# Sweden4Platooning

**Public report**

Project within:

- Trafiksäkerhet och automatiserade fordon / Traffic Safety and Automated Vehicles
- Effektiva uppkopplade transportsystem / Efficient Connected Transport Systems

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FFI Fordonsstrategisk Forskning och Innovation
VINNOVA Energimyndigheten TRAFIKVERKET
FKG VOLVO SCANIA VOLVO

# Content

# 1. Summary


## Background:

Road trains, also called platoons, have a potential to increase efficiency of goods transportation. In road trains trucks are pulled together using wireless communication, called Vehicle2Vehicle-communication (V2V), directly between the trucks. A secure communication link is established and data can be shared between the vehicles in the platoon, such as speed, acceleration, retardation, weight and length of the vehicles etc, which is of great importance together with the signals from the onboard sensors when controlling the ego vehicles speed and heading.

There is also a potential to be able to drive with shorter distances between the communicating vehicles. This will reduce air drag resulting in reduced fuel consumption and thereby, reduced environmental impact.

Trucks can be controlled longitudinally as well as laterally in road trains. Due to the possibility of fully automated control of the trucks, drivers can be relieved from the monotonous driving task in motorway environments. Monotonous driving can cause driver drowsiness and by relieving the driver, incidents and accidents can be avoided. Hence, an increased safety benefit is expected. In a near future these systems can be developed to be able to control the vehicles following the manually driven lead vehicle autonomously and then facilitate unmanned followers. This will probably happen many years before completely unmanned heavy drones runs at speeds of 80 km/h on public roads.

To explore the full potential of truck platooning, trucks from different brands must understand and find each other (they must be interoperable). Further the communication among the members of the platoon must be reliable and robust in all traffic situations and meet the communication requirements on, e.g., capacity and latency, so that a stable platoon operation can be provided.

## Results:

The Sweden4Platooning project has in a pilot study demonstrated the feasibility of longitudinally controlled platooning trucks from Scania and Volvo (dual brand platooning) at the haulage company Nordanå Transport AB for 12000 km in normal goods transport operation on the public road E4 between Malmö and Jönköping in Sweden.

The project has also demonstrated platooning with both longitudinally and laterally controlled trucks with trucks from Volvo and Scania at the Astazero test site (close to Borås in Sweden) resulting in follower trucks driven without human intervention.

The V2V protocol developed within the project has been handed over to the EU funded platooning project ENSEMBLE (all seven European heavy truck brands are participating) and this is now the base for further development in this project. Also parts of the Use Case study and Risk Analysis done in the project will be used in the project EU-project.

A platooning Business Case analysis has been performed. The report will be published in a near future. Results in short:
The Swedish long distance motorway annual potential is estimated to be some 250 to 300 million SEK in societal costs and up to 600 in corporate costs, evenly distributed between less air resistance and legal speeds. The carbon dioxide decrease value is even bigger at 700 million SEK. Safety and level-of-service effects are deemed positive but very hard to quantify.

## Project work:

The project work has successfully been performed by the partners Scania CV AB, Volvo Technology Corporation (VTEC), The Royal Institute of Technology (KTH), RISE (SICS Swedish ICT at project start), DB Schenker AB and Trafikverket (Swedish Transport Administration). It has been a very good cooperation all through the project.

The project is funded by the partners and two different program councils at FFI:

- Trafiksäkerhet och automatiserade fordon / Traffic Safety and Automated Vehicles
- Effektiva uppkopplade transportsystem / Efficient Connected Transport Systems

The total budget of the project was almost 39 MSEK.

Further research within work package 4 "Off-Board system" will be carried out by KTH throughout 2020 and a final report, with this report as a base added with the results from the research during 2020, will be sent to Vinnova/EUTS 2021-01-30.

# 2. Sammanfattning på svenska

## Bakgrund

I fordonståg (även kallade fordonskonvojer eller platooner) kopplas fordon ihop elektroniskt med hjälp av trådlös kommunikation, så kallad Fordon-till-fordon-kommunikation (V2V - från engelska ”Vehicle-To-Vehicle”), som går direkt mellan fordonen. En säker kommunikationslänk upprättas och data kan delas mellan fordonen i platoonen, såsom hastighet, acceleration, retardation, vikt och längd på fordonen etc. Dessa data är av stor betydelse när de tillsammans med signalerna från sensorerna på fordonet används vid styrning av fordonhastighet och färdriktning.

