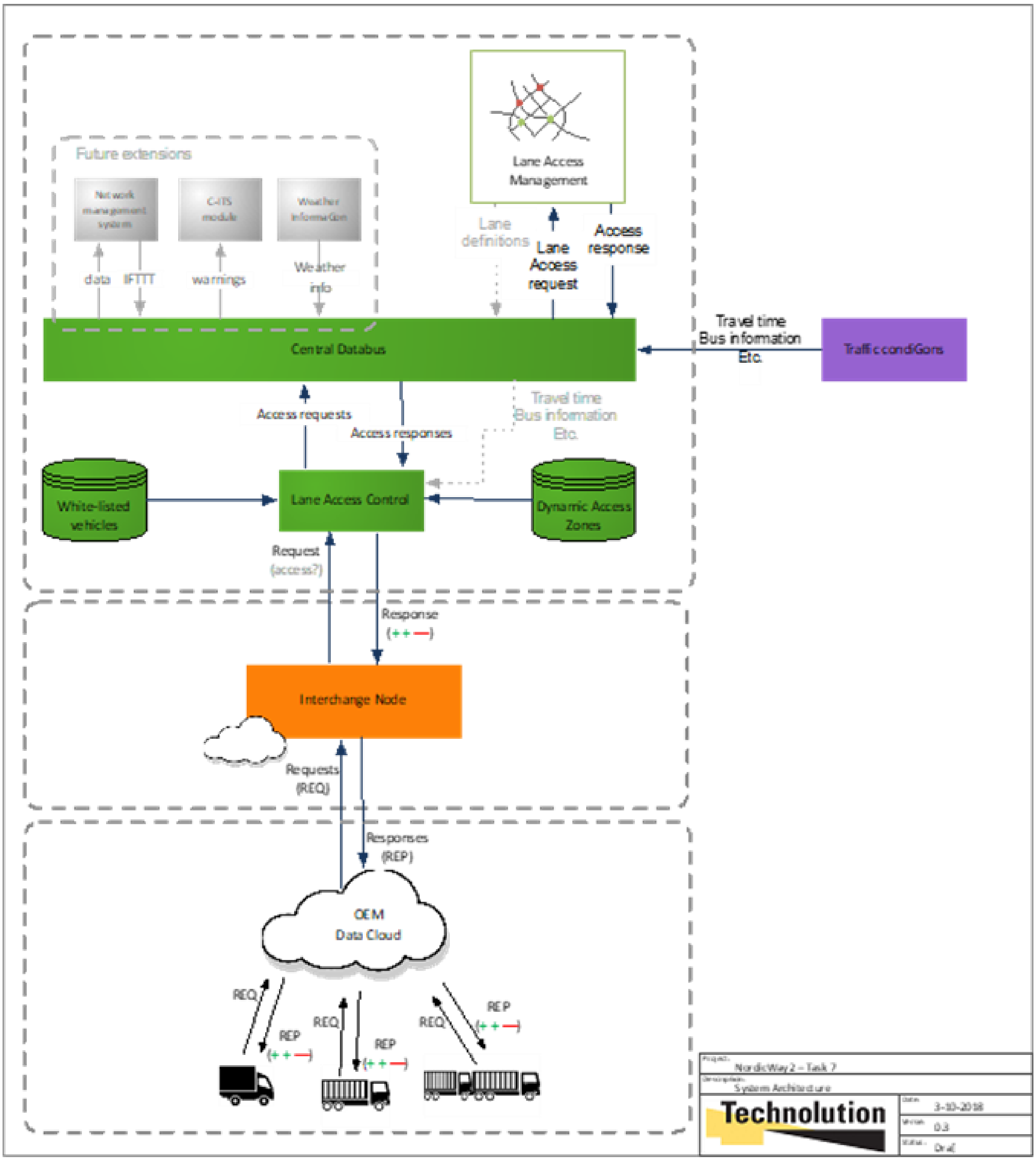

Figure 1-18. System architecture for Dynamic access control

Dynamic Environmental *zone*

For the dynamic environmental zone, the city of Gothenburg offered a test version of a city innovation platform (CIP), which was in development currently as part of the EU project IRIS. This CIP delivers a common means for data exchange and storage from a smart city perspective (Figure 1-19). Exchange of controlled zone information, restrictions, status etc. is most suitable through this platform. The central data exchange is based on the Ericsson Nordic Way 2 interchange node, which offers a common platform for information exchange between business and governmental systems. Technolution deploys an installation of their traffic management suite MobiMaestro; for this purpose, the existing central databus is extended with support for controlled zone information. MobiMaestro exchanges the controlled zone information with the CIP through a standardised REST API. Finally, Volvo Car extends the cloud enabling the controlled zone information to be received and pushed to vehicles in the area. Test software in the vehicle ensures that the vehicle automatically runs on pure electric within the zone.

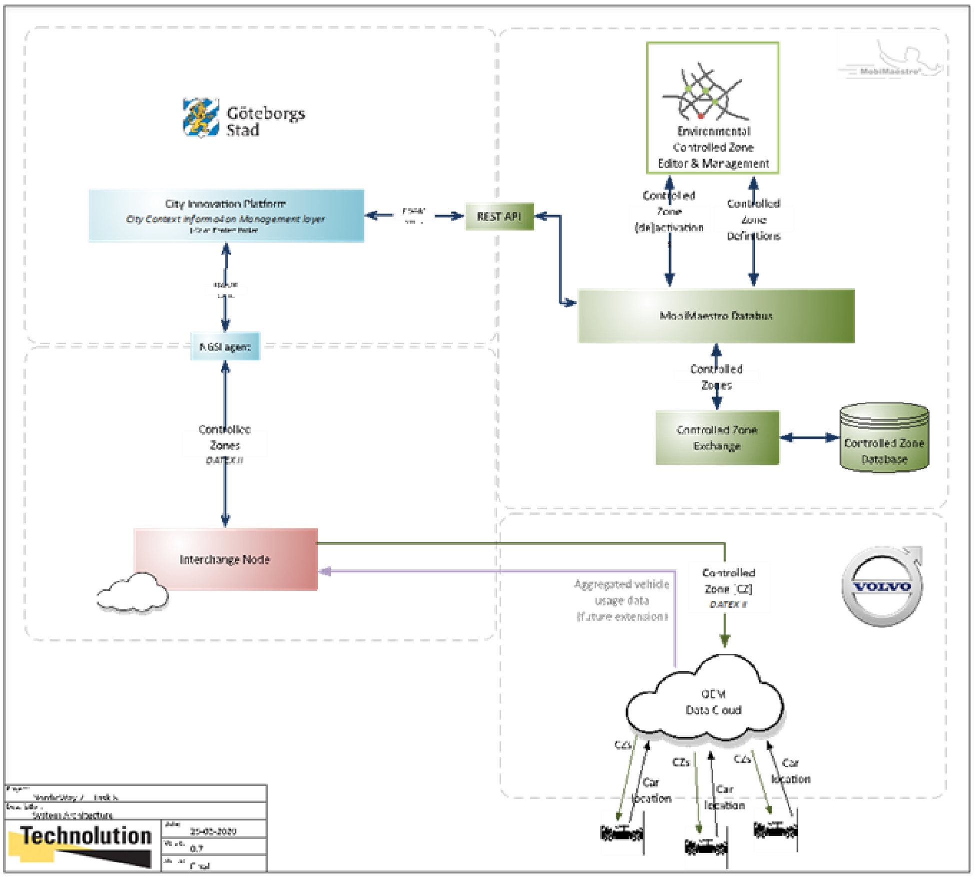

Figure 1-19. Dynamic environmental zones architecture

For geofencing, the latency was measured using the stopwatch method. The measurement corresponded to the measure of latency between changing a geofence state in the GUI and the actual response in the vehicle.

Road Works Warning

The service and warning message for Road Works Warning (RWW) was generated at the RWW unit mounted on the TMA vehicle (Figure 1-20). The message was received by the Kapsch unit, which transferred the RWW message in DENM and DATEX II format through the interchange node to the OEM cloud and finally to the vehicle. The OEM cloud also received Roadwork information messages from Trafikverket in DATEX II. Latency was not measured for this service.

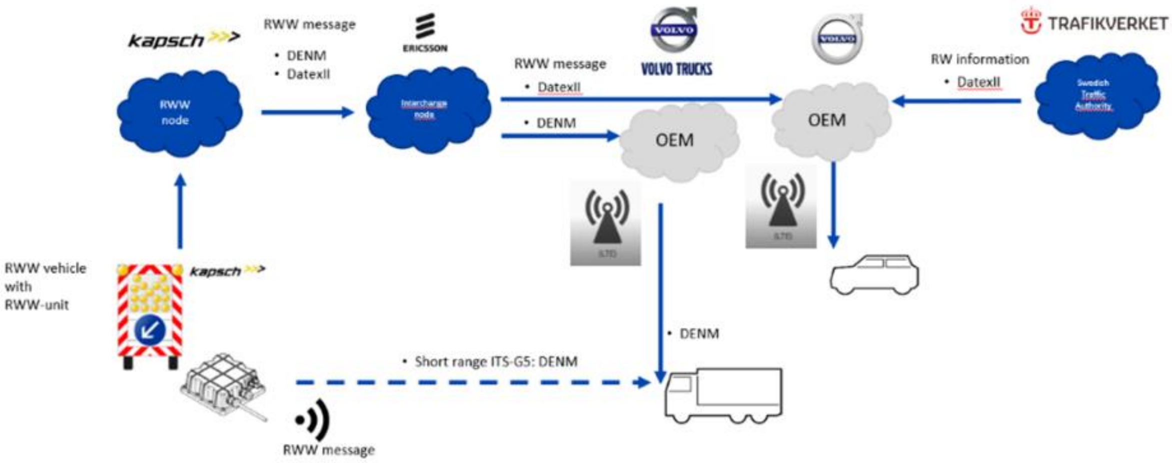

Figure 1-20. Flow of messages for Road Works Warning.

Annex 2. Ecosystem evaluation script for the first workshops

This annex presents the script — the tentative program for the first ecosystem evaluation workshops in Finland, Sweden and Norway. Note: In addition to the actual workshop manuscript below, the provided document also contained some other items. These included some general info and background on the ecosystem evaluation process, general instructions on reporting guidelines, timeline, deadlines and the flexibility rules — and also some material to be used in the workshops.

The first workshop should contain three main blocks of data collection:

I Current state and roles

II Scaling-up issues

III Expectations regarding continuation

A light pre-workshop data collection round was also included.

Section 0: Start-up (approx. 20 minutes)

Welcome, short presentation rounds, short intro on the contents, purposes and motivation of (i) the evaluation study and (ii) the workshop.

Grouping of participants into "pilot-specific groups" i.e., groups containing the stakeholders working together in NordicWay 2 in a specific ecosystem to carry out a "pilot deployment" containing one or more C-ITS services or use cases.

Section I: Current state and roles

Section I, total duration approx. 100 minutes

I.a Introduction and instructions (approx. 15 minutes)

> "The objective of the session is to describe the present ecosystem, its actors and their roles, and to describe what makes the ecosystem competitive."

I.b Current status basics (approx. 20 minutes)

- Consensus discussion based on the short questionnaire for each pilot (note: present at the workshop might be one or more representatives per company, or possibly no representation for some companies)
    - C-ITS service(s): name and short description
    - Describe user groups, number of present users
    - Service presentation and bundling of services
    - Lessons learned from the service formulation and provision phases
    - Encountered challenges and problems in forming the ecosystem (non-technical ones)
    - Issues with access to data and right to use (for service provision purposes) within the pilot

Pre-filled questionnaire to be sent to participants well before the workshop and returned to the evaluators before the workshop.

I.c Roles within the current ecosystem (approx. 75 minutes)

- Role and individual company input, pain, gain and commitment.
    - (*Pain* = the "sacrifice", i.e., input, changes in ways of thinking, changes in processes, investment, etc. *Gain* = expected business outcome of being involved in this pilot. *Commitment* = main reasons for joining. See more concrete examples in Figure 2-3)
- Working method: data collected e.g., with Post-It notes and felt pens on a whiteboard or flip chart (in pilot-specific groups) — including actors that are needed & utilised but not within the pilot consortium. Each pilot to provide its own result.
- Method:
    - Step 0 — before the workshop — some homework to be done by participants
    - Step 1. Describe the current ecosystem on a flip chart; actors (pilot consortium members, other actors), their roles and relationships (see Figure 1) (30 min)
    - Step 2. Describe the pains, gains and commitment of current actors on a flip chart. Identify especially areas where pains, gains and commitment of actors are not well known (20 min).
    - Step 3: Identify major strengths and weaknesses of the current ecosystem (10 min)

- Step 4. Presentation of ecosystem actors, their roles, pains and gains. Present major strengths and weaknesses (n*5 min, where n is the number of pilots)

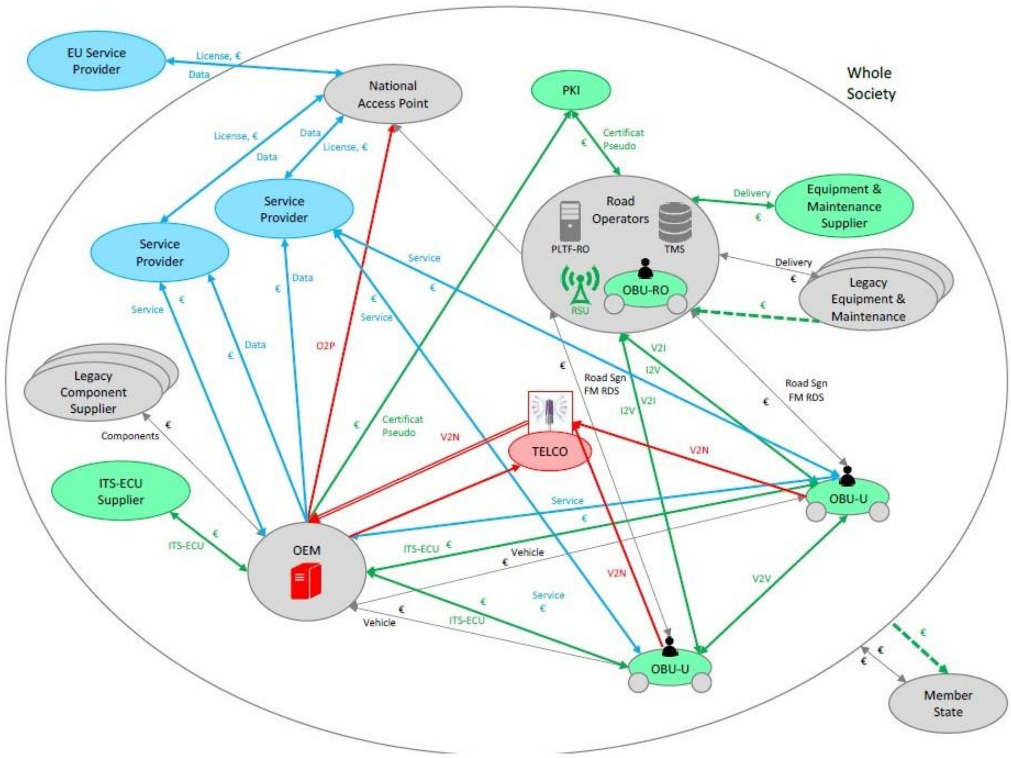

Figure 2-1. Example of ecosystem description (should include also any key actors outside the NW2 pilot group.) Figure from C-ITS Platforms final report. End-to-end content provision and service provision matrix.

