Finnish Transport and Communications Agency

NordicWay 3 Evaluation Report

Satu Innamaa

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Nordic WAY 3

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Abstract

NordicWay 3 built on the legacy from its predecessors NordicWay and NordicWay 2 to further develop the role of the different stakeholders in an ecosystem ready for deployment. This was achieved by carrying out coordinated pilots in different cities in three countries, namely Finland, Norway and Sweden. The evaluation activity of NordicWay 3 had the objectives to define an overall evaluation approach and support the separate evaluations carried out as parts of other activities. This deliverable summarises the evaluation results and draws conclusions on the feasibility of a C-ITS service provision in the Nordic countries.

All the evaluations in NordicWay 3 were built around the overall research question: *Is it feasible to provide C-ITS services in the Nordic countries?* Pilots identified evaluation topics most relevant for their next steps towards full scale implementation, and defined the method for their evaluation. Ecosystems were selected as a topic for joint evaluation. The methods for identifying user acceptance included questionnaires and interviews. Technical performance and quality of service was studied with a simulation and field experiments. Driver behaviour was studied with driving simulators and questionnaires. Socio-economic impact was studied using literature reviews, simulations and statistics. Ecosystems were assessed by organising project internal workshops and collecting views from different pilots using common templates. In addition to these research questions related to C-ITS, a literature review was made on impacts of automation in road transportation, especially in the Nordic context.

NordicWay 3 looked for specific solutions for implementing C-ITS services, especially in urban areas. A solution to predict time between red and green traffic signals, with acceptable quality, was identified for Trondheim. In Helsinki, a 3D Lidar Edge AI solution was found to work relatively well for timely prewarning the turning traffic of a cyclist approaching the crossing. NordicWay 3 also confirmed that the latencies were sufficiently low for informative services, yet, the end-user applications should be specifically designed to minimise it. The results of NordicWay 3 confirmed that 4G and 5G network technologies can provide the connectivity and capacity needed for C-ITS services, and future developments of 5G may even improve this. The study on the match between digital and real-world speed limit signs showed a mismatch of 5-11%. In conclusion, progress was made for the technical implementation of the services.

The socio-economic impact of an approaching emergency vehicle warning service was addressed. According to the results, it can lower the risk of mid-intersection collisions with civilian drivers, and shorten travel time for emergency vehicles. The overall investment for the service was estimated to be less than 2M€ and recurring costs 400k€ in total annually. However, the socio-economic value of the benefits of EVA could not be estimated.

Without awareness and acceptance, there is no use of services and the societal benefits cannot be achieved. A survey was conducted on the acceptance of service related to approaching emergency vehicles and accident zones, and confirmed the positive attitudes for both services. The results of another study showed that the transport industry has experience with some real-time information services, the attitudes towards the introduction of C-ITS services were mainly positive, and the transport companies did not experience a problem with paying for the services, provided that the benefits the services bring to the company are verifiable.

The correct reaction of the warned drivers is a necessity to gain any benefits from C-ITS services. The driver behaviour studies done in NordicWay 3 showed that the drivers reacted to the given information about the accident zone correctly and without hazardous effect in terms of mean speed change, and that in an intersection, their reaction was

slower and the gradual braking reaction was earlier than for those without the service. NordicWay 3 put effort into analysing the ecosystems, e.g. what roles are needed in the ecosystems, the characteristics of actors that have taken these roles, and what would be the requirements for these actors in general. There is no single model that would be the ultimate solution for all but there are different solutions we have described. In conclusion, new insights of the feasibility of the provision of C-ITS services were gained in NordicWay 3. Overall, the feasibility, in terms of technical implementation, acceptance and how driver behaviour impacts the services, seems promising. The current mobile networks were assessed to be well suited to carry the average expected C-ITS messaging traffic levels. There is even some willingness to pay for the services among the transport industry - if the benefits of the service are clear. However, work remains in building optimal ecosystems where the public and private stakeholders take the role fit for them and cooperate in a viable manner. As the implementation costs of the services seem substantial, long-term commitment will be needed of all stakeholders involved.			
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Nordic WAY 3

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Tiivistelmä

NordicWay 3 -hankkeen lähtökohtana olivat hankkeen edeltäjät eli NordicWay- ja NordicWay 2 -hankkeet ja niistä saadut tulokset. Tavoitteena oli määrittää entistä tarkemmin eri osapuolten roolit käyttövalmiissa ekosysteemissä. Tätä varten toteutettiin koordinoituja pilottikokeiluja kolmen eri maan eli Norjan, Ruotsin ja Suomen eri kaupungeissa. NordicWay 3 -hankkeen Arviointi-osan tavoitteena oli määrittää yleiset arviointiperusteet ja tukea muiden toimien yhteydessä tehtyjä yksittäisiä arviointeja. Tässä raportissa esitetään yhteenveto arvioinnin tuloksista ja tehdään päätelmiä C-ITS-palvelujen toteutettavuudesta Pohjoismaissa.

NordicWay 3 -hankkeen kaikissa arvioinneissa lähtökohtana on ollut seuraava yleinen tutkimuskysymys: *Kannattaako C-ITS-palveluja toteuttaa Pohjoismaissa?* Pilottikokeiluissa määritettiin arviointikohteita, jotka tukisivat kokeilujen jatkokehitystä kohti laajamittaista käyttöönottoa. Arviointikohteille määritettiin myös arviointimenetelmä. Yleiseksi arviointikohteeksi valittiin ekosysteemit. Käyttäjähyväksyntää selvitettiin kyselylomakkeilla ja haastatteluilla. Teknistä suorituskykyä ja palvelun laatua tutkittiin simuloinnilla ja kenttätestauksella. Ajokäyttäytymistä puolestaan tutkittiin ajosimulaattoreilla ja kyselylomakkeilla. Sosioekonomista vaikutusta selvitettiin kirjallisuuskatsausten, simulointien ja tilastotietojen avulla. Ekosysteemejä arvioitiin järjestämällä hankkeen sisäisiä työpajoja ja keräämällä eri pilottikokeiluihin liittyviä näkemyksiä, missä apuna käytettiin yhteisiä mallipohjia. Edellä kuvattujen C-ITS-palveluihin liittyvien tutkimuskysymysten lisäksi kirjallisuuskatsauksen avulla selvitettiin automaation vaikutuksia tieliikenteeseen, etenkin Pohjoismaiden olosuhteissa.

NordicWay 3 -hankkeessa tavoitteena oli määrittää erityisiä ratkaisuja C-ITS-palvelujen toteuttamiseksi varsinkin kaupunkiympäristöissä. Trondheimin osalta määritettiin ratkaisu, joka auttaa ennakoimaan riittävällä varmuudella liikennevalojen vaihtumiseen kuluvan ajan (punainen/vihreä valo). Helsingin osalta havaittiin, että reunatekoälyyn perustuva 3D Lidar -ratkaisu on suhteellisen tehokas keino varoittaa kääntyvää liikennettä etukäteen pyöräilijästä, joka lähestyy risteystä. NordicWay 3 -hankkeen tulokset osoittavat myös, että viiveet ovat tietopalvelujen kannalta riittävän alhaiset. Viiveen minimointi on kuitenkin huomioitava kehitettäessä loppukäyttäjille tarkoitettuja sovelluksia.

NordicWay 3 -hankkeen tulokset osoittavat, että C-ITS-palvelujen vaatima yhteenliitettävyys ja kapasiteetti voidaan taata 4G- ja 5G-verkkoteknologioilla, ja tilanne voi jopa parantua 5G-teknologian kehittyessä. Tutkittaessa sähköisiin tietokantoihin kirjattujen ja todellisten nopeusrajoitusten yhteneväisyyttä havaittiin, että nopeusrajoitusten välillä oli eroja 5–11 prosentissa tapauksista. Tiivistetysti voidaan todeta, että palvelujen teknisessä toteutuksessa on edistytty. Hankkeessa selvitettiin lähestyvästä hälytysajoneuvosta varoittavan EVA-palvelun sosioekonomista vaikutusta. Tulosten mukaan palvelu voisi vähentää risteysten keskialueella tapahtuvia siviilikuljettajiin liittyviä onnettomuuksia ja lyhentää hälytysajoneuvojen ajoaikaa. Arvioiden mukaan palvelu edellyttäisi yleisesti alle kahden miljoonan euron investointia, ja sen toistuvat kustannukset olisivat yhteensä 400 000 euroa vuodessa. EVA-palvelun sosioekonomista hyötyä ei kuitenkaan pystytty arvioimaan.

Jos käyttäjät eivät tunne palveluja tai koe niitä omakseen, palveluja ei käytetä eikä niistä saada yhteiskunnallista hyötyä. Kyselytutkimuksella selvitettiinkin suhtautumista palveluihin, jotka liittyvät lähestyviin hälytysajoneuvoihin ja onnettomuuspaikkoihin. Tulosten perusteella kumpaankin palveluun suhtaudutaan myönteisesti. Toisen tutkimuksen tulosten mukaan liikennealalla on kokemusta muutamista reaaliaikaisista tietopalveluista, C-ITS-palvelujen käyttöönottoon suhtaudutaan pääasiassa myönteisesti ja liikennealan yritykset eivät koe palvelun maksullisuutta

<table>
<tr><td colspan="4">ongelmaksi, kunhan palveluista on yritykselle konkreettista hyötyä.
C-ITS-palveluista on aidosti hyötyä vain, jos varoituksen saavat kuljettajat reagoivat toivotulla tavalla. NordicWay 3 -hankkeessa tutkittiin myös kuljettajien ajokäyttäytymistä. Tulokset osoittavat, että kun kuljettajat saivat tiedon onnettomuuspaikasta, kuljettajat reagoivat tietoihin toivotulla tavalla eikä keskimääräisestä ajonopeuden muutoksesta aiheutunut vaaraa. Lisäksi havaittiin, että risteysalueilla reagointi oli hitaampaa, mutta asteittainen jarrutus aloitettiin silti nopeammin kuin niiden kuljettajien tapauksessa, jotka eivät käyttäneet palvelua.
NordicWay 3 -hankkeessa pyrittiin analysoimaan ekosysteemejä eli sitä, mitä rooleja ekosysteemeissä tarvitaan, mitä ominaisuuksia näissä rooleissa toimivilla olisi oltava ja mitä näiltä toimijoita vaaditaan yleisesti. Mikään yksittäinen malli ei sovellu yleispäteväksi ratkaisuksi, mutta raportissa kuvataan erilaisia vaihtoehtoisia ratkaisuja.
Tiivistetysti voidaan todeta, että NordicWay 3 -hankkeessa saatiin uutta tietoa C-ITS-palvelujen toteutettavuudesta. Tulokset ovat lupaavia tarkasteltaessa teknistä toteutusta, käyttäjähyväksyntää ja sitä, miten ajokäyttäytyminen vaikuttaa palveluihin. Arvioiden mukaan nykyiset matkaviestinverkot riittävät hyvin täyttämään odotetun keskimääräisen tiedonsiirtotarpeen C-ITS-viestien välittämiseksi. Liikennealan toimijat ovat jopa valmiita maksamaan palveluista – kunhan palvelusta on selvästi hyötyä. Vielä on kuitenkin kehitettävä optimaalisia ekosysteemejä, joissa julkiset ja yksityiset osapuolet voivat toimia niille sopivissa rooleissa ja tehdä yhteistyötä järkevästi. Koska palvelujen toteutuskustannukset vaikuttavat merkittäviltä, kaikilta osapuolilta vaaditaan pitkäaikaista sitoutumista.</td></tr>
<tr><td>Yhteyshenkilö
Anna Schirokoff, Traficom</td><td>Raportin kieli
Englanti</td><td>Luottamuksellisuus
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Traficom</td><td colspan="3">Kustantaja
Traficom</td></tr>
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Nordic WAY 3

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Sammandrag

NordicWay 3 fortsatte bygga på sina föregångare NordicWay och NordicWay 2 för att vidareutveckla de olika intressenternas roller i ett ekosystem som är redo for ibruktagande. Detta uppnåddes genom samordnade pilottester i olika städer i tre länder, Finland, Norge och Sverige. Utvärderingen av NordicWay 3 hade som mål att definiera en övergripande utvärderingsapproach och stöda de olika utvärderingarna som utfördes som delar av andra aktiviteter. Detta dokument sammanfattar utvärderingens resultat och drar slutsatser om möjligheterna att tillhandahålla C-ITS-tjänster i de nordiska länderna.

Alla utvärderingar i NordicWay 3 skapades kring den övergripande forskningsfrågan: *Är det möjligt att erbjuda C-ITS-tjänster i de nordiska länderna?* Pilottesterna identifierade de mest relevanta utvärderingstemana för de kommande stegen mot full implementering och fastställde utvärderingsmetoderna för dessa. Ekosystemen valdes ut som ett tema för gemensam utvärdering. Metoderna för att identifiera användaracceptans omfattade frågeformulär och intervjuer. Tjänstens tekniska prestanda och tjänstens kvalitet undersöktes genom simulering och experiment ute på fältet. Förarbeteendet undersöktes med körsimulatorer och frågeformulär. Den socioekonomiska inverkan undersöktes med litteraturöversikter, simulationer och statistik. Ekosystemen utvärderades genom att ordna interna workshoppar inom projektet och samla in åsikter från olika pilottester med gemensamma mallar. I tillägg till dessa forskningsfrågor kopplade till C-ITS utfördes en litteraturöversikt om effekterna av automation i vägtransporter, särskilt i en nordisk kontext.

NordicWay 3 letade efter specifika lösningar för implementeringen av C-ITS-tjänster, särskilt i urbana områden. En lösning för att förutsäga tiden mellan rött och grönt trafikljus med accepterad kvalitet identifierades för Trondheim. I Helsingfors fann man att en 3D Lidar Edge AI-lösning fungerade relativt väl för att i rätt tid förvarna om en cyklist som närmar sig korsningen och kommer att svänga. NordicWay 3 bekräftade även att latensen var tillräckligt låg för informativa tjänster, men att slutanvändarnas tillämpningar borde utformas för att minska den. Resultaten från NordicWay 3 bekräftade att 4G- och 5G-nätverksteknologin kan erbjuda den uppkoppling och kapacitet som behövs för C-ITS-tjänsterna och den kommande utvecklingen av 5G kan även förbättra detta. Undersökningen av hur digitala och fysiska skyltar med hastighetsbegränsningar matchar varandra visade en missmatchning på 5–11 procent. Som slutsats gjordes framsteg för den tekniska implementeringen av tjänsterna.

Den socioekonomiska inverkan av en tjänst som varnar om ett utryckningsfordon som närmar sig togs upp. Enligt resultaten kan denna minska risken av kollisioner mitt i korsningar med civila förare och förkorta restiden för utryckningsfordonen. Den övergripande investeringen för tjänsten uppskattades vara mindre än 2 miljoner euro och driftkostnaderna 400 000 euro varje år. Men värdet av EVA-tjänstens socioekonomiska fördelar kunde inte uppskattas.

Utan kännedom och acceptans använder ingen tjänsterna och de sociala fördelarna kan inte nås. En enkät utfördes om acceptansen av en tjänst kopplad till utryckningsfordon som närmar sig och om olycksplatser. Enkäten bekräftade de positiva inställningarna till båda tjänsterna. Resultaten av en annan undersökning visade att transportindustrin har erfarenheter av vissa informationstjänster i realtid, att attityderna mot ibruktagandet av C-ITS-tjänster är mest positiva och att transportbolagen inte upplevde några problem med att betala för tjänsterna under förutsättning att deras fördelar för företaget går att verifiera.

