SARPA

Safe And Robust Platform for Autonomous machines

The demonstrater running autonmously

Project within FFI - Fordons- & Trafiksäkerhet 2012-12-19

Diarie Nummer: 2012-04621

Author: Johan Tofeldt

Date: 2017-02-23

FFI

Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport,

reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1 Executive summary

The SARPA project was a joint project between GTT (Global Trucks Technology)/ ATnR (Advanced Technology & Research), MdH (Mälardalens Högskola), Chalmers University, C-PAC and Volvo CE. SARPA was funded by the Vinnova funding agency and was raised during September 2013. It is in line with the overall initiative of machine intelligence and HMI and with the goal towards zero accidents with Volvo vehicles and machines which is one major approach within the technology planning strategy.

The SARPA project provided an autonomous Articulated Hauler A25F TIER2 as a demonstrator. A major goal is the investigation of an electronical architecture to provide and propose a platform for autonomous machines. This should take also other construction machines into account. An investigation is also raised if the architecture will meet and fulfil all safety standards which are stated by the machine regulation. The project achieved a thorough understanding and knowledge built of autonomous functionality and functional architecture and demonstrated this in the hauler.

The project has pushed the needle in terms of building know ledge on this topic on various levels. The following conclusions are related to the developed functionality; Before taking on the task to develop the autonomous functionality, the basic machine control algorithms (i.e steering control and speed control) must be in place. We need to have a god understanding what performance the low -level functions must provide in order to support autonomous operation. The systems and know ledge that have been built around the demonstrator has been directly transferable to other projects.

2 Background

The SARPA project was a joint project between GTT (Global Trucks Technology)/ ATnR (Advanced Technology & Research), MdH (Mälardalens Högskola), Chalmers

University, C-PAC and Volvo CE. SARPA was funded by the FFI - Fordonsstrategisk Forskning och Innovation funding agency and was raised during September 2013. It is in line with the overall initiative of machine intelligence and HMI and with the goal towards zero accidents with Volvo vehicles and machines which is one major approach within the technology planning strategy. As we are moving towards automated functions and eventually autonomous machines this project includes a machine demonstrator with autonomous operated functionality and functions and is in line with already finished or still ongoing projects like Autonomous Excavator, Autonomous Mining truck,I&II as well as Autonomous Wheel Loader.

There is a general trend for autonomous technologies and functions within construction machines and construction equipment manufacturers. And even within trucks and automotive area there are clear signs for the demand of autonomous technologies and functionalities. Examples are the Google Car project or Volvo Autonomous Car initiative. The main focus in the first step will be on converting autonomous functions into assistance systems to support the driver during autonomous parking or other repeatable functions. Long-term wise these functionalities could be extended to maximum support. For construction machines these technologies could also be implemented as additional options to support the operator during repeatable monotonous tasks in a quarry or landscaping use cases.

The SARPA project is providing an autonomous demonstrator machine. An Articulated Hauler A25F TIER2 is used as a demonstrator machine which should be the research object. A major goal of the SARPA project will also be the investigation and study on an electronical architecture to provide and propose a platform for autonomous machines. This should take also other construction machines into account and not only the Articulated Hauler. With the already existing autonomous machine projects there was mainly the functionality itself developed within the project to get the autonomous functions up on running. Besides the intense work on the electronic architecture there should be also an investigation raised if the architecture will meet and fulfil all safety standards which are stated by the machine regulation.

As there are already other autonomous machine projects like 760026 Autonomous Wheel Loader, P42916 Autonomous Excavator-I and 760071 Autonomous Excavator-II there is a need for a concept development of a common autonomous architecture which could be a basis for autonomous machines for multiple usages on different kind of machines.