	End-to-End				
	Content provision		Service provision		End User
	Content Collection	Content Processing	Service Provision	Service Presentation	
	T1: Detection T2: Data delivery T3: Data reception T4: Data preprocess T5: Data delivery T6: Communication	T7: Data reception T8: Content fusion T9: Data processing T10: Quality check T11: Content delivery T12: Communication	T13: Content reception T14: Content fusion T15: Service generation T16: Pre-formatting T17: Servicedelivery T18: Communication	T19: Service reception T20: Service decoding T21: Info fusion T22: Service rendering T23: Service presentation T24: Communication	
Actors					

Figure 2-2. Actors and their role in the value network.

Actor	Pain	Gain	Commitment

”Pain”: what input or changes are needed
- Business as Usual (BaU)
- Requires development of new technology
- Requires renewing of infrastructure
- Requires investments
- Requires training and education
- Etc.

”Gain”: what can be gained from doing
- BaU
- New business opportunity
- Enlarged market share
- New customers
- Higher price
- Lower cost
- Improved competitiveness
- Etc.

Commitment: how committed is the actor to change
- Active actor in the market
- Involved in related R&D activities
- Supports strategic objectives
- Providing competing solution
- Conflicting objectives
- Etc.

Figure 2-3. Actors and their motivations etc. in the value network.

Conclude with brief reflections on the results of section I + instructions for section II.

Coffee break (15 min) (or lunch break 1h, depending on the workshop start time etc.)

Section II: Scaling up the ecosystem or the service provision – perceived ambitions and challenges

Section II, total duration approx. 60 minutes

- What will be needed in your own company, in the ecosystem (new partners, etc.)
  - Moving from the pilot stage to a deployment “in real life” — what is needed? (incl. public actor roles, access to data and right to use)
- Joint vision of the ecosystem five years from now
  - Scaling up from local (or restricted user base, e.g., Posti) to national level, from national to Nordic level, and up to European or Global level?
  - What new actors or data sources are needed in various scaling-up levels? Any of the current ones becoming marginal?
  - Implications (pros & cons) of the federation model?
  - Where is investment and/or development needed?
  - What should be the public sector’s role? (Please differentiate clearly between city actors and other types of public actors, since cities are of special interest in NW2 C-ITS.)
  - Other issues?

Method:

- Step 1. (15 min) Write an estimate describing your view of the business potential five years from now. E.g., estimate of user numbers (own country, Nordic, global) and, if possible, preferably also the annual turnover or growth trend % from 2020 to 2025.
  - Use a Post-It card. Describe to the pilot group why you chose this estimate.
  - Discuss the service portfolio that you would likely offer five years from now.
  - Discuss and try to find a joint vision of the business potential.
- Step 2. (30 min) Use the current ecosystem model from Section I to describe where in the ecosystem changes are needed in order to achieve the defined business potential and service portfolio. Use Post-It cards to document the needed changes. Discuss the need for changes within the group.
- Step 3. (3*5 min) Presentation e.g., by pilot leader of business potential and needs for up-scaling

Conclude with brief reflections on the results of section II + instructions for section III.

Section III: Expectations from i) the user acceptance study and ii) next Workshop

Section III, total duration approx. 20 minutes

III.a Wishes for the user acceptance study:

- Short intro on what the user acceptance study is (Risto)
- Discussion on what the participating organisations would like to learn from the user acceptance study, if possible.

III.b Wishes for the next workshop:

There are many other players in the field, either connected to or disconnected from the now running NordicWay 2 C-ITS service pilots (e.g., providers of free or purchased data, Here, TomTom, Google, and in Finland e.g., Väylä, ITMF, HäKe, etc.). Which of those players would we like to invite to take part in the next workshop?

Conclude with brief reflections on the results of the workshop, thanks and with encouragement to join the 2nd workshop.

Annex 3. NordicWay 2 User acceptance survey

The survey presented in this Annex is the English version of the survey. It was translated into Danish, Finnish, Swedish and Norwegian.

Welcome to participate in the survey on cooperative traffic information services

The purpose of this survey is to gain more insight into drivers' willingness to use new types of traffic information services.

This survey is part of a Nordic collaboration, the NordicWay2 project, co-funded by the EU. In [country], [organisation] is responsible for the work. The results of the study will be used to develop traffic information services. Survey results will be analysed within the project confidentially and reported anonymously, ensuring that the answers of individual respondents cannot be identified.

It takes about 10 minutes to complete the survey.

Q0. On average, I drive a car …. kilometres per year.

- Less than 1 500 (→ do not proceed with the survey)
- 1 501 to 10 000
- 10 001 to 20 000
- 20 001 to 30 000
- 30 001 to 50 000
- More than 50 000

Cooperative traffic information services

Road users and the providers of transport services can exchange real-time messages about topics important for mobility when vehicles or mobile devices (e.g., phones) are connected wirelessly. These new services are called cooperative services. Vehicles or mobile devices where these services are installed can also be connected to e.g., traffic lights and traffic signs or to traffic information service providers. Cooperative services automatically warn their users about hazardous situations or conditions (such as obstacles on the road or slippery road). They can also provide information aiming to improve the fluency of traffic or to support travelling in other ways (e.g., by informing the driver at what speed to approach a traffic light to arrive on green, or about available street parking).

Q1. How aware are you of the cooperative traffic information services described above?

- I have not heard about these services before
- I am somewhat familiar with these services
- I am familiar with these services but I have not used them myself
- I know these services well and have used them myself

(Please continue, even if you have not heard about these services.)

Q2. Below is a list of information content that can be provided by cooperative services. Please indicate the importance of each information type by rating them from 1 to 7 (1 = not at all important, 7 = very important).

First, think of a trip you would make on main roads or motorways, and provide your ratings for each item below.

Information or warning shown on in-vehicle display or mobile device	Importance							
	Not at all important – very important							I don't know / Not relevant to me
	1	2	3	4	5	6	7	
1. Current posted speed limit								
2. Local adverse weather or road condition								
3. Slow or stationary vehicle ahead								
4. Emergency vehicle approaching								
5. Traffic jam ahead								
6. Emergency braking in traffic ahead								
7. Large animal on the road								
8. People on the road								
9. Obstacle on the road (e.g., dropped cargo)								
10. Accident ahead								
11. Road or lane closure ahead								
12. Road works ahead								
13. Mobile road maintenance vehicle (such as snowplough) nearby								
14. Traffic situation and smart routing to less congested routes								
15. Location of alternative fuelling & charging stations nearby								

Now, think about driving on **urban streets** and provide your ratings in this case with regard to information content.

Information or warning shown on in-vehicle display or mobile device	Importance							
	Not at all important --- very important							I don't know / Not relevant to me
	1	2	3	4	5	6	7	
1. Current posted speed limit								
2. Local adverse weather or road condition								
3. Emergency vehicle approaching								
4. Emergency braking in traffic ahead								
5. Accident ahead								
6. Road or lane closure ahead								
7. Road works ahead								
8. Mobile road maintenance vehicle (such as snowplough) nearby								
9. You are about to go through a red light								
10. In the intersection ahead, someone is going through a red light								
11. Time to green, or advice on optimal speed for the next traffic lights								
12. Traffic situation and smart routing to less congested routes								
13. Free parking slots and their type on nearby streets								
14. Location of alternative fuelling & charging stations nearby								

Nordic WAY 2

Q3. What is your opinion about this kind of cooperative traffic information services? Do you agree with the statements below?

	Fully disagree – fully agree							
	1	2	3	4	5	6	7	I don't know
These services improve traffic safety								
These services improve traffic fluency								
These services would help me avoid congested areas								
These services are useless; I receive the same information by other means								
These services would increase my driving comfort								
These services would distract me too much from driving								
I would be willing to use these services on main roads and motorways								
I would be willing to use these services on urban streets								
I would be willing to pay to get these services								

Q4. To improve the quality of the services, would you be willing to share certain data about your trip with your information service provider? Note that the data will not be linked to your identify for any other use, and will not be made available to e.g., law enforcement.

Type of data	Yes	Maybe	No	I don't know
Location of my vehicle				
Speed of my vehicle (to detect congestion)				
Emergency braking of my vehicle				
Data on weather and road condition collected by my vehicle				
My manually sent warnings of hazards on the road (with an application or via voice command)				

Q5. For what kinds of trips you would use cooperative services?

a) For selected trips

If a) please specify

- When I have a tight schedule
- For longer trips
- When driving on congested routes
- In adverse weather conditions
- On unfamiliar routes
- Other: ____________________

b) Always / for most trips
c) I would never use the services
d) I don't know

Q6. Do you drive abroad?

- Yes
- No [move to Background questions]

[If Q6 = Yes]

Q7. Regarding driving abroad, please indicate your level of agreement with the statement on a scale from 1 to 7 (1 = fully disagree, 7 = fully agree)

Statement:	Fully disagree – fully agree							
	1	2	3	4	5	6	7	I don't know
When I drive in other countries, it is important to me that I can use the same cooperative service or application that I use in my home country								

[If Q7 > 3:]

Q8. Which countries would be relevant to you? (You may select several)

- Nordic countries
- Baltic countries
- Russia
- Central Europe
- Southern Europe
- Other continents and countries

Background questions

Q9. My gender is:

- Male
- Female
- Other
- Prefer not to say

Q10. Year of birth: _____________

Q11. Are you a professional driver or is driving a core part of your work?

- No
- Yes

Q12. The type of vehicle I mainly use is

- A motorcycle
- A car
- A van
- A truck/lorry
- Another type of motorised vehicle

Q13. The fuel / energy source(s) of the motor vehicle I mainly use is
(You may select several alternatives)

- Gasoline/petrol
- Diesel
- Gas
- Electricity
- Other

Q14. When it comes to trying a new technology product, I am generally.... to try it

- Among the last
- In the middle
- Among the first

Q15. I drive

a) Outside urban areas
- Daily
- Weekly
- Monthly
- More seldom
- Never

b) In urban areas
   - Daily
   - Weekly
   - Monthly
   - More seldom
   - Never

Annex 4. Porokello survey questions on driving behaviour effects

This annex includes an English translation for a subset of questions addressing the effects of reindeer warnings on driving behaviour. See Kotituomi et al. (2019) for the full survey and results.

Think about the last time you got a warning from the Porokello app. Answer the questions based on that.

Q1. Did you prepare or somehow change your driving behaviour because of the warning?

- Yes
- No

How did the reindeer warning affect your driver behaviour? Think specifically about the impact of the warning, i.e., compare the situation before you received the warning with that after the warning.

DRIVING SPEED

Q2. How did the warning affect your driving speed?

- No impact
- I slowed down after receiving the warning while in the warning area
- I slowed down only after I saw a reindeer
- I drove more slowly for the rest of the trip
- Other impact, what
- I cannot say

FOLLOWING DISTANCE

Q3. How did the warning affect your distance to the vehicle ahead?

- No impact
- I kept a longer distance
- I kept a longer distance only after I saw a reindeer
- Other impact, what
- I cannot say

OVERTAKING

Q4. How did the warning affect your overtaking behaviour?

- No impact
- I overtook more carefully
- I overtook less often
- I tried to avoid overtaking
- Only seeing a reindeer affected my overtaking
- Other impact, what
- I cannot say

USE OF CONTROL DEVICES

Q5. How did the warning affect your use of control devices (steering wheel, pedals, gears, other controls)?

- No impact
- Steering, how?
- Accelerator pedal use, how?
- Brake pedal use, how?

- Clutch pedal use, how?
- Gear use, how?
- Only seeing a reindeer affected my use of control devices
- Other impact, what
- I cannot say

ACTIVITIES PERFORMED WHILE DRIVING

Q6. How did the warning affect your activities performed while driving?

- No impact
- Use of radio, how?
- Use of mobile phone, how?
- Use of other in-car devices, how?
- Talking with fellow travellers, how?
- Only seeing a reindeer affected my secondary activities
- Other impact, what
- I cannot say

DISCUSSION ABOUT THE WARNING

Q7. If you had a fellow traveller in the vehicle, did you discuss the warning after receiving it?

- Yes, we discussed the purpose of the warning
- Yes, we discussed what should be done
- Only after seeing a reindeer did we discuss the warning
- No, we did not discuss the warning
- No, I drove alone
- Other, what?

FOCUSING ATTENTION

Q8. How did the warning affect your focus of attention (what information were you looking for from the traffic environment)?

- No impact
- I monitored the roadsides more carefully for reindeer and other animals
- I focused more on my own driving
- I focused more on the driving behaviour of other passenger cars and vans
- I focused more on the driving behaviour of other trucks/lorries and buses
- I monitored the traffic behind me more carefully
- I monitored oncoming traffic more carefully
- I focused more on the behaviour of pedestrians and bicyclists
- I focused on road weather
- My attentiveness increased only after seeing a reindeer
- Other, what?
- I cannot say

OTHER IMPACTS

Q9. Did the warning affect you in some other way?