Det finns också en potential att kunna köra med kortare avstånd mellan de kommunicerande fordonen. Detta kommer att minska luftmotståndet vilket leder till minskad bränsleförbrukning och därmed minskad miljöpåverkan.

Lastbilar kan styras längsgående såväl som i sidled i vägtåg. På grund av möjligheten till helt automatiserad kontroll av lastbilarna kan förare befrias från den monotona köruppgiften i motorvägsmiljöer. Monoton körning kan orsaka dåsighet hos föraren och genom att frigöra föraren från den körningen kan incidenter och olyckor undvikas. Därav förväntas en förbättrad säkerhet på vägarna.
Inom en snar framtid kan fordonens styrsystem utvecklas till att automatisk kunna styra följefordonen att följa efter den manuellt körda ledarbilen, vilket i förlängningen kan möjliggöra obemannade följebilar i platoonen. Detta kommer förmodligen att ske många år innan helt obemannade tunga drönare går att köra i hastigheter på 80 km per timme på allmänna vägar med andra trafikanter.

För att uppnå den fulla potentialen av lastbilsplatooner måste fordon från olika märken kunna kommunicera och hitta varandra. Vidare måste kommunikationen mellan platoonens medlemmar vara tillförlitlig och robust i alla trafiksituationer och uppfylla kommunikationskraven på t.ex. kapacitet och latens så att en stabil och säker konvojkörning kan erhållas.

## Projektet

**Projektbakgrund**
Projektet "Sweden4Platooning" startade den 1 januari 2017 och planerades vara klart den 31 december 2019. Projektet är ett samarbete mellan partnerna Scania CV AB, Volvo Technology Corporation (VTEC), Kungliga Tekniska Högskolan (KTH), RISE ( SICS Svenska IKT vid projektstart), DB Schenker AB och Trafikverket.
Projektet finansieras av partnerna och två olika programråd på FFI/Vinnova:

- Trafiksäkerhet och automatiserade fordon, TSAF
- Effektiva uppkopplade transportsystem, EUTS

Projektets totala budget uppgick till 39 MSEK.

EUTS har efter projektets förfrågan godkänt vidare forskning inom arbetspaket 4 ”Off-Board system”, vilket kommer att utföras av KTH under hela 2020 och slutrapporteras 2021-01-30.

**Projektets programrelevans för TSAF:**
Säkerhet och Automation Koncept 2, som handlar om det prediktiva och uppkopplade fordonet, som syftar till kommersialisering av forskningsresultat inom tidsramen 2020-2025.

Flera programområden täcks av projektet:
• Funktionella säkerhetsaspekter av nya transportlösningar (programområde A)
• Studier och utvärdering av interaktionen mellan föraren och systemet (programområde A)
• Forskning om HMI (programområde D)
• Kooperativt system (programområde B)
• Delvis automatisering på allmän väg (programområde E)

**Projektets åtta arbetspaket**:
AP1 Projektledning
AP2 Användarfall och funktionellsäkerhet
AP3 On-board funktionalitet
AP4 Off-board funktionalitet
AP5 Pilot och utvärdering
AP6 Demonstration
AP7 Affärsmodeller för platooning
WP8 Informationspridning

## Samarbete

Projektet har haft ett mycket bra samarbete mellan alla sex parter (Scania, Volvo Technology Corporation, KTH, RISE, DB Schenker och Trafikverket) och med Nordanå Transport AB, som inte är en partner, men som utfört pilotkörningen i samarbete med DHL.

Samarbetet mellan parterna skedde främst genom Workshop-diskussioner och analyser vid ett tiotal möten hos de olika parterna, samt genom ett större antal web-baserade möten.

Projektet har haft en styrgrupp med sju ledamöter som har haft möten regelbundet (via Skype) inför alla statusrapporter och då projektet stått inför förändringar av planer och liknande.

Det har också funnits en projektgrupp, bestående av projektledaren och alla arbetspaketledare. Dessa har initierat, styrt och följt upp det pågående projektarbetet, samt rapporterat status till styrgruppen.

## Mål och metod

Huvudmålen var att:

- Demonstrera genomförbarheten av godstransport utförd av ett kommersiellt transportföretag körande i platoon på publik väg med automatisk longitudinell reglering med fordon från Scania och Volvo med fungerande fordon-till-fordonskommunikation.
- Demonstrera platooning, med automatisk longitudinell och lateral reglering av fordonen, med fordon från Volvo och Scania.