To be competitive in this area it is an absolute need to invest in this emerging technology in time and not to lose the time to market compared to other OEMs like Caterpillar and Komatsu who are already running commercial test sites with autonomous vehicles

If the project should provide a high level evaluation of the implementation possibilities of autonomous functions into the construction machines it needs to be handled with extreme care and uncertainty. The project achieved a thorough understanding and knowledge built of autonomous functionality and functional architecture. With the creation of a high number of very detailed and specific technical reports we provide a good basis for upcoming initiatives in this specific area of intelligent machines.

3 Objective

Automation technology is an enabler for both safety and productivity. Automated vehicles are already being explored by competitors to Swedish OEM. Automation has the potential of significant contributions to safer traffic and construction environments, less fuel consumption and higher productivity, thus are customers already asking for the technology. Compared to competitors has Swedish industry advantages with the wide range of vehicles and machines in their product portfolio. The mix of vehicles allows for early introduction in niche applications where the technology can mature to later entering the higher volume of road vehicles with their cost and quality advantages.

The objective is to propose and develop an electronic platform that does support future needs from electronic perspective such as:

- Automated and autonomous functions,
  Comment: Functionality has been developed in WP5.

- Active safety,
  Comment: Could be rated as completed as the active safety was provided by the WP7 via AtnR support. Especially the system which was developed and presented in cooperation with the Zero Accidents Projects provided a potential solution.

- Production architecture
  - Scope and use cases definition
    Comment: Use cases and scope have been identified for automated haulers, wheel loaders, and excavators. Analysis of first introduction use cases has been performed.

  - Functional architecture analysis
    Comment: We have performed an analysis on how to structure a functional architecture in form of platform support, and flexibility.

  - Preliminary hazard analysis of an autonomous hauler
    Comment: A PHA workshop and analysis of hazards have been performed.

  - Strategies for SW modularity
    Comment: A modular architecture is suggested on how to make the platform flexible, scalable, and fast to verify.

  - HW topology and mapping of functional architecture to HW topology (separation of functionality into HW and SW)

Comment: Guidelines have been constructed from the analysis results and investigations made in WP4 .

- Safety analysis document
  Comment: An analysis have been performed, mainly based on the results of the preliminary hazard analysis.

- CEA2+ adaption to autonomy
  Comment: An analysis of a TEA2+ adaption for automated vehicles has been performed.

- PhD dissertation
  Comment: The thesis work will be completed in December and the defence will be hold in early 2017.

A Demonstrator built with autonomous functions

- 70% in productivity in selected use-case (tons per hour, compared with skilled drivers)
  Comment: Performed at end of September; with the current autonomous set up on the Hauler demonstrator it achieved this goal

- Equal or increased fuel efficiency (tons per liter fuel compared with skilled driver).
  Comment: Performed at end of September; with the current autonomous set up on the Hauler demonstrator it achieved this goal.

- Demonstrator running 10 cycles on the rough terrain track in Braas.
  Comment: The internal demonstration was successfully performed on the test track in Braas end of June 2016. See VIDEO as well. The 10 cycles were done without any major interruption. It was recorded via a GPS logger

4 Project realization

As this project was a joint project with 4 major partners it was a necessity to structure the main work-packages in a most suitable and logical way.

The project main lead was done via ATnR. The main SARPA work-packages were defined from GTT/ ATnR and are as follows:

WP1	Project Coordination	ATnR
WP2	**State of art analysis**	**VCE support**
WP3	Functional architecture	ATnR
WP4	**Architecture integration**	**VCE support/ MdH**
WP5	**Automated vehicle and infrastructure**	**VCE support**
WP6	Vehicle decision, interaction and mission	Chalmers

WP7	Safe vehicle	ATnR
WP8	**Verification and Validation**	**VCE support**
WP9	Demonstration and dissemination	ATnR, VCE, MdH

WP2, WP5 and WP8 has the main focus. VCE has also engaged a PhD student that is participating in WP4.

5 Results and deliverables

5.1 Work-package results

This section presents the result of all work packages with the main focus.

5.1.1 WP1 Project Coordination

The Project Coordination was managed by GTT/ ATnR. The Project Leader was Erik Nordin. He led this project from September 2013 till end of 2015. After Erik Nordin moved to a new position Johan Tofeldt was the successor for the overall project lead.

