Born to Drive

Public report

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Projekt inom Effektiva och uppkopplade transportsystem

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

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För närvarande finns fem delprogram; Energi & Miljö, Trafiksäkerhet och automatiserade fordon, Elektronik, mjukvara och kommunikation, Hållbar produktion och Effektiva och uppkopplade transportsystem. Läs mer på www.vinnova.se/ffi.

1 Summary

The Born to Drive project took place between 2015 and 2018 and included eight different companies/institutions with over fifty personnel involved. The institutions/companies involved were Actia, Combitech, Consat, Semcon, Trafikverket, RISE, Volvo Cars and VTI combined their competence into creating and showcasing a concept called autonomous transportation.

The primary focus was to support the FFI program “Efficient and Connected Transport Systems” but due to the project nature, it has spanned over almost all of the FFI programs including many of the sub programs. The project has contributed towards the FFI “Efficient and Connected Transport Systems” goals through enabling the following; less risk for human injuries, decreased number of movements of vehicles and a reduced lead time in the logistics process.

The autonomous transport concept is defined as a combination of the capabilities for the Autonomous Driving (AD) and Automated Guided Vehicle (AGV). These combined gives a concept where a vehicle can move itself through for example a logistics process being supported by traffic control systems, These support the movement with logic and intelligence which is then not required to be located in the vehicle. This reduces the requirements on how much capabilities that the vehicle require which means that the penetration rate becomes higher. The goal of the project was to use an existing production car without extra sensors to prove this.

The autonomous transport concept and demonstration consisted of being able to create a solution within a “gated” area where a production vehicle would transport itself through the logistic flow using a traffic control support system together with the already existing capabilities of the vehicle. This was demonstrated at both Semcon and Volvo Cars Logistics premises with a good success. The demonstration consisted of showing a number of different flows which included, interaction between traffic control and vehicle, sending a transport mission to the vehicle but also executing the transport mission. During these demonstrations, the different benefits were also discussed and there were at least thirteen of these that were found.

The project included a number of different work packages with the goal of tackling as many questions as possible around this concept. That included both creating a technical concept as well as proving as well as investigating the current legal situation for this area. The investigated management principles for how to govern open innovation alliances performing R&D. Another point that was investigated was also the future infrastructure questions related to leaving the “gated” area. The outcome of these meant that it most likely would be possible to conduct this outside the “gated” area but more research were required. Some topics that came up was that the legal framework wasn’t clear on this topic as well as it needed to be investigated how other existing traffic would be impacted by these vehicle once they start to move on public roads.

2 Sammanfattning på Svenska (summary in Swedish)

Projektet Born to Drive ägde rum mellan 2015 och 2018 och omfattade åtta olika företag/institutioner med över femtio anställda. De berörda institutionerna/företagen var Actia, Combitech, Consat, Semcon, Trafikverket, RISE, Volvo Cars och VTI kombinerat sin kompetens för att skapa och visa upp ett koncept kallat autonom transport.

Det primära fokuset var att stödja FFI-programmet "Effektiva och anslutna transportsystem" men på grund av projektets natur har det spänt över nästan alla FFI-programmen inklusive många av delprogrammen. Projektet har bidragit till FFI-målen "Effektiv och ansluten transportsystem" genom att möjliggöra följande: mindre risk för personskador, minskat antal rörelser av fordon och minskad ledtid i logistikprocessen.

Det autonoma transportkonceptet som tagits fram i projektet definieras som en kombination av möjligheterna till autonom körning (AD) och ”automatic guided vehicle” (AGV). Dessa kombinerade ger ett koncept där ett fordon kan flytta sig genom exempelvis en logistikprocess som stöds av trafikstyrningssystem. Dessa stöder rörelsen med logik och intelligens som då inte behöver vara helt placerad i fordonet. Detta minskar kraven på hur mycket kapacitet som fordonen kräver vilket innebär att penetrationshastigheten blir högre. Projektets mål var att använda en befintlig produktionsbil utan extra sensorer för att bevisa detta.

Det autonoma transportkonceptet och demonstrationen bestod av att kunna skapa en lösning inom ett "gated" område där ett produktionsfordon skulle transportera sig genom logistikflödet med hjälp av ett trafikstyrningssystem tillsammans med fordonets befintliga kapacitet. Detta visades på både Semcon och Volvo Cars Logistics områden med en bra framgång. Demonstrationen bestod av att visa ett antal olika flöden som inkluderade, interaktion mellan trafikstyrning och fordon, sändning av ett transportuppdrag till fordonet, men också genomförande av transportuppdraget. Vid dessa demonstrationer diskuterades också de olika fördelarna och det var åtminstone tretton av dessa som hittades.

Projektet omfattade ett antal olika arbetspaket med målet att ta itu med så många frågor som möjligt kring detta koncept. Det innebar både att skapa ett tekniskt koncept såväl som bevisa och undersöka den nuvarande rättsliga situationen för detta område. Projektet studerade även styrprinciper för hur leda konsortium för öppen digital innovation. En annan punkt som undersöktes var också de framtida infrastrukturfrågorna i samband med att lämna det inhägnade området. Resultatet av dessa innebar att det troligen skulle vara möjligt att utföra detta utanför den inhägnade området men mer forskning krävdes. Några ämnen som kom fram var att den rättsliga ramen inte var tydlig i detta ämne, och det var nödvändigt att undersöka hur annan befintlig trafik skulle påverkas av dessa fordon när de började flytta på allmänna vägar.

3 Background

The trend is the same the world over, digitalization and automation are leaving an ever-greater mark on more and more activities in society. Highly automated manufacturing is nothing new where for example many factories today use a high level of Automated Guided Vehicles (AGV), but the level of automation is now rapidly increasing in the distribution channel. At the same time, car manufacturers (OEMs) are working on producing cars with different levels of Autonomous Vehicle Technologies (AVT), which enables some Autonomous Driving (AD). The main focus for these functions has been towards end-customers and functions such as increased safety as well as the convenience and freedom of choosing what to do during their travel time. Society benefits from a more efficient traffic system and assumes a smaller environmental impact through optimized fuel consumption.

Born to Drive's (BtoD) vision is to take these technologies to yet another level and practical application. Using the technical expertise already available today, Born to Drive will be used as a test arena for the new expertise required for business structures, legal aspects and user perspectives. At the same time, the project has established a new concept called Autonomous Transportation, Figure 1, which is a mix of the previous mentioned technologies.

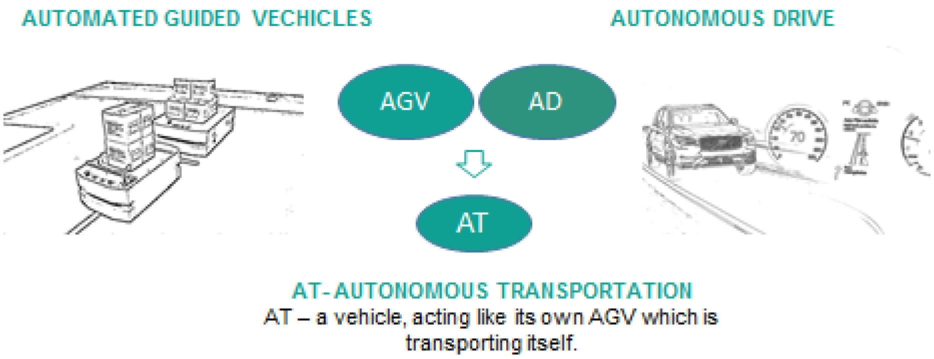

Figure 1: Definition of Autonomous Transportation

Sweden's ambition is to take the lead in terms of developing automated transport systems where Born to Drive has created expertise within this area through an early and limited application. Which provided valuable lessons and experience to other projects in the field, not least the strategic innovation program, Drive Sweden.