- Yes, how?
- No
- I cannot say

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Annex 5. Network data for socioeconomic assessment

Basic network attributes in 2030 for the networks used in the assessment

Denmark

Network attributes	DK 1 State roads
Lenght (km)	3820
Vehicle kilometres driven (million/year)	29331
Share of heavy vehicles (%)	6,7
Vehicle hours driven (million/year)	391,6
Vehicle hours spent in congestion (M/year)	19,9
Fatal accidents (number/year)	55,5
Non-fatal injury accidents (number/year)	476
Property damage only acc. (number/year)	1677
Co2 emissions (million tonnes/year)	4,8

Finland

Network attributes	FI 1 Major tunnels	FI 2 Full telematics	FI 3 Peri-urban extended	FI 4 Inter-urban extended	FI 5 Other state roads	FI 6 main streets bigger cities
Lenght (km)	13	337	748	4588	7810	671
Vehicle kilometres driven (million/year)	110	3134	6845	11876	7132	2589
Share of heavy vehicles (%)	7,6	9,6	7,0	12,1	10,7	6,0
Vehicle hours driven (million/year)	1,4	31,3	81,5	130,1	130,1	47,5
Vehicle hours spent in congestion (M/year)	0,14	2,4	5,9	2,2	2,2	2
Fatal accidents (number/year)	0,0	1,4	9,8	40,2	40,2	6
Non-fatal injury accidents (number/year)	3,1	47	184	303	303	400
Property damage only acc. (number/year)	6,3	209	837	1402	1402	1730
Co2 emissions (million tonnes/year)	0,019	0,58	1,2	2,4	2,4	0,39

Norway

Network attributes	NO 2 Full telem.	NO 3 Heavy traffic	NO 5 other state roads
Lenght (km)	563	7100	48144
Vehicle kilometres driven (million/year)	3243	15021	21355
Share of heavy vehicles (%)	2,4	2,2	1,4
Vehicle hours driven (million/year)	69,1	281,7	480,8
Vehicle hours spent in congestion (M/year)	5,2	20,6	2,4
Fatal accidents (number/year)	1,0	15,0	56,0
Non-fatal injury accidents (number/year)	28	509	1833
Property damage only acc. (number/year)	140	2545	9165
Co2 emissions (million tonnes/year)	0,52	1,8	2,2

Sweden

Network attributes	SE 1 State roads	SE 3 Stokcholm	SE 4 Gothenburg	SE 5 Uppsala
Lenght (km)	15709	129	129	149
Vehicle kilometres driven (million/year)	44513	1371	1371	1104
Share of heavy vehicles (%)	15,8	15,8	15,8	15,8
Vehicle hours driven (million/year)	474,4	14,9	15,3	12,0
Vehicle hours spent in congestion (M/year)	11,60	0,4	0,4	0,3
Fatal accidents (number/year)	55,3	2,7	2,8	2,2
Non-fatal injury accidents (number/year)	2542	78	81	63
Property damage only acc. (number/year)	18703	507	521	408
Co2 emissions (million tonnes/year)	7,5	0,22	0,23	0,18

The following pages show the network coverage, event coverage, service use and vehicle penetration percentages used in the socioeconomic calculations for the different networks in 2030.

Network coverage was defined as the percentage of road network covered by a NordicWay C-ITS service. The service is considered a NordicWay C-ITS service if it is based on V2I communication utilising the cloud interchange concept as specified in NordicWay and/or V2V communication as specified by the C-Roads platform. There needs to be at least one service provider providing the service on the network, and the services have to have at least some customers.

Event coverage here means how many (%) of the “events” warned or informed about will be covered in the required detail by C-ITS for the users of the service on the road sections covered by the service. This means, for instance, the following:

- Services relying widely on road user C-ITS input will have lower event coverage especially on roads with less traffic
- Event coverage also benefits from roadside incident detection and camera systems; relevance also matters
- For V2V services, the “event” is another vehicle equipped with V2V to communicate with in the situation — i.e., it depends on the percentage of V2V equipped vehicles
- For EVA, the event is an emergency vehicle, and coverage depends on the percentage of emergency vehicles equipped AND using the system — some vehicles may not wish to keep the system on (e.g., police in specific cases); signal priorities likely bundled with the system may increase the equipment and use of this service
- In some cases, the “event” is just accessing or getting the service; the in-vehicle signage services or the services at traffic signals (SV/IS, TTG, GLOSA, priorities) should be fully available on all road sections or signalised junctions covered by the service
- The road works warnings may be provided as a contractual obligation; if this is the case, the obligation is expected to be complied with by all main contractors likely to win the contracts on the most important networks. Some smaller contractors may not be as compliant
- The event could also be the need to charge a vehicle battery or park the vehicle; in some cases, the service might be available but not provide detailed enough information for the user; therefore the coverage may be <100%

The “use” of services refers to the percentage of vehicle kilometres driven while using the service. The NordicWay2 evaluation group agreed on the use percentages on different types of networks in Finland based on the results of the user acceptance survey regarding the following questions:

- For what kinds of trip you would use the cooperative services?
- What is your willingness to use the service on motorways and main roads?
- What is your willingness to use the service on urban streets?
- How important are different information types on motorways and main roads?
- How important are different information types on urban streets?

Vehicle penetrations focused on vehicle flow penetrations on each network. The figures show the percentage of vehicles in the traffic flow that have a device for C-ITS communication, separately for cars or vans and heavy vehicles, i.e., mostly trucks/lorries. The figures were provided by the NordicWay 2 evaluation group separately for three types of communication device:

- Short-range V2X – ITS-G5, C-V2X or similar with fixed installation in the vehicle as standard or optional equipment
- Long-range V2X – cellular as in-vehicle, after-market or nomadic devices
- Hybrid V2X – both ITS-G5, C-V2X or similar combined with cellular, likely fixed installation

Road network coverage

Network coverage	NordicWay 2 C-ITS services															
	Slow veh etc	Weather	EBL	EVA	Other haz	IVSL	RWW-RLC	RWW-Mobile	SV/IS	Priority request	TTG	GLOSA	Fuel&charging	On-street parking	TI & routing	AWWD
DK 1	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	0 %	0 %	0 %	0 %	100 %	0 %	100 %	100 %
FI 1	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	0 %	0 %	0 %	0 %	100 %	0 %	100 %	100 %
FI 2	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	0 %	0 %	0 %	0 %	100 %	0 %	100 %	100 %
FI 3	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	0 %	0 %	0 %	0 %	100 %	0 %	100 %	10 %
FI 4	30 %	100 %	100 %	100 %	30 %	30 %	100 %	100 %	0 %	0 %	0 %	0 %	100 %	0 %	5 %	0 %
FI 5	5 %	100 %	100 %	100 %	5 %	5 %	50 %	50 %	0 %	1 %	1 %	1 %	100 %	0 %	0 %	0 %
FI 6	50 %	100 %	100 %	100 %	50 %	80 %	40 %	40 %	10 %	60 %	60 %	60 %	100 %	10 %	30 %	0 %
NO 2	80 %	100 %	80 %	50 %	100 %	100 %	100 %	100 %	80 %	80 %	0 %	0 %	100 %	5 %	100 %	80 %
NO 3	70 %	100 %	70 %	50 %	100 %	100 %	100 %	100 %	80 %	60 %	0 %	0 %	100 %	5 %	100 %	80 %
NO 5	50 %	50 %	50 %	30 %	50 %	100 %	50 %	50 %	60 %	40 %	0 %	0 %	100 %	5 %	80 %	50 %
SE 1	20 %	100 %	10 %	100 %	100 %	100 %	100 %	100 %	30 %	60 %	60 %	60 %	100 %	90 %	100 %	100 %
SE 3	40 %	100 %	10 %	100 %	100 %	100 %	65 %	65 %	30 %	50 %	40 %	40 %	100 %	90 %	100 %	100 %
SE 4	40 %	100 %	10 %	100 %	100 %	100 %	65 %	65 %	30 %	50 %	40 %	40 %	100 %	90 %	100 %	100 %
SE 5	40 %	100 %	10 %	100 %	100 %	100 %	65 %	65 %	30 %	50 %	40 %	40 %	100 %	90 %	100 %	100 %

Event coverage

Network coverage	NordicWay 2 C-ITS services															
	Slow veh etc	Weather	EBL	EVA	Other haz	IVSL	RWW-RLC	RWW-Mobile	SV/IS	Priority request	TTG	GLOSA	Fuel&charging	On-street parking	TI & routing	AWWD
DK 1	60 %	90 %	9 %	15 %	75 %	100 %	90 %	90 %	100 %	100 %	100 %	100 %	50 %	0 %	100 %	85 %
FI 1	90 %	100 %	9 %	90 %	80 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	90 %	70 %	100 %
FI 2	50 %	100 %	9 %	90 %	60 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	90 %	70 %	85 %
FI 3	50 %	100 %	9 %	90 %	60 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	90 %	70 %	85 %
FI 4	10 %	90 %	9 %	70 %	20 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	20 %	90 %	30 %	0 %
FI 5	2 %	30 %	9 %	60 %	10 %	100 %	90 %	70 %	100 %	100 %	100 %	100 %	10 %	90 %	20 %	0 %
FI 6	5 %	50 %	9 %	90 %	20 %	100 %	70 %	70 %	100 %	100 %	100 %	100 %	80 %	90 %	70 %	0 %
NO 2	40 %	100 %	13 %	0 %	50 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	100 %	90 %
NO 3	40 %	100 %	13 %	0 %	50 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	100 %	90 %
NO 5	40 %	100 %	13 %	0 %	50 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	100 %	50 %
SE 1	40 %	100 %	10 %	90 %	75 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	85 %	70 %	85 %
SE 3	60 %	100 %	10 %	90 %	75 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	85 %	70 %	85 %
SE 4	60 %	100 %	10 %	90 %	75 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	85 %	70 %	85 %
SE 5	60 %	100 %	10 %	90 %	75 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	85 %	70 %	85 %

Use of services during travel

Network coverage	NordicWay 2 C-ITS services															
	Slow veh etc	Weather	EBL	EVA	Other haz	IVSL	RWW-RLC	RWW-Mobile	SV/IS	Priority request	TTG	GLOSA	Fuel&charging	On-street parking	TI & routing	AWWD
FI 1	90 %	100 %	2 %	90 %	80 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	90 %	70 %	80 %
FI 2	50 %	100 %	2 %	90 %	60 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	90 %	70 %	80 %
FI 3	50 %	100 %	2 %	90 %	60 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	50 %	90 %	70 %	80 %
FI 4	10 %	90 %	2 %	70 %	20 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	20 %	90 %	30 %	20 %
FI 5	2 %	30 %	2 %	60 %	10 %	100 %	90 %	70 %	100 %	100 %	100 %	100 %	10 %	90 %	20 %	10 %
FI 6	5 %	50 %	2 %	90 %	20 %	100 %	70 %	70 %	100 %	100 %	100 %	100 %	80 %	90 %	70 %	10 %

Vehicle flow penetration

Vehicle flow penetration (%)	Cars and vans			Heavy vehicles			Heavy vehicle share (%)	All vehicles			
Network	Short-range V2X	Long-range V2I	Hybrid V2X	Short-range V2X	Long-range V2I	Hybrid V2X		Short-range V2X	Long-range V2I	Hybrid V2X	Total
DK 1 State roads	6	30	6	20	50	20	6,7	6,9	31,3	6,9	45,2
FI 1 Major tunnels	6	30	6	20	50	20	7,6	7,1	31,5	7,1	45,6
FI 2 Full telematics	6	30	6	20	50	20	9,6	7,3	31,9	7,3	46,6
FI 3 Peri-urban extended	6	30	6	20	50	20	7,0	7,0	31,4	7,0	45,4
FI 4 Inter-urban extended	4	25	4	20	50	20	12,1	5,9	28,0	5,9	39,9
FI 5 Other state roads	4	20	4	20	50	20	10,7	5,7	23,2	5,7	34,6
FI 6 main streets bigger cities	6	25	6	15	50	15	6,0	6,5	26,5	6,5	39,6
NO 2 Full telematics	15	50	5	23	60	10	2,4	15,2	50,2	5,1	70,6
NO 3 Heavy traffic peri-urban	15	50	5	23	60	10	2,2	15,2	50,2	5,1	70,5
NO 5 Other state roads	15	50	5	23	60	10	1,4	15,1	50,1	5,1	70,3
SE 1 State roads	10	30	10	20	50	20	15,8	11,6	33,2	11,6	56,3
SE 3 Stokcholm	10	30	10	20	50	20	15,8	11,6	33,2	11,6	56,3
SE 4 Gothenburg	10	30	10	20	50	20	15,8	11,6	33,2	11,6	56,3
SE 5 Uppsala	10	30	10	20	50	20	15,8	11,6	33,2	11,6	56,3

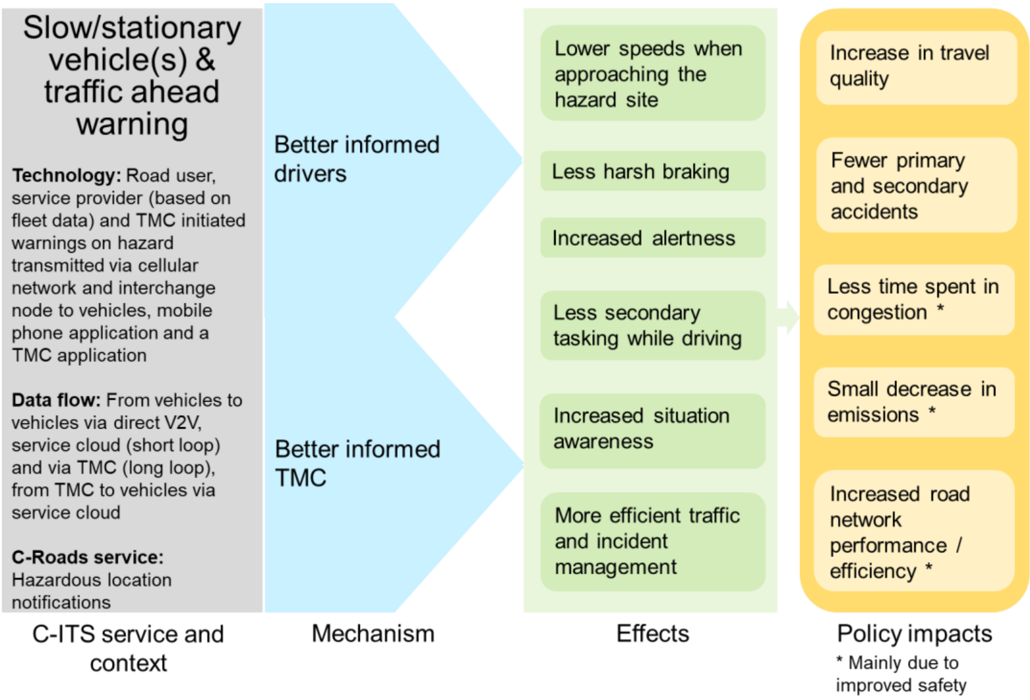
In order to simplify the assessment process, the NordicWay 2 evaluation group decided to use the Finnish data on target accidents' shares of relevant accidents (see Annex 5) and the use of services during travel also for the networks of other countries. To facilitate this, the evaluation group members determined the correspondence of their networks with the different Finnish networks. The results of this action are shown below.

