# NordicWay Evaluation Outcome Report

**NordicWay**

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# Preface

The NordicWay project has piloted Cooperative ITS (C-ITS) services in four Nordic countries: Denmark, Finland, Norway and Sweden. This report extracts the main outcome results from national evaluations of these services.

The report is based on evaluations of national pilots in the NordicWay project. Although the report is composed by SINTEF, it builds on national evaluation reports and KPI lists developed in each country. Hence, the full list of contributors to this report should further include Petter Arnesen, Lone Dörge, Jørgen Flensholt, Henrik Friis, Magnus Hjälmdahl, Satu Innamaa, Ulrik Janusson, Kimmo Kauvo, Sami Koskinen, Tomas Levin, Anna Schirokoff, Hanne Seter, Ane Dalsnes Storseter, Jonas Sundberg, Anders Bak Sørensen, and Carlos Viktorsson.

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# Executive summary

The NordicWay project has piloted Cooperative ITS (C-ITS) services in Denmark, Finland, Norway and Sweden. All pilots have used cellular communication to exchange messages, and through establishing the NordicWay Interchange node (cloud), the NordicWay project has aimed to facilitate continuous interoperable services to the users with cross-border roaming between different mobile networks.

Each pilot has been evaluated and documented in national Evaluation Outcome Reports. This report summarises and juxtaposes evaluation outcomes to provide a comprehensive evaluation of potential C-ITS services based on cellular networks. Outcomes are presented according to the NordicWay evaluation approach, which includes the following elements: technical performance and quality assessment, user behaviour, benefits and impact analysis, user acceptance, barriers and success factors for implementation, socio-economic assessment, knowledge basis for future adaption and optimising, financial performance and market potential.

In the Danish, the Finnish and the Swedish pilots, **technical performance** was a matter of latencies. The different evaluations focused on *latencies* for messages transmitted between different servers and systems. Whereas the Danish evaluation tested latencies for messages of different volumes, the Finnish evaluation tested latencies of messages transmitted between the Finnish service cloud, the Finnish node and the mobile users involved in their pilot. The Swedish evaluation presented latencies for messages transmitted between a Road Works Warning vehicle (RWWV), and clouds and vehicles belonging to OEMs Scania and Volvo. The evaluations found that latencies increase with increasing size of DatexII messages. Latencies further depend on what systems messages are transmitted between. For instance, messages between the Finnish service cloud and the Finnish node have a median latency of 0.7 seconds, whereas messages from RWW vehicles and the Volvo cloud in the Swedish evaluation have a median latency of 0.9 seconds.

Further, the same evaluations examined success rates in *message delivery*. Overall, message delivery rates were high, but it proved difficult to identify the reason why some messages were not delivered or returned. Server downtime or setups for registration or logging of events that underlie messages were commonly reported as probable causes. In order to determine the cause of lost messages, a *test of the NordicWay Interchange* was conducted: A client in a cloud outside the Interchange sent one million messages through the interchange with a payload of 2 kilobytes. No messages were lost, and messages were sent at a rate of 16 messages per second. The NordicWay Interchange does not increase the latency by more than 14 milliseconds. Although it did not cause messages to be lost, the test did reveal a message leak caused by disk swapping, which must be resolved in next phase development. Another critical issue is the packaging of DatexII messages into AMQP messages.

NordicWay evaluations also examined technical performance and quality assessment in relation to friction data and the communication range of ITS-G5. In studying *friction data*, the Norwegian evaluation showed that vehicle system's ability to detect slippery road conditions is not sufficient and data quality not sufficient for developing decision support for winter maintenances. The Swedish evaluation examined the *communication range of ITS-G5*, and found the maximum range to be less than 500 meters with a clear line of sight.

**User behaviour** was mainly evaluated based on the Finnish pilot of a mobile application which provides drivers with cooperative warnings of hazardous situations ahead. The evaluation found that receiving such warnings influences choice of speed and route, as well as focus in traffic.

The potential **benefits** of C-ITS relate directly to the characteristics of the C-ITS service. The Finnish evaluation found a direct safety impact of the service, particularly relating to warnings of slipperiness, animals or people in the road. Impacts appear in reductions in traffic accidents, travel efficiency, and benefits to the traffic management centres who receive more information.

The Norwegian evaluation discussed potential benefits of using road surface information (RSI) to design a support system that aids contractors on winter road maintenance. Benefits include opportunities to prioritise maintenance tasks and to follow up on maintenance contracts. The Swedish evaluation found that the value of interoperability depends on a penetration rate of at least five percent.

Two of the national evaluations in the NordicWay project examined **user acceptance**. The Finnish evaluation focused on users' acceptance of the mobile application and its function, and found that users were overall satisfied with the service. Particularly prominent is their satisfaction with how far ahead of an incident that users received the warning. The Norwegian evaluation focused on the attitudes of maintenance contractors and road authorities towards a hypothetical support system for winter road maintenance (i.e. acceptability), and found the acceptability to depend on the data upon which the system is based.

The **barriers and success factors** identified in the pilots are to some degree specific for the C-ITS service that was piloted, but also include issues transferrable to the establishment and delivery of any C-ITS service through the NordicWay Interchange. Critical issues include infrastructures and integration, standardisation, network coverage, information reliability, data quality, stakeholder involvement, and private-public partnerships with defined roles and responsibilities. Barriers and facilitators for deployment are further described in the NordicWay roadmap.

The Finnish evaluation also presented a **socio-economic assessment** to identity expected costs and benefits related to full-scale implementation of the C-ITS service tested in the Finnish pilot, and to determine the expected cost-benefit ratio. They found a conservative estimate of benefit-cost ratio to be 2.3, with a yearly increase between 2019 and 2030.

The national evaluations provided **knowledge basis for future adaptation and optimising** of the C-ITS services which have been piloted. The Finnish evaluation emphasises advances in the design and functionality of the mobile application, solutions for verifying or disabling messages, and integration into navigation systems. The Norwegian evaluation highlights the need for accumulating experiences with the technology, incremental development of the technological solution and validation in close cooperation with stakeholders. The Swedish evaluation calls for better definition of roles in the ecosystem and a viable business model, as well as closer definition of requirements for large scale deployment.

The Swedish evaluation discussed fundamental issues for making the interchange available to a larger **market**. Allowing access to a multitude of data is expected to increase market potential. Market potential could be further increased through facilitating scalability and interoperability with other central service nodes, and through allowing other data and service providers to join the NordicWay community. Establishing the NordicWay Interchange requires private-public partnerships in which public authorities play a leading role in the early phase. This involves defining roles and responsibilities of all actors. Because of little experience with business models and willingness to pay, this is particularly important to ease insecurities related to long-term operation of the NordicWay Interchange.

# 1. Introduction

The NordicWay project has piloted Cooperative ITS (C-ITS) services in four Nordic countries: Denmark, Finland, Norway and Sweden. NordicWay has tested and demonstrated the interoperability of C-ITS services. Although the piloted services are different in scope and focus, they are united in the use of cellular and/or hybrid communication to exchange messages. Further, through establishing the NordicWay Interchange node (cloud), the NordicWay project has aimed to facilitate continuous interoperable services to the users with cross-border roaming between different mobile networks, offering C-ITS services across all participating countries. These services are made available through exchange of data from a larger number of clouds, both national traffic clouds, and clouds belonging to OEMs, service providers, telecom industry etc. The role of the NordicWay interchange node is described in Figure 1.