The AE project management was introduced in February 2014 to the SARPA project.

5.1.2 WP2 State of art analysis

This work package has been devoted to analysing what is state of the art today in terms of autonomous vehicles. This analysis has resulted in a number of technical reports, each covering this topic from slightly different perspectives. These reports are listed next.

- **Best practices industry** – This report lists everything that is publically available regarding what our competitors are offering today in terms of autonomous machines.
- **Equipment inventory** – This report presents a component inventory from the project partners that are applicable for supporting autonomous functionality.
- **State of the art architecture** – This report is elaborating around the architecture concept. Further, it includes a survey of methods suggested by academia that are targeted against architecture evaluation.
- **State of the Art Navigation and Decision** – This report describes different methods for autonomous vehicle navigation. Further, it presents different decision making strategies suggested by academia.
- **Inventory** – This report gathers information about previous and ongoing activities as well as useful equipment for autonomous vehicles from all project partners.

5.1.3 WP3 Functional architecture

This functional architecture work package investigated into the potential functional architecture structure. The following abstract of the architecture model was provided at the start of the project.

The 4D/RCS architecture provides a reference model for military unmanned vehicles regarding how their software components should be identified and organized. It defines ways of interacting to ensure that missions, especially those involving unknown or hostile environments, can be analysed, decomposed, distributed, planned, and executed intelligently, effectively, efficiently and in coordination. In order to achieve this, the 4D/RCS reference model provides well defined and highly coordinated sensory processing, world modelling, knowledge management, cost/benefit analysis, behaviour generation, and messaging functions, as well as the associated interfaces. The 4D/RCS architecture is based on scientific principles and is consistent with military hierarchical command doctrine.

The 4D/RCS reference model architecture is naturally adaptable to the DoD/Army standards in a combined domain of vehicle systems, combat support, and software engineering. 4D/RCS provides an architectural framework to facilitate component and interface standards development, including command and control, sensors, communication, mapping, operating environments, safety, security, software engineering, user interface, data interchange, and graphics. As such, the 4D/RCS reference model architecture forms a framework for software engineering standards and guidelines.

5.1.4 WP4 Architecture integration

This work includes architecture analysis of an intended functional concept for automation of a work site with construction equipment machines from VCE. The results of this work include the definition of the method, data and analysis. The analysis aims to provide tailored guidance for designing the production solution electronics system platform for Volvo products, taking into consideration the Volvo context of usage scope, technology legacy, and business parameters.

Scope and use cases definition

We have listed prerequisites, context and assumptions. We have interviewed specialists to find the complete set of use cases that defines the SARPA usage scope.

Functional architecture analysis

From the identified use cases we derived a functional architecture for an automated hauler. We also investigated the hierarchical composition of an architecture stack. The conclusion involves that at a higher level there must be a separation of functions that does not simultaneously try to control the different actuators. Therefor we deduce that we will define a set of “machine task” functions that are mutually exclusive.

Preliminary hazard analysis of an autonomous hauler and Safety analysis

We analysed each function in the functional architecture to find plausible hazards that may occur if it is malfunctioning. Each hazard was assigned ASIL levels.

Strategies for SW modularity

There exist many architectural concerns that cause uncertainty. From our investigations we have found a need for the architecture to be evolvable. Functionality and perception systems must be able to be changed, added or removed according to an uncertain roadmap. Our suggestion is a modular design.

HW topology and Mapping of functional architecture to HW topology

Guidelines and rules for mapping the functional architecture onto hardware have been based on safety analyses and functional architecture analyses.

Safety analysis document

The analysis from the PHA shows an overview of where the hazards are located but there is still work to be done.