Att de varnade förarna beter sig på rätt sätt är nödvändigt för att C-ITS-tjänsterna ska ge fördelar. Undersökningarna av förarbeteendet som utfördes inom NordicWay 3 visade att förarna reagerar på den givna informationen om ett

olycksområde korrekt och utan skadliga effekter vad gäller ändrad hastighet. Undersökningarna visade även att deras reaktioner var långsammare i korsningar och att deras gradvisa bromsningsreaktion skedde tidigare än hos förarna utan tjänsten. NordicWay 3 satsade på att analysera ekosystemen, dvs. vilka roller som behövs i ekosystemen, särdragen hos de aktörer som intagit rollerna och vilka krav som kunde ställs på aktörerna överlag. Det finns ingen enda modell som skulle vara den ultimata lösningen för allt, men det finns olika lösningar som vi har beskrivit. Sammanfattningsvis gav NordicWay 3 insikt i genomförbarheten av erbjudandet av C-ITS-tjänster. Genomförbarheten överlag vad gäller teknisk implementering, acceptans och hur förarens beteende påverkar tjänsterna verkar lovande. Dagens mobilnät uppskattades vara väl lämpade för att klara av den genomsnittliga uppskattade nivån av C-ITS-meddelandetrafik. Transportindustrin visar även en viss vilja att betala för tjänsterna – om tjänsternas fördelar är tydliga. Det finns ännu arbete att utföra i byggandet av optimala ekosystem där offentliga och privata intressenter anammar sin lämpliga roll och samarbetar på ett livskraftigt sätt. Eftersom implementeringskostnaderna för tjänsterna verkar betydande så behövs förbindelse på lång sikt av alla involverade intressenter.			
Kontaktperson Anna Schirokoff, Traficom	Språk Engelska	Sekretessgrad Offentlig	Sidoantal 68
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FOREWORD

The Nordic countries Denmark, Finland, Norway and Sweden decided to further develop their C-ITS cooperation, which started with the NordicWay action in 2014 and continued with the NordicWay 2 (2016-2020) through extended joint pilot activities with the *NordicWay 3 - Urban connection* project. Driven by ministries and road authorities, NordicWay 3 carried out a pilot deployment of Day 1 and Day 1.5 C-ITS services as defined by the *C-ITS Platform* in addition to selected CCAM services.

NordicWay 3 was a five-year (2019-2023) real-life pilot deployment project which, in close collaboration with the C-Roads Platform, drove harmonisation of services to end users coming from different countries and provided the possibility to collect and use data from vehicles regardless of their origin.

This is the evaluation results report of Activity 2 (Evaluation) of the NordicWay 3 project, co-funded by the Connecting Europe Facility (CEF) Programme in 2019–2023. Anna Schirokoff, The Finnish Transport and Communications Agency, was the leader of Activity 2. Satu Innamaa, VTT Technical Research Centre of Finland Ltd., was responsible for compiling an overview of the evaluation results compiled under NordicWay 3 into this report.

Helsinki, 25 April 2024

Anna Schirokoff
Chief adviser
Finnish Transport and Communications Agency Traficom

ALKUSANAT

Norja, Ruotsi, Suomi ja Tanska päättivät syventää NordicWay-hankkeessa vuonna 2014 aloitettua ja NordicWay 2 -hankkeessa (2016–2020) jatkettua pohjoismaista C-ITS-yhteistyötä vielä *NordicWay 3 – Urban connection* -hankkeessa yhteisten pilottihankkeiden muodossa. Ministeriöiden ja liikenneviranomaisten johdolla toteutetussa NordicWay 3 -hankkeessa pilotoitiin *C-ITS Platform* -ryhmittymän määrittelemiä nopeasti saataville tulevia C-ITS-palveluja (Day 1 -palvelut) sekä pidemmällä aikavälillä saataville tulevia C-ITS-palveluja (Day 1.5 -palvelut). Lisäksi pilotoitiin erikseen valikoituja CCAM-palveluja.

NordicWay 3 -hanke toteutettiin viisivuotisena (2019–2023) käyttöönottoa pilotoivana hankkeena tiiviissä yhteistyössä C-Roads Platform -ryhmittymän kanssa. Hankkeessa tavoitteena oli yhdenmukaistaa palveluja, joita tarjotaan eri maista tuleville loppukäyttäjille, ja varmistaa, että ajoneuvojen tietoja voidaan kerätä ja käyttää ajoneuvon alkuperästä riippumatta.

NordicWay 3 -hankkeeseen saatiin rahoitusta Euroopan unionin Verkkojen Eurooppa -ohjelmasta vuosina 2019–2023. Tämä arviointiraportti koskee NordicWay 3 -hankkeen osaa 2 (Arviointi). Osaa 2 johti Liikenne- ja viestintäviraston edustaja Anna Schirokoff. NordicWay 3 -hankkeen arviointitulosten yhteenvedosta vastuussa oli Teknologian tutkimuskeskus VTT Oy:n edustaja Satu Innamaa. Yhteenveto tuloksista esitetään tässä raportissa.

Helsinki, 25. huhtikuuta 2024

Anna Schirokoff
Johtava asiantuntija
Liikenne- ja viestintävirasto Traficom

FÖRORD

De nordiska länderna Danmark, Finland, Norge och Sverige beslöt att vidare utveckla sitt C-ITS-samarbete vilket startade 2014 med NordicWay och som fortsatte genom NordicWay 2 (2016–2020) och med gemsamma pilotaktiviteter i projektet *NordicWay 3 – Urban connection.* Under ledning av ministerier och trafikmyndigheter utförde NordicWay 3 ett pilotförsök med snabbt tillgängliga C-ITS-tjänster (Day 1-tjänster) och C-ITS-tjänster (Day 1.5-tjänster) som kommer att bli tillgängliga på längre sikt enligt C-ITS Platform-grupperingens definitioner. Dessutom pilottestades separat utvalda CCAM-tjänster.

NordicWay 3 var ett femårigt (2019–2023) pilotprojekt för verkställande i verkliga livet som i nära samarbete med C-Roads Platform strävade efter en harmonisering av slutanvändarens tjänster från olika länder och som erbjöd möjligheter att samla och använda data från fordon oavsett var de härstammar.

Detta är utvärderingsrapporten av resultaten från Aktivitet 2 (Utvärdering) i NordicWay 3-projektet som fått samfinansiering av Fonden för ett sammanlänkat Europa (CEF) 2019–2023. Anna Schirokoff från Transport- och kommunikationsverket ledde aktivitet 2. Satu Innamaa från Teknologiska forskningscentralen VTT Ab ansvarade för att sammanställa en översikt över utvärderingsresultaten som skapades i NordicWay 3 i denna rapport.

Helsingfors, den 25 april 2024

Anna Schirokoff
Ledande sakkunnig
Transport- och kommunikationsverket Traficom

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1 Introduction

1.1 NordicWay 3

The Nordic countries Denmark, Finland, Norway and Sweden decided to further develop their C-ITS cooperation, which started with the NordicWay action (2014-EU-TA-0060-S) and continued with the NordicWay 2 (2016-EU-TM-0051-S) through extended joint pilot activities with the *NordicWay 3 - Urban connection* project. Driven by ministries and road authorities, NordicWay 3 carried out a pilot deployment of Day 1 and Day 1.5 C-ITS services as defined by the *C-ITS Platform* in addition to selected CCAM services. NordicWay 3 was a five-year (2019-2023) real-life pilot deployment project which, in close collaboration with the C-Roads Platform, drove harmonisation of services to end users coming from different countries and provided the possibility to collect and use data from vehicles regardless of their origin.

NordicWay 3 built on the legacy of its predecessors NordicWay and NordicWay 2 to further develop the role of different stakeholders in an ecosystem ready for deployment. This was achieved by carrying out coordinated pilots in different cities in three countries, namely Finland, Norway and Sweden. The goal was to ensure a production vehicle is able to drive through all cities involved and, in each city, utilise the deployed Day 1 and Day 1.5 services.

C-ITS services may be based on different communication technologies. To ensure technical interoperability, safety and reliability of the implemented services as well as avoiding technology lock-in, the viability of both cellular and short-range communications was covered in NordicWay 3. The project supported the long-term development of a safe, secure and efficient road transport system allowing for an innovative management of cross-city as well as cross-border traffic, ensuring that the implemented C- ITS services will be interoperable and continuous from one city to another.

1.2 Objectives

The evaluation activity (Activity 2) of NordicWay 3 had objectives to define an overall evaluation approach in NordicWay 3, to support the separate evaluations, to create a harmonized evaluation reporting template, and to summarize the results of the single evaluations into a common evaluation final report. A task force, involving all partners' representatives, was in charge of managing this activity. Yet, the single evaluations were carried out as a part of Activities 3-6, which were interchange node development (Activity 3), central systems and interchange network (Activity 4), coordinated C-ITS service pilots (Activity 5), and cooperative, connected and automated mobility (Activity 6).

This deliverable relates to the last objective, i.e. to summarise the evaluation results. This includes evaluations in different NordicWay 3 pilots but also assessments made across all pilots on common topics. Finally, conclusions are drawn on the feasibility of a C-ITS service provision in the Nordic countries.

2 State of the art - Evaluation findings in the previous NordicWay phases

In NordicWay 1 (2015-2017), the Finnish pilot carried out a field operational test of C-ITS services by recruiting 1 270 subjects for a field operational test where 536 of them used the pilot C-ITS service in their normal life during the 12-month pilot experiment. The effort to organise such an experiment was significant but the safety related incidents of which the C-ITS warned of were so rare that the evidence of the impacts of these warnings for other C-ITS services than road works warning totalled only 910, as many users activated the service only seldomly. Thus, the evidence of the impacts of the services on driving behaviour was not as extensive as was originally anticipated. (Innamaa et al. 2017)

NordicWay 2 (2017-2020) carried out an evaluation (Innamaa et al. 2020) to find out whether the C-ITS 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 socio-economic benefits can be expected and under which conditions. This socio-economic impact of the services was assessed by addressing the impacts on safety, transport network efficiency, the environment and mobility.

There were two studies under NordicWay 2 on driver behaviour. The results indicated that the EVA message would affect the distance to the ambulance when giving way such that the driver would give way earlier (i.e. at a greater distance before the ambulance caught up). The users of the reindeer warning reported that the service improved their focus of attention, their driving speed and overtaking. (Innamaa et al. 2020)

The NordicWay approach for a C-ITS service provision was developed to support service interoperability in a C-ITS/ITS environment, where cloud services and entities are a part of end-to-end solutions and connectivity is achieved using cellular and other communications links. The technical evaluation highlighted the need for designing solutions that are robust and scalable. A key finding of the technical performance included that for the purpose of the pilots, the measured latencies did not hinder the piloted services. The cross-organisational data sharing was confirmed. Interoperability between the different countries was tested, and events reported were visible across the Nordic countries, but there were some issues in cross-border situations with GNSS and cellular coverage/networks. Yet, 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. (Innamaa et al. 2020)

Ecosystem evaluation showed that the 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 and DATEX version discrepancies. Their concerns also included challenges in attracting users and thin revenue streams from individual private users, but investment challenges and lack of a skilled workforce as well. 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. (Innamaa et al. 2020)

User acceptance evaluation showed that over half of Nordic drivers had never heard of C-ITS services and that very few had used them (3–6%). The most important information content for trips made on motorways or main roads were all types of information content indicating some kind of road blockage. For urban environment, the top three 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 the most willing to share data related to weather or road conditions collected by their vehicle with the C-ITS service providers, whereas speed and location of one's own vehicle raised the most concerns. In total, 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 in other Nordic countries and in Central Europe was considered important by those who drive abroad. (Innamaa et al. 2020)

The socioeconomic impact assessment indicated that as a specific response to the service, the amount of travel is likely affected by the type of services on route guidance 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. The estimates of direct safety effects were largest for in-vehicle speed limits, emergency brake lights, and slow/stationary vehicle and traffic ahead warnings. Additionally, indirect safety impacts were expected. Efficiency effects were expected to result from a reduction of crash-related congestion and from the decreased distance driven due to the above mobility effects. The impacts on CO_2 were expected to be caused primarily by modal shift and by impacts on vehicle kilometres driven and speeds. The comparison of costs and benefits indicated that from the road operator perspective, in 2030 the benefits even in the low effectiveness scenario would 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 assumptions made on the coverage, use and effectiveness of the services. (Innamaa et al. 2020)

The following conclusions were made on the feasibility of a C-ITS service provision in the Nordic countries: It is technically feasible to set up C-ITS services in the Nordic countries. Challenges for the 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. (Innamaa et al. 2020)

3 Pilots

To assure that NordicWay 3 brings the piloted C-ITS services close to deployment, different C-ITS pilots were conducted. These pilots allowed for testing different aspects related to the provision of C-ITS services including the collaboration between stakeholders. (This chapter is written based on Pilot plan by Selander et al. 2021.)

All the pilots in NordicWay 3 aligned to European C-ITS (C-Roads) service definitions were applicable, i.e. when a definition for the piloted service exists. If the service was not defined by C-Roads, the pilot had the responsibility to create a common Nordic definition.

The aim of the pilots was to demonstrate the possibility to communicate between vehicles, infrastructure, and data exchange platforms and to show the technical interoperability, scalability and flexibility of the NordicWay 3 interchange network. A specific focus of the piloting was to evaluate the needs, costs and benefits associated with large-scale implementations. Table 1 describes the C-ITS services to be piloted and where there will be demonstrations.

Table 1. Pilots in NordicWay 3, which C-Roads service they represent, and in which pilot site the service was piloted.

Service	Name of service (in C-Roads)	Pilot (in NordicWay 3)	Pilot site
HLN-EVA	Emergency vehicle approaching	Emergency vehicle approaching	National (Sweden)
HLN-AZ	Accident zone	Emergency vehicle approaching	National (Sweden)
RWW-RC	Road closure	Road works warning	National (Norway) Stockholm
RWW-RM	Road works – Mobile	Road works warning	Trondheim
IVS	In-vehicle signage	Geofencing	National (Sweden)
IVS-RP*	In-vehicle signage – Road pricing	Geofencing	National (Norway)
SI-GLOSA	Green light optimised speed advisory	Traffic signal	Trondheim Gothenburg Tampere
SI-SPTI	Signal phase and timing information	Traffic signal	Trondheim Gothenburg Tampere
SI-TLP	Traffic light prioritisation	Traffic signal	Uppsala Stockholm Oslo/Viken
SI-EVP	Emergency vehicle priority	Traffic signal	Uppsala

IVS-RP*: New service, not specified in C-Roads service definitions

Emergency vehicle approaching warnings were about traffic accidents and emergency vehicles approaching the accident scenes. Drivers that are in the vicinity of an accident or are traveling towards an accident will receive warnings about the accident zone (HLN-AZ). Emergency Vehicle Approaching warnings are sent to drivers that might be affected by the path of the emergency vehicles (HLN-EVA).

Road works warnings (RWW-RC, RWW-RM) warn human drivers earlier than what can be observed on the local temporary road signs, and in the future automated driving systems can also be warned, and data about the roadworks can be disseminated via digital messaging, i.e. C-ITS messages. Such messages should follow the principle of a 'digital twin', by which no other definition is referred to than *in a digital twin all data about the roadworks shall be the same in the message as in reality*.

Geofencing technology could be used, in a Nordic context, to ensure rule obedience in areas that are of great importance to the road operator, such as trucks and special transports on sensitive parts of the road infrastructure. The main objective was to provide relevant and quality-assured geographical information from the road operator to vehicles through the backend system of the vehicle manufacturer, and demonstrate how it can be used to control the operations of the vehicle. As there will be a possibility to overrule the functionality by the driver, there will also be a feedback loop back to the road operator regarding compliance. Three use cases of geofencing were identified: high-capacity transport, road pricing, and provision of digitalized traffic regulations and recommendations.