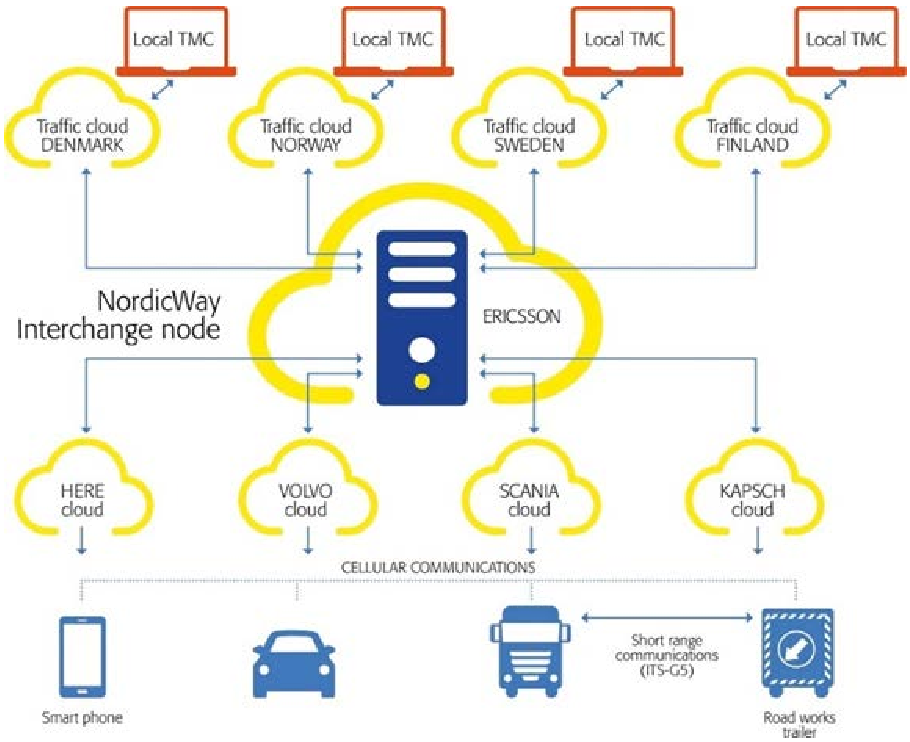


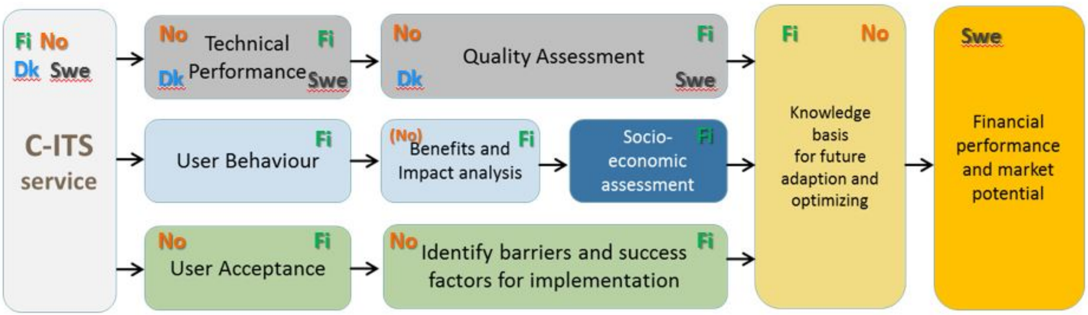

Figure 1. The NordicWay Interchange node

Each NordicWay country has evaluated a C-ITS service or technology which allows for establishing and operating a C-ITS service. Summaries of pilot evaluations are presented in chapters 2-5, and full national evaluations reports are available at the project website[1].

[1] www.nordicway.net

The national evaluation reports provide more thorough descriptions of the following aspects of the pilots: i) problems which motivate use of an C-ITS service, ii) the program theory underlying the C-ITS service, iii) design for evaluation the C-ITS service, iv) results of the evaluation, v) the impact of the C-ITS service, and vi) the transferability of results. These aspects are further described in the NordicWay Evaluation Handbook (2016_M12).

Based on full national evaluations, the purpose of this report is to extract the main outcome results from evaluations. These outcomes provide useful input to progressing C-ITS services towards full-scale deployment. Figure 1 presents issues included in the evaluation of NordicWay pilots. The evaluation of each C-ITS service has not included all these issues. By juxtaposing and collocating the evaluations, however, we can provide a comprehensive evaluation of C-ITS services based on cellular networks. This is the focus of chapter 6 of this report.




Figur 1. Issues included in NordicWay evaluation

# 2. Evaluation outline: Denmark

The performance testing in Danish evaluation (Dörge et al 2017) demonstrated the feasibility of the NordicWay approach to sharing and exchanging real-time Safety Related Traffic Information (SRTI) between various Nodes. This approach was based on representing traffic information using standard DATEX II data definitions and formats and exchanging this information using a queue based message exchange system (NordicWay Interchange).

The focus of the performance testing was on the integration of the Danish Node into the NordicWay Interchange and the exchange of SRTI messages in the form of DATEX II messages to and from the Danish TMC via a pre-production version of the NordicWay Interchange. The purpose of the assessment was to assess performance behaviour- not to test performance requirements in terms of absolute numbers.

The observed performance as regards data volumes showed a small decrease in performance within the Danish Node in addition to the decrease which can be expected with increasing data volumes. But overall, the performance was within the required performance levels in which TMC's shall operate.

As regards performance over a longer period of time it was not possible to evaluate performance with respect to integrity and availability on the basis of the available log data.

Future work is necessary to develop the pre-production implementation of the Interchange mechanism into a stable and viable production system. In addition to better performance, this will include provision of standardized services for operation, management and administration (access control, service catalogue, SLA management, charging and billing, partner on-boarding, etc.).

# 3. Evaluation outline: Finland

The Finnish NordicWay pilot consisted of a mobile application (HERE DTI) which provided ordinary road users with safety related traffic information services for one year. The application allowed users to send and receive alerts on incidents occurring on and beside the road. The purpose of the evaluation was to assess the technical feasibility of the system, readiness for wide-scale implementation as well as its commercial potential and ecosystem model. The evaluation also produced knowledge on cooperative services as a channel for providing safety-related information, and on impacts the service might have on driver behaviour and traffic management. A socio-economic assessment completed the evaluation.

According to the program theory set for the evaluation, the service evaluated in the Finnish study (Innamaa et al 2017) was expected to improve traffic safety because receiving a cooperative warning of a hazardous situation ahead makes the driver aware of the situation before observing the actual situation herself. This allowed the driver to prepare for the hazard, as manifested in increased alertness, less multitasking and a smoother approach. Additionally, the service provided the traffic management centre with information on hazardous situations not be noticed by their traditional incident detection systems/mechanisms or that confirms information they already have. It was expected that this results in more informed road users, less primary and secondary accidents, less time spent in congestion, small decrease in emissions and increased road network performance/efficiency.

The Finnish evaluation concluded that, if large penetration for the system use is achieved, societal benefits are expected. These benefits origin from the reduction in number of accidents, which also reflects a reduction of delay in traffic caused by accidents. The benefit-cost ratio was assessed for different scenarios and concluded to be at least 2.3 for the period 2019–2030 assuming linear growth up to high acceptance and use among road users in Finland.

## 4. Evaluation outline: Norway

The Norwegian evaluation (Seter & Arnesen 2017) focused on how road surface information (RFI) data on friction collected by the car as a sensor can be used as input to a decision support system for winter maintenance. The evaluation relied on two main approaches: i) a technical evaluation, which covers technical performance and quality assessment. ii) an evaluation of user acceptance, as well as identification of barriers and success factors for implementation. The RSI decision support system was suggested to provide the winter maintenance personnel with information on road friction, which could be an additional source of information or used to replace other existing data sources.

Friction data from the vehicles was collected over the cellular network, from the vehicle to the OEM. And then from the OEM cloud to the NPRA.

In the technical evaluation, the quality of the RSI data was assessed by comparing friction estimates from five Volvo cars driving on Norwegian winter roads approximately at the same time as two RoAR vehicles. The friction measurements from the two independent RoAR cars were compared to verify that RoAR data could be used as a reference data set when evaluating the quality of the Volvo fiction values. The evaluation did not find any convincing correlation between the RoAR and the five Volvo measurements, which indicates that the RSI technology currently does not provide a viable alternative for replacing today's continuous monitoring equipment, such as RoAR. It is, however, important to note that although measurements from five Volvo cars did not prove able to replace the current winter maintenance monitoring, the data could still have value if more vehicles deliver data. They could also be valuable for other purposes, such as using historical RSI data to map out critical road segments in terms of friction.

The evaluation of user acceptance included contractors that execute winter maintenance and the road authorities. In terms of acceptability, both user groups were very optimistic about the service. Representatives from the road authorities were more reserved, however, due to previous experiences with friction measures.