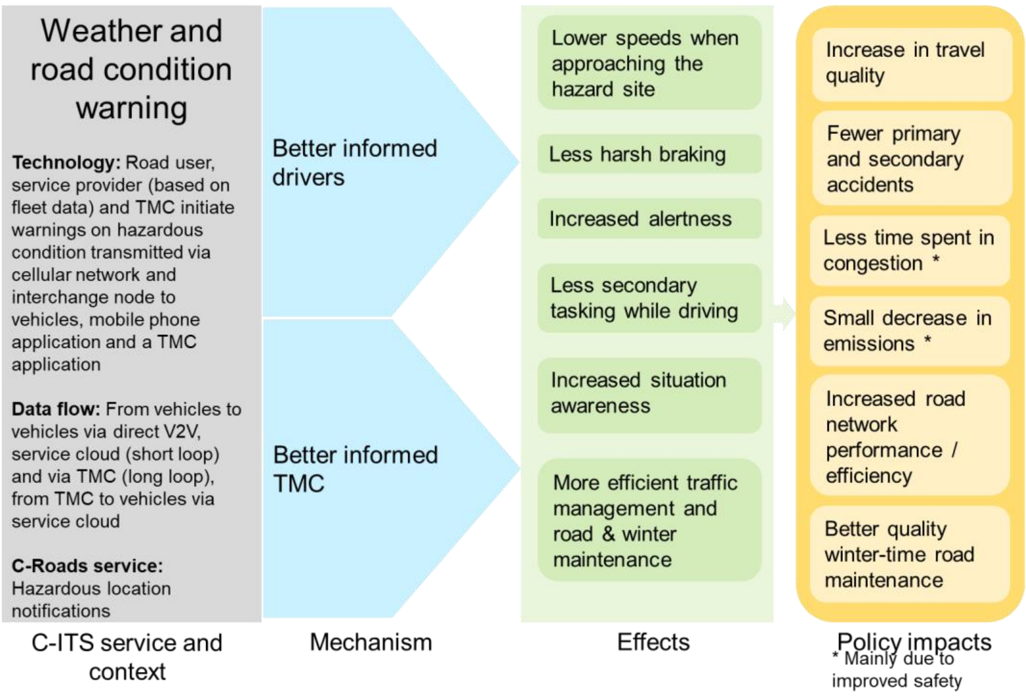
Correspondence of different networks with Finnish networks in terms of network length

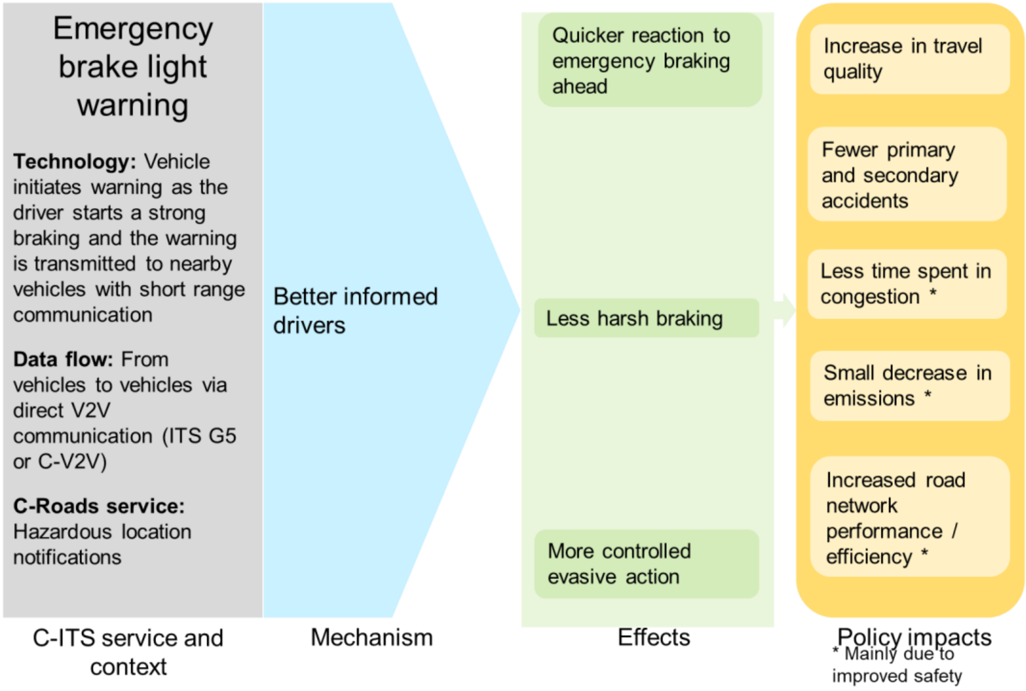
Network	FI 1	FI 2	FI 3	FI 4	FI 5	FI 6	Sum
DK 1 State roads			33 %	67 %			100 %
FI 1 Major tunnels	100 %						100 %
FI 2 Full telematics		100 %					100 %
FI 3 Peri-urban extended			100 %				100 %
FI 4 Inter-urban extended				100 %			100 %
FI 5 Other state roads					100 %		100 %
FI 6 main streets bigger cities						100 %	100 %
NO 2 Full telematics		100 %					100 %
NO 3 Heavy traffic peri-urban			100 %				100 %
NO 5 Other state roads					100 %		100 %
SE 1 State roads	0,2 %		2,8 %	40,2 %	56,8 %		100 %
SE 3 Stokcholm	3,1 %		96,9 %				100 %
SE 4 Gothenburg	8,6 %		91,4 %				100 %
SE 5 Uppsala	2,1 %		97,9 %				100 %

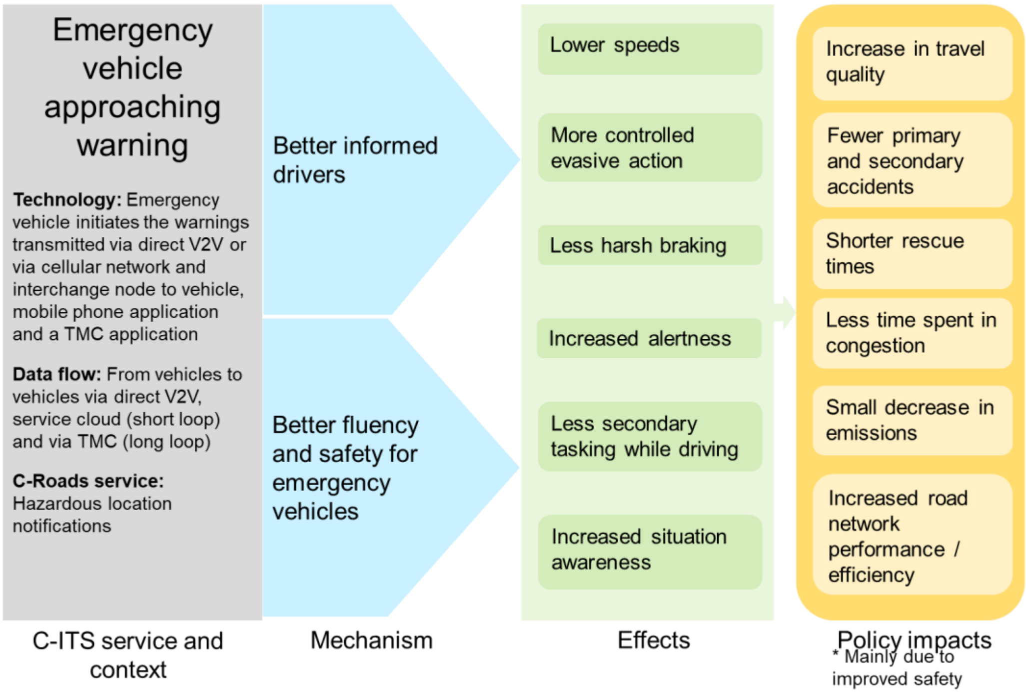
Annex 6. System theory diagrams of NordicWay2 services assessment

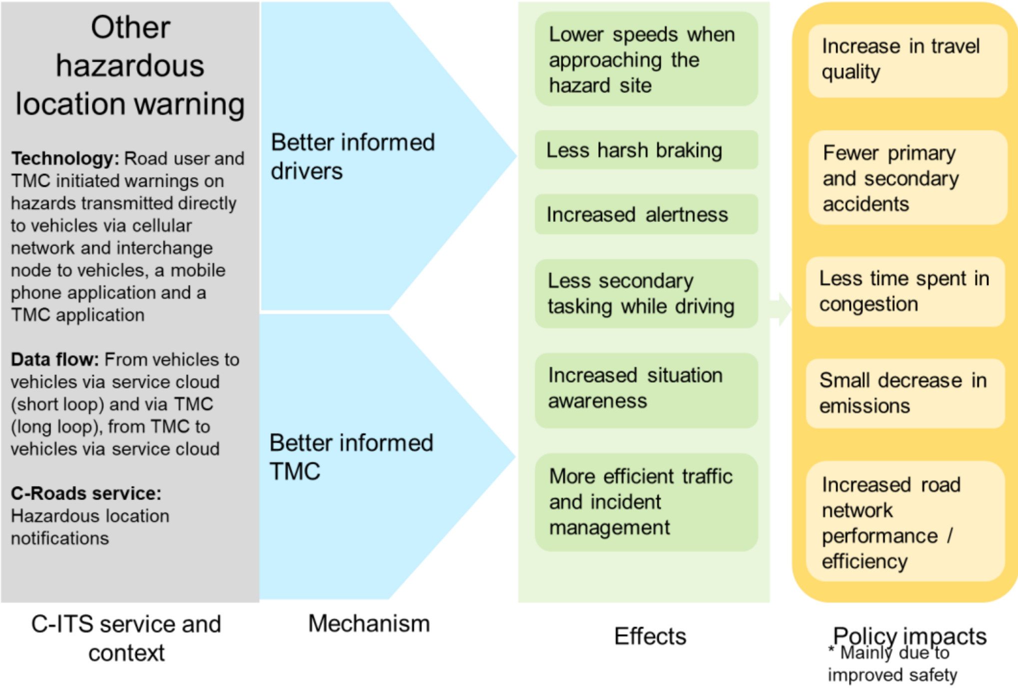
The system theory diagrams for the sixteen C-ITS services assessed in NordicWay 2 are presented below.

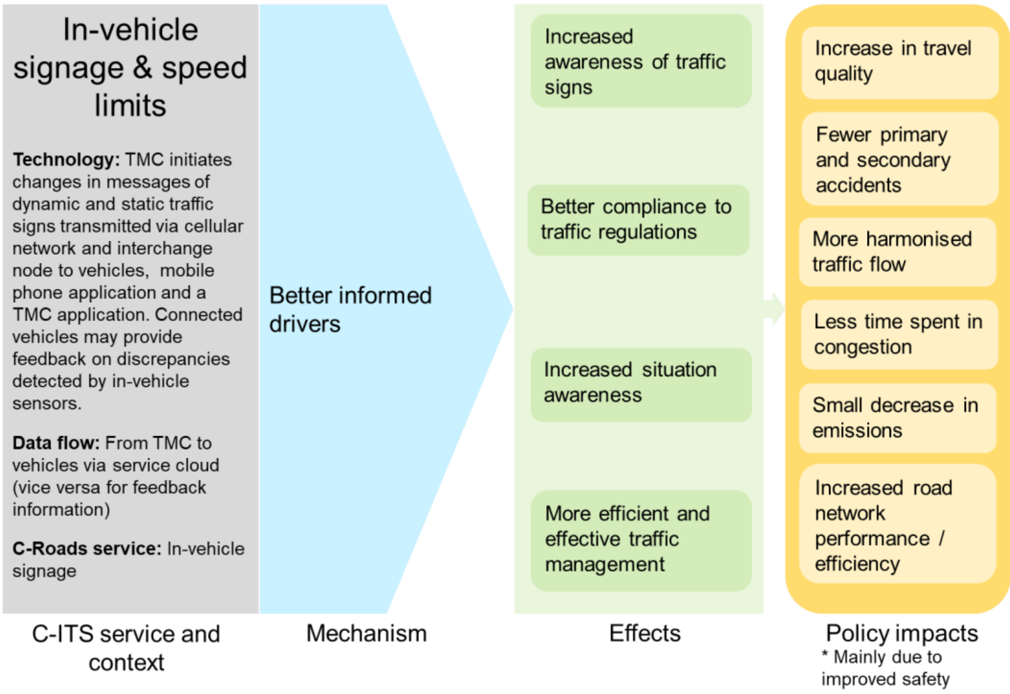


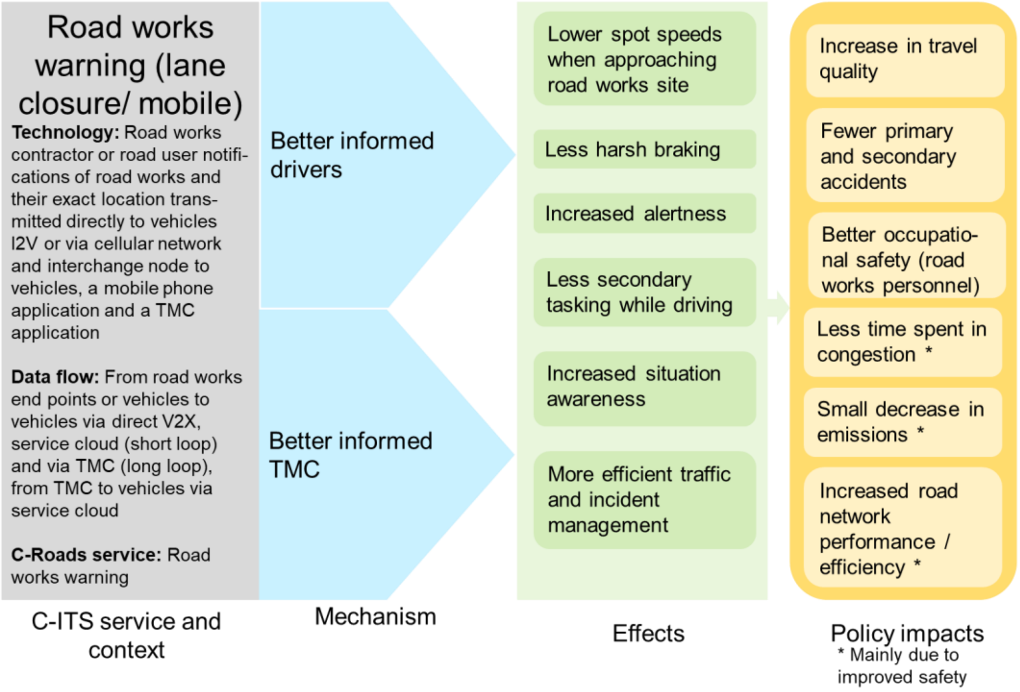


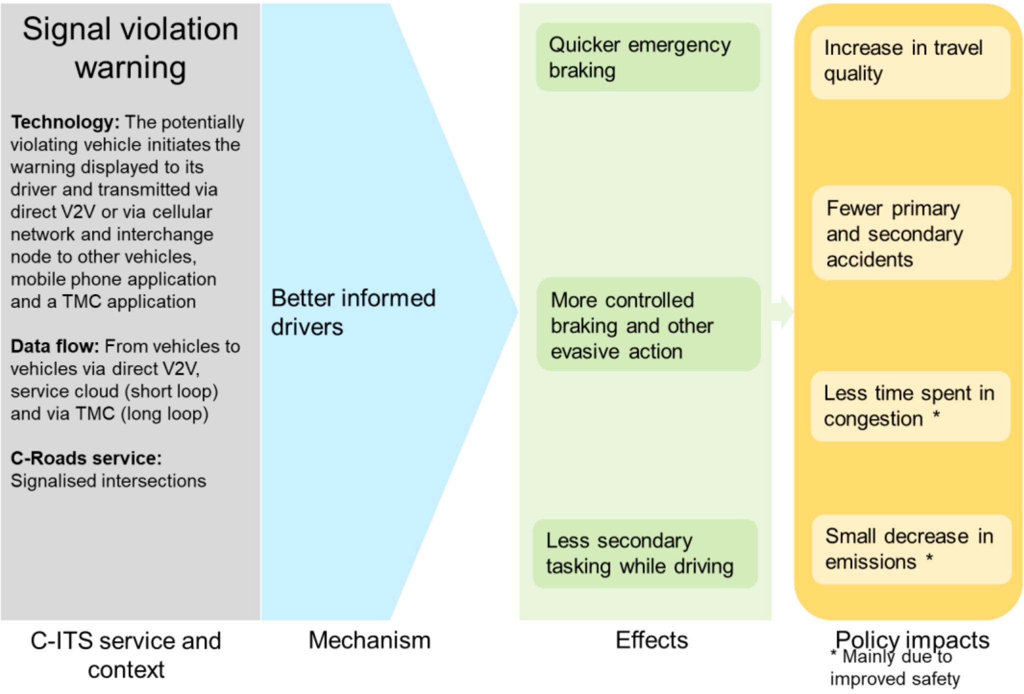

Emergency brake light warning
Technology: Vehicle initiates warning as the driver starts a strong braking and the warning is transmitted to nearby vehicles with short range communication
Data flow: From vehicles to vehicles via direct V2V communication (ITS G5 or C-V2V)
C-Roads service: Hazardous location notifications
Better informed drivers
Quicker reaction to emergency braking ahead
Less harsh braking
More controlled evasive action
Increase in travel quality
Fewer primary and secondary accidents
Less time spent in congestion *
Small decrease in emissions *
Increased road network performance / efficiency *
C-ITS service and context
Mechanism
Effects
Policy impacts
* Mainly due to improved safety