Traffic signal services are based on commonly used traffic control strategies which allocate green light for emergency vehicles (SI-EVP) and public transport (SI-TLP) and give red light for conflicting ones just when needed, aiming to make the travel time shorter for emergency and public transport vehicles. The focus of the Traffic light information pilots (SI-GLOSA, SI-SPTI) is to develop and evaluate predictions for isolated traffic-actuated traffic-signals for C-ITS services on time to green (TTG) and speed advice at traffic signals.

4 Evaluation methods

The overall evaluation approach in NordicWay 3 followed the principles of the FESTA methodology (CARTRE & FOT-Net 2017) and the main steps of the process described in FESTA V (Figure 1). The FESTA methodology was made for field operational tests (FOT), but even though the experiments in NordicWay 3 were controlled, the steps of the V process were valid. The evaluations in NordicWay 3 were in line with the C-Roads Evaluation and Assessment Plan (C-Roads 2018) for topics covered there. In addition, NordicWay 3 utilised the methodological frameworks set in the NordicWay (1) and NordicWay 2 projects where appropriate (Innamaa et al. 2017, NordicWay 2017, Innamaa et al. 2018, Innamaa et al. 2020) as well as the guidance given in European ITS Platform / EasyWay Evaluation Framework and Guidelines (Tarry, Turvey, Pyne et al. 2012 and Tarry, Turvey, Kulmala et al. 2012).

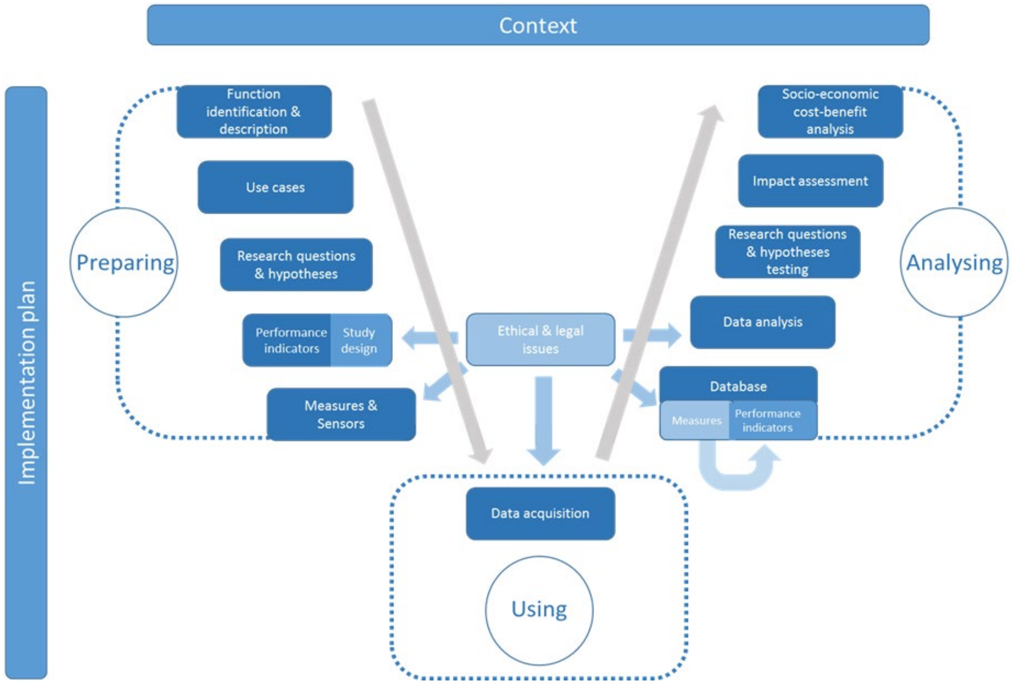

Figure 1. "FESTA V", i.e. the steps that typically have to be considered when conducting a field operational test (CARTRE & FOT-Net 2017)

All the evaluations in NordicWay 3 were built around the overall research question:

Is it feasible to provide C-ITS services in the Nordic countries?

This research question was broken down to the following high-level research questions related to different aspects of feasibility:

- Are C-ITS services accepted in the Nordic countries?
- Is the technical performance sufficient for service provision?
- Do drivers react to messages as intended?
- Can we expect socio-economic benefits from the use of C-ITS services?
- Can we find viable ecosystems for the service provision?

As the pilots were responsible for identifying evaluation topics most relevant for their next steps towards full scale implementation, it was also these pilots which defined the specific more detailed research questions under the first four high-level research questions listed above, as well as the method and collected data that they needed following the left half of the V. The last research question on ecosystems was selected as a topic for joint evaluation and the method for addressing it was jointly agreed upon.

The methods for user acceptance included questionnaires and interviews. Technical performance and quality of service was studied with a simulation and field experiments. Driver behaviour was studied with driving simulators and questionnaires. Socio-economic impact was studied using literature reviews, simulations and statistics. Ecosystems were assessed by organising project internal workshops and collecting views from different pilots using common templates. More details about the methods behind different results can be found from the Evaluation results chapter, the most detailed description being in the original report referenced therein.

In addition to these research questions related to C-ITS, a literature review was conducted on the impacts of automation in road transportation, especially in the Nordic context.

5 Evaluation results

5.1 User acceptance

5.1.1 Emergency vehicle approaching and accident zone

A web questionnaire was distributed via social media in November 2023. The questionnaire introduced different C-ITS services. For each service, there were nine statements, responses to each statement were given by indicating on a slider (0–100) the degree to which one agrees (0: I do not agree at all — 100: I totally agree). The statements were as follows:

1. I would follow the instruction and move over.
2. It would be very dangerous not to follow the instruction.
3. My fellow road users would be very annoyed if I did not follow the instruction.
4. It would be very difficult to follow the instruction.
5. This type of instruction would improve traffic safety very much.
6. This type of instruction would be of great benefit to myself as a driver.
7. This type of instruction would be of great benefit to traffic in general.
8. This type of instruction would be of great benefit to the environment and energy consumption.
9. This type of instruction would be of great benefit to the emergency responders.

Participants were required to be at least 18 years of age and to have a valid driver's license. A total of N = 1710 participated, whereof n = 1397 finished all items. (Weibull et al. 2023)

Table 2 presents the means and standard deviations for EVA and AZ, respectively, for each of the nine attitude measurements (i.e., statements). As can be seen, attitudes were generally very favourable for both EVA and AZ, and there were statistically significant differences between the two services' means for all nine statements. The attitude toward EVA with regard to following the instruction (1), and the benefit for emergency responders (9), was very favourable. Also, the estimated benefit for traffic in general (7) was very high. The greatest estimated improvement for traffic safety (5) was, however, for AZ. (Weibull et al. 2023)

Table 2. Means and standard deviations for responses in online questionnaire on EVA and AZ, respectively, for each of the nine attitude measurements. (Weibull et al. 2023)

	EVA			AZ	
	M	SD		M	SD
(1) I would follow the instruction and move over	96.4	13.4	**	94.3	15.3
(2) It would be very dangerous not to follow the instruction	69.5	31.4	**	79.8	26.5
(3) My fellow road users would be very annoyed if I did not follow the instruction	64.9	32.6	**	55.5	30.6
(4) It would be very difficult to follow the instruction	13.3	19.3	*	14.6	19.7
(5) This type of instruction would improve traffic safety very much	78.7	28.3	**	82.7	25.1
(6) This type of instruction would be great benefit to myself as a driver	70.6	33.3	**	76.6	29.3
(7) This type of instruction would be great benefit to traffic in general	82.5	26.3	**	80.3	26.1
(8) This type of instruction would be great benefit to environment, energy consumption	34.5	31.5	**	40.7	32.7
(9) This type of instruction would be great benefit to the emergency responders	92.6	18.6	**	90.2	20.9

$^{*}p < .05$ $^{**}p < .001$

5.1.2 C-ITS for freight traffic

A study was carried out to clarify the views of the transport industry on real-time traffic information services like C-ITS. The study included an online survey for freight drivers, as well as interviews with representatives of transport companies working on driving arrangement and transportation planning, as well as representatives of companies providing transport information services. In total, 79 drivers from different performance sectors responded to the survey. Eight representatives of the transport companies, as well as three representatives from service provider companies, were interviewed. (Lauhkonen & Lehtonen 2021)

According to the results of the survey, drivers had some real-time information services at their disposal. The most common information types that drivers received through these services were

- speed limit information
- service station information
- data on roadworks
- maximum road weights and widths permitted on the road, and
- estimated time of arrival.

In the services currently in use, users of the information were rarely the producers of the information. Some services took advantage of crowdsourced data collection, but the information was rarely automatically transmitted by vehicles. So far, the co-operative dimension of the information services in use was limited. Attitudes towards the introduction of services and the sharing of traffic information were mainly positive. Services were considered useful, and the drivers were prepared to use them.

The interviewees from the transport companies did not experience problems with paying for the services, provided that the benefits the services bring to the company are verifiable. (Lauhkonen & Lehtonen 2021)

Both the interviewed transport company representatives and surveyed freight drivers had a fairly congruous positive general view of the importance of information related to hazardous situations, road weather and the situation on the route. The importance of different information types for the freight transportation was rated separately for summer and winter time with information being statistically significantly more important in winter conditions than during summer (Figure 2). The positive impacts of real-time information services were clearly identified, improvement in safety being the most-agreed upon one (Figure 3). (Lauhkonen & Lehtonen 2021)

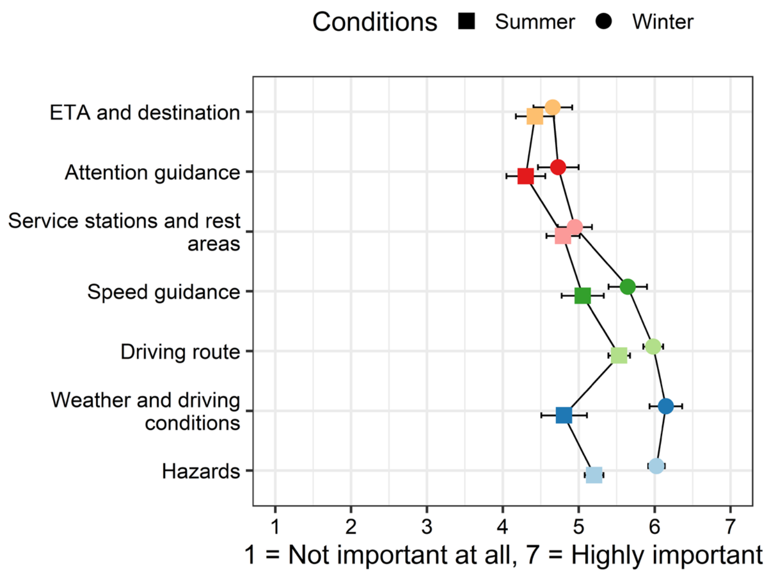

Figure 2. Usefulness for freight transport, mean and 95% confidence interval by information type (Lauhkonen & Lehtonen 2021)

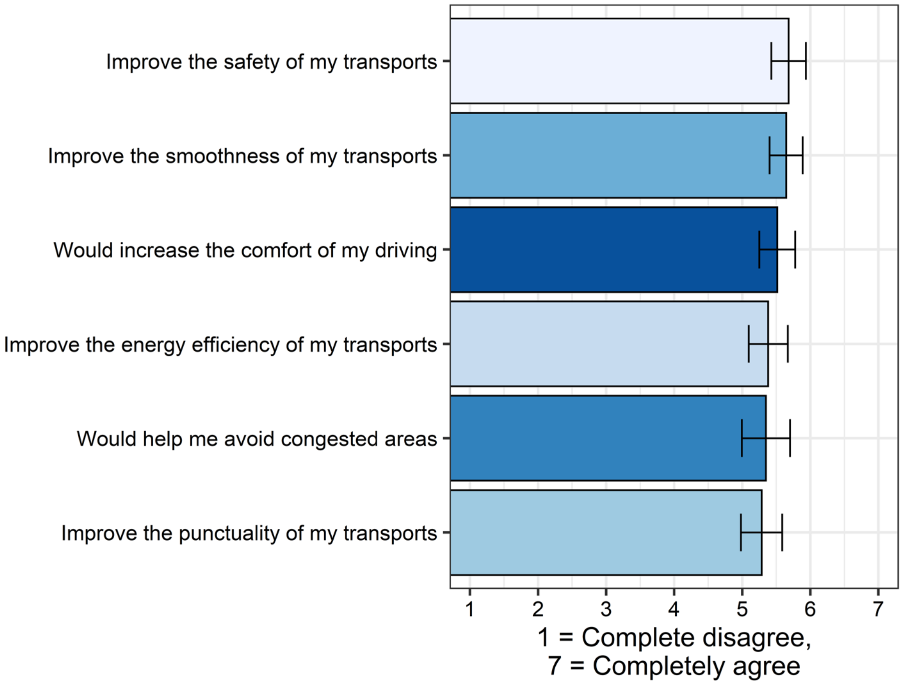

Figure 3. Perceived benefits of real-time information services, mean and 95% confidence interval (Lauhkonen & Lehtonen 2021)

The views of interviewed service providers supported the perceived need for real-time warnings and weather and driving data in the sector, especially for road weather information and for incident and hazard warnings. Better pre-information on challenges on the route or on importance of route change was highlighted. In addition, there was a high demand for width, height, and mass restriction data on roads, but problems have been identified in the timeliness of the information available publicly. (Lauhkonen & Lehtonen 2021)

5.2 Technical performance / Quality of service

5.2.1 Time to red/green

The quality of the TTR/TTG prediction solution developed by Swarco for Trondheim City was tested with a traffic simulation (Vissim) in a real environment in one intersection in Trondheim. The quality was measured as an acceptable level of difference to actual signal change at different intervals before the change (less than 1.0s difference for the last 10s, less than 2.0s difference in the 11-20s period, less than 3.0s difference in the 21-30s period before the signal change) and an average difference from the actual signal change for the last 30s change in the best proposed scenario/control mode. Testing covered both peak hour and off-peak hour time. The test intersection had a rather low traffic volume compared to the intersection capacity. (Swarco 2021)

According to the results, all tested Fixed Time Adaptive variants of traffic signal control improved the TTG/TTR prediction quality significantly compared to the original Vehicle Actuated control which showed better traffic control performance in terms of delays to traffic. This Fixed Time

Adaptive control mode fixes the green timings and estimated optimum green timing for the next (fixed time) cycle based on traffic characteristics. The prediction differed from the actual signal change time for only less than 0.5 s for the last 30 s of the TTG prediction period. The prediction quality was found acceptable and fulfilling the set criteria with results such as for afternoon peak period with the differences max 0.6s in the last 10s, max 1.3s in the 11-20s and max 2.1s in the 21-30s period. A summary of the prediction quality is presented as Figure 4. (Swarco 2021)

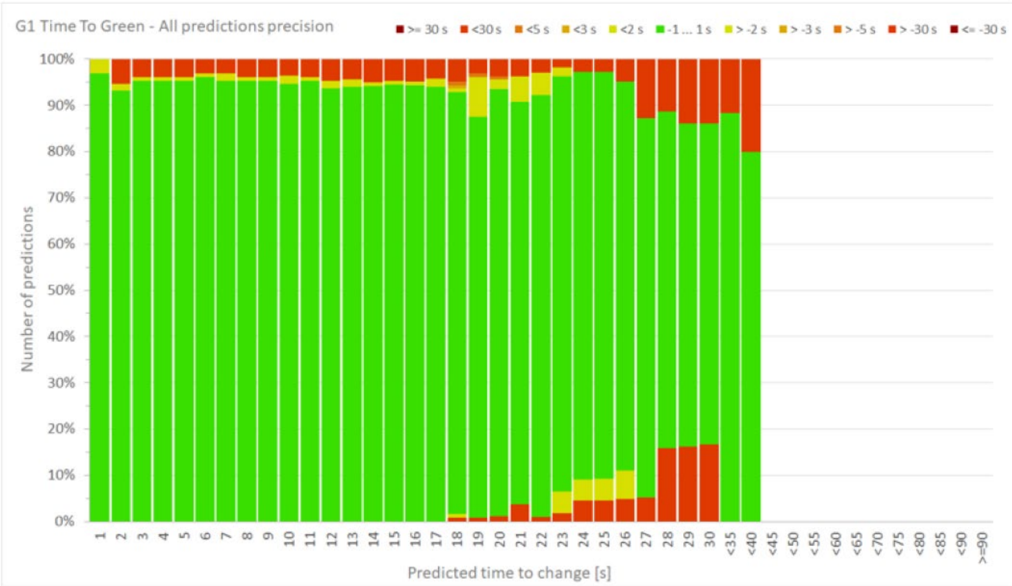

Figure 4. Prediction quality. Individual bars represent the prediction quality in terms of the difference between the estimated time to signal change against the actual time when the signal was changed. Individual colours represent different quality levels. (Swarco 2021)

5.2.2 Approaching cyclist

An experiment was conducted by Nordeon (2022) in Helsinki to find out how well 3D Lidar Edge Artificial Intelligence (AI) solutions are fit for producing information of vehicle traffic and of vulnerable road users (VRUs) in an intersection area. Specifically, information of interest covered quantity and classification of vehicles, directions, trajectories of the road users, as well as positions and speeds. In addition, the experiment tested how well the system can identify near-miss situations (conflicts).