CEA2+ adaption to autonomy

An investigation of how an automated system will impact TEA2+ has been performed. The TEA2+ architecture provides a unified Volvo electronic infrastructure for on-board systems, diagnostics, production etc. and the tools. We have seen that there are at least four areas where there are questions that would need to be resolved:

TEA2+ supports diagnostics, and an introduction of autonomy does not give rise to new requirements on TEA2+, but the complexity of the system and also the diagnostic system will increase.

For communication we conclude that there is enough support for autonomy in the next generation TEA2+, e.g. higher bandwidth and more communication.

TEA2+ supports some system states in the machine system. (key on, crank, running, etc). When the system is to support autonomy, the overall system behaviour needs to be rethought. In autonomous mode it is possible that diagnostics, braking, signalling, and all other things should behave differently. For instance all comfort aspects may be disabled and behaviour optimized for energy, or production effectiveness. These states must be analysed and defined to support the autonomy case.

We must have support for high SIL levels in the machine system if we are to support a high ASIL level autonomy system. There seems to be support for that coming with VAP2.0. (Safe communication, context protection, program flow monitoring) It remains to do the work of assuring whatever function are deemed hazardous and which these are depends on the functional scope and the choice of concept.

Sensory input study
We have clarified some procedures and technical requirements by studying real world scenarios for Vikans kross.

PhD dissertation
A PhD dissertation will be performed during fall 2016. The subject is about enduring architectures for autonomous construction machines.

Publications and talks:

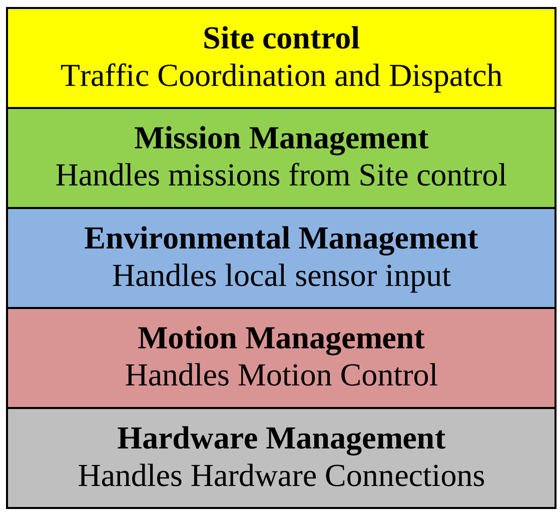
- Poster Volvo research days 2013.
- Published paper, Sara Dersten – ”An Analysis of a Layered System Architecture for Autonomous Construction Vehicles”, SysCon 2015
- Published paper, Sara Dersten – ”Finding Critical Architectural Decisions for Autonomous Vehicle Product-Lines”, Euromicro Conference series on Software Engineering and Advanced Applications (SEAA), Verona Italy, 2014.
- Presentation at conference SATURN2015: ”Using Hazard Analysis to make Early Architecture Decisions for an Autonomous Automotive Application” – (Joakim F)
- Presentation at ITS-EASY research school – Safe and Robust Platform for Automated vehicles (Sara D), 2014, 2015, 2016.
- Sics Newsletter ”Vi vill leda utvecklingen mot förarlösa fordon” January, 2015 (Joakim F)
- Published paper, Sara Dersten: - “Dealing with uncertainty in early architectural decisions”, CVT 2016.
- Published paper, Sara Dersten: - ” Analysis of the Information Needs of an Autonomous Hauler in a Quarry Site”, SoSE2016
- Presentation of poster Mdh-Volvo Celebration 2016 (Sara D)
- Published paper: - “Reinventing the ConOps for Innovative Systems Development: The Application of Design Thinking Tool in the Construction Equipment Cases”, INCOSE 2016, (Sara D)
- Presentation at IQPC: Designing for functional safety in a system architecture for an autonomous machine (Joakim) – Berlin
- Poster Volvo research days 2016 (Joakim, Sara).