Fordonstågsapplikationen är utmanande och verkligt tvärvetenskaplig. För att nå målet att köra fordonståg på allmänna vägar måste flera olika delar vara synkroniserade och väl iscensatta. Målen för detta projekt nåddes via utredning av bl.a. följande fyra områden:

- Övergripande krav och gränssnitt till det fordonsbaserade systemen
- Funktionalitet i ´molnet´ för att underlätta att fordon kan hitta varandra för att köra i platoon

- Säker, skalbar och pålitlig trådlös kommunikation med låg latens mellan fordon för utbyte av data när platoonen är ihopkopplad
- De funktionella säkerhetsaspekterna av platooningapplikationen, som är ett måste för att köra på allmänna vägar

Fler leveranser och mål tillsammans med projektets resultat kan ses nedan under rubriken ”Resultat”.

**TRL-klassning**
När det gäller TRL-klassificeringen (Technology Readyness Level) kan projektet delas i två delar. Den första delen är piloten och den andra är demonstrationen.
TRL vid start av projektet för piloten, som kördes endast med automatisk longitudinell reglering, är 6 och målet var att visa det i verklig drift, dvs TRL 7.
TRL vid start för demonstrationen av både automatisk longitudinell och lateral reglering, är TRL 5 och målet var att visa det i relevant miljö TRL 6 dvs på provbana och med säkerhetsförare.

# Utförande

Projektet utfördes på ett iterativt sätt. Först definierades användarfallen och kraven i arbetspaket 2 (AP2). Dessa utvärderades sedan i de tekniska arbetspaketen (AP3 och AP4). Resultaten från dessa matades tillbaka till AP2 för att ändra användarfall och/eller krav.
Åter definierades och bearbetades användarfall och krav inom AP2 för att sedan utvecklas och implementeras inom de tekniska arbetspaketen och så vidare. När AP3 (Implementation av fordonsfunktioner) och AP4, Off-board funktionalitet, var klar med utveckling och validering kunde AP5 Pilot utföra varutransport i verklig drift och WP6 Demonstration kunde utföra konvojkörning med ett automatiskt styrda följefordon.

Metoder bestod huvudsakligen av:
- Simuleringar (platoonsamordning, longitudinell/lateral regulator, business case-analys etc)
- Tester i testriggar (V2V kommunikationsutveckling och verifiering)
- Fordonsexperiment/-tester på väg (validering av V2V-kommunikation och reglerfunktioner, pilotdrift, demonstration på provningsbana etc.)
- Förarintervjuer/kliniker (HMI-utredning)

# Resultat

Projektet har haft stor framgång i att uppnå de mål som satts upp vid projektets uppstart och uppnått huvudmålen:
- Standardiserad platooningapplikation för att möjliggöra interoperabilitet mellan olika fordonstillverkare.
    - Initiering av standardiseringsarbete för trådlös kommunikation inom ETSI TC ITS
    - Initiering av standardiseringsarbete om funktionella säkerhetsaspekter inom ISO
- Kunskap om behov och ekonomiska värden för olika platooningrelaterade tjänster och mekanismer för bildandet av en pluton har byggts
- Kunskap om hur man väljer affärsmodell för en platooningapplikation har ökats

- Pilotkörning utförd med kooperativ adaptiv farthållare, CACC (V2V-kommunikation och longitudinell reglering), och fordon utvecklade av Scania respektive Volvo.
- Demonstration av platooning med automatisk lateral och longitudinell reglering utfördes med ett fordon från Scania och ett från Volvo på Astazeros provbana utanför Borås.
- Ett koncept för funktionellsäkerhet har utvecklats och analyserats.
- 1 Doktorsavhandling: S. van de Hoef, “Coordination of Heavy-Duty Vehicle Platooning”, http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-225109 .
- 1 licentiatavhandling: Ännu ej uppnådd. Planerad att uppfyllas under år 2020.

## Mål och Resultat per arbetspaket (AP)

**AP1 Projektledning**

Mål: Genomföra projektet med planerade resultat och inom budget och tidsplan.
Resultat:

- Planerade resultat har i stort uppnåtts
- Projektet har hållit den totala budgeten, men har lite varierat utfall hos parterna.
- Tidsplanen har hållits utom för AP4 som kommer att jobba under 2020 också.
- Till 2020-12-31 kommer alla resultat att nås och projektet kommer att ha överspenderat något.