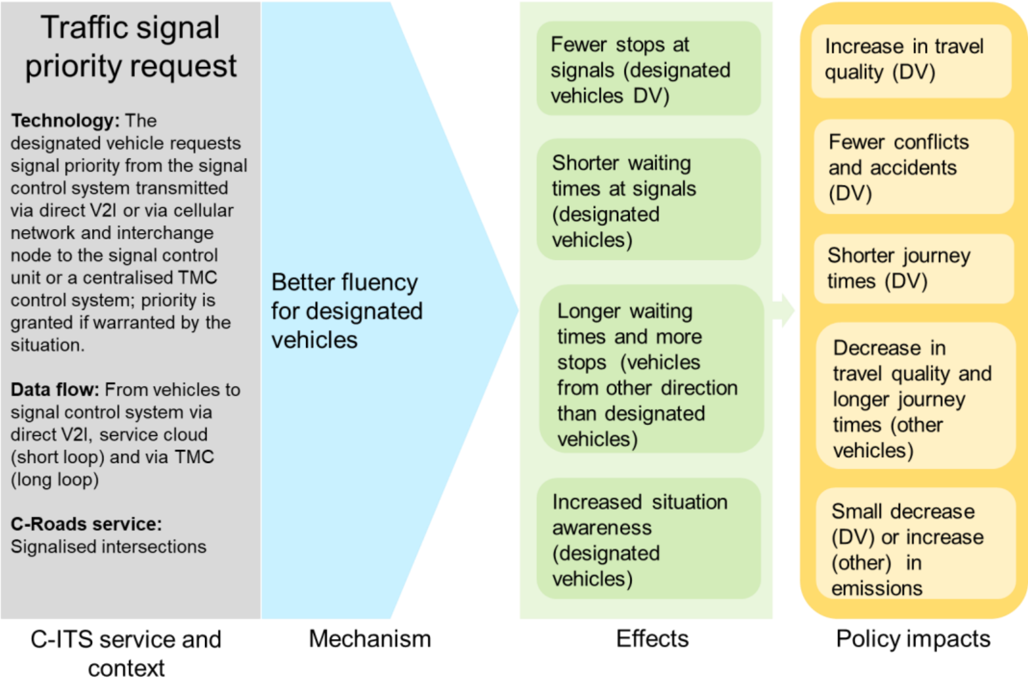

Emergency vehicle approaching warning
Technology: Emergency vehicle initiates the warnings transmitted via direct V2V or via cellular network and interchange node to vehicle, mobile phone application and a TMC application
Data flow: From vehicles to vehicles via direct V2V, service cloud (short loop) and via TMC (long loop)
C-Roads service: Hazardous location notifications
Better informed drivers
Better fluency and safety for emergency vehicles
Lower speeds
More controlled evasive action
Less harsh braking
Increased alertness
Less secondary tasking while driving
Increased situation awareness
Increase in travel quality
Fewer primary and secondary accidents
Shorter rescue times
Less time spent in congestion
Small decrease in emissions
Increased road network performance / efficiency
C-ITS service and context
Mechanism
Effects
Policy impacts
* Mainly due to improved safety

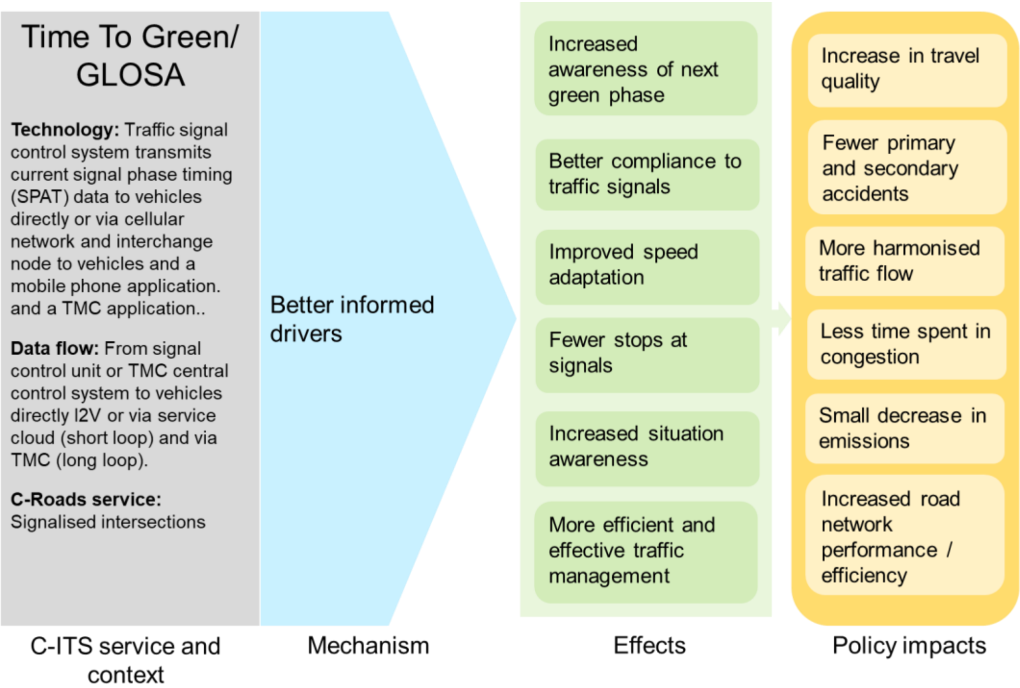

Other hazardous location warning
Technology: Road user and TMC initiated warnings on hazards transmitted directly to vehicles via cellular network and interchange node to vehicles, a mobile phone application and a TMC application
Data flow: From vehicles to vehicles via service cloud (short loop) and via TMC (long loop), from TMC to vehicles via service cloud
C-Roads service: Hazardous location notifications
Better informed drivers
Better informed TMC
Lower speeds when approaching the hazard site
Less harsh braking
Increased alertness
Less secondary tasking while driving
Increased situation awareness
More efficient traffic and incident management
Increase in travel quality
Fewer primary and secondary accidents
Less time spent in congestion
Small decrease in emissions
Increased road network performance / efficiency
C-ITS service and context
Mechanism
Effects
Policy impacts
* Mainly due to improved safety

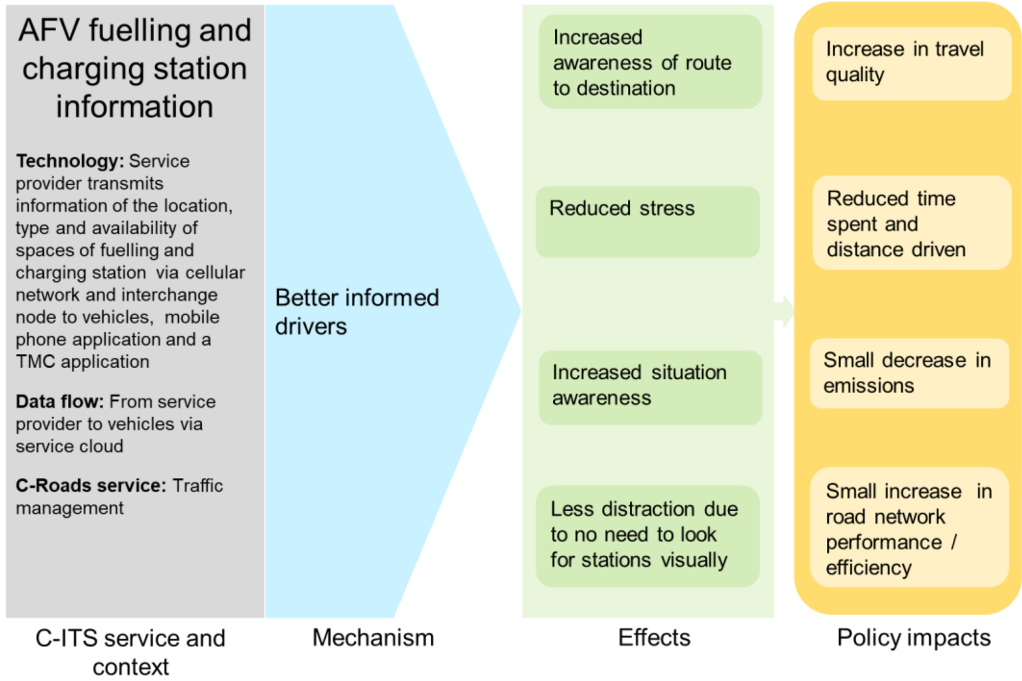

In-vehicle signage & speed limits
Technology: TMC initiates changes in messages of dynamic and static traffic signs transmitted via cellular network and interchange node to vehicles, mobile phone application and a TMC application. Connected vehicles may provide feedback on discrepancies detected by in-vehicle sensors.
Data flow: From TMC to vehicles via service cloud (vice versa for feedback information)
C-Roads service: In-vehicle signage
Better informed drivers
Increased awareness of traffic signs
Better compliance to traffic regulations
Increased situation awareness
More efficient and effective traffic management
Increase in travel quality
Fewer primary and secondary accidents
More harmonised traffic flow
Less time spent in congestion
Small decrease in emissions
Increased road network performance / efficiency
C-ITS service and context
Mechanism
Effects
Policy impacts
* Mainly due to improved safety

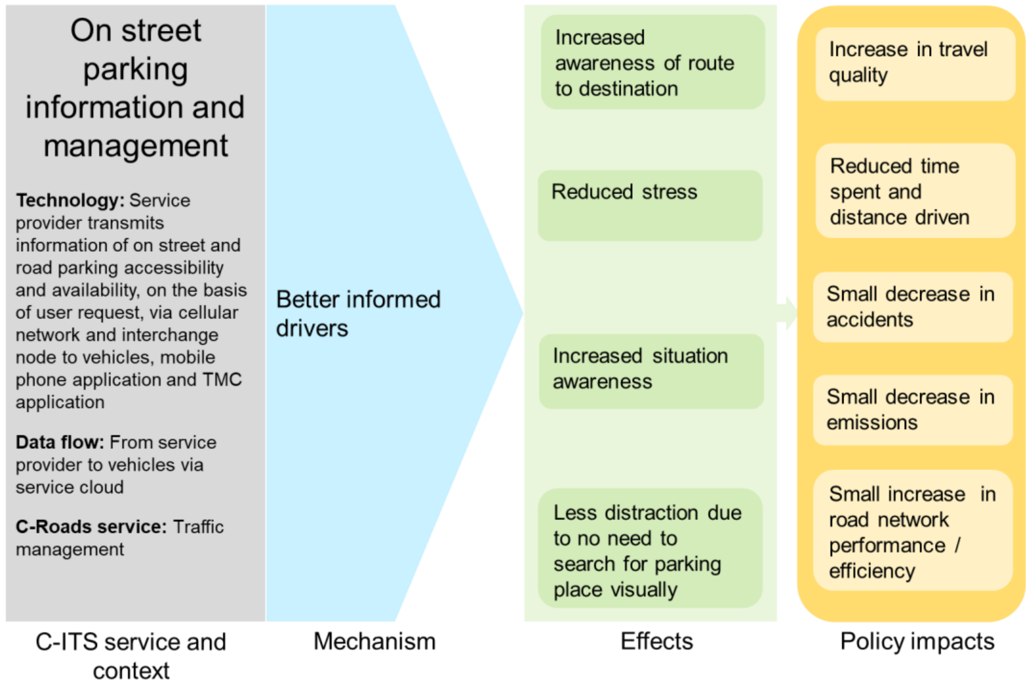

Road works warning (lane closure/ mobile)
Technology: Road works contractor or road user notifi-cations of road works and their exact location trans-mitted directly to vehicles I2V or via cellular network and interchange node to vehicles, a mobile phone application and a TMC application
Data flow: From road works end points or vehicles to vehicles via direct V2X, service cloud (short loop) and via TMC (long loop), from TMC to vehicles via service cloud
C-Roads service: Road works warning
Better informed drivers
Better informed TMC
Lower spot speeds when approaching road works site
Less harsh braking
Increased alertness
Less secondary tasking while driving
Increased situation awareness
More efficient traffic and incident management
Increase in travel quality
Fewer primary and secondary accidents
Better occupatio-nal safety (road works personnel)
Less time spent in congestion *
Small decrease in emissions *
Increased road network performance / efficiency *
C-ITS service and context
Mechanism
Effects
Policy impacts
* Mainly due to improved safety