The second objective for this experiment was to investigate if the 3D Lidar Edge AI solution together with a roadside unit of C-ITS can produce reliably and timely a C-ITS prewarning for the turning traffic of a dangerous situation where a cyclist is approaching a pedestrian crossing from the blind spot of the vehicle or from behind a corner. (Nodeon 2022)

The data collection for this experiment took place in three very complex intersections with a lot of passenger car and HDV traffic combined with public transport serving the Jätkäsaari area and the port there. These experiments lasted 7-11 weeks depending on the location. One of them was used for testing the C-ITS warning provision and all of them for testing monitoring of the intersection. (Nodeon 2022)

The experiment showed that the solution worked relatively well in the test intersections for identifying the near-miss situations. The most important further development topic is filtering out the reflections from the Lidar data point cloud. The Lidar was proven to measure very accurately the speeds of different vehicles. (Nodeon 2022)

Traffic volume information was validated by comparing the information provided by the Lidar Edge AI solution to the information manually annotated from a video. An average counting accuracy was 97%. The error was 10% at maximum for all the traffic streams for the vehicle traffic and 5% at maximum for the VRUs, the Lidar solution estimating the volumes to be smaller than in the ground truth extracted from the video. A conclusion was that one 3D Lidar sensor can monitor all the entries and pedestrian crossings of a traffic light-controlled intersection. (Nodeon 2022)

The classification of vehicles was not accurate enough for HDVs and buses but cyclists and pedestrians are classified with 97-98% accuracy. E-scooters are typically misclassified as bicycles. Detection of near misses included relatively many ghost observations due to reflection errors in the Lidar data. The near misses identified by the 3D Lidar Edge AI solution included last minute entries of the cyclists and e-scooter users to the pedestrian crossing and their weaving between cars, as well as the red-violation of all traffic participants. (Nodeon 2022)

5.2.3 Digital traffic regulation

Match between real-world and digital signs

A study was conducted to answer the question “What do we need to do to provide up-to-date digital traffic regulations?”. Traffic regulations are stored digitally using databases. Ensuring that these digital records are continuously up to date has been difficult and time-consuming. As a result, digital records of traffic regulations may be different to those indicated in the real world. In this case, autonomous and driven vehicles will be operating according to a different understanding of the traffic regulations. This can have serious safety implications. (Thorn 2023)

With the increasing use of traffic regulation data, particularly speed limit data, in applications like ISA (Intelligent Speed Adaptation) and future geofencing, it is crucial to better understand the role of regulatory authorities as data producers/providers. This includes understanding the requirements for data quality and addressing the ongoing challenge of keeping the data up to date. A study was designed to reveal instances where the signs and regulations differ, potentially causing issues when both map data and sign information are used, such as in an ISA system. (Thorn 2023)

The primary objective of this study was to develop a "gap analysis" capability that assesses the disparities between digital records of traffic regulations and real-world indications. This involves building systems and tools to compare the type, number, and location of road signs in the physical environment with their corresponding digital records. To ensure the provision of up-to-date and accurate data, the "gap analysis" system must be cost-effective and scalable. (Thorn 2023)

In order to achieve the overall objective of the project, data collection efforts were conducted in Gothenburg, specifically focusing on gathering an inventory of more than 12,000 speed signs and their positions. The study included comparing the themes and positions of road signs detected by the 3DAI City platform with the listed speed limits in NVDB (Swedish national road database) and, in the future, with the true digital representation of traffic regulations, known as TNE/HTR. The disparities between digitally stored data and the real-world features detected by 3DAI City were assessed dynamically. Any differences identified between the detected road signs and the obtained dataset were reported to Gothenburg and/or the Swedish Transport Administration. (Thorn 2023)

The algorithms employed by the app process imagery captured by smartphone cameras in real-time and identify and triangulate the positions of selected road signs. The goal of this comparison is twofold: to verify the consistency of the traffic signs and to identify any discrepancies where NVDB might be outdated due to recent changes or false measurements. Such discrepancies can trigger warnings for users. (Thorn 2023)

In Gothenburg, information was gathered of more than signs. The results revealed that a 5.2% mismatch was found between the speed limits recorded in NVDB and the corresponding road signs on roads. The margin of error for this comparison was 100 meters. In Stockholm there was a 4.2% mismatch between speed limits in NVDB and road signs, with a margin of error of 200 meters. Helsingborg had a higher discrepancy rate of 10.9%, with a margin of error of 100 meters. (Thorn 2023)

Figure 5. Results of NVDB discrepancies, and signs detected (Thorn 2023)

Reasons for mismatches have been investigated in more detail, and some examples of the reasons for the mismatch have been that road works are present (if the road work is shorter than 6 months it is not represented in NVDB), signs are positioned with additional signs downstream or that the database had not been updated for the sign in question. (Thorn 2023)

Impact of automated control processes on data quality

A pilot was carried out to investigate if better data quality can be reached through automated control processes. The scope was on traffic rule types such as speed limit, pedestrian area and heavy vehicle restrictions. The evaluation was based on sample data and a comparison of different databases with traffic sign information (TNE-HTR, the new pilot database for derived traffic regulation; NVDB, the existing national road database; road sign data provided by an external actor). TNE-HTR is built by automated translation. It is checked against existing data in NVDB and collected road sign data. (Gustin et al. 2023)

The pilot study (Gustin et al. 2023) showed some data quality issues in the data sample, such as missing location references, ambiguous location references, missing definition for the edge of pedestrian zone, missing signs, traffic sign without supporting regulation order and differences in position (sign vs. regulation order).

The share of missing machine readable BTR data was 7%. Of the roads in Gothenburg, traffic regulation is in place for 16% of them. For example, the base speed limit is missing at the moment. The new TNE-HTR database had data which was correct in the existing NVDB for 12% of instances but incorrect in 5% of instances. TNE-HTR had no data, but the base speed limit was correct for 75% of instances and incorrect for 7%. (Gustin et al. 2023)

This pilot showed that collection of sign data worked very well in most cases with mobile phones mounted on a taxi fleet. However, improved cameras can compensate for bad weather and light conditions. The overall conclusion was that the current process to prepare traffic regulation basically works. However, there is a substantial information debt regarding older (existing) traffic regulation which were issued as free text. Consequently, there should be national initiative to resolve this information debt. (Gustin et al. 2023)

5.2.4 Cybersecurity and interoperability of cellular C-ITS services

Kynsijärvi et al. (2024) conducted a study with the following research questions:

1. Can the C-ITS trust model (EU CCMS) Level 0 be used both for short-range and long-range communications?
2. How suitable are C-V2X (long-range and short-range) technologies to implement C-ITS services and how do they perform?
3. Is LTE-V2X Direct a feasible solution for transmitting C-ITS messages, and can it be used to implement C-Roads specified C-ITS services?

The study was conducted by deploying C-ITS I2V service at a traffic light-controlled intersection defined by C-Roads platform specifications (SI, Signalized Intersections). The intersection was equipped simultaneously with short-range communication capability (LTE-V2X Direct, secured with PKI (Public Key Infrastructure) certificates following EU CCMS guidelines) and long-range communication capability (commercial mobile networks). (Kynsijärvi et al. 2024)

The results indicate that, from the functional perspective, LTE-V2X Direct technology is compatible with meeting the requirements specified for C-ITS services and use-cases by C-Roads. Replacing ITS-G5 with LTE-V2X Direct did not affect the operation of the Signalized Intersection (SI) service, and the same messages could be broadcasted as signed messages. Replacing the radio protocol did not create any functional differences in the operation of the service. Thus, the results demonstrate that LTE V2X Direct is compatible together with the upper layers utilised in C-Roads. (Kynsijärvi et al. 2024)

The project highlighted the absence of a European-level standard in place for communication between Roadside Units (RSU) and Traffic Light Controllers (TLC). During the project it became clear that the communication between RSU and TLC is currently highly based on proprietary protocols specific to manufacturers. (Kynsijärvi et al. 2024)

Investigation on latency in short-range tests indicated that most latency is being generated at the end-user application (15 milliseconds average latency for the radio interface between RSU and OBU, and around 0.5 seconds at the end-user device). The signing of messages at the RSU does not seem to add significant latency (i.e. visible with the measurement accuracy of the test) to the communication and delays are similar as for unsigned messages. (Kynsijärvi et al. 2024)

5.2.5 Utilisation of commercial mobile networks in the deployment of C-ITS services

A study was made by Kilpiö et al. (2024) on the performance needs of a C-ITS service deployment in mobile networks, to define common service level framework criterion to cover various scenarios of use of services as well as to assess the capabilities of current mobile networks to support C-ITS deployment in Finland. Methods used included a literature review, interviews, a workshop and expert knowledge. The Finnish Transport and Communications Agency also provided combined mobile network coverage predictions and measurement information. The project organised an online workshop with stakeholders from national relevant authorities, mobile network operators and ITS service providers to gain insights on mobile network utilisation in C-ITS service deployment.

One of the key research questions was "How are different mobile network technologies (2G, 3G, 4G, 5G) suited to serve the needs of different C-ITS services?". According to results, 4G and 5G network technologies can provide the connectivity and capacity needed for C-ITS services. Future developments of 5G may even improve the ability to serve high-device-density and high-message-frequency services. (Kilpiö et al. 2024)

Results on how current commercial mobile networks in Finland suit to serve C-ITS services and what key deficiencies/bottlenecks they may have showed that from the coverage availability and system capacity points of view current mobile networks are well suited to carry the average expected C-ITS messaging traffic levels. Yet, the commercial mobile networks are inherently very much environment-dependent, and spots of poor service levels will persist and the methodology to enhance the usability on spots of poor service levels needs to be developed. (Kilpiö et al. 2024)

This study concluded that the currently collected coverage predictions are well suited for the situation overview of C-ITS feasibility and they enable identification of potential areas of concern. A measurement framework is proposed to complement the coverage predictions to verify the feasibility of C-ITS services through network stress tests complementing the currently available and used information. (Kilpiö et al. 2024)

5.3 Driver behaviour

5.3.1 Emergency vehicle approaching

Kunclova (2022) conducted a study with an aim to investigate if and how geofencing based C-ITS service (in-vehicle HMI) can improve driver behaviour when interacting with emergency vehicles. Three research questions were set:

- Could this C-ITS service assist drivers in responding timely and correctly when interacting with emergency vehicles in traffic, and thus decrease the accident risk?
- Can this service shorten the driving time of emergency vehicles?
- Do drivers believe that they would benefit from the service?

For a geofencing based EVA service, safety impact was assessed with a literature review to gather statistical data and information on accidents involving emergency vehicles. The findings were used to propose use cases of critical situations where geofencing might be useful to assist drivers in decision making and therefore to eliminate accidents with emergency vehicles. Two use cases were selected for a driving simulator study with the help of a workshop with representatives of authorities and organisations from both government and private sectors related to geofencing, emergency vehicles and traffic safety. Namely, these use cases were an off-ramp use case with 30 participants and an intersection use case with 34 participants. (Kunclova 2022)

With the simulator, driver behaviour was examined. Differences in driver behaviour between the current state without an in-vehicle warning system when interacting with an emergency vehicle and the potential future state using a system which gives clear commands to the driver on how to react were investigated. A questionnaire was used to collect participants' subjective attitudes after the simulator experiment on the benefits of the system. (Kunclova 2022)

In the off-ramp use case on the motorway, a simulator experiment was made to assess if the drivers were able to follow the information given to them. All the participants who got an instruction to continue straight at an off-ramp site, where an accident had occurred and an ambulance was operating on the spot, obeyed the instruction whereas the participants without these instructions took the off-ramp to the accident site. The instruction did not lead to hazardous effects on driver behaviour in terms of mean speed change. The speed was reduced approximately by 10 km/h as an effect of getting the instruction and the participants drove safely without impulsive braking. All those participants who took the ramp were able to make a complete stop in front of the accident without a crash with the accident vehicles or emergency vehicles stationary at the accident site. (Kunclova 2022)

In the intersection use case, the main aim was to investigate if the geofence based EVA service can improve the driving time of the emergency vehicles. Specifically, it was investigated if the drivers were able to react in a timely and correct manner. The results showed a noticeable effect and the instructions entailed a reaction of slower and gradual braking, more than 150 m before the intersection, and the participants with the instructions reacted earlier than those without. The participants with the instructions braked more abruptly and impulsively before the stop line than others. They seemed to react when the sirens got audible. Consequently, they came to the lowest speed after the traffic lights and pedestrian crossing before approaching the intersection when the ambulance was visible approaching from the left. Some participants without instructions from the EVA service drove through the intersection despite of the sound of ambulance sirens and the ambulance being so close that this cannot be considered to be a proper action. None of the drivers with instructions behaved this way. None of the non-reacting drivers caused a collision but exposed themselves and the ambulance to a risky situation and caused a delay for the ambulance as the ambulance was forced to stop at the intersection. The mean delay for the ambulance was 6.2 s (Figure 6). (Kunclova 2022)

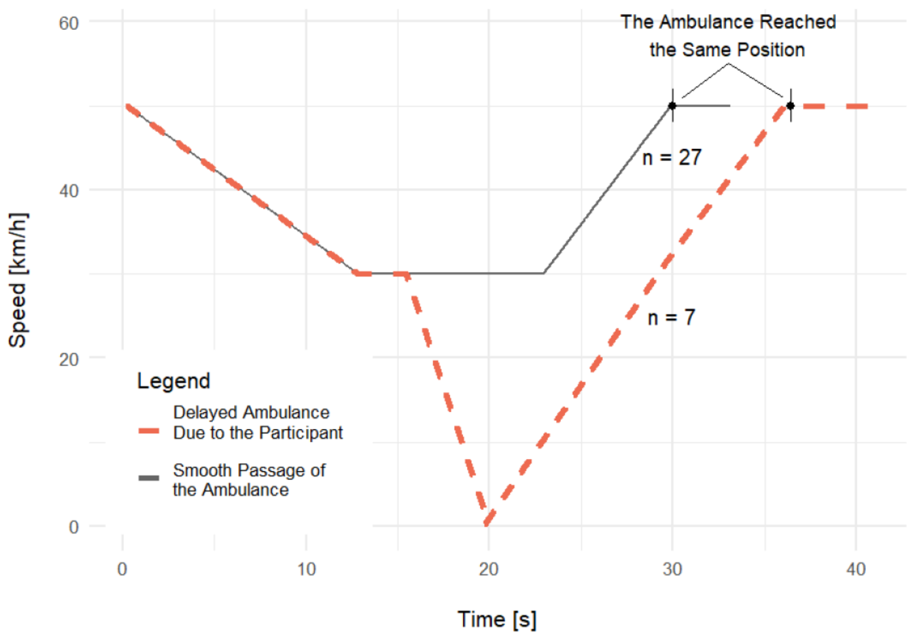

Figure 6. Delay caused to the ambulance at an intersection due to drivers not giving way to the ambulance

The participants of the geofence-based EVA service simulator experiment were asked of the benefits of the service. All the participants of both the off-ramp and the intersection use case rated their willingness to receive instructions positively in the future when interacting with emergency vehicles in their own car. Those participants who got the instructions on how to react to an approaching emergency vehicle had a significantly more positive attitude towards the willingness to have the service than those who did not receive the instruction in the experiment. (Kunclova 2022)

Additionally, Odéen (2022) conducted a simulator study on how driver behaviour is affected by EVA warnings in a motorway scenario. The warning given was auditory or visual. She also studied the attitudes of the participants. The study included a total of 113 participants, both novice and experienced drivers. The result of the study was similar in that the drivers with an EVA warning moved over earlier than those who did not receive a warning. For the acceptance, the drivers with low ADAS experience were less positive for receiving EVA warnings in the future, even though they felt that the warnings improved their driving. For all drivers, EVA warnings were a good compliment to encourage to move over when interacting with an emergency vehicle.