**AP2 Användarfall och funktionell säkerhet:**

Mål: Beskrivning av platooningscenarier/användarfall, funktioner, gränssnitt och genomföra funktionell säkerhetsanalys.
Resultat:

- Användarfallbeskrivning/Platooningscenarier, rapport (främst för projektintern användning)
- Analys av funktionell säkerhet, rapport (främst för intern användning inom projekt)

**AP3 On-board funktionalitet:**

Mål: Implementering av system på fordonen som möjliggör piloten i AP5 och demonstrationen i AP6.
Resultat:

- Funktionalitet implementerad av Scania och Volvo separat (endast för företagens interna användning).

**AP4 Off-board funktionalitet:**

Mål: Ange krav och KPI:er (Key Performance Indicators) och undersöka tekniska lösningsalternativ för en arkitektur.

- Delar återstår att göra klara under 2020.

Mål: En implementation kommer att tillhandahållas och användas vid demonstrationen av AP6.

- Genomfört av KTH, Volvo och Scania (endast för projektinternt bruk).

Mål: Dokumentation som förklarar varför val gjordes för vilka funktioner och ramverk som ska utvecklas och varför de utformades på vissa sätt.

- Delar återstår att göra klara under 2020

**AP5 Pilot och utvärdering:**

Mål: Utförande av pilotkörningen och utvärdering av fordonens reglering.

- Pilotkörningen genomförd av Nordanå Transport AB genom transport av gods och varor för DHLs räkning under fyra veckor och 12000 km på väg E4 mellan Malmö och Jönköping.

- Utvärdering utförd av Scania och Volvo separat (endast för företagets interna bruk).

**AP6 Demonstration:**
Demonstration av samordnad platooning med automatisk longitudinell och lateral reglering:
- Genomförd på Astazero December 2019. En video har produceras och kommer att visas offentligt.

**AP7 Affärsmodeller för platooning:**
Mål: Analys och dokumentation av affärsaspekter på platooning:
- En rapport kommer att publiceras inom en snar framtid, som diskuterar och analyserar affärspotentialen för platooning, modeller för kostnadsöverföring och fördelar med och mekanismer för platoonbildning och körning, samt de nödvändiga tjänsterna kopplade till detta.

**AP8 Informationspridning:**
Workshops inom projektet:
- Nio ”Face2Face” WS har hållits i olika arbetspaket under projektet
- Mer än 20 WS över Skype har hållits under projektet
- Vid fyra tillfällen har Scanias och Volvos ingenjörer samlats för att testa V2V-kommunikation i testriggar.
- Vid sex tillfällen utfördes körprov (de flesta på provbana) med ingenjörer från både Scania och Volvo.

Publikationer:
- Se kapitel 7.2 (på engelska)

Spridning till andra projekt:
- Sweden4Platooning-projektets V2V-kommunikationsprotokollet dokumenterades och distribueras till ENSEMBLE-projektet som bas för vidare utveckling inom det projektet.

# 3. Background

Road trains, also called platoons, have a potential to increase efficiency of goods transportation. In road trains trucks are pulled together using wireless communication, called Vehicle2Vehicle-communication (V2V), directly between the trucks. A secure communication link is established and data can be shared between the vehicles in the platoon, such as speed, acceleration, retardation, weight and length of the vehicles etc, which is of great importance together with the signals from the onboard sensors when controlling the ego vehicles speed and heading.

There is also a potential to be able to drive with shorter distances between the communicating vehicles. This will reduce air drag resulting in reduced fuel consumption and thereby, reduced environmental impact.

Trucks can be controlled longitudinally as well as laterally in road trains. Due to the possibility of fully automated control of the trucks, drivers can be relieved from the monotonous driving task in motorway environments. Monotonous driving can cause driver drowsiness and by relieving the driver, incidents and accidents can be avoided. Hence, an increased safety benefit is expected. In a near future these systems can be developed to be able to control the vehicles following the manually driven lead vehicle autonomously and then facilitate unmanned followers. This will probably happen many years before completely unmanned heavy drones runs at speeds of 80 km/h on public roads.

To explore the full potential of truck platooning, trucks from different brands must understand and find each other (they must be interoperable). Further the communication among the members of the platoon must be reliable and robust in all traffic situations and meet the communication requirements on, e.g., capacity and latency, so that a stable platoon operation can be provided.