5.1.5 WP5 Automated vehicle and infrastructure

This work has resulted in a technical solution manifested in the form of a working demonstrator machine, an autonomous articulated hauler. The autonomous system architecture for this machine is presented briefly in Section 5.1.5.1. The architecture presentation includes references to technical reports that describe various aspects about the demonstrator machine. Summaries of these reports can be found in Section 5.1.5.2. The last section, Section 5.1.8, presents the verification and validation of the machine.

5.1.5.1 Overview of the autonomous system architecture

This machine's autonomous system architecture can be seen as a layered architecture. Hence, the software and hardware components that constitute the autonomous system can be arranged in accordance with the aforementioned layered architecture[1] as shown below. Next follows a brief description of each of the layers including references to technical reports where applicable (a summary of each report can be found in the next section).



[1] The autonomous system architecture is essentially different from that of the layered architecture which describes the logical functions of the system. However, the logical interfaces of the latter may still coincide with the hardware and software interfaces of the former which motivates using the notion of layers to group its hardware and software components.

5.1.5.2 SARPA ART technical reports

This section collects the reports that relates to the autonomous articulated hauler implementation.

Generic speed controller prototype

This report describes the speed controller used in the SARPA ART.

Path following for articulated machines

This report briefly describes a few different approaches to design the path following controller for the SARPA ART. The described approaches are: PID tuned using the Nyquist diagram, PID tuned using Matlab's functionality for automated tuning and pole placement. In addition, a nonlinear Smith predictor is also evaluated. This document focuses on simulation based evaluations.

SARPA ART Autonomous system architecture description

This report describes the Autonomous system architecture for the SARPA ART. In addition, the underlying design choices are also presented.

SARPA ART Positioning sensor fusion

This report shows result from position and rotation estimation for the SARPA ART. The filter algorithm is the 2D filter. The estimation algorithm has been modified to provide stable state estimation during heavy roll manoeuvres. Also presented are the results from two different mounting positions for the IMU. The results suggest that an IMU utilizing the cabin suspension provides better sensor data than an IMU mounted directly on the frame. Further tests are needed to evaluate how well the estimation algorithm handles decreased GPS precision.

SARPA ART Tuning of steering angle controller

This report describes the controller that handles the steering angle in the SARPA ART. In particular it describes the method and model used for tuning the controller. In addition, it presents the model parameters that were established through measurements on the SARPA ART.

XA15 Positioning sensor fusion

This report proposes two different state observers for vehicle position estimation. The filters have been developed to provide stable state estimation during temporary loss of GPS data, assuming that vehicle speed, steering angle and 6DOF IMU data is available at all times. Additionally, when the GPS returns measurement after a longer period of no data the filters allow a graceful return to better estimates.

5.1.6 WP6 Vehicle decision, interaction and missions

Two main tasks have been carried out in WP6.

- First, a full investigation was carried out regarding path representation for autonomous vehicles, resulting in a particular choice of path representation as well as algorithms for generating, visualizing, and optimizing such paths, starting from a sequence of road points collected. Several computer programs were developed for reading, editing, and visualizing maps, optimizing path, and downloading background satellite imagery. In all cases, both standalone applications and dynamic link libraries (DLLs) were generated, such that the latter can be used in connection with existing software.

- Second, as the main part of WP6, an algorithm was developed for generating optimized, collision-free paths for a group of autonomous vehicles operating in a given area. This algorithm was also implemented in the form of computer code, both as standalone programs and as DLLs. Communication software was implemented as well. In our current work, we are focused on implementation (in vehicles) and adaptation of the multivehicle path planning algorithm for a specific application, namely underground (mining) operations.

5.1.7 WP7 Safe Vehicle

The work-package 7 had the main focus on the active safety of the vehicle. In this case the demonstrator. The cooperation with the Zero Accidents project was very successful.

In SARPA there was the need for a machine positioning solution for the Volvo hauler and such a solution had been developed within the Zero Accidents project. The solution was supplied to SARPA and functionality based on the system was demonstrated during an internal workshop in October 2014.