The study showed that drivers had a more accepting attitude towards ambulances than towards police vehicles. They felt that it is more important to move over for ambulances, that the ambulance’s emergency matters are more urgent and that is it more OK for ambulances to break traffic rules than it is for the police vehicles. Yet, everyone agreed that one must always move over for both of these emergency vehicle types. (Odéen 2022)

5.3.2 Road works warning

Using an application which provided a RWW service, several test drives were performed in a live traffic setting in the city of Trondheim over a period of two months in the summer of 2023. In total, 15 participants completed test drives without and with the application activated. Afterwards they filled a survey with questions like if they adjusted their speed towards roadworks based on the information they received. The roadworks area was outside the driven route, thus, the reaction to this functionality should therefore be conceived more on a conceptual and expectational level, more than as experience from an actual test. (Blomkvist et al. 2024.)

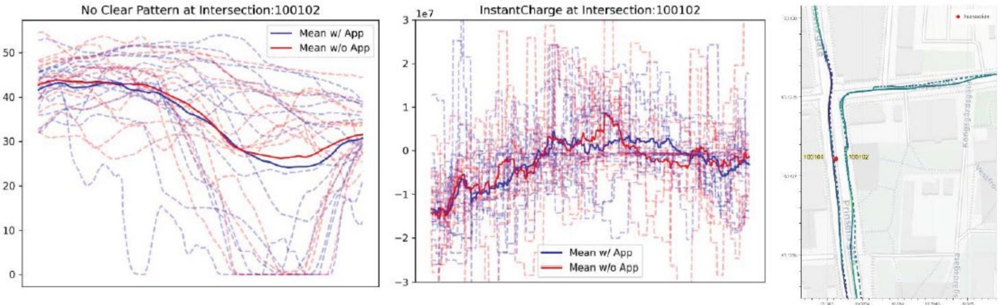

Figure 7. Change in speed (left) and instant charge (middle) and test route (right) for tested riving TLI and RWW

The collected data was not sufficient for any conclusions, but it potentially indicates that drivers responded slightly on getting information from the application (Figure 7). Additionally, the survey results indicate that most of the drivers adapted their speed when driving towards the intersection with the app being active. Interestingly, the participants thought that the application had greater influence on their driving behavior than the vehicle data shows. (Blomkvist et al. 2024.)

5.4 Socio-economic impact

5.4.1 Emergency vehicle approaching

A systematic literature review was made by Weibull et al. (2022) to understand under which circumstances the emergency vehicle accidents occur. They also searched for literature on C-ITS solutions related to emergency vehicle accidents. Three services were covered: geofencing, EVP (emergency vehicle pre-emption) and EVA (emergency vehicle approaching).

Based on a literature review by Weibull et al. (2022), risk factors of emergency vehicle related accidents were found to be, in order of frequency:

- intersections
- daytime
- dry roads
- clear weather
- urban roads
- traffic signals
- angular collisions.

Yet, the authors do not claim that there is a causal relationship between these factors and accidents. In the reviewed articles, intelligent vehicle technologies were among the most commonly suggested countermeasures. Thus, C-ITS is expected to mitigate the risks of emergency vehicle related accidents both for emergency vehicle operators and for civilian drivers.

EVA service gives surrounding drivers earlier warning than lights and sirens alone. Suggested time plan is 10-15 s to provide drivers enough time to give way. Only a few studies have investigated the potential benefits of EV related C-ITS. Yet, based on current results, it seems that both EVA and EVP can lower the risk of mid-intersection collisions with civilian drivers. In addition, EVP has been claimed to shorten travelling time for EV. A geofencing-based system has potential to mitigate accident factors in the area where it is applied by altering driver behaviour or even providing a temporarily designated lane for prioritised vehicles. C-ITS can also assist inexperienced drivers by informing how they are expected to behave. With EVA, drivers drove with a lower speed than without it. (Weibull et al. 2022)

In addition, the costs related to the EVA service were evaluated in the EVA pilot of NordicWay 3 (Weibull et al. 2023). They also assessed the overall benefits of the service with a few assumptions of the effectiveness. In the EVA pilot, it was estimated that a one-time investment of 160 k€ would be required from the input actors. In addition, a 1.7 M€ investment would be needed from the output actors (OEMs). In terms of recurring costs, the estimate was 70 k€ for input actors and 330 k€ for output actors. Other studies have shown societal benefits of getting injured people faster to the hospital. Yet, these benefits could not be estimated for the EVA service.

5.4.2 *Green light optimal speed advisory and time to green/red*

The societal impacts of GLOSA and TTG/TTR were investigated using the VISSIM micro simulation tool by Legêne et al. (2023). Their experimental design included variation in the following factors:

- Traffic signalling: fixed or vehicle actuated
- Percentage of vehicles with GLOSA: 10%, 40%, 70% or 100%
- Traffic situation: morning, the rest of the day or night
- Directions of the intersection: main or all
- Minimum speed in the advice: 20 or 30 km/h
- Distance from the intersection where the speed advice is given: 100 m or 500 m
- Continuity of advice: once or every second
- Level of intermediate cars: 0 or all (only GLOSA)
- Buffer time: 0.5 or 2 sec (only GLOSA)
- Follow up behaviour: 50% or 100% acts on given advice.

16 simulations were made with selected combinations of these factors. These simulations resulted in a set of environmental (CO_2, NOx) and accessibility indicators (vehicle hours and stop delay, the number of stops). Regression analysis was used to investigate the relationship between variables and to explore their correlation to the outcomes of the application of these C-ITS services.

Two use cases in the city of Uppsala were utilised to study the impact of GLOSA and TTG/TTR. These use cases included a solitary intersection and a corridor with chained intersections. Multiple settings were varied for the simulations. (Legêne et al. 2023)

The results of the simulation study of Legêne et al (2023) showed for the use case of the solitary intersection that with low penetration (10-40%) of vehicles equipped with C-ITS the vehicle hours and stop delay were around 1% higher with GLOSA than with TTG/TTR regardless of traffic signalling, traffic situation or minimum speed in the advice. However, when the penetration rate increases, the effects of GLOSA are better than those of TTG/TTR. They assessed this to be caused by more homogenous traffic flow.

GLOSA had a positive impact on the number of stops. The effect is highly dependent of the penetration rate, with the largest impact when 70% of vehicles were equipped. The gains with GLOSA were more than 200%

higher than for TTG/TTR. This shows the effectiveness in preventing cars from stopping. The results were positive in all conditions during "the rest of the day" scenario, but only for some in the morning and nighttime traffic scenarios. Vehicle actuated signalling improved the result. (Legêne et al 2023)

Overall, the study showed environmental gains under different circumstances for both GLOSA and TTG/TTR. Yet, the traffic signalling and traffic situation played important roles. GLOSA was found to reduce NOx and CO_2 emissions by 0.7% on system level and by 0.3% per vehicle. During the morning peak hour no impact was found for emissions on neither level. Thus, the benefits can be gained only in rather low traffic volumes. GLOSA requires fixed traffic signalling to provide reliable information. Although it can improve traffic flow, it cannot overcome the benefits of vehicle actuated traffic signals. (Legêne et al 2023)

The second use case was a corridor with chained intersections. The results showed that the impact in terms of accessibility related to vehicle hours, stop delays and number of stops was not affected by the penetration rate of GLOSA when the traffic signalling was vehicle actuated. For the emissions, the impact improved with the increasing penetration rate. The reduction of the emissions was around 1.5-5.0%. When the C-ITS is deployed with fixed traffic signalling, the penetration rate has only little influence on the accessibility benefits. The impact was a 2% decrease in the number of stops and delay, without any increase with increasing penetration. The reduction in emissions was the same as for actuated traffic signalling. (Legêne et al 2023)

Result comparison showed that the vehicle actuated traffic signalling led to higher environmental gains (3% less CO_2 emissions, 5% less NOx) than fixed signalling. Fixed traffic signalling reduces stops and delay by 5% while vehicle actuated signalling reduces them by 14%. However, the study cannot confirm that C-ITS performs better with vehicle actuated signalling than with a fixed one. (Legêne et al 2023)

5.5 Service ecosystem

5.5.1 Roles and responsibilities in C-ITS ecosystems

All pilots were asked to organise a workshop to provide insights about roles, responsibilities and costs. They were asked to draw a sketch of their ecosystem and use this sketch as a basis for the discussion. Then, the first task was to list all the actors and describe what type of stakeholders these actors represented. The second task was to describe the role that each actor had in the ecosystem in terms of

- High-level category of the role: Data/Information provider, content processor, service provider (main provider, implementer / e.g. sub-contractor), end-user (road user, vehicle), other (to allow comparability with NordicWay 2 ecosystem descriptions)
- Role in the ecosystem

- Requirements on an actor taking this role

Third task was to describe the responsibilities of an actor that has taken this role in the ecosystem in terms of

- Responsibilities in the value network set for this role
- Requirements of the actor with these responsibilities towards the service, i.e. what kind of actor can take this role/responsibility (generic actor characteristics) in the service ecosystem
- Other remarks, e.g. lessons learned

The detailed results on roles and responsibilities in C-ITS ecosystems are presented in Annex 1.

The table 'SI-SPTI (TTG), SI-GLOSA in Finland' of Annex 1 shows that the provision of the service involves a complex ecosystem of actors, each with their own specific roles and responsibilities. These actors include the National Access Point (NAP) operator, road operators, the C-ITS station provider, the traffic light controller providers, and the end-user service providers. Each of these actors has a specific role in the ecosystem, and there are certain requirements that an actor must meet in order to take on that role. The NAP operator acts as an interchange node operator and data broker, and is required to be an experienced actor for operating an interchange node and possibly even a trusted national actor. The road operator is responsible for operating the Tampere node, owning and brokering traffic controller data, and checking data quality, and this actor must be experienced for operating a node. The C-ITS station provider provides data to the interchange and the message verification service. The traffic light controller providers produce data for the brokers, including SPATem and MAPem messages from raw data, in line with specifications. They are also responsible for the correctness of the messages. The end-user service providers provide the end-user service and, in this case, also operate RSUs, OBUs, and the Tampere node in practice.

The EVA service ecosystem in Sweden is also a complex ecosystem involving multiple actors, each with their specific roles and responsibilities. The ambulances and rescue services vehicles (fire trucks) act as data originators, providing data on the vehicle positions to the system. The Public Safety Access Point (PSAP) acts as an operator of the emergency response system providing content to the service. The EVA service providers are responsible for accessing emergency vehicle data, creating EVA messages, and providing the service to end-users. The interchange node provider is a trusted actor to broke messages with a long-term commitment, facilitating the exchange of C-ITS messages between different actors. The OEM is an end user of the service, responsible for consuming standardised EVA messages and presenting the information to the end-users inside the vehicles.

In the C-ITS ecosystem for the Traffic Signal Priority (TSP) service in Sweden, the national and other road authorities such as cities are responsible for receiving and handling priority requests, distributing messages to roadside equipment, providing road data and traffic signal data, and monitor the safety and that the regulation is not abused. Software/service providers are responsible e.g. for providing data exchange and aggregation, equipment connections, quality control, security, and governance.

In the C-ITS ecosystem for Road Works Warning (RWW) service provision in Sweden, Norway, and Denmark, the actors involved include a technical consultancy company, OEM, supplier and consultant in the area of workplace safety, road administrators, a government enterprise delivering services, and an interchange node provider. Here the technical consultancy company and OEM have roles related to data and information provision and processing. In terms of the requirements on an actor taking the role, different actors have different requirements. For example, the technical consultancy company is required to have an agreement with several actors for the production of road-side data, and an agreement with the national road administration to produce and distribute data. On the other hand, the OEM is required to have the ability to consume EVA messages and display EVA messages to the end-user.

The table 'Finnish authority roles and responsibilities in C-ITS service provision' in Annex 1 provides insights of the roles and responsibilities of different authorities in the C-ITS service provision in Finland. The Finnish Transport and Communications Agency (Traficom) plays a significant role by being responsible for checking the conformity of C-ITS stations with applicable legislation, carrying out market surveillance of motor vehicles, acting as a controller of radio frequencies and supervisory authority of their use and providing C-ITS service specific permissions with respect to cyber security. Traficom is responsible for radio equipment and now proposed to be the market surveillance authority to C-ITS stations. The Finnish Transport Infrastructure Agency and municipalities are proposed to be responsible for the authorities' C-ITS implementation. Fintraffic Ltd is proposed to act as the C-ITS NAP and C-ITS central station operator. An economic operator is needed to be a root certificate authority. An operator for C-ITS RSUs and special vehicles such as emergency, public transport and road operator vehicles is also proposed.

5.5.2 Costs related to C-ITS service provision

In the ecosystem workshops described above, the last task was to identify cost elements related to the service in terms of

- Cost element
- Target price (in a situation when the service is operational after NordicWay 3)
- One-time (OT) or recurring (R)
- Additional remarks

Target costs, meaning the costs not in the pilot but estimated for true deployment, were estimated for three C-ITS services.

The cost elements for the implementation and operation of the SI-SPTI (TTG) and SI-GLOSA C-ITS services in Finland (1st table in Annex 2) can be broadly categorised into development and implementation, operation, and licensing costs. The development and implementation costs relate to an interface to traffic light information, the data sharing node, SPaT and MAP messages in the interchange, short-range communication and end-user service server. The operation costs include the operation of the interface to traffic light information, operation of the interchange, and operation of the end-user service server. The licensing costs include the license fee for the node and the fee for the end-user application. Some target price estimates were given to all of these, except to the operation of the interchange and end user service server as they are also used for other purposes and it is hard to differentiate costs. It was assumed that using the service would be free of charge. The largest costs related to implementation of the messages was 50 k€, one time cost, and implementation of the data sharing node, 26 k€, one time cost. The recurring costs per month per intersection were estimated to be small, yet, the annual cost can be significant if all the intersections are included.

The costs of implementation of EVA service in Sweden (2nd table in Annex 2) included a one-time cost of 160,000€ for input actors and 1,700,000€ for OEMs (Original Equipment Manufacturers). The recurring costs of operation were estimated to be 70,000€ per year for input actors and 330,000€ per year for OEMs. The cost for the interchange node was unknown.