Regarding the TRL classification the project can be divided in two parts. The first part is the pilot and the second is the demonstration. The start TRL for the pilot is 6 and the goal is to demonstrate it in operating environment, i.e. TRL 7. The start TRL for the demonstration is TRL 5 and the goal is to demonstrate it in relevant environment i.e. TRL 6.

The project “Sweden4Platooning” started 1st of January 2017 and was planned to be finished 31st of December 2019 and the project is a cooperation between the partners Scania CV AB, Volvo Technology Corporation (VTEC), The Royal Institute of Technology (KTH), RISE (SICS Swedish ICT at project start), DB Schenker AB and Trafikverket (Swedish Transport Administration).
The project is funded by the partners and two different program councils at FFI/Vinnova:

- Trafiksäkerhet och automatiserade fordon / Traffic Safety and Automated Vehicles
- Effektiva uppkopplade transportsystem / Efficient Connected Transport Systems

The total budget of the project was 39 MSEK.

The project was performed in an iterative way. First the use cases and the requirements were defined in WP2 and then evaluated in the technical WPs (WP3 and WP4). The result from these was fed back to WP2 to modify the use cases and/or requirements. Then new use cases and requirements will be addressed in WP2 and then developed in the technical WPs and so on. When WP3 (Implementation) was ready with the development and validation, the WP5 Pilot could perform the goods transport and the WP6 Demonstration could perform platooning with an autonomously controlled follow vehicle.

# 4. Purpose, research questions and method

## Purpose

The purpose of the project was to increase the research and innovation capacity in Sweden through research on coordinated platooning and how functional safety should be applied to cooperative systems and to contribute to the development of standards for platooning which can be used for affecting the standards in Europe and thereby secure our competitiveness.

## Research questions:

WP3: What is the best mode of cooperation between drivers and the automated application in different scenarios?
WP4: Which methods for determining when formation of platoons is beneficial from a transport assignment perspective where routing and timing constraints are encompassed?
WP7: How does penetration level for platooning technology affect choice of business model?
WP7: Under what circumstances is there a need for economic compensation between vehicles and how is this to be set up?
WP7: Under what circumstances, e.g. gap lengths, do the drivers need to be motivated to participate in a platoon, and how can this be done?
WP7: What is the potential and also effects for safety and level-of-service for other traffic?

## The methods used in the project:

Workshop discussions (used in all WP:s)
Simulations (Platooning coordination, CACC regulators, Business Case analysis, etc)
Tests in test rigs (V2V communication development and verification)
Real life vehicle experiments/tests (validation of V2V-communication and on-board control functions, Pilot drive, Demonstration on test track, etc)
Driver interviews/clinics (HMI investigation)

# 5. Objective

## The overall project goals

Demonstrate the feasibility of longitudinally controlled trucks from Scania and Volvo together with the haulage company Schenker (only longitudinal control of the truck is called cooperative adaptive cruise control, CACC)
Demonstrate platooning (both longitudinally and laterally controlled trucks) with trucks from Volvo and Scania at test site

## Goals/Deliveries per Work Package (WP)

**WP2 Use cases and safe cooperative functionality:**
Description of a common assumptions, functionality, interface and functional safety analysis.
Platooning scenarios including use of certain services, e.g. geofencing and match-making

**WP3 On-board functionality:**
On-board systems facilitating the pilot in WP5 and the demonstration in WP6

**WP4 Off-board functionality:**
Provide requirements and key performance indicators (KPIs), and investigate technical solution options for an architecture.
One implementation will be provided and used in the demonstration of WP6.
Documentation that explains why all choices were made regarding which functions and frameworks to develop and why they were designed in certain ways.

**WP5 Pilot and evaluation:**
Evaluation of longitudinal control of the vehicles

**WP6 Demonstration:**
Demonstration of coordinated platooning with longitudinal and lateral control.

**WP7 Business model for platooning:**
Documentation of the business aspects of platooning.

**WP8 Dissemination:**
Workshops.
Publications.
Concepts and evaluations for standardization.

# 6. Results and deliverables

## Programme relevance for TSAF

In the TSAF's program, the project fits very well to the Safety and Automation Concept 2 dealing with the predictive and connected vehicle, which aims at commercialization of research results in the time frame 2020-2025. Several program areas are included in the project:

- Functional safety aspects of new transport solutions (Program Area A)
- Studies and evaluation of the interaction between driver and the system (Program Area A)
- Research on HMI (Program Area D)
- Cooperative system (Program Area B)
- Partial automation on public road (Program Area E)

## Programme relevance for EUTS

The research areas which are most applicable to our project in the EUTS' program are Automation and Connected Services.