The emergency brake function was also developed within the Zero Accidents project for the automated hauler. The emergency brake algorithm described was implemented on the A25 haulers and demonstrated on the internal workshop in October 2014. **Error! Reference source not found.** shows a picture from a testing session in Eskilstuna.

The test shows that the algorithms developed within the Zero Accident project are flexible and since they are model based, can be adapted for different machine types with only minor modifications. The results from the collaboration and the internal demonstration (poster and movie) were presented on the FFI program conference in Gothenburg, November 2014.

Figure 2: Testing of emergency brake on A25 Hauler in Eskilstuna. The positioning units can be seen on top of the machine and on the pile of tires. To avoid damages to the equipment in case of missed interventions, some safety margins were added around the object antenna as indicated by the pallets.

5.1.8 WP8 Verification and validation

During the course of the project the machine has been operating autonomously on different test tracks in different scenarios while logging relevant data, such as deviation from path, fuel consumption etc. This data alongside visual monitoring of the machine has been used for verification of the functionality of the machine components.

For validation of the demonstrator machine a number of success criteria were defined. These criteria and the results of testing against the criteria are presented next.

Criterion 1 – The demonstrator machine should achieve 70% productivity in a selected use-case (tons per hour compared with skilled driver)

This criterion was successfully evaluated at the end of September at VCE test track.

Criterion 2 – The demonstrator machine should achieve equal or increased fuel efficiency (tons per liter fuel compared with skilled driver)

This criterion was successfully evaluated at the end of September at VCE test track.

Criterion 3 – The demonstrator machine should execute 10 rounds on the rough terrain track in Braås.

In March 2016 measurements were performed to see how the positioning system handles the terrain track that runs in forest vegetation. As it turned out the GNSS system had poor accuracy at a majority of the test track. Therefore, this criterion was altered to include another of the Braås tracks.

Consequently, in June 2016 a machine test was performed on the altered Braås track for evaluation of this criterion. The criterion was successfully evaluated. The machine operated for one hour without any unplanned interruption. Over this time it executed more than 10 rounds with good accuracy. The test run has been documented in terms of data logs.

5.1.9 WP9 Demonstration and dissemination

5.1.9.1 Demonstration

All internal project demonstrations were recorded as videos and are evidence for the incremental development and stepwise increased maturity level. See also work-package 8. In addition the machine was demonstrated at the following events:

- Volvo CE Innovation conference 2016
  - Demonstration for i-Coaches, invited researchers, and presenters
- Volvo CE Exploration forum 2016
  - Demonstration for Key account
  - Demonstration for VIP-Press
  - Demonstration for EMEA

5.2 Delivery to FFI-goals

Automation of vehicle functions is essential for achieving the Swedish vision of “Zero killed or injured in traffic”. The aerospace industry, with its heredity of safety, has for a long time strived for automation of functionality. It is recognized that more than nine of ten accidents are due to human operation error. The safety significant improved by automating functionality. Automation leads to that vehicle systems can be run in more optimal manners then when each driver has their own mission for their vehicle. Large savings can be made both in fuel consumption and efficiency, especially in off-road applications. There is a high commercial interest for automated vehicles. Volvo has already been asked to supply automated vehicles, but has currently not the products required for doing so. Volvo’s competitors in the construction segment e.g. Caterpillar and Komatsu are already running commercial test sites with autonomous vehicles. It is essential for the competiveness of Swedish automotive industry that competence is developed within the area of automated vehicles where we expect a rapid growth in the coming decade. AB Volvo is a multinational company with production all over the world. Despite this fact, is the main part of the research and development made in Sweden. Sweden has a strong tradition and competence within automotive industry. Many of the competences necessary for automation of vehicles inform of vehicle technology and telecom is already established but there is a lack regarding automated vehicle systems. It is particular essential to establish a framework for automation which can handle flexible environments such as traffic and construction sites. The competitors do rely on central controlled sites for automation and we believe that Swedish industry has the possibility to take the lead by creating more flexible automation solutions. A robust research platform for automated systems is essential for taking the lead within automotive automation. We are convinced that cleaver designed architecture will lead to resource efficient research and development of automated vehicles. The aim with SARPA is to develop such platform and to validate it in a challenging application that is highly automated and relatively close to possible market introduction. The parties involved in this project will share this platform and use it for coming research within active safety and automated vehicles. The architecture for automated vehicles needs to be developed from the philosophy of active safety systems where each vehicle have a high “intelligence” to handle the flexible environment on its own. The approach will be quite different compared to the center control that is used for AGVs. It is this approach that we see as the key for successful automation but it is also extremely challenging with the implications of self-organizing systems and a new generation of active vehicle safety. Within the project will workshops with Swedish academia and research institute be arranged to exchange and build knowledge in this area.