This project is the first of a planned series of projects, where the long term goal is to let production vehicles autonomously drive the entire path from factory to ship/train/carrier truck for further transportation throughout the world. In this first project, the aim is to demonstrate the possibility of autonomous transport of production cars from the factory to the factory parking lot for further transport by cargo train and carrier truck. This includes both prototypes of self-driving vehicles, control system as well as rules and regulations for implementation.

The long-term goal of the Born to Drive is to create a logistic system that enables fully autonomous displacement of production vehicles, from factory to onboard ship/cargo train/carrier truck. This is also described as the overall project "Vision".

4 Purpose, research issues and methods

The Born to Drive project was initiated by the ambition to create an early adaptation of Autonomous Transportation for the outbound logistic organization at Volvo Cars Cooperation which was executed by Actia, Combitech, Consat, Semcon, Trafikverket, RISE, Volvo Cars and VTI, .

Given the fact that the project is working on innovating a new concept related to autonomous transportation. A lot of effort was put into getting a good understanding of the current logistical process.

The project was divided into eight different work packages:

- WP1 - Requirements and scenarios description
- WP2 - Development and implementation of new functionality
- WP3 - Vehicle adaptations
- WP4 - Traffic management system
- WP5 - Test and Demonstration
- WP6 - Regulatory framework and infrastructure
- WP7 - Founding of consortium, implementation and management of innovation barriers
- WP8 - Project management and coordination

The project and all the work packages has been characterized by a process where a number of participants from the different companies were involved in different tasks such as both workshops and development. Since the focus was to create and demonstrate something utilizing a real production vehicle, the focus was on hands-on work as well.
The process has been successful and lead to the fact that each participant shared their competence with the others. This developed a deeper insight into the different technologies as well a broader contact network between different participants working within the automotive cluster in Gothenburg.

Initially, the project was impacted by delays related to the late startup decision at Vinnova but this delay was later on caught up

5 Goal

The goal of the Born to Drive was to strengthen the Swedish automotive industry capability to work with autonomous transportation solutions. During this first project, the focus was on the logistics and steering of fleets of vehicles. This competence was to be used in a system for managing the autonomous transportation of the vehicles. The overall goals for this project were;

- Create and demonstrate a concept related to the production which transports itself within the factory area with TRL level 3 to 4
- To a significant degree increase the competence within the participating companies and gain international interest.
- Engage small and medium sized companies with different competencies thus increasing the competence exchange.
- Engage research within institutes through the application orientated focus of the project
- Create an interest within the logistic organizations/companies by showcasing the possibilities of automation

The focus is also to support the roadmap of the "Efficient and Connected transport systems"" which included:

- Contribute to increasing the efficiency of the flow for the vehicle in the outbound logistic process thus decreasing the environmental impact
- Increase the security in the transportation flow
- Increase the competence and competitiveness of the Swedish automotive industry (both with the OEM and consultant companies)
- Raise the image, status and attract new people to the transportation industry

6 Result and goal fullfillment

6.1 Delivery to FFI – Goals

The Born to Drive project has been focusing on finding new ways of utilizing automation technologies within the logistic process for existing vehicle technologies. The primary focus was to support the FFI program "Efficient and Connected Transport Systems" but due to the project nature, it has spanned over almost all of the FFI programs including many of the sub programs. Many of the ideas and findings could also be applied on the other FFI programs and touch the subsequent program goals. The only exception which was not covered was the FFI "Energy and Environment" program.

The project has contributed towards the FFI "Efficient and Connected Transport Systems" through first establishing a viable requirement baseline which lead to a concept which manages the movement of the vehicles through the logistics process. This leads to less risk for human injuries, decreased number of movements of vehicles and a reduced lead time. This combined with the focus on using existing vehicle capabilities hence using already developed functionality in a new way.
Another add-on was that the concept was also shared with the designers of the road system of tomorrow hence giving them insights on how a minor autonomous transportation system was established.

The project supports the strategy for the FFI program "Sustainable Production" by finding ways to improve the quality for the future logistics flow and reducing the lead time for moving the vehicles. The findings is that it will also increase the flexibility in the logistics process.

Born to Drive has also contributed towards the FFI program "Electronics, software and communication". Both the findings of the WP2, WP3 and WP5 could be applied here where the development has been done between several different companies compared to the normal product development process. This has led to new ways of developing and sharing the concepts as well as idea on how the future electrical architecture for the vehicles could be used.

The project has contributed towards reaching the goals within the FFI program "Traffic safety and automated vehicles" through analyzing the safety factor in all the different parts of the autonomous transportation process. This has been an important factor since the overall goals has been to reduce the number of injuries as well as to increase the quality of the logistics process through combining the existing vehicle technologies enabling a new solution.

During the project, a number of workshops and work meetings has been held where the participants has been able to broaden their perspective and find new ways of applying the automation process on complex transport systems. This has both directly and indirectly contributed to the overall goals that the FFI has set.

6.2 Collaboration during project

During the project, a lot of focus were put into collaboration between the different involved parties. This was natural since the project was driven with a service minded focus and included many competing companies. Given this, it was important that work packages involved the different parties in order to facilitate a good cooperation. The structure of this can be seen in Table 1.

Work package	Involved parties
1. Requirements and scenarios description	Combitech, **Consat**, Semcon, RISE, Volvo Cars

2. Development and implementation of new functionality	Actia, Combitech, Consat, **Semcon**, RISE, Volvo Cars
3. Vehicle adaptations	Actia, Combitech, Consat, Semcon, RISE, **Volvo Cars**
4. Traffic management system	**Consat**, RISE, Volvo Cars,
5. Test and Demonstration	Combitech, **Semcon**, RISE
6. Regulatory framework and infrastructure	Combitech, Consat, Semcon, Trafikverket, RISE, Volvo Cars, **VTI**
7. Consortium management of innovation barriers	Actia, Combitech, Consat, Semcon, **RISE**, Volvo Cars
8. Project management and coordination	**Combitech**

Table 1: Cooperation in work packages

The work in the different packages have been performed in cross functional teams where experts from different areas have combined their competence into the different deliverables. Technology readiness level (TRL) was used to coordinate the joint effort, to ensure innovation trajectory in the project. The project also adopted Action Design Research to govern the R&D work performed, especially in work package 1-5. The elicit of complimentary principles to manage the joint R&D in the project is presented in section 6.8 in this report.

Table 2 summarizes the R&D process by pointing out key events mapped to the project phases, timeline and the evolution of the BtoD-CPS (cyber-physical system) prototype against the TRL scale[1].