The project has contributed to point 1 for Automation – Milestone 2020 through our pilot which was carried out at one of our customers in real life conditions. We have also looked at a business model and standards for platooning.

The project also contributed to point 1 for Connected Services – Milestone 2020 because the coordination of vehicles to form platoons can also be used to coordinate goods and enable re-loading of goods from one of the vehicles to the other.
The work has also contributed to point 2 for Connected Services – Milestone 2020 through the development of advanced control algorithms for vehicle control and safe communication.

The project was evaluated through the demonstration of platooning with lateral control on test track and the pilot which was done at a customer in real life conditions where a Scania and a Volvo platooned during real transport assignments on public roads.

## Results

**Tangible results from the project**:

- Standardized platooning application to facilitate interoperability between different brands
    - Initialization of standardization work on the wireless communication aspects within ETSI TC ITS
    - Initialization of standardization work on the functional safety aspects within ISO
- Knowledge on the needs and economic values for different platooning related services such as mechanisms for the formation of a platoon has been built
- Knowledge on how to select business model for a platooning application has increased
- Pilot of CACC (longitudinal control) together with the Swedish haulage company Nordanå Transport AB doing transportation for DHL
- Demonstration of platooning (both lateral and longitudinal control of trucks) was successfully performed and documented (video)
- Functional safety concept has been developed and analysed

- 1 PhD dissertation: S. van de Hoef, “Coordination of Heavy-Duty Vehicle Platooning”, http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-225109
- 1 licentiate thesis: Not yet achieved. Planned to be met during year 2020.

**Results per Work Package (WP):**

**WP2 Use cases and safe cooperative functionality:**

Goal: Description of a common assumptions, functionality, interface and functional safety analysis:

- Use Case description report (mainly for project internal use)
- Functional Safety analysis report, (mainly for project internal use)

Platooning scenarios including use of certain services, e.g. geofencing and match-making:

- Use Case description report (mainly for project internal use)

**WP3 On-board functionality:**

Goal: On-board systems facilitating the pilot in WP5 and the demonstration in WP6

- Functionality implemented by Scania and Volvo separately (only for company internal use).

**WP4 Off-board functionality:**

Goal: Provide requirements and key performance indicators (KPIs), and investigate technical solution options for an architecture:

- Still to be finished during 2020.

Goal: One implementation will be provided and used in the demonstration of WP6:

- Implementation done by KTH, Volvo and Scania (only for project internal use).

Goal: Documentation that explains why all choices were made regarding which functions and frameworks to develop and why they were designed in certain ways:

- Still to be finished during 2020

**WP5 Pilot and evaluation:**

Goal: Evaluation of longitudinal control of the vehicles:

- Evaluation performed by Scania and Volvo separately (only for company internal use).

**WP6 Demonstration:**

Goal: Demonstration of coordinated platooning with longitudinal and lateral control:

- Performed at Astazero December 2019. Video produced and this will be publicly shown.

**WP7 Business model for platooning**:

Goal: Documentation of the business aspects of platooning:

- A report will be published in near future, which discusses the business potential of platooning, models of cost and benefit, mechanisms for platoon formation and driving, and the necessary services.

**WP8 Dissemination**:

Workshops within project:

- Nine face to face WS has been held in different WPs during the project
- More than 20 WS over Skype has been held in different WPs during the project
- At four occasions Scania and Volvo engineers have gathered and tested V2V-communication in test rigs
- At six occasions driving tests is performed (most of them on test tracks) with engineers from Scania and Volvo working together.

Publications:

- See chapter 7.2

Concepts and evaluations for standardization:

- The Sweden4Platooning V2V-communication protocol is documented and distributed to the ENSEMBLE project for acceptance and as a base for further development within that project.