SARPA is a novel project addressing an area of high research interested. An architecture for automated vehicle in flexible environments is not only unique but would make it possible to use current known and well established technology in a new emerge business areas. Although the immaturity of automated vehicles can this approaches lead to fast commercial application of the results on construction vehicles. The introduction of fully automated road vehicles is in the future, but the migration of the technology for the construction vehicles will soon lead to automated functions in low speed and well defined situations. These are functions that can be viewed as continues driver support and significant improve road safety. SARPA will put both Sweden and Volvo Construction Equipment on the map since project aim to run an autonomous articulated hauler at a customer site, something that has never been done anywhere in the world before. In the mining industry rigid trucks have been used to perform part of the operation.

6 Dissemination and publications

6.1 Knowledge and results dissemination

Main driving forces for Automation is safety and productivity. In both these areas automation shows promise to be game changer. A non-scientific compare between AGV (Automated Guided Vehicles, self-driving forklifts) and manual forklifts tells us that that AGV have almost zero accident while manual forklifts is one of most dangerous machines in a factory. The driver salary has a big impact on the productivity, bigger than any other know technology today. If similar results are possible to achieve with heavy vehicles, this will completely change the safety and productivity for heavy vehicles and machinery.

PhD dissertation
A PhD dissertation will be performed during fall 2016. The subject is about enduring architectures for autonomous construction machines.

Publications and talks:

- Poster Volvo research days 2013.
- Published paper, Sara Dersten – ”An Analysis of a Layered System Architecture for Autonomous Construction Vehicles”, SysCon 2015
- Published paper, Sara Dersten – ”Finding Critical Architectural Decisions for Autonomous Vehicle Product-Lines”, Euromicro Conference series on Software Engineering and Advanced Applications (SEAA), Verona Italy, 2014.
- Presentation at conference SATURN2015: ”Using Hazard Analysis to make Early Architecture Decisions for an Autonomous Automotive Application” – (Joakim F)
- Presentation at ITS-EASY research school – Safe and Robust Platform for Automated vehicles (Sara D), 2014, 2015, 2016.
- Sics Newsletter ”Vi vill leda utvecklingen mot förarlösa fordon” January, 2015 (Joakim F)
- Published paper, Sara Dersten: - “Dealing with uncertainty in early architectural decisions”, CVT 2016.
- Published paper, Sara Dersten: - ” Analysis of the Information Needs of an Autonomous Hauler in a Quarry Site”, SoSE2016
- Presentation of poster Mdh-Volvo Celebration 2016 (Sara D)
- Published paper: - “Reinventing the ConOps for Innovative Systems Development: The Application of Design Thinking Tool in the Construction Equipment Cases”, INCOSE 2016, (Sara D)
- Presentation at IQPC: Designing for functional safety in a system architecture for an autonomous machine (Joakim) – Berlin
- Poster Volvo research days 2016 (Joakim, Sara).

6.2 Publications

- Analysis of the information needs of an autonomous hauler in a quarry site, Sara Dersten, Peter Wallin, Joakim Fröberg, Jakob Axelsson, will be presented at System-on-Systems Engineering Conference in Kongsberg, June 12-16 2016 (SoSE2016) (12).