Time-line	Phase	Account of Key Events	TRL progress
Spring-Fall 2015	Explorative study	In spring of 2015 the BtoD idea was identified by participants in the open innovation arena VICTA. An explorative study staffed by the participants developed a design vision that indicated autonomous vehicle technology as an opportunity to transform manual driven movements to a driverless automotive logistic chain of movements. The conceptualized idea was rated as TRL 1.	1
		Establishment of the R&D consortium and securing project funding	
Spring 2016	Concepts design	With the design vision as point of departure, the open innovation alliance researched empirical, theoretical sources and state-of-art technologies, and developed three alternative concepts for a BtoD-CPS prototype. A set of criteria to assess the concepts was researched in parallel using literature, as well as intended customer requirements, as base. The outcome was a defined assessment model	1→2
	Concept selection and refinement	Using the grounded assessment model one of the three concept designs were selected. The selected concept was refined based on constraints and opportunities identified. It was by summer 2016 awarded TRL 2.	2
Fall 2016	Component building	Systems engineers from five of eight open alliance partners formed, together with a researcher from one of the participating research institutes, three development teams, each with specific responsibilities. The car team developed and assessed the autonomous transport component to be integrated in the cars on-board control unit. The traffic control team developed the intelligent traffic component that define the autonomous transport route (based on data from a legacy logistic system), coordinate vehicle transitions and informs the logistic system about the status of the vehicle. The connectivity team developed a communication protocol to ensure that a BtoD-CPS enabled car could receive orders, feedback data about progress and be coordinated by the traffic control system.	2→3

[1] *Hjalmarsson A., (forth) Managing Action Design Research: Developing Principles from Cyber-Physical Systems R&D. Submitted and Accepted for presentation at SIGPRAG 2018*

	System and vehicle integration	The work streams performed by the parallel teams were combined during the fall of 2016 through an integration task aiming to link the components in the solution prototype to a complete system; including integration of the system in a test car made available to the project. The integration resulted in a need to refine and improve individual components. However, in the end of 2016 the concept was proofed, and the BtoD-CPS prototype was rated TRL 3.	3
Spring 2017	Test of vehicle integrated prototype	The test vehicle with the integrated autonomous transport prototype and the connected traffic control components was tested on an experimental area.	3→4
	Refinement of prototype and concept design expansion	Continual testing of the system integrated in the vehicle generated requirements to refine the autonomous transport algorithms and enhance the graphical interface for the traffic control system. The prototype was validated and successfully operated in 100 trials. In parallel to the technology refinement, the concept was with a business case for industrialisation and an explorative investigation into legislative and regulative issues regarding autonomous transport in restricted areas.	3→4
Fall 2017	Demonstration of finalized systems prototype in real environment	The research and innovation project was concluded with four closed demonstrations of the BtoD-CPS prototype in its short-term environment, followed by an open demonstration of the solution accessible to invited stakeholders, press and media. The steering group of the project defined that the prototype at this stage had reach TRL 4; i.e. the target level for the project (with parts of fulfilment needed for level 5 status).	4 (→5)

Table 2: Project Process: Timeline, Account of Events and TRL progress

6.3 How the vehicle is moved today

As a part of the Born to Drive project, the focus was also to create a baseline on how the existing yard is being managed and how the potential customer (Volvo Cars Logistics) would benefit from such a solution.

The cars produced at VCT are destined for a variety of destinations, both domestic and international. When a vehicle has reached its completion in the factory, it enters a state called Factory Complete (FC), as the car is driven off the production line in the factory building and out onto the yard, to a nearby handover location called Drop Plan or “Droppen”. This process is carried out by factory personnel working in teams to move the vehicles which is then later on picked up and moved onwards using carriers. This can be carriers such as trains, trucks and boats. This process is depicted in Figure 2.

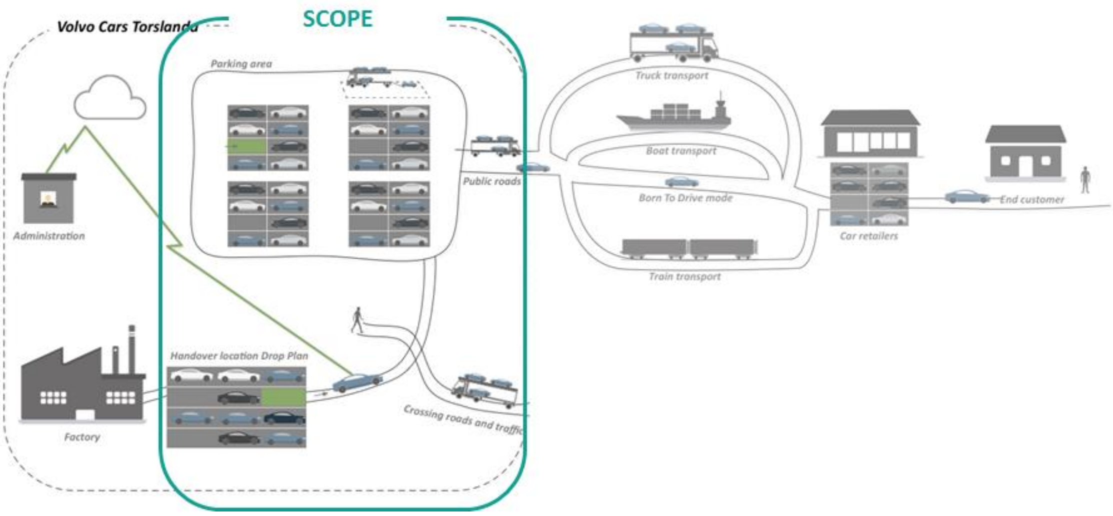

Figure 2: Existing logistics process targeted by the Born to Drive project

A small amount of cars, such as Polestar vehicles, the XC90 Executive and commercial vehicles are finalized with extra features by Special Vehicle Services(SVS). SVS also serves as an internal workshop for damaged vehicles.

Some cars produced outside of the Torslanda factory which are aimed for the Swedish market are also managed in the same area. These cars arrive to Gothenburg by RORO ships and are transported to the yard by carrier trucks. Gent cars are dropped off at a handover location called Drip Plan or simply "Drippen" (marked *DRIP* on the map). The carriers are responsible for unloading the trucks and parking the Gent cars on the Drip Plan. Hence, three handover locations for FC cars exist (*DROP, SVS, DRIP*), depending on their origin.

These need to be available for the different types of logistical missions that are carried out. Some of these missions are:

- Onward movement of the car from the factory drop off point
- Movement of vehicles to/from SVS
- Reallocation of vehicles in the yard

In the Figure 3 depicting the yard, there are a number of different actors working with the onwards transportation of the produced cars.

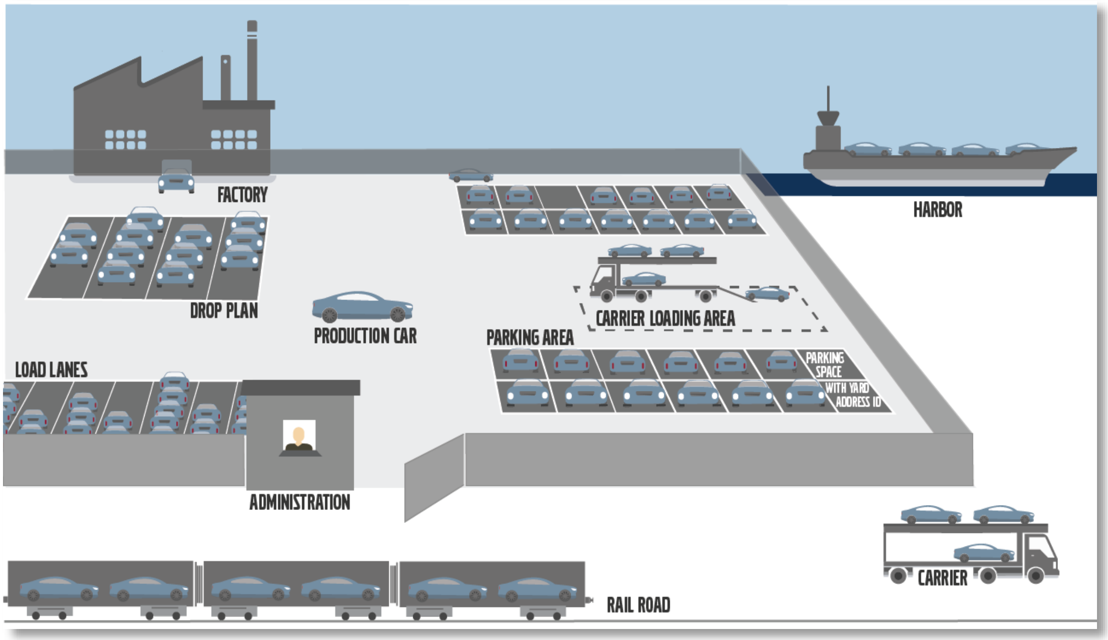

Figure 3: Yard actors

The main and possible future actors working with the transportation are:

- Ranger: Responsible for transport production cars from hand over location to various parking areas and parking spaces accessed through scanning using a hand held device.
- Carrier Truck: Collect production cars from hand over location (Drop Plan) load lanes, loading spaces and various parking areas.
- Administration: Include logistics and distribution of the whole yard, possible introduction of a new system for the solution, and current systems used ATACQ (Answer to all Car Questions) and TMS (Transport Management System).
- Future BtoD vehicle: Include a possible future BtoD vehicle with extended functionality from today's cars such as a BtoD signal or status that can be sent between the systems but also for user interaction and feedback.
- Factory – Product driver: Responsible for transporting the production cars from the end of production line to the handover location Drop Plan.