# 5. Evaluation outline: Sweden

The aim of the Swedish pilot (Hjälmdahl et al 2017) was to demonstrate communication between vehicles, infrastructure and clouds, and to demonstrate the interoperability, scalability and flexibility of the NordicWay interchange network. This was demonstrated by implementing a Road Works Warning (RWW) use case consisting of a RWW unit on a road works vehicle sending a notification to the road user. In this setup, a Truck Mounted Attenuator (TMA) on the road works vehicle was activated, and triggered a message to be broadcasted over ITS-G5 which could be received by approaching vehicles. The message was also transmitted to the RWW backend via cellular networks, where the message was transformed into the DATEX II format for RWW and forwarded to the NordicWay Interchange. The Interchange server distributed the RWW message to all subscribing service providers. The service provider then sent an alert message to subscribed users in the event area through the cellular network.

In the Swedish pilot, ten road works vehicles were equipped and transmitted messages to twelve Volvo cars and four Scania vehicles. The vehicles were in normal operation in the cities of Gothenburg and Södertälje. In addition, controlled tests were carried out to perform repeated measurements. More than 7000 events were recorded during the trial.

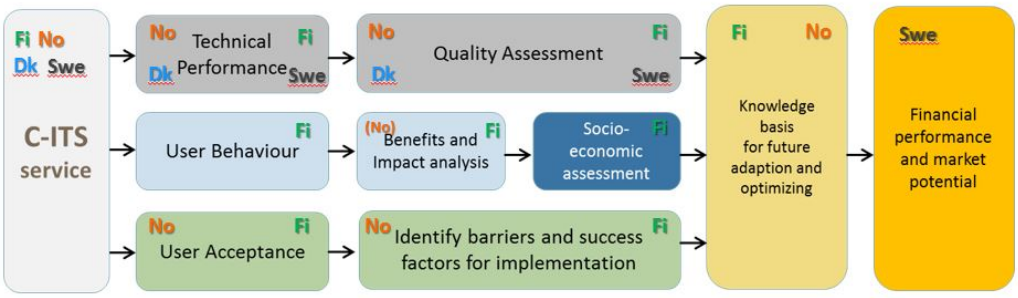
In addition to the technical testing, the Swedish evaluation pilot included a study on business models. Further, the evaluation elaborates on the value of interoperability.

# 6. Evaluation outcome

This chapter describes the main results from the national evaluations in NordicWay. The description is structured according to evaluation approach to the Nordic Way project, as presented in the NordicWay Evaluation Handbook, and consists of the nine elements displayed in the figure below.

Each national pilot and evaluation has not covered all the elements in evaluation approach. Individually, they will therefore not provide a complete evaluation of the C-ITS service in question. The national evaluations are complementary, however, and combining their results allows us to provide an overall evaluation of C-ITS-services based on exchanging messages over the cellular network.

In the following, each element included in the evaluation approach is presented with reference to the results from relevant national evaluations. Each section provides an overview over evaluation findings and draws, as far as possible, conclusions on congruent results.




## 6.1. Technical Performance and Quality Assessment

This section describes tests and trials that have been conducted within the NordicWay pilots. Most evaluations describe latencies of message transmission, but what types of messages and between what nodes or systems these messages have been transmitted varies from one pilot to another. Further, most evaluations investigate whether messages are successfully transmitted, i.e. received at end-point and/or returned to sender. This has particularly been a prominent focus in the Danish evaluation, and the following interchange test described in 6.1.3. The Norwegian and Swedish evaluations are further distinguished by addressing issues of technical performance and quality relating to friction data and communication range of ITS-G5 respectively.

### 6.1.1. Latencies

In the Danish, the Finnish and the Swedish pilots, technical performance was a matter of latencies. However, the different evaluations focused on latencies for messages transmitted between different servers and systems. Whereas the Danish evaluation tested latencies for messages of different volumes, the Finnish evaluation tested latencies of messages transmitted between the Finnish service cloud, the Finnish node and the mobile users involved in their pilot. The Swedish evaluation presented latencies for messages transmitted between a Road Works Warning vehicle (RWWV), and clouds and vehicles belonging to OEMs Scania and Volvo. The table below summarises results of latency testing in NordicWay. These results are elaborated in the following.

| Evaluation | Messages tested | Median latency |
|---|---|---|
| Denmark | Messages with 10 DatexII situation recordsc | 0.2 s |
| | Messages with 50 DatexII situation records | 0.2 s |
| | Messages with 450 DatexII situation records | 1.5 s |
| | Messages with 950 DatexII situation records | 3.8 s |
| Finland | Confirmation message service cloud – mobile user | 0.3 s |
| | Service cloud – Finnish node | 0.7 s |
| | Finnish node – service cloud – mobile user | 2.0 s |
| Sweden[2] | RWWV – Scania cloud | 2.0 s/1.1 s |
| | RWWV – Scania vehicle | 2.5 s/1.3 s |
| | RWWV – Volvo cloud | 0.9 s |
| | RWWV – Volvo vehicle | 2.5 s |

Table 1. Overview of latencies in NordicWay

**The Danish evaluation** of technical performance tested latencies for messages of different volumes from the Danish TMC, via the Danish node to the interchange, and back again. It found that latencies increase when the size of DatexII message increases. For instance, whereas the latency of messages with 10 DatexII situation records per publication was 0.2 seconds, the latency of messages with 950 DatexII situation records per publication was more than 3 seconds. This was due to packaging of DatexII messages into AMQP messages.

**The Finnish evaluation** presented latencies for confirmation messages from the service cloud to the mobile user, once the user had reported an incident. Nine of ten messages were confirmed by the service cloud in less than 0.7 seconds, and the average latency was 0.3 seconds.

[2] Left Scania numbers refer to driving study, whereas right numbers refer to controlled trial. Volvo numbers refer to controlled trial only. This is further elaborated below the table.

Secondly, the Finnish evaluation tested latencies of messages transmitted between the service cloud and the Finnish node, where the median latency was 0.7 seconds, and average latency 1.8 seconds. Latency delays related to poor or lack or network connection, or phone related software issues.

Finally, the Finnish evaluation tested latencies in transmitting messages from the Finnish node, via the service cloud, to the mobile users. Median latency was found to be 2 seconds.

The technical assessment in the **Swedish evaluation** used road works warning to evaluate the technical performance of the interchange. The pilot consisted of i) a driving study, and ii) a controlled trial with one RW equipment and three client vehicles on test tracks. Three indicators were included in the evaluation: latency, message success rate, and communication range of ITS-G5.

| | Driving study | Controlled trial |
|---|---|---|
| Source - Scania cloud | 2.001 s | 1.102 s |
| Source – Scania vehicle | 2.452 s | 1.254 s |
| Source - Volvo cloud | - | 0.879 s |
| Source – Volvo vehicle | - | 2.486 s |

**Table 2. Swedish evaluation. Median latencies for messages between source and cloud/vehicle**

Latencies between source and Scandia vehicle described in the driving study (grey cell) were of expected size. However, latencies between source and Scandia cloud were slightly higher than expected. This was partly due to congested communication networks, and periods of malfunctions where messages were stuck in servers for several hours. Under controlled conditions there were no malfunctions which influenced latency. The added time for the message to reach the Scania vehicle (green cell) was quite small, and within expectations.

The orange cell shows latencies in controlled measurements with Volvo. As the limited number of vehicles in the driving study generated insufficient data, only controlled latency measurements were included. These showed source-cloud latencies to be low, but a relatively large time add-on in reaching the Volvo vehicle. One explanation for this is that the measurement setup included the time it takes the vehicle to send an acknowledgement message back to the Volvo cloud.

#### 6.1.2. Message delivery

In addition to testing latencies, the Danish, Finnish and Swedish evaluation also examined success rates in message delivery. Overall, message delivery rates were high, but it proved difficult to identify the reason why some messages were not delivered or returned. Server downtime or setups for registration or logging of events that underlie messages were commonly reported as probable causes. Tests on message delivery are further elaborated below.