The cost elements for TSP in Sweden (3rd table in Annex 2) included one-time costs for the implementation of the priority service, road authority central proxy for processing of priority requests and the road-side equipment. The magnitude of some of the costs depend on the number of vehicles and intersections included and scales rather linearly. It was also assumed that if the investment is made when re-investing anyhow, it is possible that there are no extra costs compared to no C-ITS. There are significant one-time costs (up to 500k€) for the implementation of the OBU in public transport but most Nordic public transport agencies have already made investments in central servers and OBUs, which can be used for this service, too. There are several elements with recurring costs. They relate to the operation in the priority service but also the road-side communication, interchange and MAP depot. The largest recurring cost item relates to operation of the interchange node, up to 1M€, but there are significant costs for the requestor of e.g. priority service of public transport vehicles also, up to 500k€ annually for up to 3,000 vehicles. The costs to traffic light controllers were unknown.

A Finnish national interchange operator estimated the costs of the implementation of a national node and its operation. Their estimate for the implementation cost of a national interchange node would be in the magnitude of 75k€. The operation of the interchange node would be on annual level in the magnitude of 240k€.

The last table in Annex 2 lists different costs elements which relate to IVS, RWW-LC and RWW-RM services. These elements are divided into implementation costs and operation/maintenance costs. No estimates were given of the magnitude of these costs.

5.5.3 Ecosystem for warning of approaching trains

Lessons learned were collected about an ecosystem which related to publishing, and later consuming, information of warnings of approaching trains at unattended level crossings for the car drivers (Rönne 2023). The main conclusion was that information between different modes of transport (e.g. trains and cars) is important as well as challenging for the transportation system. Importance is related to the transportation system containing many modes of transportation that collaborate when goods and passengers travel from point A to B. It is also challenging as organisations representing different modes of transportation (e.g. train operators) create and use transport information to fit their organisational need only (e.g. timeliness of a train arriving at a railway station). One consequence is that specific information needed for one mode of transportation (e.g. warnings for cars of approaching trains at unattended level crossings) may not be readily available (e.g. high-resolution positioning information of trains). The solution to the problem has been to actively collaborate with, for example, railway companies to close organisational information gaps to be able to provide the necessary information e.g. equip trains with special purpose positioning devices.

Organisational gaps affect the efficiency of the current as well as the future transportation system.
As argued for above, the current transportation system suffers from inefficiencies partly due to organisational information gaps between its actors. Improvement initiatives not limited to specific organisations (e.g. C-Roads) are one example of trying to bridge these gaps in order to promote a more efficient transportation system. The experience is that minimising organisational information gaps between ingoing actors in improvement initiatives is equally important i.e. to act accordingly when new solutions are developed in order to be able to improve the efficiency of the future transportation system. (Rönne 2023)

5.6 Impact of automation in road transport

Aittoniemi et al. (2024) carried out an extensive literature review on the impacts of automation in road transport on different impact areas: vehicle kilometres travelled and modal split, traffic flow, environment, traffic safety and interaction between road users. The impacts were addressed separately for privately owned passenger cars, public transport, robotaxis and logistic solutions. This study also evaluated the applicability of the found results to Nordic conditions.

Aittoniemi et al. (2024) summarised that there is plenty of research on the potential impacts of automation in road transport, but these results cannot be directly interpreted as the likely impacts in real traffic. The impacts of automation have not usually been directly observed, but rather assessed through simplifications and assumptions by using, for example, virtual environments and surveys.

From a Nordic perspective, it is important to consider results related to challenging weather and winter conditions. For example, in Finland almost half (45%) of vehicle kilometres are driven during the winter months (November-March). Yet, most research on driving automation has been done under idealized and simplified conditions, ignoring weather conditions and the variety of vehicles in traffic. Only some studies were found for Nordic conditions related to target accidents. So far, there is no detailed information on how the driving automation would work on snowy and slippery roads or what their effects would be in different conditions. At least in the beginning, likely poor weather conditions will not be a part of the operating environment of automated passenger cars. Low-speed minibuses and delivery robots on separate lanes may work in more challenging conditions, but likely require better winter maintenance than human drivers. So far, there is not much research on this and, therefore, the results on the impacts of automation may not be generalisable to real traffic in Nordic conditions. (Aittoniemi et al. 2024)

There are many ways how automation in road transport can affect vehicle kilometres travelled and modal split. These impacts result from the perceived costs of different travel modes and travel modes enabled by automation. Automation in passenger cars can free the driver from the driving task and, consequently, the perceived travel time cost is reduced, journeys of longer duration are seen acceptable and there will be a shift from public transport to passenger cars. This would lead to an increase in the total vehicle kilometres, which, however, may increase congestion and travel times, which again could act as a constraint on the growth of vehicle kilometres travelled. Automated passenger cars may somewhat improve traffic flow but the demand increase could quickly offset the benefits of improved flow. (Aittoniemi et al. 2024)

Effects of a robotaxi service are influenced by the size of the fleet and the proportion of shared rides. More robotaxis provide a better service and more use of it. Ride sharing reduces the modal share but empty kilometres may lead the combined vehicle kilometres of passenger cars and robotaxis to probably increase rather than decrease. The transition from owning a private car may be speeded up with robotaxis, as they outperform traditional public transport. However, the usage fees encourage considering other travel modes or travel needs overall more carefully. For the long distances in sparsely populated areas, which are typical in the Nordic countries, combining robotaxis and public transport might be a good option. This combination can also be a viable alternative in situations where car use is less appealing, such as in traffic congestion, road tolls, or with parking constraints and charges. However, these services will not be able to operate in the near future in traffic conditions that are challenging for automated vehicles, such as single-carriageway roads with relatively high speed limits outside built-up areas, common in the Nordics. (Aittoniemi et al. 2024)

Overall, research indicates that driving automation can enhance the efficiency of transport. Yet, impacts on e.g. travel time have mostly been studied in certain limited conditions that are not generalisable to other contexts. Studies on the impacts on traffic flow and the environment have focused on motorways with large traffic volumes. In reality, in the Nordic countries motorway traffic volumes are relatively low and they constitute only a small proportion of roads. Consequently, the potential benefits of automation on motorways will likely be minor on the level of the entire transport system. The two-lane roads are particularly important for freight in the Nordic countries, and it would be important to develop automated driving for such an environment, too. (Aittoniemi et al. 2024)

The impact of automated passenger cars on emissions aligns with the impact on traffic flow because they often result from changes in traffic flow and vehicle kilometres travelled. Emissions impact results depend also on the assumptions about the composition of the automated vehicle fleet and their powertrains, specifically on the share of electric vehicles and the carbon footprint of electricity production. The field test results of commercial adaptive cruise control (ACC) suggest in steady-state driving conditions that the fuel consumption and CO_2 emissions of automated vehicles can be lower than those of human-driven vehicles. Yet, the result can be the opposite if there are even small fluctuations in speed. (Aittoniemi et al. 2024)

The studies on the impacts of automation in road transport usually do not cover all three dimensions of traffic safety: accident risk, exposure and severity. The majority of results address the accident risk of the user or the vehicle type under evaluation and are based on simulation, especially for the higher-level automation. Simulation results are heavily affected by the software and used assumptions and parameters for the vehicle's behaviour. According to research results, automation in road transport reduces the accident risk but the effect size depends on the use case, study area and penetration rate. For example, results indicate that automated truck platooning on motorways reduces the number of rear-end collisions but deteriorates the safety of lane changes. (Aittoniemi et al. 2024)

There are some studies on the proportion of target accidents of high-level automation of passenger cars that take into account the Nordic conditions. The share of target accidents depends on the automated driving system under investigation. For example, in Finland a system for motorways not operating in bad weather conditions may affect 3% of accidents that result in deaths and serious injuries annually, and automated passenger cars which do not operate in bad weather or in the dark could affect 20–28% of all fatal accidents between pedestrians and passenger cars. In simulation studies, the snowy and icy conditions have not been taken into account, and the results concern ideal conditions. Yet, different types of snowfall and slippery road surfaces are the most dangerous weather conditions from the viewpoint of a single human driver (Malin et al. 2019). If winter conditions are outside the operational design domain, the driver has to drive themselves in these most dangerous conditions. Thus, research on the traffic safety impacts of automated driving in winter conditions would be particularly important for the Nordic countries. (Aittoniemi et al. 2024)

6 Discussion and conclusions

6.1 Main findings

Evaluation activities in NordicWay 3 were designed to fill in the gaps in knowledge towards the deployment of C-ITS services in the Nordic countries. Different pilots addressed topics relevant to them. In addition, cost of a C-ITS service provision and ecosystems were addressed as cross-cutting topics of joint evaluation.

User acceptance

The results of Weibull et al. (2023) on user acceptance showed that both Emergency vehicle approaching (EVA) and Accident zone warning (AZ) were both well accepted. The respondents of the survey expected that they would follow the instructions and that these services would be of great benefit to the emergency responders and to the traffic in general. These warnings were assessed to improve traffic safety and the respondents considered that not following the instructions, especially an accident zone warning, would be dangerous.

The results of the study by Lauhkonen and Lehtonen (2021) on the views of the transport industry indicated acceptance on real-time traffic information services like C-ITS. According to the results, drivers had some real-time information services at their disposal. Attitudes towards the introduction of cooperative services and the sharing of traffic information were mainly positive. Information about hazardous situations, road weather and the situation on the route was seen more important in wintertime than in summertime. Services were considered useful, and the drivers were prepared to use them. The results also indicated willingness to pay, provided that the benefits the services bring to the company are verifiable. Positive impacts of real-time information services were clearly identified, improvement in safety being the most agreed one. Better pre-information on challenges on the route or on importance of route change was highlighted.

Technical performance / Quality of service

The quality of TTR/TTG prediction solution developed by Swarco (2021) for Trondheim City was measured in a simulation study to have an acceptable level of difference to actual signal change at different intervals before the change. According to results, all tested Fixed Time Adaptive variants of traffic signal control improved significantly the TTG/TTR prediction quality compared to the original Vehicle Actuated control which showed better traffic control performance in terms of delays to traffic. The prediction quality was found acceptable and fulfilling the set criteria.

Nodeon (2022) conducted an experiment in Helsinki to find out how well 3D Lidar Edge AI solution can produce information of vehicle traffic and of VRUs in an intersection area and if this solution together with a roadside unit of C-ITS can produce reliably and timely C-ITS prewarning to the turning traffic of a dangerous situation where a cyclist is approaching a pedestrian crossing from the blind spot of the vehicle or from behind a corner. The experiment showed that the solution worked relatively well in the test intersections for identification of the near-miss situations measuring vehicle speeds accurately. The accuracy of traffic volume information was 97% on average. The most important further development topic is filtering out of reflections from the Lidar data point cloud causing ghost objects. Yet, their conclusion was that one 3D lidar sensor can monitor all the entries and pedestrian crossings of a traffic-light-controlled intersection, but that the vehicle classification was not accurate enough for HDVs and buses.

Thorn (2023) conducted a study on what needs to be done to provide up-to-date digital traffic regulations. Specifically, the pilot project was designed to reveal instances where the traffic signs and regulations differ and to develop a "gap analysis" capability that assesses the disparities between digital records of traffic regulations and real-world indications. The results revealed a 5.2% mismatch in Gothenburg and 10.9% mismatch in Helsingborg between the recorded speed limits recorded in NVDB and the corresponding road signs on roads with a margin of error of 100 meters. In Stockholm there was a 4.2% mismatch, with a margin of error of 200 meters. Reasons for mismatches included e.g. road works, signs with additional signs downstream or that the database had not been updated for the sign in question.

Gustin et al. (2023) carried out a pilot study to investigate if better data quality can be reached through automated control processes for traffic rule types: speed limit, pedestrian area and heavy vehicle restrictions. The pilot showed some data quality issues in the data sample related to location references, missing signs, and traffic signs without supporting regulation provisions. The share of missing machine-readable data was 7%. Of the roads in Gothenburg, traffic regulation is in place for 16% of signs and e.g. the base speed limit is missing at the moment. This pilot showed, that collection of sign data with mobile phones mounted on a taxi fleet worked very well in most cases. The overall conclusion was that the current process to prepare traffic regulations basically works, but there is a substantial information debt regarding older (existing) traffic regulations which were issued as free text. Consequently, there should be national initiative to resolve this information debt.

Kynsijärvi et al. (2024) concluded based on their pilot on C-ITS I2V service at a traffic light-controlled intersection that the design and implementation of an end-user application can significantly influence the overall performance of the application and it should be optimised to minimise latency and to provide the most real-time service possible. The measured latencies were sufficiently low for informative services like SI Signal Phase and Timing Information with no critical safety aspects requiring faster message delivery. However, the RSU requires reliable connections to the Traffic Control Centre and the PKI, through a fixed line or mobile connection. The results indicated that both short- and long-range communication solutions provided a well-functioning platform for informative C-ITS applications.

Kilpiö et al. (2024) studied the performance needs of C-ITS service deployment in mobile networks, to define common service level framework criterion to cover various scenarios of use of services as well as to assess the capabilities of current mobile networks to support C-ITS deployment in Finland. According to results, 4G and 5G network technologies can provide the connectivity and capacity needed for C-ITS services, and future developments of 5G may even improve this. Results showed that the mobile networks in Finland are already largely capable of carrying the estimated 2030 C-ITS messaging traffic levels. Still, due to the nature of mobile networks, local issues on coverage and service level availability are very likely. For this reason, it is important to consider this in the design of C-ITS services.

Driver behaviour

Kunclova (2022) conducted a study with an aim to investigate if and how a geofencing-based C-ITS service can improve driver behaviour when interacting with emergency vehicles. In the off-ramp use case on the motorway, all the participants who got an instruction to continue straight at an off-ramp site, where an accident had occurred and an ambulance was operating on the spot, obeyed the instruction, whereas the participants without these instructions took the off-ramp to the accident site. The instruction did not lead to hazardous effects on driver behaviour and all participants were able to make a complete stop in front of the accident without a crash with the accident vehicles or emergency vehicles at the accident site. In the intersection use case, the results showed how the instructions entailed a reaction of slower and gradual braking reaction earlier than those without. The participants with the instructions came to the lowest speed when the ambulance became visible while approaching.

Additionally, the result of the simulator study by Odéen (2022) showed that drivers with an EVA warning moved over earlier than those who did not receive a warning. The study showed that drivers had a more accepting attitude towards ambulances than towards police vehicles. Yet, everyone agreed that one must always move over for both of these emergency vehicle types.

The study on RWW indicated that drivers responded to the given information by adapting their speed. Unfortunately, the data set was too small for statistical significance. (Blomkvist et al. 2024.)

Socio-economic impact

Literature review of Weibull et al. (2022) was conducted to understand under which circumstances the emergency vehicle accidents occur and on C-ITS solutions related to emergency vehicle accidents. Risk factors of emergency vehicle related accidents were found to be, in order of frequency: intersections, daytime, dry roads, clear weather, urban roads, traffic signals and angular collisions, even though there may not be a causal relationship between these factors and accidents. The EVA service gives surrounding drivers an earlier warning than lights and sirens alone. Based on literature, it seems that both EVA and EVP can lower the risk of mid-intersection collisions with civilian drivers and EVP can shorten travel time for EV.

The costs and benefits related to the EVA service were evaluated in the EVA pilot by Weibull et al. (2023). They estimated that a one-time investment of 160k€ would be required from the input actors and 1.7 M€ investment would be needed from the output actors (OEMs). In terms of recurring costs, the estimate was 70k€ for input actors and 330k€ for output actors. Societal benefits are expected for EVA. Yet, their socio-economic value could not be estimated.