Based on this, the different requirements from the different stakeholders were documented as in Figure 4.

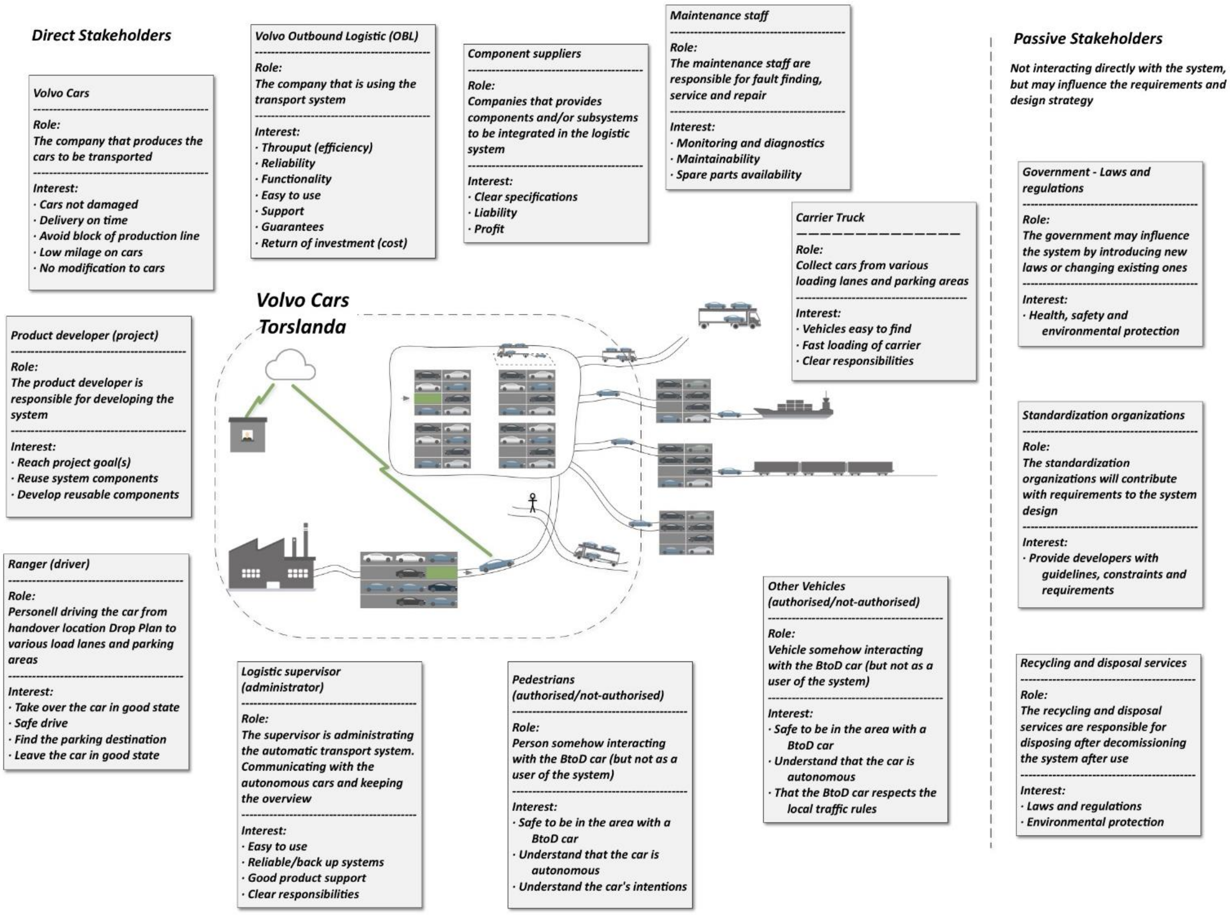

Figure 4: Illustration of the logistic system at Torslanda, at its stakeholders

As seen in the previous figure, different stakeholders have different requirements/needs from the future autonomous transportation system. Besides this, there are also a number of non-functional aspects that needed to was identified:

- The potential concept needs to work during different weather conditions (snow, rain, sun, ice)
- The cost per car needs to be kept low
- The aspect of vehicle covers should be included
- Be able to manage the laws and regulations
- Industrialization would need to be possible in a near future (2021-2022)

This input from this activity were than used as input to the subsequent work packages in the form of requirements and demands from the future customer.

6.4 How can the car be moved in the future

Through the project, many different possible solutions were discussed and evaluated in order to find a futureproof concept. As a part of this, it was clear that three key components were needed in order to facilitate the solution. These were:

- Traffic control
- Logistics system
- Vehicle

These can be seen in Figure 5.

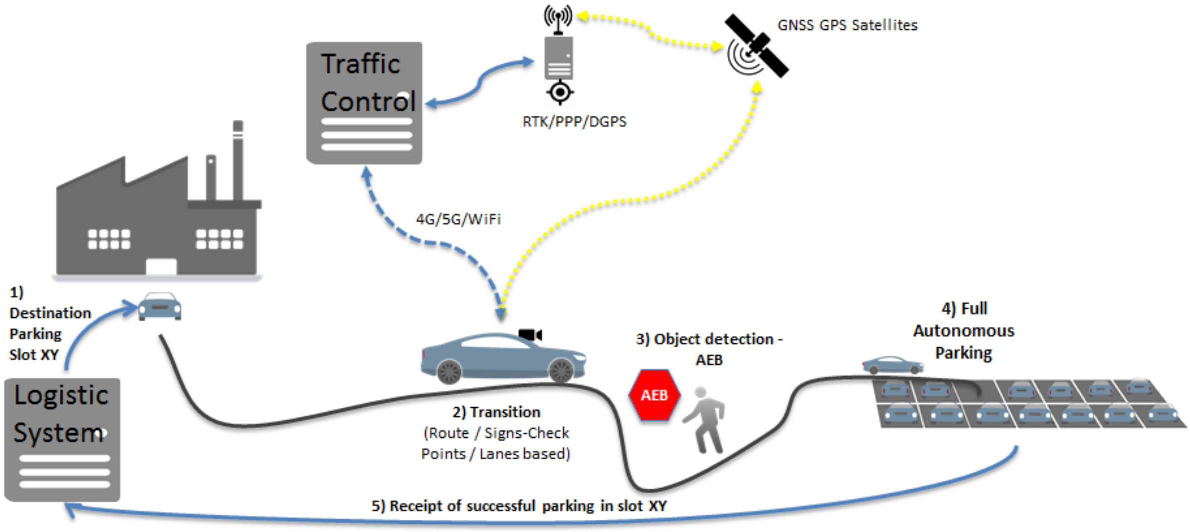

Figure 5: Short overview of selected movement flow

In the figure above, the different components can be seen together with the corresponding interaction between these. The main idea is that the traffic control and logistics system interacts with each other while the traffic control maintains the control over the autonomous transport of the vehicle.
During the project, reference architectures and software were created in order to facilitate the mentioned functionality.