**The Danish evaluation** included a functional test where safety related traffic information (SRTI) messages were sent from Danish node to i) Finnish node, ii) Swedish node, and ii) back to Danish node. The purpose of the test was to investigate end-to-end message transmission, and showed that all except two messages were successfully transmitted.

Further, the Danish evaluation included testing of performance over a longer period of time, through transmitting messages from the Danish TMC via the NordicWay interchange for one month. Results showed that approximately 80 % messages from other nodes than the Danish were received and recognized as valid and unique messages by the Danish TMC. Further, 75 % of messages from the Danish node were returned. Although the log did not provide data to determine why some messages were not received/returned, a server breakdown of 15 hours might explain some of the deficit.

One of the technical issues addressed by **the Finnish evaluation** is whether messages (incident alerts) were delivered to users who passed an incident location. Through searching for and analysing candidate events manually, it did not find evidence suggesting that any messages were not delivered. The Finnish evaluation thus concluded that the servers were aware of the movement and sessions of mobile phone clients.

However, there were cases, where a server had sent a message but the mobile phone had not logged receiving it. This might be due to the problems in sending the last logs, since GPS logs were also missing from these cases. Further, data indicated that logging started a brief while after the app was turned on, as a few cases had logged an alert even though they had not received a message.

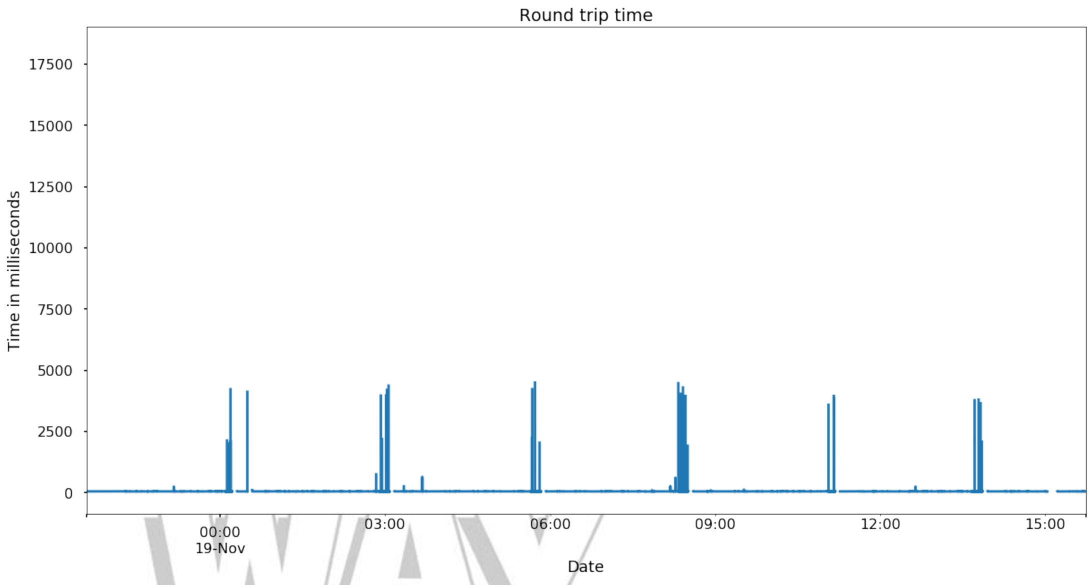
In **the Swedish evaluation**, the message success rate was 100 % in both the driving study and the controlled study. However, the driving study involved several periods of server downtime. Further, one failure to position the roadworks in the controlled study produced a dummy position that caused the message to be filtered out in the interchange.

### 6.1.3. TEST OF THE NORDICWAY INTERCHANGE

As described in 6.1.2, the Danish evaluation showed a significant share of messages to be lost for reasons unknown. Almost all of the message loss occurred, however, within the Danish Node (TMC and Cloud). In order to ensure next phase deployment, it is essential to verify that the loss of messages was not caused by the NordicWay Interchange. This was tested by setting up a simple scheme for sending and receiving messages.

In this set-up, a client in a cloud outside the Interchange sent one million messages through the interchange with a payload of 2 kilobytes. The ping time between the NordicWay Interchange and the message node was 47 milliseconds. Ping time is the roundtrip time for the smallest data packet one can send. The Interchange test showed a median ping time of 61 milliseconds for the 2 kilobyte message. No messages where lost in the transmission of the 1 million messages. The messages were sent at a rate of 16 messages per second. This shows that the NordicWay Interchange does not increase the latency by more than 14 milliseconds.

A memory leak in a part of the NordicWay Interchange caused some severe delays due to disk swapping. A simple workaround was created to clear the memory and continue posting to the interchange. This was achieved by monitoring the round trip time: when the round trip time exceeds 5 seconds, a restart request is sent to the interchange. Although this is an error which will be fixed when the NordicWay Interchange is developed further, it is important to note that no messages were lost.




The figure above shows the NordicWay Interchange operating at 16 messages per second and having a memory clean-up operation run about every 2.5 hours.

The results of the test showed that the NordicWay Interchange is not losing messages, but that there is a memory leak in the test set-up. The memory leak must be repaired when the Interchange node is further developed. However, this underlines that although the NordicWay Interchange is not losing messages, surrounding systems might be losing messages. This probably relates to the transmission of Datex messages and incompatibilities in these messages. Hence, there is a crucial need for profiling of the messages in the Datex standard.

### 6.1.4. Friction Data

**The Norwegian evaluation** investigated the potential use of friction data from the car to monitor the road surface and use data to inform and monitor winter road maintenance contractors. In NordicWay, this involved evaluating Volvo's road surface information (RSI) system when used in real world driving. The system's ability to deliver friction data was evaluated in terms of spatial coverage and quality. The Volvo RSI system delivers friction measurements approximately every 10 milliseconds.

However, the system can only delivery friction estimates with high values on Volvo's quality parameter when triggered by acceleration. The Norwegian evaluation showed this to occur about 3 % of the time. Hence, although the system is able to deliver friction data on important road segments, such as turns and steep hills, the system's ability to detect slippery road conditions is not sufficient, particularly for winter maintenance purposes. Its potential use in winter road maintenance is further discouraged, as all respondents in the semi-structured interviews in the Norwegian evaluation highlight sufficient data quality as a precondition for using RSI.

Public-private partnerships are essential for ensuring availability and use of friction data. This depends on the willingness of private actors to cooperate and share their data. Because of Volvo's involvement in the Norwegian pilot and the NordicWay project, Volvo has publicly encouraged the car industry to cooperate with governments to share safety related traffic data[3].

### 6.1.5. Communication range of ITS-G5

The Swedish pilot also measured the communication range of ITS-G5, through determining the maximum distance behind a RWW vehicle that a message can be received. Measurement were conducted for line of situations. Hence, communication range was measured in a controlled trial without simulating a naturalistic environment with potential signal blocking, interference or other complications. Testing in naturalistic environments is a precondition for predicting real world performance.

For two different antennas, the maximum communication range was identified as 460 and 495 meter with a clear line of sight.

## 6.2. User behaviour

User behaviour resulting from C-ITS services provided over the cellular network is naturally highly dependent on the type of service provided. For instance, providing information on road works, as in the Swedish evaluation, might influence route choices. Or, as in the Norwegian evaluation, providing friction data to road maintenance contractors might influence their strategies when deciding which routes and road segments to prioritise.

However, in the NordicWay project, user behaviour that result from introducing C-ITS services based on transmitting messages over the cellular network, is primarily investigated through **the Finnish evaluatio**n. The Finnish pilot consisted of a one-year field test of a mobile application which provides drivers with cooperative warnings of hazardous situations ahead. The national evaluation report from Finland[4] showed that drivers who send and receive traffic related warnings via the cellular network change their

[3] https://www.media.volvocars.com/global/en-gb/media/pressreleases/207164/volvo-cars-ceo-urges-governments-and-car-industry-to-share-safety-related-traffic-data

[4] See NordicWay project website: www.nordicway.net.

driving behaviour. The evaluation identified significant speed reductions among drivers when they receive warnings about accidents (1.9 km/h speed reduction), roadworks (4.3 km/h speed reduction) and obstacles in the road (0.4 km/h speed reduction). User consultation further showed that receiving such warnings influenced the users' choice of route (min. 40 % of users, all warning types), their focus in traffic (min. 39 %, all warning types) and speed choice (min. 30% of users, all warning types).