The results of the simulation study by Legêne et al (2023) showed for a solitary intersection with low penetration (10-40%) of vehicles equipped with C-ITS that the vehicle hours and stop delay were around 1% higher with GLOSA than with TTG/TTR regardless of traffic signalling, traffic situation or minimum speed in the advice. However, when the penetration rate increases, the effects of GLOSA were better than those of TTG/TTR, likely due to more homogenous traffic flow. GLOSA had a positive impact on the number of stops, the effect being highly dependent of the penetration rate, with largest impact when 70% of vehicles were equipped. The gains with GLOSA were more than 200% higher than for TTG/TTR which shows the effectiveness in preventing cars from stopping. Vehicle actuated signalling improved the result. On a corridor with chained intersections, the results showed that the impacts were not affected by the penetration rate of GLOSA when the traffic signalling was vehicle actuated. When the C-ITS is deployed with fixed traffic signalling, the penetration rate has only little influence on the accessibility benefits. The impact was a 2% decrease in the number of stops and delay, without any increase with increasing penetration.

Overall, the study of Legêne et al (2023) showed environmental gains under different circumstances for both GLOSA and TTG/TTR. Yet, the traffic signalling and traffic situation played important roles. In case of a solitary intersection, GLOSA was found to reduce NOx and CO_2 emissions by 0.7% on system level and by 0.3% per vehicle. During the morning peak hour, no impact was found for emissions on neither level. Thus, the benefits can be gained only in rather low traffic volumes. GLOSA requires fixed traffic signalling to provide reliable information. Although it can improve traffic flow, it cannot overcome the benefits of vehicle actuated traffic signals. On a corridor with chained intersections, the emissions impact improved with the increasing penetration rate. The reduction of the emissions was around 1.5–5.0% for both fixed and actuated traffic signalling. Some results indicated that C-ITS would perform better with vehicle actuated signalling than with fixed signalling, but it could not be confirmed. (Legêne et al 2023)

Ecosystems

The description of different C-ITS service ecosystems in NordicWay 3 provided insights which are useful for understanding the complexities and challenges involved in the C-ITS service provision and for developing strategies to address these challenges, even if the roles of these actors vary depending on the service.

Based on the results, it is clear that the C-ITS service provision in the Nordic countries involves a wide range of actors, with different roles and responsibilities. The successful implementation and operation of C-ITS services require close collaboration and coordination among these actors. Therefore, it is good to underline that the complexity of the C-ITS service ecosystem highlights the importance of clear definitions of roles and responsibilities, as well as effective communication and information sharing among the actors.

There was not yet a single best practice solution for ecosystems that would be scalable to all C-ITS services in all the Nordic countries, and the set ecosystems differed case by case – depending on the location and service type. The stakeholder types varied per type of information needed for the service. For example, the ecosystems of services needing traffic light data typically included road operators and traffic light controller providers, and the ecosystem requiring data of emergency vehicles included rescue service providers. Yet, all ecosystems included C-ITS service providers for providing the end user service and someone to operate the interchange node.

One of the key findings is the importance of having experienced and trusted actors in some key roles, such as a National Access Point (NAP) operator or a road operator, in addition to different commercial actors. Another important conclusion is the need for close collaboration between the different actors in the ecosystem. The provision of the C-ITS service involves the exchange of data and information between multiple actors which requires effective communication and coordination between them to ensure that the data and information are exchanged in a timely and accurate manner.

Another key insight is the importance of technical expertise and knowledge of C-ITS systems for the public and private actors taking on different roles in the ecosystems, such as how different solutions impact system architecture and processes. Software/service providers are required to have the ability to provide data in line with C-ITS standards and to produce messages in standard ETSI formats.

The example of the roles and responsibilities of different Finnish authorities in C-ITS service provision showed the complexity in terms of number of authorities required for different aspects. Some authorities, such as Finnish Transport and Communications Agency, has a multitude of different responsibilities. Clarification of the authority side of C-ITS service provision was seen as a very useful task to ensure that all necessary roles are carried by a specified authority.

The implementation and operation of the C-ITS services will require significant investment especially in the development and implementation of the system. Secondly, there are both one-time and recurring costs, thus, the operation of these services require long-term financial commitment. Thirdly, some costs, such as the operation of the interchange in a true large scale deployment phase, were still considered somewhat unknown. The estimates given for an interchange node used for TSP service in Sweden gave a cost estimate of up to one million euros for its operation as a service and the implementation of the interchange node for RWW service in Norway was estimated to have a similar magnitude of cost, close to one million euros, whereas other estimates were smaller: the operation of a national generic interchange node in Finland for a magnitude of 240k€ in addition to 75k€ for its implementation, and implementation of an interchange node for RWW in Sweden for 16k€. Thus, the magnitude of the cost estimates varies greatly case by case.

The initial investment for the implementation of the EVA service and TSP service in Sweden were estimated to be significant. EVA was estimated to have a combined one-time cost of 1,860,000€ for input actors and OEMs. However, the recurring costs for the operation of the service were relatively lower, with a combined yearly cost of 400,000€ for input actors and OEMs. For the TSP service, there are one-time and recurring costs for all stakeholders. The largest recurring cost, up to 1M€, is estimated to be related to the operation of the interchange node but there the costs to the requestors of the service were considered to be rather significant too.

Impacts of automation in road transportation

An extensive literature review on the impacts of automation in road transport by Aittoniemi et al. (2024) showed that there is plenty of research on the potential impacts, but they cannot be directly interpreted as likely impacts in real traffic. These impacts have not usually been directly observed, but rather assessed through simplifications and assumptions. From a Nordic perspective, it would be important to consider results related to challenging weather and winter conditions. Yet, most research on driving automation has been done under idealised and simplified conditions, ignoring weather conditions and the variety of vehicles in traffic. Only some studies were found for Nordic conditions related to target accidents. So far, there is no detailed information on how driving automation would work on snowy and slippery roads or what their effects would be in different conditions. At least in the beginning, poor weather conditions will not likely be a part of the operating environment of automated passenger cars, but low-speed minibuses and delivery robots on separate lanes may work in more challenging conditions with good winter maintenance.

Results showed that as automation in passenger cars can free the driver from the driving task, thus the perceived travel time cost is reduced and journeys of longer duration are seen as acceptable and there will be a shift from public transport to passenger cars. Automated passenger cars may somewhat improve traffic flow, but the demand increase could quickly offset benefits of improved flow. For the long distances in sparsely populated areas, which are typical in the Nordic countries, combining robotaxis and public transport might be a good option. The challenge remains that these services will not be able to operate in the near future in the conditions common in the Nordics, such as single-carriageway roads with relatively high speed limits outside built-up areas. (Aittoniemi et al. 2024)

Studies on the impacts on traffic flow and the environment have focused on motorways with large traffic volumes, yet in the Nordic countries motorway traffic volumes are mostly relatively low and they constitute only a small proportion of roads. Thus, the potential benefits of automation on motorways will likely be minor. The impact of automated passenger cars on emissions aligns with the impact on traffic flow. (Aittoniemi et al. 2024)

According to research results, automation in road transport reduces the accident risk but the effect size depends on the use case, study area and penetration rate. There are some studies on the proportion of target accidents of high-level automation of passenger cars that take into account the Nordic conditions. In simulation studies, the snowy and icy conditions have not been taken into account, and the results concern ideal conditions. As snowfall and slippery road surfaces are the most dangerous weather conditions, research on the traffic safety impacts of automated driving in winter conditions would be particularly important for the Nordic countries. (Aittoniemi et al. 2024)

6.2 Conclusion for feasibility of implementation

The aim of the evaluation was to assess the feasibility of C-ITS service provision in the Nordic countries. Specifically, there must be a technically feasible solution for the provision of the services, drivers must accept these services and react to given information and warnings correctly, societal benefits must be foreseen, if public investments are needed, and viable ecosystems must be found for the provision of the services.

The NordicWay approach for C-ITS service provision was developed to support service interoperability. The technical evaluation in NordicWay 2 highlighted the need for designing solutions that are robust and scalable and confirmed the cross-organisational data sharing. NordicWay 3 looked for specific solutions for implementing C-ITS services, especially to urban areas. A solution to predict time to red and green with acceptable quality was found for Trondheim. In Helsinki, a 3D Lidar Edge AI solution was found to work relatively well for timely prewarning of the turning traffic of a dangerous situation where a cyclist is approaching a pedestrian crossing from the blind spot of the vehicle or from behind a corner, but the vehicle classification was not accurate enough for HDVs and buses. NordicWay 2 concluded that the measured latencies did not hinder services. NordicWay 3 confirmed that the latencies were sufficiently low for informative services like SI Signal Phase and Timing Information. Yet, the end-user applications should be specifically designed to minimise it. However, there were no critical safety aspects requiring faster message delivery. NordicWay 2 tested the use of cellular networks for provision of C-ITS services cross-border. The results showed that despite of some issues, the cellular networks were seen fit to support C-ITS services, delivering excellent economy of scale and nationwide road network coverage. The results of NordicWay 3 confirmed that 4G and 5G network technologies can provide the connectivity and capacity needed for C-ITS services, and future developments of 5G may even improve this. The technical evaluation in NordicWay 3 also studied the match between digital and real-world signs; this was studied in Gothenburg, Helsingborg and Stockholm with the mismatch being 5-11%. A need for national initiative to resolve these issues was identified. In conclusion, progress was made for the technical implementation of the services. Some issues still remain but hopefully they can be solved with the proposed initiatives.

NordicWay 2 did an extensive evaluation of the socio-economic impact of C-ITS services. Different benefits were identified for the services and the comparison of costs and benefits indicated that from the road operator perspective, the benefits would exceed the sum of annual operating and maintenance costs that year and the investment costs up to that year in all countries. Yet it was acknowledged that the outcome of socio-economic impact assessment depended highly on the assumptions made on the coverage, use and effectiveness of the services. In NordicWay 3, the socio-economic impact of the EVA service was addressed anew. According to the results, EVA and EVP can lower the risk of mid-intersection collisions with civilian drivers, and EVP can shorten travel time for EV. The overall investment for the service was estimated to be less than 2M€ and recurring costs 400k€ annually in total. However, the socio-economic value of the benefits of EVA could not be estimated.

Without awareness and acceptance, there is no use of services and the societal benefits cannot be achieved. The large survey across Nordic countries showed in NordicWay 2 that over half of Nordic drivers had never heard of C-ITS services, very few have used them (3–6%) but, in total, 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. In NordicWay 3, a web questionnaire investigated specifically the acceptance of EVA and AZW alert confirmed the positive attitudes for both services. Another study was carried out to clarify the views of the transport industry on real-time traffic information services like C-ITS. The results showed experience with some real-time information services, and attitudes towards the introduction of C-ITS services were mainly positive. Drivers indicated willingness to use these services, and the transport companies did not have a problem with paying for the services, provided that the benefits the services bring to the company are verifiable. In conclusion, professional drivers were experienced in use of real-time services, they saw C-ITS useful and companies indicated willingness to pay. The last result is important as a lack of willingness to pay was earlier identified as one of the main challenges.

The correct reaction of the warned drivers is a necessity to gain any benefits of C-ITS services. In NordicWay (1), the Finnish pilot carried out a large-scale field operational test but as the incidents of which the C-ITS warned of were so rare, the evidence of the impacts on driving behaviour were limited (Innamaa et al. 2017). NordicWay 2 had two studies which both indicated that drivers with EVA or a reindeer warning service would react as intended to the warning. The driver behaviour studies in NordicWay 3 confirmed this as the simulator study results showed that the drivers reacted to the given information related to an accident correctly and without hazardous effect in terms of mean speed change. In the intersection use case of EVA, the instructions entailed a reaction of slower and gradual braking, reacting earlier than those without, and everyone with the service reacted to the ambulance while some of those without it exposed themselves and the ambulance to a risky situation and caused a delay for the ambulance.

The lack of feasible ecosystem(s) was seen as one of the main obstacles hindering the introduction of the C-ITS services in NordicWay 2. The public sector has had a significant role in the early stages of C-ITS development, and that active participation was seen as necessary in the long run as well. NordicWay 3 put effort into analysing the ecosystems, e.g. what roles are needed in the ecosystems, the characteristics of actors that have taken these roles, and what would the requirements be for these actors in general. There is no single model that would be the ultimate solution for all but different solutions were sketched. All the ecosystems included both public and private stakeholders. For Finland, a study was also conducted on different authority roles and which authority should carry them out. NordicWay 3 identified service specific costs to different actors in the ecosystem, both in the implementation phase but also for operation of the service were specific. As all costs could not be estimated, no more detailed cost-benefit assessment of the socio-economic impact were made. Yet, the result shows that the authority costs, estimated in NordicWay 2 for provision of the C-ITS services in general, are only one subset of costs, and that it depends greatly on the specific C-ITS service what costs and to whom they are required for service provision.

In conclusion, new insights of provision of C-ITS services were gained in NordicWay 3. Overall, technical implementation, acceptance and driver behaviour impacts of the services seem promising. There is even some willingness to pay for the services among transport industry - if the benefits of the service are clear. Yet, work remains in building optimal ecosystems where the public and private stakeholders take the role fit for them and cooperate in a viable manner. As the implementation costs of the services seem significant, long-term commitment will be needed of all stakeholders involved.

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Annex 1 – Roles and responsibilities in C-ITS ecosystems

Different pilots testing C-ITS services were asked to describe different roles and responsibilities in their ecosystems.

SI-SPTI (TTG), SI-GLOSA in Finland

Actor	High-level category for the role	Role in the ecosystem	Requirements on an actor taking the role
National access point (NAP) operator	Data/Information provider	Interchange node operator Data broker	Experienced actor for operating an interchange node Trusted and national actor?
Road operator	Data/Information provider, Content processor	Tampere node operator Owner and broker of traffic controller data Data quality checker (NULL for non-existing data or data with too long latency)	Experienced actor for operating a node Trusted actor?
C-ITS station provider	Data/Information provider	C-ITS station provider Data broker	Experienced actor for providing the station which fulfils the requirements specified for it
Traffic light controller providers	Data/Information provider	Traffic light controller provider Responsible for quality of raw data	Able to provide traffic light controller and data
Road operator	Data/Information provider	Owner of traffic light controller data	Able to procure traffic control services
End-user service providers	Service provider, Content processor, Other: RSU & OBU solution provider	End-user service provider OBU & RSU information provider who signs the message	Able to provide end-user services Able to produce data which is in line with C-ITS standards

Actor	Responsibilities in the value network set for this role	Requirements of the actor with these responsibilities towards the service
NAP operator	To act as a message broker In the future also: to provide C-ITS messages from NAP data and to sign them	Experienced actor for operating an interchange node Trusted and national actor? No decision on whether this role must be given to a national actor or e.g. an actor with public funding
Road operators	To ensure that MAPem and SPATem messages are mediated via the node To sign the messages	Able to specify service requirements and procure it
C-ITS station provider	To provide data to the interchange To provide message verification service (signing)	Able to provide the station which fulfils the requirements specified for it
Traffic light controller providers	To produce data for the brokers, incl. SPATem and MAPem messages from raw data Responsible of the correctness of the messages	Able to provide messages in line with the specifications
End-user service provider	To provide the end user service To provide RSU and OBU equipment and short-range communication	Able to provide the end-user service Able to provide short-range communication and related equipment
End-user service provider	To provide the end user service To operate RSUs, OBUs and Tampere node in practice	Able to provide the end-user service Able to operate RSUs, OBUs and the node in practice

EVA in Sweden

Actor type	High-level category for the role	Role in the ecosystem	Requirements on an actor taking the role
Ambulances and rescue services vehicles (fire trucks)	Data/Information provider	Data originator	Connected emergency vehicle operator, reporting vehicle positions
Public Safety Access Point (PSAP)	Data/Information provider, content processor	PSAP	Operator of emergency respond system. Prioritize missions and dispatch emergency vehicles
EVA service provider	Service provider, content processor	EVA service provider	Access to emergency vehicle data (positions, path). Ability to create EVA messages.
EVA service provider, software provider	Service provider, content processor	EVA service provider, software provider	Access to emergency vehicle data (positions, path). Ability to create EVA messages.
Interchange node provider	Other	Interchange node provider	A trusted actor with the ability to deliver a long-term commitment with high SLA, performance and quality.
OEM (vehicle manufacturer)	End-user (Vehicle)	EVA message consumer	Ability to consume EVA messages. Access to vehicle fleet, distribute and display EVA message to end user.