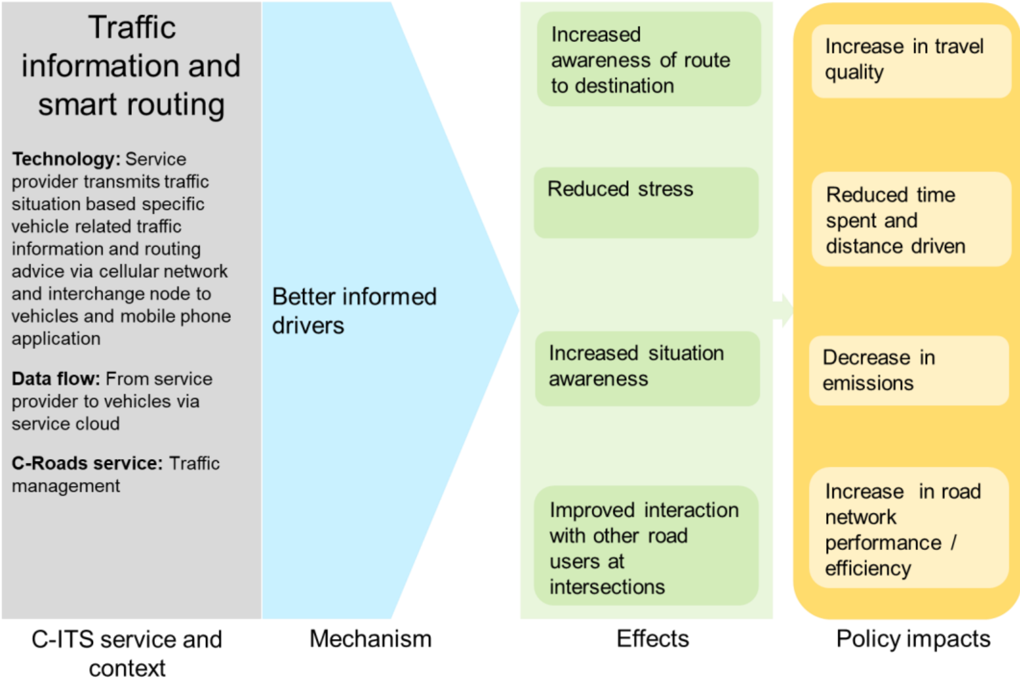

Signal violation warning
Technology: The potentially violating vehicle initiates the warning displayed to its driver and transmitted via direct V2V or via cellular network and interchange node to other vehicles, mobile phone application and a TMC application
Data flow: From vehicles to vehicles via direct V2V, service cloud (short loop) and via TMC (long loop)
C-Roads service: Signalised intersections
Better informed drivers
Quicker emergency braking
More controlled braking and other evasive action
Less secondary tasking while driving
Increase in travel quality
Fewer primary and secondary accidents
Less time spent in congestion *
Small decrease in emissions *
C-ITS service and context
Mechanism
Effects
Policy impacts
* Mainly due to improved safety

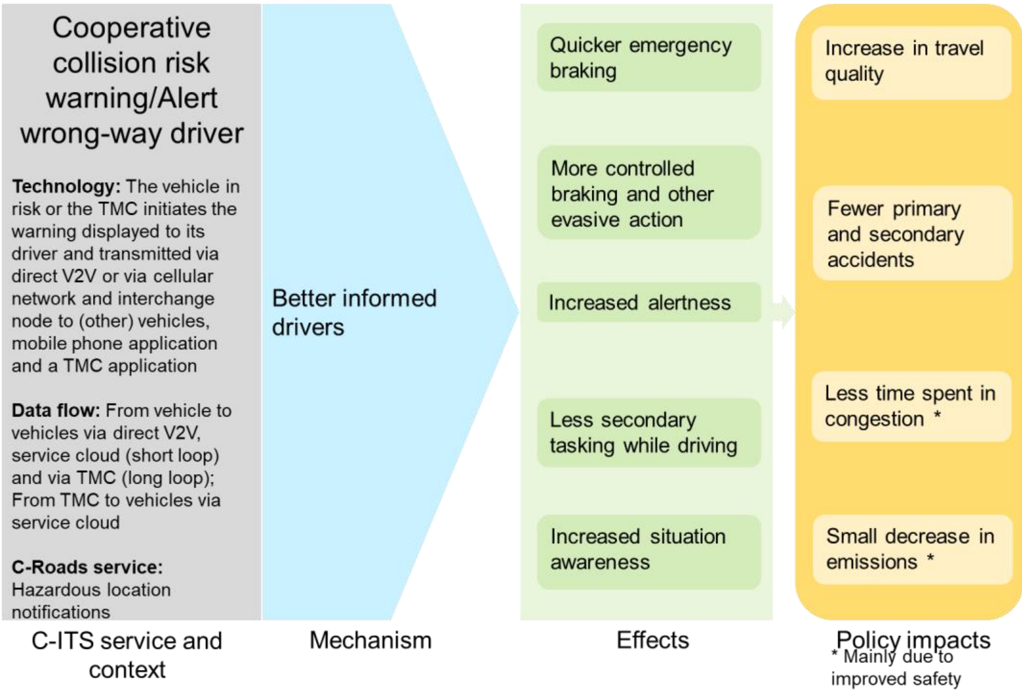

Traffic signal priority request
Technology: The designated vehicle requests signal priority from the signal control system transmitted via direct V2I or via cellular network and interchange node to the signal control unit or a centralised TMC control system; priority is granted if warranted by the situation.
Data flow: From vehicles to signal control system via direct V2I, service cloud (short loop) and via TMC (long loop)
C-Roads service: Signalised intersections
Better fluency for designated vehicles
Fewer stops at signals (designated vehicles DV)
Shorter waiting times at signals (designated vehicles)
Longer waiting times and more stops (vehicles from other direction than designated vehicles)
Increased situation awareness (designated vehicles)
Increase in travel quality (DV)
Fewer conflicts and accidents (DV)
Shorter journey times (DV)
Decrease in travel quality and longer journey times (other vehicles)
Small decrease (DV) or increase (other) in emissions
C-ITS service and context
Mechanism
Effects
Policy impacts


Time To Green/ GLOSA
Technology: Traffic signal control system transmits current signal phase timing (SPAT) data to vehicles directly or via cellular network and interchange node to vehicles and a mobile phone application. and a TMC application..
Data flow: From signal control unit or TMC central control system to vehicles directly I2V or via service cloud (short loop) and via TMC (long loop).
C-Roads service: Signalised intersections
Better informed drivers
Increased awareness of next green phase
Better compliance to traffic signals
Improved speed adaptation
Fewer stops at signals
Increased situation awareness
More efficient and effective traffic management
Increase in travel quality
Fewer primary and secondary accidents
More harmonised traffic flow
Less time spent in congestion
Small decrease in emissions
Increased road network performance / efficiency
C-ITS service and context
Mechanism
Effects
Policy impacts


AFV fuelling and charging station information
Technology: Service provider transmits information of the location, type and availability of spaces of fuelling and charging station via cellular network and interchange node to vehicles, mobile phone application and a TMC application
Data flow: From service provider to vehicles via service cloud
C-Roads service: Traffic management
Better informed drivers
Increased awareness of route to destination
Reduced stress
Increased situation awareness
Less distraction due to no need to look for stations visually
Increase in travel quality
Reduced time spent and distance driven
Small decrease in emissions
Small increase in road network performance / efficiency
C-ITS service and context
Mechanism
Effects
Policy impacts


On street parking information and management
Technology: Service provider transmits information of on street and road parking accessibility and availability, on the basis of user request, via cellular network and interchange node to vehicles, mobile phone application and TMC application
Data flow: From service provider to vehicles via service cloud
C-Roads service: Traffic management
Better informed drivers
Increased awareness of route to destination
Reduced stress
Increased situation awareness
Less distraction due to no need to search for parking place visually
Increase in travel quality
Reduced time spent and distance driven
Small decrease in accidents
Small decrease in emissions
Small increase in road network performance / efficiency
C-ITS service and context
Mechanism
Effects
Policy impacts


Traffic information and smart routing
Technology: Service provider transmits traffic situation based specific vehicle related traffic information and routing advice via cellular network and interchange node to vehicles and mobile phone application
Data flow: From service provider to vehicles via service cloud
C-Roads service: Traffic management
Better informed drivers
Increased awareness of route to destination
Reduced stress
Increased situation awareness
Improved interaction with other road users at intersections
Increase in travel quality
Reduced time spent and distance driven
Decrease in emissions
Increase in road network performance / efficiency
C-ITS service and context
Mechanism
Effects
Policy impacts


Cooperative collision risk warning/Alert wrong-way driver
Technology: The vehicle in risk or the TMC initiates the warning displayed to its driver and transmitted via direct V2V or via cellular network and interchange node to (other) vehicles, mobile phone application and a TMC application
Data flow: From vehicle to vehicles via direct V2V, service cloud (short loop) and via TMC (long loop); From TMC to vehicles via service cloud
C-Roads service: Hazardous location notifications
Better informed drivers
Quicker emergency braking
More controlled braking and other evasive action
Increased alertness
Less secondary tasking while driving
Increased situation awareness
Increase in travel quality
Fewer primary and secondary accidents
Less time spent in congestion *
Small decrease in emissions *
C-ITS service and context
Mechanism
Effects
Policy impacts
* Mainly due to improved safety

Annex 7. Safety assessment framework

Determination of target accidents

On the basis of the relevant accident type selection, a more detailed choice of target accidents was carried out. The detailed accident type number is the one used in the Finnish Tiira (2020) accident data base.

The choices made were the following:

Slow or stationary vehicle(s) & traffic ahead warning
- Detailed accident type = 8 (Rear-end collision with vehicle stopped by traffic obstacle) & More than two participants

Weather and road condition warning
- Cases of exceptional adverse weather difficult to observe on the basis of Malin et al. (2017)

Emergency brake light
- Detailed accident type = 6 (Rear-end collision with braking vehicle) & More than two participants

Emergency vehicle approaching
- Accident involving emergency vehicles, based on Kuiri & Koivisto (2015) and Liikennefakta (2020)

Other hazardous location notifications
- Surprising appearance of pedestrians or animals on road. Detailed accident type = 70, 71, 72, 73, 74, 90 (Pedestrian coming from behind stationary vehicle; Other crossing of carriageway by pedestrian; Pedestrian stationary on carriageway; Pedestrian walking in direction of traffic; Collision with animal); 30% of accident types 71–74 were seen as sudden for rural and street networks. On motorways and similar, all such cases were regarded as surprising).

In-vehicle speed limits
- All accidents

Roadworks warning – road or lane closure
- Accidents at fixed roadworks. Code roadworks = Yes

Roadworks warning – mobile road works
- Accidents involving a road works or maintenance vehicle, based on FTIA (2020a)

Signal violation / intersection safety
- Accidents involving a vehicle driving against red, based on City of Tampere (2018) and Tiira: Junction type = 4 (Traffic lights equipment) & detailed accident type = 60, 61, 62, 63, 64, 69, 40, 50, 51, 52, 53 (Collision with pedestrian on crossing; Intersecting directions)

Traffic signal priority request by designated vehicles
- Accidents at signalised junctions involving public transport vehicles or emergency vehicles, based on Junction type = 4 (Traffic lights equipment), Kuiri & Koivisto (2015), Liikennefakta (2020)

Time to Green
- Rear-end crashes at approaches to signalised junctions, based on Junction type = 4 (Traffic lights equipment) & detailed accident type = 6, 10, 12 (Rear-end collision with braking vehicle, rear-end collision while turning left/right)

Green light optimal speed advisory (GLOSA)
- Rear-end crashes at approaches to signalised junctions, based on Junction type = 4 (Traffic lights equipment) & detailed accident type = 6, 10, 12 (Rear-end collision with braking vehicle, rear-end collision while turning left/right)

Information on alternative fuel vehicle fuelling & charging stations
- None

On-street parking information and management
- Accidents involving a vehicle searching for a parking place, based on assumption

Traffic information & smart routing
- None

Alert wrong-way driver
- Accidents involving a wrong-way driver, based on Finnra (2003)

The proportions of crashes of the relevant accident type, and the target accidents out of the aforementioned on the different road networks in Finland, are shown below.

Table 7-1. Percentages of crashes of the relevant accident type, and target accidents out of the aforementioned for the C-ITS services selected on different road networks in Finland. Services from Slow low vehicle warning to mobile road works warning.

FINNISH NETWORK	SLOW VEH.	WEA-THER	EBL	EVA	OTHER HAZ	IVSL	RWW-RLC	RWW-MOB.
PERCENTAGE OF RELEVANT ACCIDENT TYPE OUT OF ALL ROAD ACCIDENTS FOR DIRECT SAFETY EFFECT OF THE SERVICE								
1: Long and/or heavily trafficked tunnels	45.5	0.0	45.5	54.6	0.0	100	100	100
2: “Full telematics network” – E18 including Ring III	40.5	27.2	40.5	53.2	8.1	100	100	100
3: Heavy traffic peri-urban motorways and roads	41.9	19.9	41.9	70.0	5.4	100	100	100
4: "TEN-T main network" excluding the above	20.4	20.0	20.4	56.3	13.1	100	100	100
5: Other main public roads network	18.7	16.1	18.7	54.3	12.2	100	100	100
6: Main street networks in the biggest cities	20.8	15.4	20.8	72.4	14.0	100	100	100
PERCENTAGE OF TARGET ACCIDENTS OUT OF THE RELEVANT ACCIDENT TYPES ABOVE								
1: Long and/or heavily trafficked tunnels	12.6	3.5	21.2	0.2	60.8	100.0	5.4	0.7
2: “Full telematics network” – E18 including Ring III	12.6	3.5	21.2	0.2	60.8	100.0	5.4	0.7
3: Heavy traffic peri-urban motorways and roads	12.6	3.5	21.2	0.2	60.8	100.0	5.4	0.7
4: "TEN-T main network" excluding the above	14.7	0.5	8.3	0.2	40.0	100.0	2.4	0.7
5: Other main public roads network	14.7	0.5	8.3	0.2	40.0	100.0	2.4	0.7
6: Main street networks in the biggest cities	20.3	0.5	10.8	0.2	5.9	100.0	2.1	0.7

Table 7-2. Percentages of crashes of the relevant accident type, and target accidents out of the aforementioned for the C-ITS services selected on different road networks in Finland. Services from Signal violation warning to Alert wrong-way driver.