## 6.3. Benefits and impact analysis

As for user behaviour, the potential benefits of C-ITS relate directly to the characteristics of the C-ITS service. In **the Finnish evaluation**, benefits thus relate to the effects of providing cooperative warnings of hazardous situation to drivers. As seen in the description of driver behaviour, providing incidents warnings over the cellular network i) contributes to speed reductions in areas where traffic incidents occur, ii) allows drivers to avoid incidents with potential impacts on traffic safety and travel efficiency, and iii) leads driver to be more focused on changes in the traffic environment. As such, this warning represent benefits to users of the application for sharing warnings.

The Finnish evaluation found the direct safety impact on target roads to be largest for warnings on i) slipperiness and ii) animals or iii) people on the road. The over-reliance on system being able to warn of hazards was expected to cause a slight increase to the speed affecting also safety. The overall safety impact of the service was assessed to be 0.00–0.09% reduction in the injury accidents and 0.00–0.08% fatal accidents in 2019 on the motorways in Southern Finland, and correspondingly 0.8–4.6% in injury and non-injury accidents and 0.6–4.0% in fatal accidents in 2030 on all main roads. The service will have also travel time benefits if number of accidents and therefore delay caused by them is reduced.

Sharing information on incidents on the road also represents benefits to the traffic management centre (TMC). Some of the warnings received by the TMC were first reported by a road user via the mobile application. Information from road users on accidents could be more precise than the first located provided in the current system. The same applies for other unplanned incidents, such as local fogs, obstacles on the road, end of queue, cause of congestion. Also, involving road users (drivers) means the TIMC receives information of smaller incidents that are normally no reported to them (e.g. animal on roadside, local fogs, local slipperiness, load on road etc.).

**The Norwegian evaluation** discussed potential benefits of using road surface information (RSI) to design a support system that aids contractors on winter road maintenance. Benefits were identified through semi-structured interviews with these contractors. As such a system has yet to be designed, the evaluation was based on a hypothetical tool for decision support. An RSI decision support system could generate several benefits to the contractors. Because such a system would allow historical data with high temporal and geographical resolution it could make it easier to prioritise where and when to perform maintenance. An RSI decision support system that reports real time information directly to the contractors could further allow contractors to be one step ahead of weather events and increase the quality of winter maintenance.

Additionally, the RSI decision support system could have several benefits to the public road authorities. Road surface information can indicate where the road authorities should perform random inspections of road surface friction values, and thus follow up on contracts with road maintenance contractors. RSI data could also be collected and analysed to provide important statistics for other uses than an RSI decision support system, for instance to help determine whether the Norwegian winter maintenance class determined by Handbook R610, chapter 9 is correctly specified.

One benefit from organising C-ITS services over the cellular network, i.e. through the NordicWay Interchange, is increasing interoperability. **The Swedish evaluation** studied the value of interoperability. Value is estimated by reference to the time it takes a connected vehicle to detect an event and pass the information on. This was studied for various penetrations rates by using Vissim microsimulation. The evaluation concluded that for a penetration rate less than 5% there is a limited value of having communication between vehicles but the effect on time to detection and communication of a hazardous event increases rapidly for every vehicle and already at 5% and above the effect has saturated to some degree. This means that all brands except the top three would benefit from interoperability between brands.

## 6.4. User acceptance

User acceptance refers to how users perceive the service in question, and is typically studied in relation to theories of reasoned behaviour (Fishbein & Ajzen 1975), the Technological Acceptance Model and theories derived from it (Davis 1989, Venkatesh & Davis 1996, Venkatesh et al 2003). Under these perspectives, issues relating to user-friendliness and human-machine interface are prominent. Further, depending on their design and program theory, the use of C-ITS services provided over the cellular network also depends on pre-use attitudes, also known as acceptability (for instance Schage & Schlag 2003, Vlassenroot 2011, Bjerkan & Nordtømme 2015, Gaunt 2007). These relate to the user's assessment of the C-ITS service's logic, effectiveness and efficiently, relevance and equity.

Two of the national evaluations in the NordicWay project examined user acceptance. Whereas the Finnish evaluation focused on users' technological acceptance of the mobile application and its function, the Norwegian evaluation focused on the attitudes towards a hypothetical support system for winter road maintenance (i.e. acceptability).

**The Finnish evaluation** studied how road users experienced sending or receiving warnings over the cellular network experience. Overall, less experienced users were more satisfied than experienced users, but all users are satisfied overall. The aspect of satisfaction which most closely relates to using the cellular network for transmitting messages (warnings) is *timing of information.* This refers to whether the users considered the 1-2 km ahead of the hazardous location to be a good moment to receive the warning.

Four in five users (82%, N=113) were satisfied with timing of information. Sending a warning was considered the challenging aspect, but still 79% of the experienced users (N=113) were satisfied with how this was done, the proportion being only 35% for the others. It is important to stress, however, that the pilot was conducted with a prototype service and not polished to a production version.

The **Norwegian** case study focused on the acceptability of a RSI decision support system among two main user groups; the maintenance contractors and the Norwegian road authorities (NPRA). Overall, both user groups were positive to the RSI decision support system. For the contractors it was important that an RSI decision support system explains or shows the relevant data that its decisions are based on. The NPRA had some reservations towards whether the RSI technology will provide good enough information. These attitudes might be traced back to the experiences the NPRA have with other point measures.

## 6.5. Barriers and success factors for implementation

This section describes the factors which are most important for implementing the C-ITS services through the NordicWay interchange. The NordicWay Deployment Roadmap (Meland & Bjerkan 2017) discusses barriers and success factors more elaborately.

As described above, **the Danish evaluation** presented performance testing of sharing and exchanging messages between different nodes. The Danish evaluation found that establishing infrastructure and integration with the NordicWay interchange is essential for succeeding. This requires sufficient maturity of systems and implementations, and sufficient mobile network coverage. This is ensured through continuous pilots that include performance testing of all relevant aspects, and through further developments (for instance 5G).

Experiences from the Danish evaluation also emphasised the importance of structures for governance, including management, operation and updating the interchange, as well as organisational cooperation, cooperation processes and development of viable business models. One way of securing efficient cooperation is establishing service level agreements, with as defined and established through cooperation.

Another critical issue for ensuring implementation is standardisation of data, content and user handling. This also includes interoperability between systems. Exchanging messages requires a common understanding of message content and format. One way of facilitating this is providing a catalogue of meta-data descriptions and standardisation of tools.

**The Finnish evaluation** studied the use of a mobile application with which drivers could send and receive warnings on hazardous incidents ahead of them. One of the main barriers for implementation experienced in the Finnish evaluation related to quality of service, both in terms of information reliability and coverage. High quality services with high added value for the users are thus essential. One way to raise quality is through automated message creation (through in-vehicle systems), and increasing use by making message creation as easy as possible. Ensuring increased use is essential for achieving sufficient penetration, or else the expected societal impact will diminish. This relates to the service providers' willingness to cooperate and share data: when different service providers share respective data on hazardous events, both coverage and the number of users is expected to increase. However, quality is also a matter of harmonising procedures for message content and lifetime; i.e. ensuring that messages from different sources have the same meaning and that procedures for activating and deactivating messages are consistent. Finally, inability to provide a business model for providing SRTI will obstruct implementation.

**The Norwegian evaluation** investigated the use of road surface information (RSI) on friction in a hypothetical tool decision support system for improving winter road maintenance. A key issue for implementing the RSI decision support system is to provide users with documentation of data quality. Another key success factor is combining the RSI data with other data sources, such as for instance temperature and images of the road.

The largest barrier for implementation is lack of data quality, an aspect that must be addressed before implementation. As the individual vehicle will not be able to identify a slippery patch on the road unless it is manoeuvring on the spot, vehicle-to-vehicle information for relaying information is not a good use case. The use case needs to be redefined, e.g. to be based on an aggregate of multiple observations over a period of time. This would, however, introduce a delay.