Traffic control
The traffic control maintains the transport missions and ensures some of the following;

- Receive and send information to the logistics system related to transport missions. This would form transport mission which instruct the vehicle to move from position A to B.
- Tracking of vehicles
- Plan & monitor traffic environment
- Support in movement of the vehicle

A graphical representation of the traffic control UI is available in Figure 6.

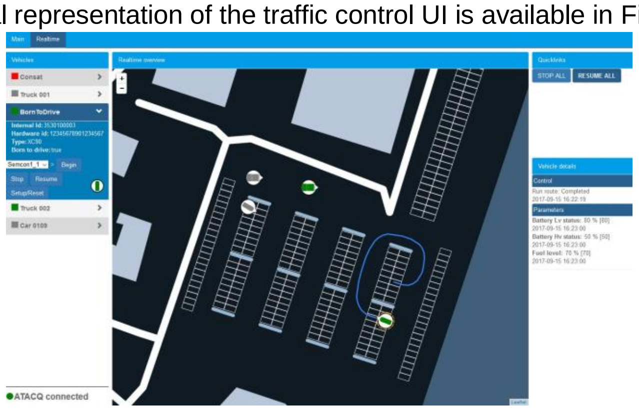

Figure 6: Graphical representation of the traffic control UI

Logistics system

This system maintains the necessary logistical information for example;

- Type of vehicle
- Destination of vehicle:
- Other manufacturer information

The idea with this is that each logistical organization today already has an existing system for this. Through this integration to their system, there would be little impact of the logistical organization.

Vehicle

Each vehicle in the system keeps track of its own position and maintains the communication to the traffic control system. This is possible by adding Born to Drive software which uses the vehicles existing capabilities of the vehicle such as sensors and 3G/4G communication.

6.5 Demonstration

Given the focus of the project which was to build and show the possibilities, it was important to host demonstration that fulfilled the project goals. Some criteria's that were fulfilled during the demonstration;

- Demonstrate that autonomous transportation is possible without a driver present
- Demonstrate several use cases applicable within the logistic flow
- Show the steps towards industrialization
- Show the systems included in the movement

The demonstrations were also performed at different locations;

- Lindholmen, Gothenburg at Semcon premises – this location was used during development as well as during the public demonstrations
- Volvo Cars yard, Torslanda – several live demonstrations was conducted here to show how it would work in the real logistic process

Demonstration area at Volvo:

The demonstrations consisted of the following maneuvers:

1. The Vehicle and Traffic control initated contact with each other and the traffic control ordered the vehicle to move from the start position to a parking spot. This transport mission replicates how a vehicle is moved today.

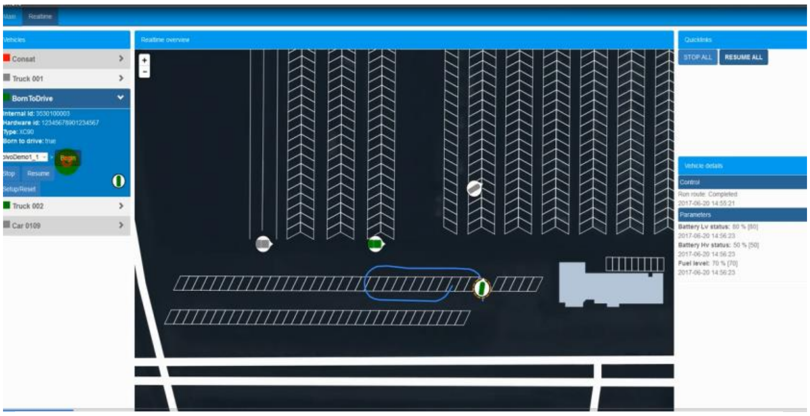

Figure 7: Traffic control orders the vehicle to move to finish position

2. The vehicle executes the transport mission and remains in contact during the full flow with the traffic control. Dual handshake takes place to ensure that the vehicle will stop if there are any issues with connectivity. The movement of the vehicle is displayed in Figure 8.

Figure 8: Autonomous transport of vehicle

3. During the full demonstration, the vehicle moves in an autonomous transportation move without any interaction with a driver. A view of how this looked like can be seen in Figure 9.

Figure 9: View from inside vehicle during demonstration

4. .During the demonstration, the vehicle is also exposed to a crash doll representing a pedestrian. This to show how the vehicle interacts with the surrounding environment. In the demonstration, the vehicle stops and wait for the dummy to be moved. Once it's moved, the vehicle syncs with the traffic control system and continues to execute the transport mission. This process is seen in Figure 10.

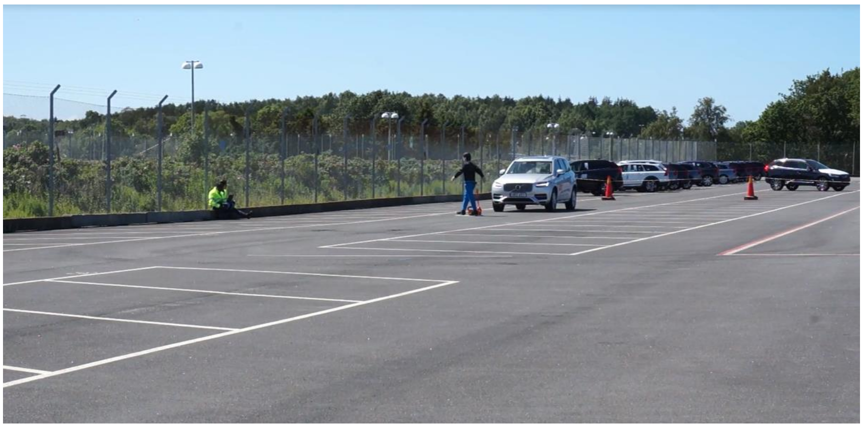

Figure 10: Stop for simulated pedestrian

5. In the end of the demonstration, the vehicle has moved to the parking spot that was pointed out in the transport mission. This can be seen in Figure 12.

Figure 12: Finish of transport mission

At the same time, the traffic control system is also notified about the success of the mission. This is seen in Figure 11.

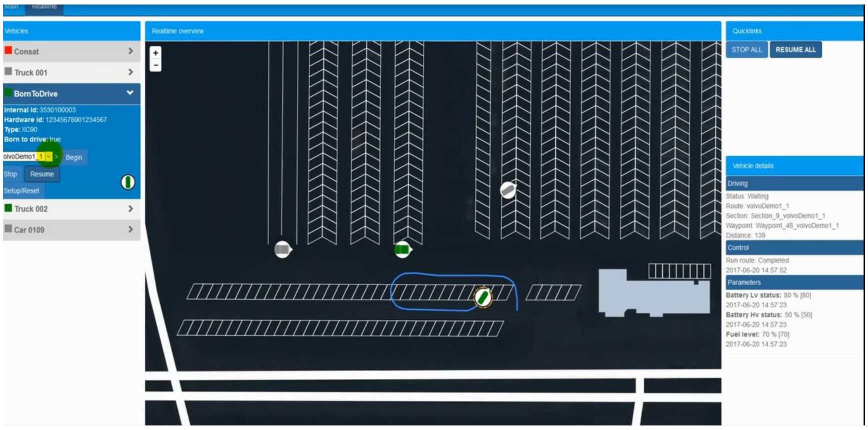

Figure 11: Vehicle notifies the traffic control about the success of the transport mission

In all of the demonstrations performed, the feedback was excellent and many good discussions/ideas came up as a part of this. In some of the demonstrations, media was also included which can be seen in section 7.3.