- Dealing with uncertainty in early architectural decisions - Applications for autonomous construction vehicles, (Mar 2016) Sara Dersten, Joakim Fröberg, Proceedings of the 4th Commercial Vehicle Technology Symposium (CVT 2016) (9).

- An analysis of a layered system architecture for autonomous construction vehicles, (Apr 2015) Sara Dersten, Joakim Fröberg, Jakob Axelsson, 9 th Annual IEEE international System conference (SysCon2015) (7).

- Finding critical architectural decisions for autonomous vehicle product-lines, (Aug 2014) Sara Dersten, The 40th Euromicro Conference on Software Engineering and Advanced Applications (SEAA 2014) (19).

- Reinventing the ConOps for innovative systems development, Yan Yang Zhao, Peter Sjöberg, Larry J. Leifer, Sara Dersten, will be presented at 26th Annual INCOSE International Symposium, Edinburgh, Scotland, July 18-21, 2016 (INCOSE IS 2016) (20).

- Defining a method for identifying architectural candidates as part of engineering a system architecture, (Apr 2014) Joakim Fröberg, Stig Larsson, Sara Dersten, PerÅke Nordlander, 8th Annual IEEE International Systems conference (SysCon2014) (21).

7 Conclusions and future research

As the name suggests the work in SARPA has been targeted towards a platform for autonomous vehicles. However, to develop such a platform during the course of one project when starting almost from the beginning is a rather ambitious target to say the least. Still, the project has pushed the needle in terms of building knowledge on this topic on various levels. The following conclusions are related to the developed functionality.

- Before taking on the task to develop the autonomous functionality, the basic machine control algorithms (i.e. steering control and speed control) must be in place. This was not the case in the start of the project and as a result a lot of the effort of developing the autonomous machine has been devoted to such work and not on the more advanced features, such as detection of objects around the machine, connectivity etc.
- Functions that enable the demonstrator machine to operate autonomously have been developed. The steering on the other hand was more of a custom development for the demonstrator machine requiring hydraulic and mechanical adaptions. However, today we have a much better understanding what performance the low-level functions must provide in order to support autonomous operation.
- We have built knowledge on GNSS based localization (i.e. how to determine the position of the machine using a satellite system).
- The systems and knowledge that have been built around the demonstrator in SARPA has been directly transferable to the Electric Site project. The technical results were used as a

baseline for developing the autonomous functions for the XA15. These systems will be further developed during the course of Electric Site, although perhaps with tailoring towards a more specific target.

- The demonstrator machine has performed successful operation in different use-cases, such as running multiple laps on the test track in Braås. However, there are still many constraints that need further attention in order for the machine to be applicable at a customer's site.

On a higher level, more general conclusions can be drawn as presented next.

- The architecture analysis shows that the complete concept for an automated site must be considered in order to understand and design a viable commercial system. Without knowing interactions with site and other machines, an optimal design is difficult. The producible system necessarily includes a large scope, such as customer training, site equipment, integration, Volvo services, as well as an add-on machine system. As a result, the safe and robust platform is yet to be determined.
- The hazard analysis shows that an intended autonomy system necessarily involves high ASIL levels. Furthermore, the idea of an autonomy add-on system requires decisions on whether to assure the conventional system for this special case.
- The autonomous technology is maturing in a faster pace than the regulations. Therefore, there are currently no regulations available that clearly states how autonomous systems should be developed and tested.

8 Participating parties and contact person

- Volvo ATR (Advanced Technology & Research)
  Johan Tofeldt: johan.tofeldt@volvo.com

- MdH (Mälardalens Högskola)
  Joakim Fröberg: joakim.froberg@mdh.se

- CTH (Chalmers University)
  Mattias Wahde: mattias.wahde@chalmers.se

- C-PAC
  Greger Landen: greger.landen@cpacsystems.se

- Volvo CE (Construction Equipment)
  Veit Kleeberg: veit.kleeberg@volvo.com