FINNISH NETWORK	SV/IS	PRIORITY REQ.	TTG	GLOSA	FUEL & CHARG.	ON-STR. PARK	TI & ROUT.	AWWD
PERCENTAGE OF RELEVANT ACCIDENT TYPE OUT OF ALL ROAD ACCIDENTS FOR DIRECT SAFETY EFFECT OF THE SERVICE								
1: Long and/or heavily trafficked tunnels	0.00	0.00	45.5	45.5	100	100	100	45.5
2: “Full telematics network” – E18 including Ring III	1.7	0.6	40.5	40.5	100	100	100	51.5
3: Heavy traffic peri-urban motorways and roads	11.2	9.3	41.9	41.9	100	100	100	68.3
4: "TEN-T main network" excluding the above	11.0	10.0	20.4	20.4	100	100	100	55.6
5: Other main public roads network	14.6	13.5	18.7	18.7	100	100	100	53.2
6: Main street networks in the biggest cities	28.7	16.3	20.8	20.8	100	100	100	52.9
PERCENTAGE OF TARGET ACCIDENTS OUT OF THE RELEVANT ACCIDENT TYPES ABOVE								
1: Long and/or heavily trafficked tunnels	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.3
2: “Full telematics network” – E18 including Ring III	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.3
3: Heavy traffic peri-urban motorways and roads	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.3
4: "TEN-T main network" excluding the above	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.0
5: Other main public roads network	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.0
6: Main street networks in the biggest cities	4.6	0.8	11.6	11.6	100.0	0.1	100.0	0.5

Effectiveness of services

In order to estimate the direct safety effects, we need to determine the effectiveness of the services with regard to the target accidents. The effectiveness of a service is expressed as the percentage (%) of prevented target accidents due to the driver being informed/warned by the C-ITS service. It can also be regarded as the proportion of the target accidents that would have occurred if the driver had not received the C-ITS warning/information.

Actual empirical evidence was only found for in-vehicle speed limits, which according to Elvik & Høye (2015) reduce injury crashes by 3–5%. Other effectiveness figures were based on the earlier NordicWay evaluation report (Innamaa et al. 2017) and NordicWay2 evaluation group expert assessment based on knowledge about the impacts of similar, non-C-ITS services.

The effectiveness of the service would also depend on whether the service user had previously used a similar non-C-ITS service or no service at all. The effectiveness of services is likely much lower for people who already use a similar C-ITS service. Such similar non-C-ITS services were available for many of the C-ITS services. These are listed below.

Slow or stationary vehicle(s) & traffic ahead warning
- Road operator/TMC service utilising internet, radio, TV & VMS (if available), different event information services (e.g., HERE, TomTom, Google, …)
- Use of these services about 20% in 2030 based on Penttinen et al. (2018)

Weather and road condition warning
- Road operator/TMC/Met office service utilising internet, radio, TV & VMS (if available), different event information services (e.g., HERE, TomTom, Google, Waze, etc:
- Use of these services in 2030: 100%. Based on….

Other hazardous location notifications
- Road operator/TMC service utilising internet, radio, VMS (if available), different event information services (e.g., HERE, TomTom, Google, Waze …).

- Use of these services in 2030: 100% based on Öörni, R. (2014).

In-vehicle speed limits

- Vehicle navigation systems and Intelligent Speed Assistance systems mandatory in new type-approved vehicles in Europe according to the General Safety Regulation Directive.
- Use of services: 25% in 2030. Based on Lähderanta (2018): Penetration of traffic sign recognition system in the Finnish car fleet in 2018 indicates the following status: standard equipment = 1%; possible additional equipment = 8%. Calculation assumes annual renewal of the car fleet 5% (Liikennefakta 2020); by 2030 more vehicles equipped with cameras.

Roadworks warning – road or lane closure

- Road operator/TMC service utilising internet, radio, TV, road signs & VMS (if available), different event information services (e.g., HERE, TomTom, Google, …).
- Use of services in 2030: 100%. Based on…

Roadworks warning – mobile road works

- Road operator/TMC service utilising internet, radio, TV & VMS (if available), different event information services (e.g., HERE, TomTom, Google, …).
- Use of services in 2030: 20%. Based on Penttinen et al. (2018) RTTI: 11% at least monthly, and that there is an annual increase in usage by 7%.

Traffic signal priority request by designated vehicles

- Traffic signal priorities are in wide use already: share of equipped traffic lights in 2012: City of Helsinki 40%, City of Espoo 10%, City of Vantaa 15%, City of Oulu: 6% and City of Tampere 55% (HSL 2012 & Niittylä 2012).
- Estimate of equipped signalised junctions in 2030: 60%, based on the calculations: average share of equipment: 25%, annual increase of 5%.

Information on alternative fuel vehicle fuelling & charging stations

- Existing non-C-ITS service apps (all vehicle owners/drivers of alternative fuel vehicles assumed to use these).
- Use of services in 2030: 100%, especially in urban areas.

On street parking information and management

- Existing non-C-ITS apps are available.
- Use of service in 2030: 25%. Based on that, globally, of all parking spaces smart 11% in 2018 and 16% by 2023, and assumption of annual increase of 7% (Smart cities world, 2018).

Traffic information & smart routing

- In-vehicle or nomadic non-C-ITS navigation systems (TomTom, Waze, …).
- Use of services in 2030: 22%. Based on Öörni (2014): dynamic navigation, built-in: 5-20% and aftermarket & nomadic: 10-40%. Assumption that 2014 = 10%, annual increase in usage 5%.

The following table shows the effectiveness of different C-ITS services in the different road networks in Finland.

Table 7-3. Effectiveness of C-ITS services in preventing target accidents for the C-ITS services selected on different road networks in Finland in 2030. Effectiveness estimates given in the range Low-High. Blank cells are irrelevant for the services; i.e., the service has no similar non-C-ITS service in use, or all users are using a similar non-C-ITS service.

EFFECTIVENESS ESTIMATES SITUATION TO BE COMPARED WITH	SLOW VEH.	WEA-THER	EBL	EVA	OTHER HAZ	IVSL	RWW-RLC	RWW-MOB.
HIGH-TRAFFIC-VOLUME HIGHWAY NETWORKS (FINNISH NETWORKS 1–3)								
No service at all	20–30		30–40	20–30		3–5		30–40
Similar non-C-ITS service	5–10	15–25			15–25	0–1	5–15	15–25
LOW-VOLUME HIGHWAY NETWORKS (FINNISH NETWORKS 4–5)								
No service at all	15–25		25–35	20–30		3–5		30–40
Similar non-C-ITS service	5–10	10–20			15–25	0–1	5–15	15–25
URBAN STREET NETWORKS (FINNISH NETWORK 6)								
No service at all	0–5		5–10	10–20		3–5		15–25
Similar non-C-ITS service	0	5–10			5–10	0–1	5–10	10–15

EFFECTIVENESS ESTIMATES SITUATION TO BE COMPARED WITH	SV/IS	PRIORITY REQ.	TTG	GLOSA	FUEL & CHARG.	ON-STR. PARK	TI & ROUT.	AWWD
HIGH-VOLUME HIGHWAY NETWORKS (FINNISH NETWORKS 1–3)								
No service at all	30–40	10–20	5–10	10–20				30–40
Similar non-C-ITS service								
LOW-VOLUME HIGHWAY NETWORKS (FINNISH NETWORKS 4–5)								
No service at all	30–40	10–20	5–10	10–20				30–40
Similar non-C-ITS service								
URBAN STREET NETWORKS (FINNISH NETWORK 6)								
No service at all	30–40	10–20	5–10	10–20	0	0–5	0	
Similar non-C-ITS service		0			0	0	0	

The overall effectiveness of the service is calculated as a weighted average of the effectiveness figures using the percentages of users not using the similar non-C-ITS service and users not using such a service.

Annex 8. Detailed user acceptance results

In this annex, selected user acceptance survey results are presented separately for each country.

Importance of information on motorways and main roads

Table 8-1. Importance of information on motorways and main roads, Finland.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Accident ahead	1.0	0.7	1.7	3.6	11.0	26.2	55.8
Obstacle on the road	1.3	0.9	1.9	5.4	12.1	27.5	50.9
Large animals on the road	1.0	0.7	2.6	4.6	14.1	26.9	50.1
Road or lane closure ahead	1.2	1.1	2.3	6.7	17.8	32.7	38.1
Emergency vehicle approaching	1.7	2.7	3.8	10.1	21.8	23.9	36.0
People on the road	2.0	1.4	4.1	7.9	15.2	26.1	43.2
Emergency braking in traffic ahead	2.7	2.0	6.0	11.5	19.6	25.1	33.0
Traffic jam ahead	2.1	1.8	3.9	11.1	24.0	27.8	29.3
Slow or stationary vehicle ahead	1.8	2.4	5.7	14.1	22.9	25.1	28.0
Road works ahead	1.7	2.4	5.2	15.4	33.4	26.5	15.4
Current posted speed limit	4.6	5.5	6.1	10.5	18.5	23.9	30.7
Local adverse weather	3.4	3.5	5.2	11.5	21.8	28.0	26.6
Traffic situation and smart routing	3.3	4.1	9.2	20.3	29.0	23.3	10.8
Mobile road maintenance vehicle nearby	2.3	3.3	7.8	19.9	31.5	22.3	12.8
Location of alt. fuel/charging	11.4	11.0	13.9	25.8	18.9	11.8	7.1

Table 8-2. Importance of information on motorways and main roads, Denmark.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Accident ahead	0.8	0.6	1.3	5.7	15.1	22.6	54.0
Obstacle on the road	1.0	1.1	3.2	9.0	22.4	21.5	41.8
Large animals on the road	1.3	1.5	3.8	10.5	19.7	21.2	42.1
Road or lane closure ahead	1.1	0.7	2.3	8.4	15.9	26.3	45.4
Emergency vehicle approaching	1.0	0.9	2.2	7.9	14.4	19.9	53.7
People on the road	1.3	1.2	2.7	12.0	16.5	19.8	46.5
Emergency braking in traffic ahead	1.3	0.9	2.8	9.0	16.3	22.4	47.3
Traffic jam ahead	1.2	1.1	3.6	8.8	22.1	25.8	37.4
Slow or stationary vehicle ahead	2.1	1.8	5.9	12.6	22.2	23.7	31.8
Road works ahead	1.0	1.6	5.2	15.1	26.4	23.5	27.3
Current posted speed limit	4.9	4.4	5.0	13.3	19.5	18.5	34.4
Local adverse weather	3.4	4.8	9.3	19.9	24.1	17.8	20.8
Traffic situation and smart routing	1.8	2.2	5.4	19.3	24.1	24.0	23.2
Mobile road maintenance vehicle nearby	1.7	3.4	9.6	19.7	26.2	19.8	19.6
Location of alt. fuel/charging	8.2	9.6	17.2	24.8	23.7	9.5	7.1

Table 8-3. Importance of information on motorways and main roads, Norway.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Accident ahead	1.0	0.2	0.9	4.1	13.2	25.8	54.8
Obstacle on the road	1.0	0.8	1.3	5.0	16.0	29.1	46.7
Large animals on the road	1.1	0.5	2.3	5.6	17.0	27.5	45.9
Road or lane closure ahead	0.8	0.8	1.7	5.9	18.6	27.4	44.8
Emergency vehicle approaching	1.5	1.0	3.0	6.3	16.3	25.3	46.5
People on the road	1.4	1.1	3.6	8.8	18.7	26.4	39.9
Emergency braking in traffic ahead	1.3	0.9	3.3	9.0	19.4	25.7	40.4
Traffic jam ahead	1.1	1.6	4.6	13.9	29.0	28.1	21.7
Slow or stationary vehicle ahead	1.2	1.5	4.3	12.9	24.9	28.1	27.0
Road works ahead	0.6	1.4	4.7	15.7	32.4	26.4	18.8
Current posted speed limit	3.1	2.9	5.7	10.7	19.6	20.2	37.8
Local adverse weather	1.4	1.8	4.0	12.6	29.3	24.1	26.7
Traffic situation and smart routing	1.3	1.9	5.1	15.3	29.3	29.8	17.1
Mobile road maintenance vehicle nearby	1.5	2.7	7.3	21.8	30.5	20.2	16.0
Location of alt. fuel/charging	13.8	8.7	11.9	21.4	22.3	11.9	10.1

Table 8-4. Importance of information on motorways and main roads, Sweden.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Accident ahead	0.1	0.3	1.3	3.2	11.3	25.7	58.1
Obstacle on the road	0.5	0.3	1.1	5.9	15.2	24.8	52.1
Large animals on the road	0.7	0.4	1.5	4.4	15.0	27.2	50.8
Road or lane closure ahead	0.2	0.4	0.9	6.9	15.9	27.9	47.7
Emergency vehicle approaching	0.9	0.5	1.3	6.0	12.3	19.9	59.0
People on the road	1.0	0.6	1.9	6.0	13.7	26.1	50.7
Emergency braking in traffic ahead	1.8	0.7	2.8	8.3	14.3	21.7	50.4
Traffic jam ahead	0.5	0.3	3.6	10.3	23.6	30.4	31.2
Slow or stationary vehicle ahead	1.2	0.7	3.3	10.7	17.0	28.5	38.6
Road works ahead	0.5	0.3	3.5	11.4	25.2	31.6	27.4
Current posted speed limit	3.0	3.8	5.0	12.4	18.3	21.0	36.4
Local adverse weather	0.8	0.8	3.6	9.8	20.1	29.0	35.9
Traffic situation and smart routing	0.4	1.0	3.7	12.3	24.9	32.3	25.3
Mobile road maintenance vehicle nearby	1.3	2.7	7.5	19.3	27.3	25.9	16.1
Location of alt. fuel/charging	9.3	7.8	11.0	21.1	22.4	18.1	10.4

Importance of information on urban streets

Table 8-5. Importance of information on urban streets, Finland.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Emergency vehicle approaching	3.2	3.6	4.7	11.4	18.7	25.2	33.1
Accident ahead	2.9	1.9	4.9	10.5	18.3	27.4	34.0
Road or lane closure ahead	2.7	2.4	4.6	9.8	20.9	30.2	29.3
You are about to go through a red light	7.2	4.2	6.0	13.1	15.7	19.5	34.4
Someone passing through a red light at an intersection	8.9	7.5	9.0	14.8	14.6	18.8	26.4
Emergency braking in traffic ahead	4.7	4.8	11.3	15.2	24.2	20.0	19.8
Roadwork ahead	3.7	3.7	8.0	18.0	26.7	24.9	15.0
Free parking slots	4.9	3.7	7.3	15.6	23.6	27.5	17.3
Traffic situation and smart routing	5.5	4.8	10.0	20.4	26.5	20.7	12.0
Current posted speed limit	6.5	4.3	7.4	14.4	16.9	22.5	28.0
Mobile road maintenance vehicle nearby	5.2	5.7	12.4	21.5	24.8	18.6	11.8
Time to green or optimal speed	8.2	7.9	8.4	18.0	23.9	22.2	11.3
Local adverse weather	6.9	7.1	15.0	22.3	19.0	16.8	12.8
Location of alt. fuel/charging	15.3	11.9	14.6	23.5	17.7	10.0	7.1