# 7. Dissemination and publications

## 7.1 Dissemination

This report lists the dissemination activities (WP8) in the Sweden for platooning project. In summary we have made significant impact on the European project ENSEMBLE https://platooningensemble.eu and we have participated in international standardization efforts. Results from the project has been published (or submitted) to 10 international conferences or journals. Over 20 presentations have been held worldwide. And we made a press release in Oct 2017. In March 2020 we will organize a project conference in Stockholm, program and registration can be found here: https://sites.google.com/view/s4pcc

| How are the project results planned to be used and disseminated? | Mark with X | Comment |
|---|---|---|
| Increase knowledge in the field | X | 1) Specifying and analysing the platooning use cases and making the safety analysis of it.<br>2) Running the platooning functionalities on open road and real operation has significantly increased the robustness of the inter-operability, and the understanding of what is missing.<br>It cover multi brand platooning, but also on multi brand functions like C-ACC.<br>3) The platooning business case study performed within the project has increased the knowledge at the participating partners and there will be a public article released for other to learn from. |
| Be passed on to other advanced technological development projects | X | The project made a major input to the EU project Ensemble of the V2V concept among other results from the S4P and Ensemble is now a continuation of this work with all OEMs in Europe and a lot of other stakeholders involved. |
| Be passed on to product development projects | X | Parts of the result will be used within both Volvo and Scania as support in different development projects using V2V communication technique. |
| Introduced on the market | | Not introduced on the market yet. |
| Used in investigations / regulatory / licensing / political decisions | (X) | Trafikverket has been an active partner in S4P and even if we at this stage can´t point out a specific investigation or regulation that have been affected, at least awareness has increased at Trafikverket. |

## 7.2 Publications

### Presentations and lectures

1. FFI Resultatkonferens inom Trafiksäkerhet och autonoma fordon, Poster, 2017-09-17, Göteborg.

2. Marstrand Match Cup event presentation, DB Schenker, 2018-07-05.
3. Logistik och Transport event presentation, DB Schenker, 2017-12.
4. Projektpresentationsdag - FFI Effektiva och uppkopplade transportsystem, FIFFI och BADA. 2018-11-20, Jan Dellrud
5. Platooning- status of current projects in Sweden, Possible barriers, opportunities, next steps. 20 November 2018 EUROPEAN TRUCK PLATOONING CHALLENGE, NETWORK WORKSHOP, Hamid Zarghampour
6. Resultatkonferens Energiforsk 3 dec 2019, invited lecture, Jonas Mårtensson KTH.
7. NTU-NXP Smart Mobility Conference, Singapore, Oct 2018, Jonas Mårtensson KTH.
8. IEEE Smart City Summer School, Singapore, Lecture, Jan 2017, Jonas Mårtensson KTH.
9. Chalmers, Department of Electrical Engineering, Lecture, Apr 2018 and Feb 2019, Jonas Mårtensson, KTH.
10. Skogforsk, samverkansgruppen för transportteknik, seminarium, Apr 2019, Jonas Mårtensson KTH
11. WASP Winter Conference, Jan 2018, Jonas Mårtensson KTH
12. IEEE CSS Distinguished Lecture, Lodz, Poland, 2019, K H Johansson KTH
13. Workshop on Connected and Automated Vehicles for Energy Efficiency and Environmental Impact, IFPEN, Paris, France, 2019, K H Johansson KTH
14. IFAC Workshop on Control of Transportation Systems, Haifa, Israel, 2019, K H Johansson KTH
15. IAVSD Workshop on Dynamics of Road Vehicles, Ann Arbor, Michigan, USA, 2019, K H Johansson KTH
16. ETH Distinguished Seminar in Robotics, Systems and Control, Zurich, Switzerland, 2019, K H Johansson KTH
17. Institute for Pure and Applied Mathematics (IPAM) Workshop on Autonomous Vehicles, UCLA, USA, 2019, K H Johansson KTH
18. Harry Nicholson Distinguished Lecture in Control Engineering, University of Sheffield, 2018 , K H Johansson KTH
19. Department of Electrical and Electronic Engineering, The University of Hong Kong, 2018, K H Johansson KTH
20. Institute of Transportation Studies Seminar, UC Berkeley, 2017, K H Johansson KTH

## Press releases

1. Pressrelease, DB Schenker, 2017-10-19: https://www.consulting.dbschenker.se/co-se/innovation/sweden-4-platooning ; https://www.scania.com/group/en/scania-takes-part-in-multi-brand-platooning-project/ https://www.volvogroup.com/en-en/news/2017/oct/trucks-talking-to-each-other-in-multi-brand-platooning-project.html https://www.sics.se/media/news/trucks-talking-to-each-other-in-multi-brand-platooning-project https://www.kth.se/forskning/artiklar/kth-hjalper-volvo-och-scania-att-kommunicera-1.765684 https://www.trafikverket.se/om-oss/nyheter/Nationellt/2017-10/konvojkorning-sparar-drivmedel/
2. Nordanå Transport AB Homepage 2019-12-03: https://nordanatransport.se/nyheter/transportforskning/