Another barrier for implementation is not including the users in the implementation process. It is particularly important to include representatives from the road authorities because they have valuable experiences. User involvement is particularly important as anchoring among users is a precondition for accepting the system. For instance, organisations are not necessarily prepared to handle new data types, and in order to encourage these to use data in new ways they must be involved at early stages of the implementation process. User involvement should also include the general public. Public perception and acceptance of new types of (in-car) information is essential.

Lessons learned from **the Swedish evaluation** are based on technical testing and stakeholder consultations. They find that one essential challenge in securing live implementation of C-ITS services over the cellular network, is that someone needs to take the upfront cost for stablishing the digital infrastructure, in the NordicWay project represented by the interchange. For one, this requires a clearly defined business model. Second, roles and responsibilities should be clearly described and distributed. There is a slight disagreement on who should take the leading role, and one can expect even greater challenges on pan-European level. This could make it difficult to board partner, both private and public, outside the Nordic region. However, this will be facilitated in ensuring interoperability and harmonised communication profiles, and through publishing a reference architecture for the interchange node to make it possible for multiple service providers to interact in the interchange network.

## 6.6. Socio-economic assessment

The C-ITS service in the NordicWay project that is most extensively demonstrated, is the mobile application for sending and receiving warnings on hazardous incidents on and beside the road, as presented in **the Finnish evaluation**. The purpose of the socio-economic assessment in the Finnish evaluation (Innamaa et al 2017) was to identity expected costs and benefits related to full-scale implementation of the C-ITS service, and determine expected cost-benefit ratio.

The evaluation provided socio-economic assessment for two different scenarios, as described in the table below. The '2019' scenario applied only to main roads in Southern Finland. These are mainly motorways, and include roads 3, 4 ,51, E18, and ring roads in Helsinki and Tampere. The '2030' scenario applied to all main roads in Finland, including 2-lane roads.

| | **2019**<br>**Southern Finland motorways (appr. 600 km)** | **2030**<br>**All main roads (appr. 13 000 km in total)** |
|---|---|---|
| **Road network** | Main roads Southern Finland | All main roads in Finland |
| **Penetration of C-ITS service** | 5 % | 100 % among professional drivers<br>50-75 % among non-professional drivers |
| **Km driven with C-ITS service in use** | Professional drivers: 70-80% of km<br>Non-professional drivers: 20-30% | Professional drivers: 90-95% of km<br>Non-professional drivers: 40-80 % |

Table 3. Scenario description for socio-economic assessment

### 6.6.1. Input to socio-economic assessment

The socio-economic assessment described by the Finnish evaluation was based on expected accident rates, expected changes in travel time, and expected costs. The evaluation investigated anticipated effects of direct and indirect influences on accident rates. Direct influences refer to direct modification of driving tasks and direct influence from the roadside system, whereas indirect influences refer to speed effects resulting from over reliance on the C-ITS service.

Estimates of *anticipated accident rates* were based on proportion of accidents targeted by the C-ITS service, coverage of C-ITS service, effectiveness of sending warnings, and penetration rates. The evaluation found that the largest in-group accident reductions for both scenarios relate to slipperiness (0.004-2.12 % reduction), accidents with animals or people on the road (0.006-1.68 %), and roadworks (0.004 – 0.58 % reduction). The overall effect of the C-ITS service, from both direct and indirect influences, was for the 2019 scenario assessed to be a 0-0.09 % reduction in injury accidents and a 0.-0.08 reduction in fatal accidents. For the 2030 scenario, injury accidents were expected to be reduced by 0.8-4.6 %, and fatal injuries by 0.6-4.0 %.

Full-scale implementation of the C-ITS service is also expected to change travel time, as reduction of traffic accidents results in reduced delays. This is particularly prominent in areas with high traffic volumes, such as the 2019 scenario in Southern Finland.

| | **2019** | **2030** |
|---|---|---|
| Fatal accidents prevented (n per year) | 0.00 – 0.01 | 0.4 – 2.6 |
| Injury accidents prevented (n per year) | 0.00 – 0.18 | 6.5 – 38.9 |
| Non-injury accidents prevented (n per year) | 0.02 – 1.08 | 35.6 – 231.3 |
| Prevented delays for light vehicles (hours/year) | 95 – 4 320 | 121 000 – 727 000 |
| Prevented delays for light vehicles (hours/year) | 18 – 803 | 19 000 – 116 000 |

**Table 4. Estimates on prevented accidents and time savings from C-ITS service**

Further, any costs induced by establishing and making the C-ITS service available should be included in the socio-economic assessment. Although the evaluation (Innamaa et al 2017) anticipated some additional costs to the TMC, such as providing the traffic management system with an intelligent analytic layer, investments will be made regardless of the introduction of the C-ITS service. These costs were hence not included in the evaluation of socio-economic effects. The evaluation did include, however, a service fee for public authorities which increased with increasing coverage and penetration of the C-Its service. Finally, approximately 40 % of new users will probably have to purchase a phone holder in their car in order to use the service.

### 6.6.2. Cost-benefit ratio

The table below gives an overview of estimations of anticipated costs and benefits following the implementation of the C-ITS service. These were used to calculate a cost-benefit ratio for both scenarios (time period 2019-2030). The conservative estimate of benefit-cost ratio is 2.3. The benefit-cost ratio is expected to increase each year between 2019 and 2030.

| | **2019** | **2030** |
|---|---|---|
| Safety and travel benefits | 3000 – 204 000 € | 5 200 000 – 31 600 000 € |
| Costs/year | 790 000- 1 040 000 € | 850 000 – 1 280 000 € |

**Table 5. Anticipated costs and benefits from implementing C-ITS service**

## 6.7. Knowledge basis for future adaptation and optimising

As mentioned above (6.5), the NordicWay Deployment Roadmap (Meland & Bjerkan 2017) provides more elaborate discussions on paths towards future deployment and therein extracts knowledge from the NordicWay project used to define next phase. Thus, the following merely presents evaluation specific issues that are relevant for optimising C-ITS *services* provided over the cellular network evaluated in national pilots.

**The Finnish evaluation** studied a C-ITS service that allows drivers to send and receive warning on hazardous incidents ahead of them. The Finnish traffic management centre (TMC) argued that one should not allow road users to cancel warnings, because road users might not have sufficient information to do so. For instance, there might be roadworks on the roadside, or roadwork equipment, loose rocks on the road or shoulder, that the user is not able to observe. Further, they argued, there should be a procedure for verifying warning types sent by users, and for cancelling warnings from individual users. If a single user fills the system with warnings, the TMC should be able to disable the user's permission to send warnings.

Both the TMC and users emphasised the benefit of distinguishing between more warning types, i.e. distinguishing between different types of animals. Users suggested to add more hazard types (special transports, damaged road, traffic jam, animal on road, driver with abnormal behaviour, police, traffic cameras) and adding short description of the incident. They further suggested integration into navigation systems, which filter out incidents that do not apply to the chosen route. The user would also benefit from knowing in what lane incidents occur.

**The Norwegian evaluation** investigated the use of road surface information for improved winter road maintenance. In the interviews, maintenance contractors brought accumulating experiences with technology before preparing full-scale implementation forward as a critical aspect. The experiences with the RSI data in NordicWay are therefore of great importance. Incremental technology development followed by small-scale verification and validations testing in close cooperation with potential users is important. Only by working with the technology, in close cooperation with the users of the technology (in this case winter maintenance personnel), will the users of the technology learn to trust the new tools derived from it. Further, cooperating with private actors, such as telecom and the car industry, are essential for both providing data and establishing appropriate systems and mechanisms for facilitating data exchange. As described above (6.1.4), involving private actors in projects such as NordicWay is constructive in providing private actors with knowledge and experience with the potential inherent in their data. Volvo's commitment to continued cooperating with governments is one example of this.

Future work based on the findings from **the Swedish evaluation** includes a better definition of the roles in the ecosystem and the business models for this. That requires further studies of costs and benefits to have better information to base the decision on. There is also more work needed on the requirements for large scale deployment.