Actor	Responsibilities in the value network set for this role	Requirements of the actor with these responsibilities towards the service
Ambulances and rescue services vehicles (fire trucks)	Share position data from emergency vehicles	Frequent and accurate position updates
PSAP Public Safety Access Point	Access to emergency vehicle information (position, destination)	Emergency vehicle dispatch responsibility
EVA service provider	EVA service provider	Access to interchange node or similar national access point that gives access to end users.
Interchange node provider	Interchange node provider	An interchange node needs to be provided by a trusted actor with the ability to deliver a long-term commitment with high SLA, performance and quality, i.e. road operator.

OEM	Display EVA messages to the effected vehicles and drivers	Standardized data with high availability, quality and coverage Remarks: Stability regarding standardization and service availability is vital! The alignment of standardization for ITS-G5 and cellular communication simplifies implementation.

TSP in Sweden

Actor	High-level category for the role	Role in the ecosystem	Requirements on an actor taking the role
National road authority	Road authority, Data/Information provider. Implementer, Data receiver.	Receives and handles priority request in RA environment. Distributes messages to roadside equipment.	Knowledge of C-ITS systems and understanding of how different solutions effect system architecture, processes like how to administrate MAPEM data, knowledge of regulations etc.
Road authority	Road infrastructure, road data, public procurement, local policies	Public strategies and policies for the city roads. Public procurement for C-ITS (hardware and software). Local work to implement C-Roads standardization	General knowledge of C-ITS systems, investments, political decisions
Software/Service provider	PT Proxy on the left side of the interchange	Fully C-ITS provider in Stockholm (Right side of the Interchange and C-ITS to RSMP in Uppsala (incl. map files and controller programming)	Spec on interface to the interchange and also spec how it should work out to the controllers. (Protocols)
Software/Service provider	Software/Service provider	Provide priority requests services on both sides of the Interchange node	Political decisions and stability in technology choices.
Software/Service provider	Data/Information provider/Service Provider	Generating vehicular data locally. Priority request creation handling.	Political decisions and stability in technology choices.
Software/Service provider	Software/Service provider	Providing the software/services for data exchange and aggregation, equipment connections and quality control, security, governance etc.	Services support multiple deployment scenarios and standards, are of production grade (TRL9) and available for procurement

Actor	Responsibilities in the value network set for this role	Requirements of the actor with these responsibilities towards the service	Other remarks, e.g. lessons learned
National road authority	Overall monitoring of solutions to verify road authority useability and possibility for early effects. Monitor safety and that various regulation is not abused.	Knowledge of C-ITS systems and understanding of how different solutions impacts system architecture, processes, knowledge of regulations.	Some solutions can affect how we can manage our system architecture, we need to learn more. It is important to verify integrity and data correctness across the architecture. The actual methods and chosen data that is used for priority isn't always working well with all existing methods.
Road authority	Provider of road data and traffic signal data, local policies,	National guidelines for C-ITS standards, Interchange node, cooperation and networking	Important with a deepened dialogue with public stakeholders (PT authorities and Emergency authorities)
Software/Service provider	Service and software provider in the network	Provide data up to the interchange and also the prio request to the controllers (Also provide data back to vehicle) Create Map files and get data from the City first)	Compatibility on the controller side, (Spec to the city or owner of the equipment) and good Data network out to the equipment.
Software/Service provider	Software/Service provider	Provide priority requests services on both sides of the Interchange node	Accurate and secure vehicle data and compatibility on the controller side.
Software/Service provider	Data provider / Service Provider	Generating an accurate priority request	Political decisions and stability in technology choices so that one solution can be deployed, at the minimum, nationally but preferably internationally.
Software/Service provider	Software/Service provider	Deploy and maintain the Interchange, with support to the partners	The use-cases showed the need for deeper data analytics functionalities that are enabled by the TLEX solution

RWW in Sweden, Norway and Denmark

Actor	High-level category for the role	Role in the ecosystem	Requirements on an actor taking the role
Technical consultancy company	Service provision	Data processing	Produce messages on standard ETSI formats and distribute data to the Interchange Node
OEM	Service provision	Data reception	Consume messages and present information inside vehicles
Supplier and consultant in the area of workplace safety	Service provider, equipment provider	RWW service provider, equipment	Help in how to comply with safety regulations, provide equipment to utility areas and construction zones
Road administrators	-	National Road Administrator, national pilot	-
Government enterprise delivering services	Maintenance operator	Maintenance operator	Legal obligations to inform road owner and road users
Interchange node provider	Interchange node provider	Interchange node provider, C-ITS data aggregator	-

Actor number	Responsibilities in the value network set for this role	Requirements of the actor with these responsibilities towards the service*
Technical consultancy company	Receive data from Road side and produce RWW messages based on business rules.	Agreement with road work companies of production of road side data. Agreement with the national road administration to produce and distribute data
OEM	Receive data from Interchange node	-
Supplier and consultant in the area of workplace safety	Supplier and consultant in the area of workplace safety	-
Road administrators	National pilots	-
Government enterprise delivering services	Make agreement with road authority	Maintenance operator, requirements defined in contracts
Interchange node provider	Interchange node provider	-

Finnish authority roles and responsibilities in C-ITS service provision

Authority	Role	Responsibilities
Finnish Transport and Communications Agency (Traficom): Authority that is entitled to check the conformity of a C-ITS station with the applicable legislation	Competent national authority of C-ITS (proposal for a new role)	Authority that is entitled to check the conformity of a C-ITS station with the applicable legislation (European Commission 2019b)
Finnish Transport and Communications Agency (Traficom): Market surveillance authority	Market surveillance authority: motor vehicles	Responsible for the implementation of market surveillance of motor vehicles in Member State
Finnish Transport and Communications Agency (Traficom): Authority and executive power (radio frequencies)	Controller of radio frequencies	Finnish government: Confirms the frequency plan for the use of radio frequencies applied at the national level by the decree of the Government Council with regard to certain separately defined cases, as well as the general principles regarding the use of radio frequencies. Finnish Transport and Communications agency (Traficom): Gives the national level regulations regarding the use of radio frequencies for different purposes, taking into account the government decree on the use of frequencies and the frequency plan.
Finnish Transport and Communications Agency (Traficom): Authority (radio equipment)	Authority responsible for notification, radio equipment	Assessment of conformity assessment bodies according to the Radio Equipment Directive, notification to the EU Commission and supervision of notified bodies
Finnish Transport and Communications Agency (Traficom): Authority (radio equipment and use of radio frequencies)	Supervisory authority, radio equipment and use of radio frequencies	Supervises compliance with the Finnish Law on Electronic Communication Services (917/2014) and the regulations and decisions issued pursuant to it, with certain exceptions. These include e.g. the use of radio frequencies in Finland governed by national regulations. Issuing regulations on the use of radio frequencies. For now, the duties also include the prevention and investigation of radio interference.
Finnish Transport and Communications Agency (Traficom): Authority (radio equipment)	Market surveillance authority, radio equipment	Market surveillance of products covered by the Radio Equipment Directive.
Finnish Transport and Communications Agency (Traficom): Authority of a Member State responsible for carrying out market surveillance on its territory	Market surveillance authority: C-ITS stations (proposal for a new role)	Implementation of market surveillance of C-ITS stations in the Member State

Authority	**Role**	**Responsibilities**
Finnish Transport Infrastructure Agency (national road network) and municipalities (road and street network): Highway network and street network operators, rail network manager	Responsible for the authorities' C-ITS implementation (proposal for a new role)	Management of C-ITS implementation, e.g. sharing and use of data, procurement, installations and maintenance of intelligent traffic systems as well as evaluation and monitoring of C-ITS services. (C-Roads WG1 Operations) The road operator can be a public or private entity that is responsible for the maintenance and management of the road and the regulation of traffic flows. Interpretation of responsibility: the task includes the acquisition of C-ITS stations and the Interchange node operations.
Fintraffic Ltd: National Access Point (NAP) is an interface for accessing, exchanging and reusing traffic-related data (European Commission: National Access Points), the requirements of which are part of the ITS directive and its delegated regulations.	C-ITS National Access Point (proposal for a new role)	NAPs can possibly support and implement some C-ITS functions, e.g. a register of C-ITS service providers (public and private sector), which can be used per member state or region (e.g. municipality) to integrate services into a part of the end- user services. The register can likely also be utilized for in-vehicle data. In addition, monitoring the availability of C-ITS services, information security and communication networks, e.g. in the TEN-TEC map service. (C-Roads WG1 Operations)
Fintraffic Ltd or Fintraffic Road Ltd (national road network) and municipalities (road and street network): Natural person or legal entity (public and/or private actor) providing C-ITS central and stations' operation	C-ITS central station operator (proposal for a new role)	Responsible for the commissioning and operation of C-ITS units and day 1 C-ITS services, when using long-range communication. Interpretation of responsibility: task includes the operation of the C-ITS central station
Finnish Transport and Communications Agency (Traficom): Authority (service-specific permissions (SSP))	C-ITS cybersecurity: service-specific permissions (SSP)	Responsible for issues related to rules for assigning service-specific licenses to C-ITS stations and operators (SSP).
Economic operator: Legal and/or operational entity (economic operator) for Root Certificate Authority and sub-CAs	Root Certificate Authority (RCA), Enrolment Authority (EA), Authorisation Authority (AA)	Several tasks and responsibilities according to the European Union C-ITS Security Credential Management System (EU CCMS).
Fintraffic Ltd or Fintraffic Road Ltd (national road network): Natural person or legal entity (public and/or private actor	Interchange Node operator (*proposal for a new role*)	Responsible for the exchange of C-ITS messages between C-ITS actors

Authority	Role	Responsibilities
providing C-ITS central and stations operations)		
None (Currently no short-range C-ITS service involving public authorities is planned in Finland although hybrid C-ITS stations may include also short-range communication)	Operator for C-ITS road side stations and special vehicles (emergency, public transport, road operator) (*proposal for a new role*)	Responsible for the commissioning and operation of C-ITS units and day 1 C-ITS services when using short range communication. Interpretation of responsibility: task includes the operation of fixed and special mobile C-ITS stations.

Annex 2 – Target prices for C-ITS service provision

Target price estimates resulting from workshops with different ecosystems in NordicWay 3. These prices were estimated for different cost elements either as one-time cost or as recurring cost.

SI-SPTI (TTG), SI-GLOSA in Finland

Cost element	Target price (€)	One-time (OT) or recurring (R)
Development of an interface to traffic light information	10 000+ €	OT
Operation of the interface to traffic light information	100+ €/month/intersection	R
License fee for the node (incl. development and operation)	120 €/month/intersection (in the pilot)	R
Development and implementation of the data sharing node, incl. testing	26 000 €	OT
Implementation of SPaT and MAP messages in the interchange	50 000 €	OT
Operation of the interchange	Unknown	R
Implementation of short-range communication, equipment (one RSU and a few OBUs)	3 000 €	OT
Implementation of short-range communication	8 000 €	OT + R
Implementation and operation of the end-user service server	100 000 €/year	R
Fee for the end-user app	0 €?	R

EVA in Sweden

Cost element	Target cost (€)	One-time (OT) or recurring (R)
Implementation (input actors)	160 k€	OT
Operation (input actors)	70 k€/year, some costs unknown	R
Implementation (for OEMs), cost increases with number of OEMs	1.7 M€	OT
Operation (for OEMs)	330 k€/year	R
Interchange node cost	Unknown	

TSP in Sweden

Cost element	Target price (€)	One-time (OT) or recurring (R)
Vehicle equipment/OBU for Emergency vehicles (implementation), included here in other items below	0 €	OT
Vehicle equipment/OBU for public transport (Most Nordic PTAs have already made investments in central servers and onboard units)	0.0-0.5 M€ depending on need to upgrade central server systems and onboard units (supporting real-time positioning >1 Hz) C-ITS onboard units 2000 €/vehicle (applicable if the goal is to implement C-ITS standard also on vehicle level)	OT
Priority Service Emergency vehicles (Requestor) (Operational cost)	For all Swedish emergency vehicles 0.18 M€/month as additional service, scales rather linearly from small volumes to larger	R
Vehicle equipment/OBU for Freight vehicles	12.5 €/month mobile app service	R
Priority Service PT Vehicles (Requestor)	100-500 vehicles: 20-100 k€ 500-3000 vehicles: 100-500 k€	OT and R (yearly)
Interchange node	250 k€ – 1 M€	R yearly, (as a service)
Interchange to roadside communication system	360–600 €/Intersection, including aggregation, data quality control, governance, privacy, security etc.	R yearly per TLC, (as a service)
Road Authority Central Proxy (Priority request processing)	0.1-0.5 M€?	OT and R (yearly)?
Road-side equipment / R-ITS-S (optional)	5.0-7.5 k€/intersection (R-ITS-S) New installation/retrofit. Less if required when re-investing. Possibly no extra compared to no C-ITS.	OT
Traffic Light Controller enabled for priority request	Unknown	Unknown
MAP depot (operational costs)	120–360 €/Intersection, depends on volume and service duration	R yearly (as a service)

RWW in Norway and Sweden

	Cost element	Cost	Recurrence	Remarks
Data provider costs	Application to collect data	0		Exists already
	RSU as an element in the digitalization of the roadworks zone and collect data	0		Exists already
	OBU	Unknown		
	Datex	0		The entrepreneurs are already obliged to send information to the road authorities about static roadworks
Service provider costs	Application to collect road works data and convert it to DENM messages (per actor)	30 k€	OT	
		6 k€	R	
	Conversion of RSU data for 8 000 – 9 000 vehicles	500 k€	OT	
		300 k€	R	
	C-ITS server to validate DENM messages	170 k€	OT	
		4 k€	R	
	Norwegian interchange	980 k€	OT	Estimate
	Swedish interchange	16 k€	OT	
	Android automotive app used by car brand #1	40 k€	OT	
	Android automotive app used by car brand #1	110 k€	OT	

Summed up estimates for different cost categories of RWW. Estimates are annual costs for operating the Interchange and services, including upscaling, based on historical financial numbers. Developing costs are not included due to a high level of uncertainty regarding timeline and required resources. The costs are only related to the public agencies' activities, and not to commercial companies.

Summary of operation costs for RWW

Category	Comment	Annual estimate
Operational costs	Operation with up-time from 7pm to 4am 7 days a week.	100 k€
Server costs	Monthly fee to e.g., Google Cloud.	2500 – 3500 €
Human resource costs	Costs related to in-house competence, one full time employee working full-time with the Interchange	60–80 k€
In total		162.5–183.5 k€

National interchange node for all C-ITS services in Finland

Cost element	Price (annual)	Recurrence
Implementation of the interchange node	75 k€	One time, using open source solutions
Operation of the interchange (capacity)	180 k€	Recurring
Operation of the interchange (human resource)	60 k€	Recurring

IVS, cost elements

Service	Cost type	Cost element	Remarks
IVS	Implementing cost	Back-office: Data exchange platform	Shared by many
		Interchange: Preliminary, joint cost to share data, one service	
	Operation and maintenance cost	Back-office: DEP/DUP	Datex / ETSI drift
		Interchange	

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