## Publications

1. S. van de Hoef, “Coordination of Heavy-Duty Vehicle Platooning” (PhD dissertation). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-225109

2. S. Van De Hoef, J. Mårtensson, D. V. Dimarogonas, and K. H. Johansson. 2019. “A Predictive Framework for Dynamic Heavy-Duty Vehicle Platoon Coordination”. ACM Transactions on Cyber-Physical Systems. Vol 4, nr 1, Nov 2019. DOI: https://doi.org/10.1145/3299110
3. J. Axelsson and A. Kobetski, "Towards a risk analysis method for systems-of-systems based on systems thinking," 2018 Annual IEEE International Systems Conference (SysCon), Vancouver, BC, Canada, 2018, pp. 300-307. doi: 10.1109/SYSCON.2018.8369501.
4. J. Axelsson, "An initial analysis of operational emergent properties in a platooning system-of-systems," 2018 Annual IEEE International Systems Conference (SysCon), Vancouver, BC, Canada, 2018, pp. 308-315. doi: 10.1109/SYSCON.2018.8369506.
5. A. Johansson and J. Mårtensson, "Game Theoretic Models for Profit-Sharing in Multi-fleet Platoons," 2019 IEEE Intelligent Transportation Systems Conference (ITSC), Auckland, New Zealand, 2019, pp. 3019-3024, DOI: 10.1109/ITSC.2019.8917349
4. A. Johansson, E. Nekouei, K. H. Johansson, and J. Mårtensson, “Multi-fleet platoon matching: A game-theoretic approach,” 2018 21st International Conference on Intelligent Transportation Systems (ITSC), pp. 2980–2985, Nov 2018, DOI: 10.1109/ITSC.2018.8569379
6. J. Axelsson, “Business Models and Roles for Mediating Services in a Truck Platooning System-of-Systems,” in IEEE Systems of Systems Conference, Orlando, Florida, 2019, pp. 113–118. DOI: 10.1109/SYSOSE.2019.8753887
7. J. Axelsson, T. Bergh, A. Johansson, B. Mårdberg, P. Svenson, V. Åkesson, ”Truck Platooning Business Case Analysis”, RISE Technical report 2020.

## Pending publication

8. A. Johansson, V.Turri, E. Nekouei, K. H. Johansson, and J. Mårtensson, “Truck Platoon Formation at Hubs: An Optimal Release Time Rule” submitted to IFAC 2020. Berlin 2020.
9. A. Johansson, E. Nekouei, K. H. Johansson, and J. Mårtensson, “Strategic Hub-Based Platoon Coordination Under Uncertain Traveling Times” submitted to IEEE Transactions on Intelligent Transportation Systems.
10. M. El-Hawwary and J. Mårtensson, “Distributing Potential Games on Graphs Part I. Game formulation” submitted to IFAC 2020. Berlin 2020.
11. M. El-Hawwary and J. Mårtensson, “Distributing Potential Games on Graphs Part II. Learning with application to platoon matching” submitted to IFAC 2020. Berlin 2020.

# 8. Conclusions and future research

## Conclusions:

The Sweden4Platooning has reach almost all goals and deliverables what were planned from start and mentioned in the application. There is still some research work to be done during 2020 within the WP4 Offboard work package. The EUTS part of the project will carry until 31st of December 2020 to complete the deliverables and to fill all goals.

The project work is considered, among the project partners, to have been very successful and the knowledge has grown from day one and during the complete project. The obstacles that arise during the project was handled and solved in good cooperation between the partners.

## Future research:

More research in the area of Platooning with manually driven lead vehicle and unmanned follower vehicles is of very high interest and would really contribute to more efficient transportation of goods in a relatively near future.

# 9. Participating parties and contact persons

List of partners in the Sweden4Platooning project:

| Partner | Org.number | Contact person | Email address |
|---|---|---|---|
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| DB Schenker AB | 556250-3630 | Viktor Åkesson | viktor.akesson@dbschenker.com |
| Trafikverket | 202100-6297 | Hamid Zarghampour | hamid.zarghampour@trafikverket.se |

**Other cooperation's:**
Anders Clarén, CEO at Nordanå Transport AB, helped with preparing and performing the platooning pilot (in cooperation with DHL), even though Nordanå was not an official project partner.