6.6 Legal aspects

During the project, the focus has been on movement inside the factory (“fenced”) area. However it was also investigated how the possibility would be to also move outside the “fenced” area and how this movement on the public roads would be impacted by the current laws.

Several legal concepts, terms and definitions were problematized such as "type approval", "fenced area" and "free-port area" as well as the definition of "machine". It can be noted that there is currently no legal framework that supports automated transportation. Current vehicles appear not to be covered by the regulatory framework closest to hand, that is to say type approval and machinery directive, by strict interpretation. To the extent that a somewhat stretched extensive interpretation makes one of the directives applicable, it falls to the fact that neither the technology nor the phenomenon itself (here referred to as automated logistics) is covered by what the legislator had in mind when the legislation was drafted. Legislation here refers to both national and EU law.

The regulatory framework which is being drafted and intended is, first, Directive 2007/46 / EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers and of systems, components and separate technical units intended for such vehicles (type approval directive 2007/46 / EC) and the basic health and safety regulations applicable to all machines placed on the market within the EU or put into operation for the first time (machine directive 2006/42 / EC). A very simplified description of the regulations is that the first directive, from the control and safety aspect, is traffic-oriented, and the other work environment-oriented.

As current vehicles are not covered by the Machinery Directive 2006/42 / EC, a thought experiment is presented in the part - a view of current vehicles as "virtual Automated Guided Vehicles (AGV)", transforming transformed vehicles into machines, at least in a figurative way. Such a legal design would be required to comply with the directive's objective of a high level of protection of health and safety in order for a machine to be released on the EU market, handed over to be put into service or put into service. In the absence of applicable legislation, "virtual AGVs" would be legally justified on the grounds that it enables implementation of the project's purpose while ensuring the protection of health and safety in accordance with or within the framework of relevant legislation. One problem, however, is that the requirements imposed on AGVs are not adapted to AGVs in traffic, i.e. by public road. Such a legal structure would thus be geographically restricted to the industrial area i.e “fenced area”. It would exclude the realization of the entire sequence of self-driving vehicles "from stock to location for further maritime, road or rail transport". The legal structure, if it is even possible, would therefore only solve part of the sequence of self-propelled vehicles, more specifically only when "virtual AGVs" are in the industrial field.

The study found that Regulation (2017: 309) on self-driving experiments enables realization of the entire sequence of self-driving vehicles "from stock to location for further maritime, road or rail transport". Unlike the legal design of "virtual AGVs", a proposed experiment with self-propelled vehicles is not geographically determined. To apply for permits for testing and evaluating automatic features that are not part of a type-approval, individual approval or registration survey under the Vehicle Act (2002: 574) could be seen as a temporary solution pending legislation on self-propelled vehicles on public roads. This enables automated transportation, at least "on trial".

6.7 Future route from the factory and onwards

During this project, the focus was to stay inside the gates but also to investigate the possible infrastructure topics if further movement outside the factory area would be performed. In order to investigate this, a short route between the Volvo Cars Torslanda factory and the harbor was identified as shown in Figure 13.

Figure 13: Proposed route

The route investigated shows that there are many different stakeholders included in a movement outside of a gated area. In this case, the road which is populated with busy traffic is primary owned by the Gothenburg municipal as well as private companies. In this case, no part of the route was owned by the government. However it puts the topic towards who would to what once the technology is mature enough to leave the gated area.

Another possible conflict point would the interaction with other traffic and management of crossings. A number of bicycle, pedestrian and vehicle crossings were found which also included several round-about crossings.

All of the topics would need to be clarified before any autonomous transportation would be possible outside the gated areas.

6.8 New business possibilities

Since this is a new area where technology was applied in a new context, a number of benefits and positive impacts were identified. This is useful in order to understand who will benefit from this project in the future. The main benefits are as follows:

- No or less follow-cars (with drivers) required
- More efficient use of the ranger role (inspector)
- Fewer cars in inventory/on yard
- Shorter lead times to customers
- Fewer accidents (cars, persons and material)
- Higher delivery precision in internal process
- Less in-steps into cars
- More efficient use of the yard area
- More efficient maintenance and car status
- Eliminated need for relocating vehicles in sequence
- Less risk of overloaded Drop Plan lanes
- Less administration
- More efficient yard processes (carrier trucks)

6.9 Consortia management: managing joint R&D performed by an Open Strategic Alliance

When the consortia won funding for BtoD in fall of 2015, the two-year R&D was organized through a series of planning activities. These activities were driven by the project manager and involved key representatives from each partner. TRL was selected to gate the project process. The main reason was to ensure that the work in each work package would align to the common objective to build an CPS, that on one hand demonstrates the benefits with autonomous transport, and on the other hand become an artefact fit for industrialisation in the automotive industry domain. R&D was operationalized through the adoption specific Action Design Research (ADR)[2] principles to govern different phases during the project. In order to capture experiences from applying ADR and thus consortia management, on-going evaluation was organized as a recurrent activity throughout the project. The on-going evaluation was organized as a part of work package 7 using retrospective assessment that followed the nine first steps in Guba & Lincoln’s fourth generation evaluation methodology[3].

Hjalmarsson (forth.)[4] provides an account and analysis of how the collaborative R&D was managed in BtoD. In short, this process was structured as regular meetings involving the project manager, work package leaders, principal researchers and key engineers. During these meetings, the progress of the R&D against the TRL scale was reviewed, and experiences from adopting ADR principles were also shared and discussed. In the beginning of the project the meetings were

[2] *Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., and Lindgren, R. (2011) “Action Design Research”. MIS Quarterly, (35:1), pp 37-56.*
[3] *Guba, E., G., & Lincoln Y., (1989): Fourth Generation Evaluation. SAGE Publication.*
[4] *Hjalmarsson A., (forth) Managing Action Design Research: Developing Principles from Cyber-Physical Systems R&D. Submitted and Accepted for presentation at SIGPRAG 2018*

held on two-weeks basis, however it was changed to a monthly activity when the project picked up pace. At the time of this shift a third purpose was proposed by the industry partners; that was the joint identification of complementary principles that facilitate that the R&D process not only is twisted toward a knowledge-creation agenda, but also produce an artefact that meet defined industry objectives. Table 3 summarise the adoption of ADR principles in different project phases. The table also depicts (in ***bold italics***) the complementary management principles conceptualised as a consequence of the on-going evaluation sessions.

Phase	ADR stages				TRL progress
	Problem formulation	**Building, Intervention and Evaluation**	**Reflection and learning**	**Formalization of learning**	
Explorative study	P-in Re, Th-in Art ***P-in Dev, Te-in Art***			GenOut ***AdopOut***	1
Concepts design	P-in Re Th-in Art ***P-in Dev Te-in Art***	ReSh, MuInRo *StruDev*	GuiEm		1→2
Concept selection and refinement	Th-in Art, ***Te-in Art***	ReSh, MuInRo Au&ConEv ***StruDev***	GuiEm ***SuccAnch***	GenOut ***AdopOut***	2
Component building	Th-in Art, ***Te-in Art***	ReSh, MuInRo Au&ConEv ***PropDesRes*** ***StruDev*** ***BarMgmnt***	GuiEm		2→3
System and vehicle integration	Th-in Art, ***Te-in Art***	ReSh, MuInRo Au&ConEv ***PropDesRes*** ***StruDev*** ***BarMgmnt***	GuiEm ***SuccAnch***	GenOu ***AdopOut***	3
Test of vehicle integrated prototype		ReSh, MuInRo Au&ConEv ***PropDesRes*** ***StruDev*** ***BarMgmnt***	GuiEm		3→4
Refinement of prototype and concept design expansion	P-in Re Th-in Art ***P-in Dev*** ***Te-in Art***	ReSh, MuInRo Au&ConEv ***PropDesRes*** ***StruDev*** ***BarMgmnt***	GuiEm		3→4
Demonstration of finalized prototype in real environment			GuEm ***SuccAnch***	GeOut ***AdopOut***	4 (→5)