## 6.8. Financial performance and market potential

Estimating financial performance and market potential requires large-scale demonstrations over a larger period of time, with a setup which resembles, as much as possible, a permanent production system. Hence, the NordicWay evaluations do not contain data to assess financial performance. However, **the Swedish evaluation** discusses fundamental issues for making the interchange available to a larger market. Particularly important is defining roles and responsibilities of all actors that need to be involved, and how these should cooperate in private-public partnerships.

One purpose of the Swedish evaluation was to get a better understanding of how open data can be made available and exchanged between relevant actors and how this best can be implemented. The main Swedish partners involved in NordicWay were interviewed separately. In addition, the Norwegian, Finnish and Danish road authorities were interviewed using the same interview material as for the Swedish interviews. These were carried out by local personnel and may have differed somewhat in setup.

Through interviews with road operators in Denmark, Finland, Norway and Sweden, in addition to interviews with commercial actors in Sweden, approaches to realising market potential were discussed. The NordicWay interchange node is considered useful, as it allows users of data to communicate through one access point or one federated system rather than a range of access points from several data providers.

The NordicWay interchange node is considered useful, as users of data will relate to one federated system rather than a range of access points from several data providers. Allowing access to a multitude of data is expected to increase market potential. Market potential could be further increased through facilitating scalability and interoperability with other central service nodes, and through allowing other data and service providers to join the NordicWay community.

Establishing the interchange requires private-public partnerships in which public authorities play a leading role in the early phase. Through setting up projects such as NordicWay, participating in standards discussions and providing basic infrastructure public authorities can facilitate further private enterprise. The interviews showed that commercial actors are intent on financing and building infrastructure for their own systems, but do not consider it their responsibility to establish central infrastructure for the NordicWay interchange.

Further, equipment and vehicle manufacturers considered it their responsibility to provide technology, provide data and data protection. At this point, the telecom industry has the most unclear role, but is the actor with most knowledge and experience with interchange servers and administrating payments. Their involvement depends on willingness to pay for services, which requires a third party to facilitate and sponsor the start-up phase of the interchange. In the interviews, it was implied that the third party should be a public actor.

Road authorities in NordicWay do not necessarily have a unified view of what role authorities should play in bringing the interchange to the market. In the interview, road authorities considered themselves providers of data, but expect the market to develop and deliver services based on these, and other, data. Although they agreed that road operators can take a larger role in the start-up phase, to what degree road operators should take a leading role, what level of authority that should take the lead and at what point it should be left to the market, was at debate.

Thus, the role of authorities is still unclear and perspectives vary between national road authorities. The role of road authorities must take into consideration risks of competing with private interests, to what degree they can provide data used in commercial products, potential costs and benefits, and mandate for providing data.

Because of little experience with business models and willingness to pay, the largest insecurities relate to long-term operation. One possible solution for business involvement is to establish an adaptive business model, in which the eco system of the interchange is built stepwise. When one piece of data and functionality to be included in the interchange is defined, costs and responsibilities related to including each piece are determined and allocated. Each piece is defined before allowing for additional pieces, that are included through following the same procedure.

# 7. Concluding comments

This report summarises the main outcome of evaluations of national pilots conducted in the NordicWay project. In line with the NordicWay evaluation approach presented in Figure 1, this report is an attempt to synthesise valuable inputs from individual evaluations in order to achieve a holistic understanding of experiences with providing C-ITS services over the cellular network, as represented by the NordicWay Interchange. These experiences are also discussed in the NordicWay roadmap for next phase deployment (Meland & Bjerkan 2017).

This report describes some of the many potential use cases that can be defined through providing services over the NordicWay Interchange, and for the most part, evaluating such services strongly correlates with the design, logic and function of each C-ITS service. Hence, the evaluation results relating to one C-ITS service are not necessarily transferrable to another.

However, common to all C-ITS services enabled by the NordicWay Interchange is the reliance on technical performance and quality in data and the technical solution. The delivery of services further relies on an appropriate organisation of the interchange and a well-functioning and constructive eco-system surrounding its operation. Thus, experiences and results presented in chapters on technical performance (6.1) and market potential (6.8) might have greatest value beyond the NordicWay project. These are also the key elements in progressing joint efforts in the Nordic countries to establish an interchange that allows and enables marked-based C-ITS services which contribute to achieving transport policy goals. T*he NordicWay project shows that using the cellular network to provide C-ITS services works. Further, it shows the NordicWay Interchange is a viable, scalable solution for enabling these services.*

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# Appendix A.

## A.1. KPI list: Denmark

| KPI | C-ITS service | Unit of Indicator | Weather, slippery road | Hazardous location | RESULTS |
|---|---|---|---|---|---|
| KPI_27 | Location accuracy | Km | x | x | Not adressed in Danish testing |
| KPI_30 | Send/receive latency – time from timestamp sent to timestamp received of message (ms) | Milliseconds | x | x | 200 ms ≤ send/receive latency time ≤ 3.800 ms (from Danish TMC to Danish TMC using a pre-production demonstration version of the system). Latency (and response times) increases with increasing message size but not disproportionately. No data available for communication with other Nodes. |
| KPI_31 | Message success rate | % of messages revived when sent | x | x | Message success rate ~ 75 % (from Danish TMC to Danish TMC in a one-month period using a pre-production demonstration version of system). Observed deficit is probably due to server breakdown at Danish Node. Available log data are not sufficent for further analyzing the deficit and for assessing this KPI. No data available for communication with other Nodes. |
| KPI_32 | Up-time | % of time the system is working | x | x | The Danish Node was unavailable during a 15-hour period in a one-month test period. See comment on KPI result for message success rate. |

| | | | | | |
|---|---|---|---|---|---|
| KPI_50 | Integrity (The extent to which output and input by the TMC are similar) | | x | x | All executed tests of integrity of end-to-end DATEX II message transfer passed (input and ouput messages are similar) except for two messages which is not implemented by the Danish TMC. The tests include message transfer from the Danish TMC and back again and message transfer between the Danish TMC on one hand and the Finnish Node (16 messages) and the Swedish Node (2 messages) on the other. |
| KPI_51 | Availability (Availability Period, Uptime, Data loss) | | x | x | See above comments on KPI results for send/receive latency and message success rate. |
| KPI_52 | Frequency (Time intervals between input of messages to the TMC and recipt of these messages by the TMC) | | x | x | See above comments on KPI result for send/receive latency. |
| KPI_53 | Volume | | x | x | See above comments on KPI result for send/receive latency. |
| KPI_54 | Timeliness (Delay) | | x | x | Not addressed in Danish testing, but the observed delays do not indicate any adverse effects on overall timeliness. See comment on KPI result for send/receive latency |
| KPI_55 | Load | | x | x | See above comments on KPI result for send/receive latency. The observed send/receive latency covers message size from 43 kb to 3.905 kb. |
| KPI_56 | Capacity of Link or Junction | | x | x | Not adressed in Danish testing. Note that the system used for testing is a pre-production version used for demonstration. |
| KPI_57 | Latency (Time used in the interaction between the TMC, Cloud and Interchange) | | x | x | See above comments on KPI result for send/receive latency. No data available for assessing the latency in the individual links of the communication path from the Danish TMC and back again. |

| | | | | | |
|---|---|---|---|---|---|
| KPI_58 | Response time (Time interval between input of messages to and receipt by the TMC) | | x | x | See above comments KPI result on send/receive latency. In general, observed response times (from Danish TMC to Danish TMC) meet requirements to response time from a Danish TMC point of view. |
| KPI_59 | Throughput (Capacity or load in a given period of time) | | x | x | See comments on KPI results for load and send/receive latency. |