Table 8-6. Importance of information on urban streets, Denmark.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Emergency vehicle approaching	2.7	2.6	3.9	11.0	16.1	21.2	42.5
Accident ahead	2.1	2.7	4.3	11.3	18.9	23.1	37.6
Road or lane closure ahead	2.2	2.4	5.3	12.2	21.5	22.7	33.7
You are about to go through a red light	4.8	4.2	4.8	9.6	13.2	14.9	48.6
Someone passing through a red light at an intersection	6.7	4.0	6.6	11.1	13.5	14.7	43.5
Emergency braking in traffic ahead	3.8	3.2	9.0	15.1	19.7	18.5	30.7
Roadwork ahead	2.3	4.0	7.4	17.5	26.1	19.8	22.9
Free parking slots	4.0	3.0	6.8	18.7	27.8	21.4	18.3
Traffic situation and smart routing	3.3	3.5	9.2	19.7	26.1	21.5	16.7
Current posted speed limit	8.7	5.1	8.8	16.5	18.8	15.6	26.6
Mobile road maintenance vehicle nearby	4.4	6.7	13.0	19.8	25.5	14.9	15.8
Time to green or optimal speed	5.4	4.7	7.4	20.1	26.7	19.7	16.0
Local adverse weather	10.2	9.4	15.7	24.9	18.7	10.1	11.1
Location of alt. fuel/charging	10.3	11.0	18.9	25.9	19.9	7.3	6.8

Table 8-7. Importance of information on urban streets, Norway.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Emergency vehicle approaching	1.8	2.8	3.8	8.8	19.0	23.4	40.3
Accident ahead	2.0	1.7	5.3	12.3	22.0	24.4	32.3
Road or lane closure ahead	1.3	2.1	3.6	11.5	21.7	28.0	31.8
You are about to go through a red light	4.3	3.3	5.5	9.4	15.8	16.8	45.0
Someone passing through a red light at an intersection	8.1	6.5	8.0	15.2	19.1	16.8	26.4
Emergency braking in traffic ahead	3.4	4.3	7.6	16.9	22.5	19.7	25.6
Roadwork ahead	1.8	3.2	8.3	19.0	30.7	21.1	15.9
Free parking slots	2.9	3.1	8.3	16.3	29.2	24.5	15.7
Traffic situation and smart routing	2.1	3.7	5.7	16.0	32.0	25.0	15.5
Current posted speed limit	5.9	8.2	9.4	15.8	18.6	15.5	26.5
Mobile road maintenance vehicle nearby	3.2	5.1	13.3	23.4	24.7	15.5	14.7
Time to green or optimal speed	6.9	7.9	12.4	21.4	28.9	16.6	6.0
Local adverse weather	5.8	7.9	15.4	22.6	25.1	14.3	9.0
Location of alt. fuel/charging	14.2	11.4	14.6	21.8	20.1	9.9	7.9

Table 8-8. Importance of information on urban streets, Sweden.

INFORMATION CONTENT	1 = NOT AT ALL	2	3	4	5	6	7 = VERY IMPORTANT
Emergency vehicle approaching	1.1	1.1	2.0	6.4	14.2	21.6	53.6
Accident ahead	0.7	0.9	3.2	9.7	18.6	29.1	37.8
Road or lane closure ahead	0.6	1.0	2.6	8.8	20.7	28.2	38.1
You are about to go through a red light	4.3	5.6	3.5	10.4	13.4	19.6	43.3
Someone passing through a red light at an intersection	3.7	2.6	3.8	7.4	12.4	15.0	55.1
Emergency braking in traffic ahead	2.7	3.1	5.2	10.1	16.6	24.9	37.3
Roadwork ahead	0.8	1.7	3.9	16.2	24.9	28.6	23.8
Free parking slots	1.3	3.5	4.9	14.3	24.4	27.1	24.4
Traffic situation and smart routing	1.4	2.6	5.5	15.5	25.5	28.7	20.8
Current posted speed limit	4.7	4.8	7.3	13.9	17.8	19.4	32.1
Mobile road maintenance vehicle nearby	3.8	4.8	10.3	21.5	25.9	20.1	13.7
Time to green or optimal speed	7.3	6.7	8.8	20.5	25.1	18.6	13.0
Local adverse weather	5.3	5.8	11.4	19.9	23.6	16.9	17.1
Location of alt. fuel/charging	12.1	8.1	12.9	22.1	20.1	14.6	10.1

Willingness to pay

Table 8-9. Willingness to pay for C-ITS services per country

I WOULD BE WILLING TO PAY FOR THESE SERVICES…	1 = FULLY DISAGREE	2	3	4	5	6	7 = FULLY AGREE
Finland	38.4	19.3	16.8	14.8	6.2	2.8	1.8
Denmark	37.0	18.1	14.8	15.5	7.3	3.6	3.6
Norway	37.8	19.4	16.5	15.1	7.1	2.2	1.8
Sweden	30.5	18.9	13.4	16.6	11.5	4.0	5.1

Annex 9. Benefits of C-ITS services in 2030 on different road networks

The tables below show the effects of C-ITS services in 2030 in both low and high effectiveness scenarios. The effects are presented as changes in the road network indicators for travel time, road accidents and CO_2 emissions.

Denmark

Indicator	Total	Change	%	Change	%
State road network incl TERN		Low	Low	High	High
Vehicle hours driven (million/year)	391,6	-0,17	-0,04 %	-0,37	-0,1 %
Vehicle hours spent in congestion (M/year)	19,9	-0,00079	-0,0040 %	-0,1739	-0,87 %
Fatal accidents (number/year)	55,5	-1,86	-3,3 %	-2,48	-4,5 %
Non-fatal injury accidents (number/year)	475,5	-7,55	-1,6 %	-13,03	-2,7 %
Property damage only accidents (number/year)	1677,0	-26,64	-1,6 %	-45,94	-2,7 %
Co2 emissions (million tonnes/year)	4,8	-0,0024	-0,05 %	-0,0034	-0,07 %

Norway

Indicator	Total	Change	%	Change	%
Network 2: "Full telematics network"		Low	Low	High	High
Vehicle hours driven (million/year)	69,1	-0,05	-0,08 %	-0,07	-0,1 %
Vehicle hours spent in congestion (M/year)	5,2	-0,00013	-0,003 %	0,035	0,7 %
Fatal accidents (number/year)	1,0	-0,06	-5,57 %	-0,07	-7,5 %
Non-fatal injury accidents (number/year)	28,0	-0,71	-2,55 %	-1,23	-4,4 %
Property damage only accidents (number/year)	140,0	-3,57	-2,55 %	-6,1	-4,4 %
Co2 emissions (million tonnes/year)	0,5	-0,00063	-0,12 %	-0,00094	-0,2 %
Network 3: Peri-urban extended TERN		Low	Low	High	High
Vehicle hours driven (million/year)	281,7	-0,22	-0,08 %	-0,29	-0,1 %
Vehicle hours spent in congestion (M/year)	20,6	-0,00052	-0,003 %	-0,14	-0,7 %
Fatal accidents (number/year)	15,0	-0,84	-5,57 %	-1,12	-7,5 %
Non-fatal injury accidents (number/year)	509,0	-12,98	-2,55 %	-22,42	-4,4 %
Property damage only accidents (number/year)	2545,0	-64,92	-2,55 %	-112,08	-4,4 %
Co2 emissions (million tonnes/year)	1,8	-0,0021	-0,11 %	-0,0031	-0,2 %
Network 5: Other main public roads network		Low	Low	High	High
Vehicle hours driven (million/year)	480,8	-0,08	-0,02 %	-0,11	0,0 %
Vehicle hours spent in congestion (M/year)	2,4	-0,000264	-0,01 %	-0,0538	-2,2 %
Fatal accidents (number/year)	56,0	-2,57	-4,60 %	-3,35	-6,0 %
Non-fatal injury accidents (number/year)	1833,0	-33,55	-1,83 %	-58,57	-3,2 %
Property damage only accidents (number/year)	9165,0	-167,76	-1,83 %	-292,83	-3,2 %
Co2 emissions (million tonnes/year)	2,2	-0,0004	-0,02 %	-0,0006	-0,03 %

Finland

Indicator	Total	Change	%	Change	%
Network 1: Long / heavily trafficked tunnels		Low	Low	High	High
Vehicle hours driven (million/year)	1,4	-0,0005	-0,03 %	-0,001	-0,05 %
Vehicle hours spent in congestion (M/year)	0,14	-0,000003	-0,002 %	-0,0007	-0,5 %
Fatal accidents (number/year)	0,0	0,00	-3,88 %	0,00	-5,3 %
Non-fatal injury accidents (number/year)	3,1	-0,06	-1,92 %	-0,10048236	-3,3 %
Property damage only accidents (number/year)	6,3	-0,12	-1,92 %	-0,21	-3,3 %
Co2 emissions (million tonnes/year)	0,019	-0,000007	-0,03 %	-0,0000173	-0,09 %
Network 2: "Full telematics network"		Low	Low	High	High
Vehicle hours driven (million/year)	31,3	-0,01	-0,04 %	-0,01	-0,05 %
Vehicle hours spent in congestion (M/year)	2,4	-0,00004	0,00 %	-0,012	-0,5 %
Fatal accidents (number/year)	1,4	-0,05	-3,88 %	-0,07	-5,3 %
Non-fatal injury accidents (number/year)	47,2	-0,89	-1,88 %	-1,52	-3,2 %
Property damage only accidents (number/year)	208,7	-3,92	-1,88 %	-6,74	-3,2 %
Co2 emissions (million tonnes/year)	0,6	-0,00030	-0,05 %	-0,0042915	-0,7 %
Network 3: Peri-urban extended TERN		Low	Low	High	High
Vehicle hours driven (million/year)	81,5	-0,03	-0,03 %	-0,04	-0,05 %
Vehicle hours spent in congestion (M/year)	5,9	-0,00011	-0,002 %	0,03	0,5 %
Fatal accidents (number/year)	9,8	-0,37	-3,72 %	-0,50	-5,0 %
Non-fatal injury accidents (number/year)	183,9	-3,25	-1,77 %	-5,60	-3,0 %
Property damage only accidents (number/year)	837,0	-14,79	-1,77 %	-25,48	-3,0 %
Co2 emissions (million tonnes/year)	1,2	-0,0006	-0,05 %	-0,0009	-0,07 %
Network 4: Rural extended		Low	Low	High	High
Vehicle hours driven (million/year)	130,1	-0,0005	-0,0004 %	-0,0007	-0,0005 %
Vehicle hours spent in congestion (M/year)	2,2	-0,00006	-0,003 %	-0,013	-0,6 %
Fatal accidents (number/year)	40,2	-0,37	-0,92 %	-0,52	-1,29 %
Non-fatal injury accidents (number/year)	303,3	-1,36	-0,45 %	-2,47	-0,8 %
Property damage only accidents (number/year)	1402,3	-6,27	-0,45 %	-11,40	-0,8 %
Co2 emissions (million tonnes/year)	2,4	0,0005	0,02 %	0,0009	0,04 %
Network 5: Other main public roads network		Low	Low	High	High
Vehicle hours driven (million/year)	86,7	-0,0003	-0,0004 %	-0,000030	-0,0000003
Vehicle hours spent in congestion (M/year)	0,4	-0,000002	-0,0005 %	-0,0005	-0,1 %
Fatal accidents (number/year)	25,0	-0,04	-0,15 %	-0,06	-0,2 %
Non-fatal injury accidents (number/year)	305,8	-0,24	-0,08 %	-0,47	-0,2 %
Property damage only accidents (number/year)	1134,7	-0,91	-0,08 %	-1,74	-0,2 %
Co2 emissions (million tonnes/year)	1,4	-0,000001	-0,0001 %	-0,000002	0,00 %
Network 6: Main street networks in biggest cities		Low	Low	High	High
Vehicle hours driven (million/year)	47,5	-0,01	-0,01 %	-0,005	-0,011 %
Vehicle hours spent in congestion (M/year)	2	-0,0000146	-0,00073 %	-0,00455	-0,227 %
Fatal accidents (number/year)	6	-0,20	-3,26 %	-0,25	-4,2 %
Non-fatal injury accidents (number/year)	400	-5,84	-1,46 %	-9,1	-2,3 %
Property damage only accidents (number/year)	1730	-25,26	-1,46 %	-39,4	-2,3 %
Co2 emissions (million tonnes/year)	0,39	-0,000089	-0,023 %	-0,00013	-0,03 %

Sweden

Indicator	Total	Change	%	Change	%
Network 1: State road network		Low	Low	High	High
Vehicle hours driven (million/year)	474,4	-0,07	-0,02 %	-0,10	-0,02 %
Vehicle hours spent in congestion (M/year)	11,60	-0,000002	-0,00002 %	-0,2255	-1,9 %
Fatal accidents (number/year)	55,3	-2,13	-3,8 %	-2,82	-5,1 %
Non-fatal injury accidents (number/year)	2541,6	-41,4	-1,6 %	-72,8	-2,9 %
Property damage only accidents (number/year)	18703,0	-304,9	-1,6 %	-536	-2,9 %
Co2 emissions (million tonnes/year)	7,500	-0,00150	-0,02 %	-0,0022	-0,03 %
Network 3: Stockholm		Low	Low	High	High
Vehicle hours driven (million/year)	14,9	-0,006	-0,04 %	-0,01	-0,1 %
Vehicle hours spent in congestion (M/year)	0,4	-0,000008	-0,0021 %	-0,0020	-0,5 %
Fatal accidents (number/year)	2,7	-0,123	-4,49 %	-0,16	-6,0 %
Non-fatal injury accidents (number/year)	78,3	-1,62	-2,07 %	-2,75	-3,5 %
Property damage only accidents (number/year)	506,8	-10,50	-2,07 %	-17,82	-3,5 %
Co2 emissions (million tonnes/year)	0,2	-0,000108	-0,05 %	-0,000150	-0,07 %
Network 4: Gothenburg		Low	Low	High	High
Vehicle hours driven (million/year)	15,3	-0,006	-0,04 %	-0,01	-0,1 %
Vehicle hours spent in congestion (M/year)	0,4	-0,000008	-0,0021 %	-0,0021	-0,5 %
Fatal accidents (number/year)	2,8	-0,13	-4,50 %	-0,17	-5,86 %
Non-fatal injury accidents (number/year)	80,5	-1,67	-2,08 %	-2,84	-3,53 %
Property damage only accidents (number/year)	521,3	-10,84	-2,08 %	-18,41	-3,53 %
Co2 emissions (million tonnes/year)	0,2	-0,000111	-0,05 %	-0,000154	-0,07 %
Network 5: Uppsala		Low	Low	High	High
Vehicle hours driven (million/year)	12,0	-0,01	-0,04 %	-0,01	-0,1 %
Vehicle hours spent in congestion (M/year)	0,3	-0,000006	-0,0021 %	-0,0016	-0,5 %
Fatal accidents (number/year)	2,2	-0,10	-4,50 %	-0,13	-6,0 %
Non-fatal injury accidents (number/year)	63,1	-1,31	-2,08 %	-2,23	-3,5 %
Property damage only accidents (number/year)	408,1	-8,50	-2,08 %	-14,43	-3,5 %
Co2 emissions (million tonnes/year)	0,2	-0,00009	-0,05 %	-0,00012	-0,07 %