Table 3: ADR Stages and Applied Principles throughout BtoD

Practice-inspired Research (Pr-in Res) was used as principle to stimulate development of understanding about the solution domain. Applying the *Pr-in Res* principle, supported the project to shape a vision for a BtoD-CPS and identify knowledge creation opportunities regarding autonomous transport with connections to the problem class cyber-physical systems in the emerging understanding about how to digitally transform manufacturing process to Industry 4.0 standard. The principle of *Theory-ingrained Artefact* (*Th-In Art*) was applied to stimulate that the concept design process was influenced by learnings about e.g. autonomous driving and outbound logistics. *Th-In Art* was also used to theoretically anchor the heuristics used to assess the three concepts that was designed in spring of 2016 as candidate designs for the BtoD-CPS. What emerged during the on-going evaluation was a reaction from the industry partners that the applied ADR principles emphasised research, and not sufficiently emphasised development of a digital artefact fit for industrialisation. The on-going evaluation was able to conceptualise two complementary principles in the Problem Formulation stage that emphasise industry relevant R&D, acting as balancing force to the established research principles in ADR. The first, *Practice-inspired Development* (*Pr-in Dev*) enable the consortia to also anchor the impending design in requirements and needs in the solution domain. It also emphasis that R&D not only involves knowledge creation but also involves the development of an artefact that should meet short as well as long term industrialisation ambitions. The engineers made the additional argument that an emerging design not only should be ingrained with theory, but that the design also is iterative work influenced by state-of-art technology. This generated the second complementary principle, *Technology-ingrained Artefact* (*Te-in Art*).

When the project moved to the build stage, the selected concept design was transformed to the BtoD-CPS. *Reciprocal Shaping* (*RecShap*) was manifested in several ways during this stage. For example, the constraint to integrate the autonomous transport component in the car ECU required that the solution was built with size in mind. The algorithm to execute the car transition is required to be small and fast to fit in a car ECU, and also interact with other system components in the car. Another example, related to the traffic control system, is that traffic control interacts with a legacy logistic system to receive transition orders and also feedback information about the status of the cars in the logistics flow. On an overall level the BtoD-CPS system also re-shapes the logistic process, as the driverless capability affected the division of labour between the staff and the machines. As less drivers are needed this will affect what staff does and how much staff is needed to operate the logistics process. During the build and evaluation iterations *Mutual Influential Roles* (*MuInRo*) was used to ensure that the three separate development teams interacted to align the three components to a complete system. The principle was also used to stimulate researcher and developer collaboration; e.g. That the design choice to use RTK was anchored in a theoretical anchored assumption that this technic could be used to boost the GPS based positioning of the car during autonomous transition from point A to point B. Formative evaluation was used to ensure *Authentic and Concurrent Evaluation* (*AutConEva*) of the artefact, from concept design selection to the extensive trials of the vehicle integrated system.

During fall of 2016 and spring 2017, when the build, intervention and evaluation work was accelerated, the ongoing evaluation identified three industry principles to balance the research principles in the original ADR model. R&D with the aim to develop a digital artefact that meets the requirements on TRL 4 need to be able to use design resources made available to the ADR team; resources could here be technology (e.g. a car as open platform), schemes (e.g. signal database to interpret signals from different components) and human expertise (e.g. specific expertise required in the development). This need created the basis to formulate the complementary principle *Proper Design Resources* (*PropDesRes*) to emphasise the absolute need of design resources in order to move beyond TRL2 on the TRL scale. During the on-going evaluation of the ADR principles *RecShap* and *MuInRo* was praised to be of key importance also from an engineer perspective in R&D. However, in order to facilitate structured shaping and influencing, the engineers argued that a common language is used to organise the development. In BtoD this language became the scrum based development model used by the development teams to organize the systems development, testing and integration. Hence as second complementary principle, *Structured Development* (*StruDev*) was proposed. R&D is not a simple and straightforward journey; obstacles will surface during consortia-organized R&D projects. When it is a high profiled R&D with the aim to reach TRL 4 such obstacles must be mitigated or removed in situation that they occur. The third complementary principle defined is thus *Barrier Management* (*BarMgnmt*).

Guided Emergence (*GuiEm*) was utilized to stimulate articulation of learnings from the design of the BtoD-CPS. An example is the coining of Autonomous Transport in the crossover between AGV and AD. Another is the framing of the BtoD solution as a CPS that create an opportunity to digitally transform the physical process of outbound logistics in the automotive industry. A third example of the emergence of learnings are the complementary principles displayed in this section. In the conceptualisation of these learnings, the principle of *Generalized Outcomes* (*GenOut*) was used to stimulate abstracting that enables transferability of the system to other application areas, not only automotive logistics. One example is that the CPS could be enabled when the car is used by the end-user to enable valet parking in large parking facilities to make more efficient use of space. In the on-going evaluation at this stage, the engineers reflected that R&D with an aim to not only generate sound research, but also a solution that fits industrialised needs, must be anchored in top management to ensure that the next phase is included in the recurring budget process. *Successive Anchoring* (*SucAnc*) was thus proposed as a complementary principle to stimulate that the outcome from the R&D is matched to solve a need in the where the digital artefact should be industrialised. In addition, *Adoptable Outcomes (AdoptOut)* was proposed as a complementary principle to balance that the ADR not only develop outcomes that are generalized from a scientific perspective. It is also necessary that the outcomes are fit for adoption. The TRL scale is suggested as a tool to ensure such a fit.
Table 4 summaries the complementary management principles defined through-out the on-going evaluation performed during BtoD.

ADR stage	Industry Principles	Description
Problem Formulation	Practice-Inspired Development (P-in Dev)	Applying ADR in an R&D consortia requires from an industry perspective that the identified knowledge-creation opportunity, not only is casted as an industry challenge relevant to pursuit.
	Technology-ingrained Artefact (Te-in Art)	Artefacts created and evaluated by an open innovation alliance using ADR should, from an industry point of view, be informed by state-of-art technology.
Building, Intervention and Evaluation	Proper Design Resources (PropDesRes)	Design resources (e.g. platform, technology, scripts) should, from an industry perspective, be made available to facilitate reciprocal shaping of the artefact in the ADR process.
	Structured Development (StruDev)	In order for the emerging artefact to be in adoptable, an appropriate development structure should be used to systematize the build, intervention and evaluation stage in ADR.
	Barrier Management (BarMgmnt)	Barriers in appearing during the R&D should be managed either by mitigation or removal.
Reflection and Learning	Successive Anchoring (SuccAnch)	The artefact developed using ADR to cope with an industry challenge should be anchored in a successive manner to facilitate absorption.
Formalization of Learning	Adoptable Outcomes (AdopOut)	From an industry perspective, participation in a consortium that uses ADR for R&D requires that the artefact becomes adoptable; one way of ensuring this is stage the R&D with a readiness level structure

Table 4: Complementary Principles for ADR to Manage Collaborative R&D[5]

[5] *Hjalmarsson A., (forth) Managing Action Design Research: Developing Principles from Cyber-Physical Systems R&D. Submitted and Accepted for presentation at SIGPRAG 2018*

7 Distributions and publications

7.1 Knowledge and result spreading

How is the project result to be used and spread?	Mark with X	Comment
Increase the competence within the area	X	During the project, a number of different persons from the different companies with different competencies has been involved which has meant that these persons have been able to learn from each other. The project and future concept was also presented at the 5th of September 2016 in Lund. An article and presentation has been produced and will be done at the 2017 ITS World Congress in Montreal.
Usage within other advanced technical research projects	X	There is a plan to use the project content for a joint project between Volvo Cars and AB Volvo. The project is called Ants and the idea is to selfload the cars on the truck . Once its selfloaded using Born to Drive technologies, the truck moves the load autonomous from the factory down to the harbor.
Applied in a product development	X	The outcome from the project could be used in the product development of both autonomous cars as well as transports that utilize autonomous transportation
Introduced into the market	X	The concept could be productified and sold to the logistics market as a service to manage transportation of vehicles.
Used in investigations/rules/permits/political decision		

Volvo Cars is investigating the possibility to setup and internal product development project which would be based on this concept.