## A.2. KPI list: Finland

| C-ITS service | Unit of Indicator | KPI available for Weather, slippery road | KPI available for Hazardous location |
|---|---|---|---|
| Fleet Size | Number | Number of test vehicles | Number of test vehicles |
| Fleet utilisation rate | | No | No |
| Range of Impact Zone | Km | Yes | Yes |
| Ratio of traffic weighted trip lengths to distance as the crow flies | | No | No |
| Travel Time (Average and Standard Deviation) | Hour | No | No |
| Total door-to-door travel time | Hour | No | No |
| Additional travel time caused by incidents | Hour | Yes | Yes |
| Spot Speed (average and standard deviation) | Km/h | Yes | Yes |
| Vehicle km travelled in congestion | Passenger km, vehicle km, ton km, person hours ton hours | No | No |
| Stability of Traffic Flow | number of changes in speed | No | No |
| Incident proneness of traffic flow (share of short headways or time to collision values) | | No | No |
| Capacity of Link or Junction | Veh/h | No | No |
| Need for overtaking | | No | No |
| Number of Delays | Number | No | No |
| Perceived fluency of traffic flow | | No | No |
| Success of information services | | Yes | Yes |

| | | | |
|---|---|---|---|
| Average Traffic Flow | Veh/h | No | No |
| Average Traffic Speeds | Km/h | No | No |
| Average delay per vehicle kilometre (Congestion) | Hour | No | No |
| Length of Queues | Meters | No | No |
| Traffic Control Indicators (green times, inter-green times, cycle times) | Seconds | No | No |
| Willingness to Pay (service) | | No | No |
| User attitudes on services | | Yes | Yes |
| Travel comfort experienced by users | | Yes | Yes |
| Feeling of personal security | | No | No |
| Number of users of a service | Number | Yes | Yes |
| CO2 emissions | ppm | No | No |
| Use of Salt | Tonnes | No | No |
| Transport Energy consumption | | No | No |
| Average and standard deviation of Spot speeds | Km/h | No | No |
| Number of Traffic Accident Fatalities | Number (per Veh-km) | Yes | Yes |
| Number of Traffic Accident Injuries Serious and Slight reported separately | Number (per Veh-km) | No | No |
| Number of Accidents – injury and non-injury reported separately | Number | Yes | Yes |
| Number of Conflicts | Number | No | No |
| Amount of Traffic | Number of vehicles | No | No |

| | | | |
|---|---|---|---|
| Vehicle km driven | Veh-km | No | No |
| Person km travelled (number of person hours / or passenger km) | Number of person hours or passenger km | No | No |
| Goods Tonnes transported Tonne/km | Tonnes/km | No | No |
| Average and Standard Deviation of Travelling Speeds | Km/h | No | No |
| Number of traffic violations | Number | No | No |
| Number of drunk-driver offences | Number | No | No |
| Alertness | | Yes | Yes |
| Attentiveness | | Yes | Yes |
| Share of short accepted time gaps (gap acceptance) | | No | No |
| Short (under 0.5 seconds) headways as a share of all platooning headways | | No | No |
| Share of short (under 1 second) Time to Collision (TTC) vales | | No | No |
| Number of crimes committed in vehicles and terminals | Number | No | No |
| Feeling of Safety | | Yes | Yes |
| Physical coverage | % of km road | Yes | Yes |
| Number of vehicles equipped | % of total vehicles | Yes | Yes |
| Event coverage - Number of events detected | % of total events | Estimate | Estimate |
| Error false events - Number of false events detected | Number or Number/Hour | No | No |
| Location accuracy | Km | Rough estimate | Rough estimate |
| Timeliness start – time from occurrence to detection | Minutes | No | No |

| | | | |
|---|---|---|---|
| Timeliness end – time from end of occurrence to detection | Minutes | No | No |
| Send/receive latency – time from timestamp sent to timestamp received of message (ms) | Milliseconds | Yes | Yes |
| Message success rate | % of messages received when sent | Yes | Yes |
| Up-time | % of time the system is working | No | No |
| Average speed | km/h | No | No |
| Variance of speed | km^2/h^2 | No | No |
| Top speed | km/h | No | No |
| Maximum longitudinal acceleration | m/s^2 | No | No |
| Maximum latitudinal acceleration | m/s^2 | No | No |
| Proportion of distance driven when speeding 1-5 km/h | % | No | No |
| Proportion of distance driven when speeding 6-9 km/h | % | No | No |
| Proportion of time when longitudinal deceleration above 0.125 m/s^2 | % | No | No |
| Improved road safety | | Yes | Yes |
| Traffic network performance | | Rough estimate | Rough estimate |
| Enhanced information | | Yes | Yes |
| Comfort | | Yes | Yes |
| Environmental impact | | No | No |
| Innovation and economic growth | | No | No |
| Privacy and data protection | | Yes | Yes |
| Digital security | | Yes | Yes |

| | | | |
|---|---|---|---|
| Cost | | Rough estimate | Rough estimate |
| Perceived usefulness | | Yes | Yes |

## A.3. KPI list: Norway

| KPI | C-ITS service | Unit of Indicator | Weather, slippery road | Hazardous location | Results |
|---|---|---|---|---|---|
| KPI_01 | Changes in the content and timing of network maintenance measures | | (x) | (x) | Attitude towards changing content and timing of network maintenance is positive. |
| KPI_02 | Fleet Size | Number | x | x | No available data |
| KPI_03 | Cost of fleet utilisation (personnel and vehicle operating costs) | Monetary | x | | No available data, but indicated that cost reduction is possible. |
| KPI_04 | Need for additional equipment | Number | x | | RSI-data are not proven to give sufficient quality, therefor additional equipment is required. |
| KPI_05 | Range of Impact Zone | Km | x | | High quality data (as defined by Volvo) 3% of the time for each vehicle |
| KPI_08 | Success of information services | | x | x | No available data |
| KPI_09 | Willingness to Pay (service) | | (x) | | No available data |
| KPI_10 | User attitudes on services | | x | | Users are positive |
| KPI_13 | Number of users of a service | Number | x | | No service developed |
| KPI_15 | Use of Salt | Tonnes | x | | No available data, but indicated that reduction of salt is possible |
| KPI_23 | Physical coverage | % of km road | x | x | High quality data (as defined by Volvo) 3% of the time for each vehicle |
| KPI_24 | Number of vehicles equipped | % of total vehicles | x | x | 5 vehicles used in pilote |
| KPI_25 | Event coverage - Number of events detected | % of total events | x | x | No available data |
| KPI_26 | Error false events - Number of false events detected | Number or Number/Hour | x | x | No available data |

| | | | | | |
|---|---|---|---|---|---|
| KPI_27 | Location accuracy | Km | x | x | No available data |
| KPI_31 | Message success rate | % of messages revived when sent | (x) | (x) | No available data |
| KPI_32 | Up-time | % of time the system is working | (x) | (x) | No available data |
| KPI_35 | Enhanced information | | x | x | User believe that RSI decision support system will increase they available information |
| KPI_38 | Privacy and data protection | | x | x | No available data |
| KPI_39 | Digital security | | x | x | No available data |
| KPI_40 | Cost | | x | x | No available data |
| KPI_41 | Perceived usefulness | | x | x | Users see several benefits: Information, cost and efficiency |

## A.4. KPI list: Sweden

| KPI | C-ITS service | Unit of Indicator | Weather, slippery road | Hazardous location | RESULTS |
|---|---|---|---|---|---|
| KPI_02 | Fleet Size | Number | x | x | 10 RWW vehicles, 12+4 recieving vehicles |
| KPI_23 | Physical coverage | % of km road | x | x | Same as cellular communication network coverage |
| KPI_24 | Number of vehicles equipped | % of total vehicles | x | x | 10 RWW vehicles, 12+4 recieving vehicles |
| KPI_25 | Event coverage - Number of events detected | % of total events | x | x | 7320 |
| KPI_27 | Location accuracy | Km | x | x | Not included in pilot. Focus of the Swedish trial was to create a proof of concept with the entire eco-system involved. Not to perform a technical evaluation of GPS-accuracy. Accuracy is the same as GPS accuracy. |
| KPI_28 | Timeliness start – time from occurrence to detection | Minutes | x | x | 0 |
| KPI_29 | Timeliness end – time from end of occurrence to detection | Minutes | x | x | 0 |
| KPI_30 | Send/receive latency – time from timestamp sent to timestamp received of message (ms) | Milliseconds | x | x | Ranging from 1.25 - 2.48 seconds source to vehicle depending on scenario |
| KPI_31 | Message success rate | % of messages | x | x | 100% when all systems were up and running. |

| | | | | | |
|---|---|---|---|---|---|
| | | revived when sent | | | |
| KPI_32 | Up-time | % of time the system is working | x | x | 100% when all systems were up and running. |