7.2 Publications

The Born to Drive project has resulted in a number of scientific papers, master reports, PM and other background information. The content has then later on been edited and is included in this report.

List of publications:

Name and content	ID	Author
Rättslig belysning för automatiserad logistik ”från lager till uppställnings-plats för vidare sjö-, väg- eller järnvägstransport”	WP6-1	Wanna Svedberg
Arbetspaket nr 6 för Born to Drive: Regelverk och infrastruktur	WP6-2	Patrik Benrick, Magnus Palm
Autonomous Transport: Transforming Logistics Through Driverless Intelligent Transportation,	WP7-Paper 1	Anders Hjalmarsson, Mikael Edvardsson, Martin Romell, Johan Isacson, Niklas Sundin Carl-Johan Aldén

TRB 2018. ***Full paper accepted and included in Proceedings.***		
Disrupting Automotive Logistics, through a combined Intelligent and Autonomous Transport Solution, ITS 2017. ***Full paper accepted and included in Proceedings.***	WP7-Paper 2	Anders Hjalmarsson, Mikael Edvardsson, Johan Isacson, Carl-Johan Aldén
Born to Drive: Transforming Automotive Logistics through and Intelligent Autonomous Transport Solution. ITSC 2017 IEEE. ***Full paper submitted, not accepted.***	WP7-Paper 3	Anders Hjalmarsson, Martin Romell, Johan Isacson, Carl-Johan Aldén
Re-thinking Automotive Logistics Merging a Novel Driverless Transport Solution with ADAS Functionality ELIV 2017 ***Abstract submitted, not accepted.***	WP7-Paper 4	Carl-Johan Aldén, Anders Hjalmarsson, Mikael Edvardsson, Johan Isacson, Niklas Sundin
Managing Action Design Research: Developing Principles from Cyber-Physical Systems R&D, ***Full paper submitted and accepted for presentation at SIGPRAG 2018***	WP7-Paper 5	Anders Hjalmarsson
Accelerating Open Digital Innovation in the Automotive Industry, ACIS 2017. ***RIP accepted and included in Proceedings***	WP7-Paper 6	Gustaf Juell-Skielse and Anders Hjalmarsson
Digital Transformation of Automotive Logistics: The case of Autonomous Transport, MIS Quarterly Executive. ***Full paper to be submitted in Spring 2018***	WP7-Paper X	Anders Hjalmarsson och Daniel Rudmark
Autonomous Transport: Changing the Future of Automotive Logistics. Preliminary invitation to be published in Journal of the Transportation Research Board. ***Full paper to be submitted in Spring 2018***	WP7-Paper X	Anders Hjalmarsson, Mikael Edvardsson, Martin Romell, Johan Isacson, Niklas Sundin Carl-Johan Aldén
Master thesis - Challenges of using autonomous drive technology for autonomous transports in car manufacturing	MT1	Louise Alinde Sundbeck, Josefin Karlqvist
Master thesis – Visual Odometry for Road Vehicles Using a Monocular Camera	MT2	Henrik Berg, Raman Haddad

7.3 Articles/Media

List of articles/media:

Name and content	URL	Author
Bilen flyttas från fabrik till kund – utan förare	https://www.nyteknik.se/fordon/bilen-flyttas-fran-fabrik-till-kund-utan-forare-6871910	Johan Kristensson, Nyteknik
Den självparkerande bilen är här	http://www.gp.se/nyheter/ekonomi/den-sj%C3%A4lvparkerande-bilen-%C3%A4r-h%C3%A4r-1.4707095	Marie Kennedy, Göteborgs posten
Här kör bilen själv från fabriken	https://www.di.se/bil/har-kor-bilen-sjalv-fran-fabriken/	Karin Olander, Dagens Industri

8 Conclusion and future research

The important result that the project has demonstrated is that autonomous transportation is possible and feasible within a short term future. This will have a positive impact on both the environment as well as the effectiveness of the logistical operations. However for each different area that the project has touch, the maturity level is different and due to this, the conclusions can be divided into subcategories.

Technical

As presented in the earlier parts of the report, the technology exists today is deemed as sufficient in order to facilitate autonomous transportation. However at the moment, this would most probably be possible using vehicles with more advanced sensors and as the technology matures. More and more vehicles will be equipped with the latest technology which will facilitate for a higher penetration rate. Since the solution is done using only software, this will ensure a quick time to market once this technology will be built into the vehicles.

Laws

In the project, it was clear that there are different laws and regulations that apply and it’s a bit unclear specifically which that will apply. Since the project took place in Sweden, only the Swedish laws and regulations were analyzed but it soon became clear that these might not be adapted to this new logistical process. A big question that came up and was discussed was when a car becomes a car since this would basically control which laws that apply. Since there are two main directives, the “Type approval of motor vehicles (Directive 2007/46/EC)” and the “Act on machinery (Machine directive) (Directive 2006/42/EC)”, it was clear that in the beginning of the manufacturing process, the vehicle is ruled by the machinery directive but at some stage, it crosses over to being a car where the Motor vehicle directive takes over. In the project, the conclusion is that the vehicle is not a car until it’s actually is delivered to the customer which means that it’s believed that the Machine directive would apply when transporting the vehicle within the “fenced” factory area.

Benefits

Many different benefits were discovered during the project once the different participants started to see the benefits from the technology shift. Many of these were focused on improvements on the existing logistical process but many were also related to actually revolutionizing the logistical process and trying to leave old paths. By possible changing the process, new ways of moving the vehicles could be done which could mean that the process could be streamlined. An example was that there might not be a need for that many parking spots out in the yard area since the vehicles will be moving out faster from the factory area, This would lead to a better usage of the available space as well as be used in other industries such as the rental industry where transportation of vehicles is a time consuming task.

8.1 Future research

Through the project, it has been proven that autonomous transportation is possible both from a technical as well as business perspective. This insight within the different parties has been communicated to external parties as well and the conclusion is more when this technology will be introduced to the market. What was discovered are other areas that would be subject for future research?

Example about topics that would suit future research:

- As discovered, the legal aspect of the autonomous transportation on public roads are quite unclear. Since there would be no driver in the vehicle, the aspect of responsibility would be a bit unclear and this requires further research. This also includes the terminology of when a vehicle is defined as a vehicle in the logistic process.

- Another point would be how the infrastructure on public roads would need to be setup in order to facilitate this type of transportation. Would it for example require certain prepared roads and would there be a need for time slots to limit the impact on other traffic?
- What would be needed from a traffic safety perspective to support the flow of autonomous transported vehicles?
- Another topic that is important today is security of the solution. How would such a solution be setup on a larger scale and be protected against external intrusion. And how should such a solution be handled once an attack has been confirmed and the damage is done?

9 Participating parties and contact persons

9.1 Involved parties

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