Towards Zero Accidents and Increased Productivity in Roadside Construction

Project within FFI – Vehicle and Traffic Safety

Author: Stefan Bergquist and Peter Wallin

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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.**

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1. Executive summary

The main purpose of this project is to increase the safety at road-construction sites. The main long-term goal is to create the possibility for Volvo to reach zero accidents and high productivity for our customers. The focus has been on identifying safety risks at construction works, to develop an electronic safety cage (active safety functions), and to implement and test those in demonstrators. The goals for this project were:

- Investigate accident data from roadside construction to increase the knowledge and understanding of the safety risks.
- Define an electronic safety cage (active safety functions) to reduce the risk for accidents between people and machinery on construction sites. The productivity of the process should be taken into consideration.
- Investigate sensor systems for absolute or relative positioning for people and machinery.
- To implement a number of safety functions (chosen based on the result of the accident analysis) in a demonstrator.
- Present the results using the demonstrator and presentations as well as dissemination of research results.
- Appoint an industrial Ph.D. student within this area who will write a licentiate thesis within the project.

To fulfill the goals, the work was carried out within five work packages. In the first work package, the accident situation was investigated. It was concluded that the most common severe accident is workers on foot being struck by either machines or vehicles from the traffic.

In the second work package, possible safety functions to increase the safety at road construction sites were analyzed. It was decided that collision warning and automatic emergency brake functions should be implemented and demonstrated within the project. Those functions does not only have the potential to increase the safety in road construction but could potentially also be transferred to other type of machines and construction works.

In the third work package, possible sensors solutions were investigated and the safety functions were developed. Three sensors system was used in the project: GPS including communication between units, stereo vision, and radar. They all had specific advantages but none fulfilled all requirements for optimal performance of the developed algorithms. One zone-based collision warning function was implemented where dynamic safety zones are used to assess the risk for collision. Moreover, an automated emergency brake function was developed which predicts if the driver could avoid an obstacle. If not, the brakes are automatically applied.

In the fourth work package, the system and algorithm was integrated on construction machines. For the majority of the testing, the GPS with communication system was used.

It provided information to the algorithm which warned the driver or automatically applied the brakes when a collision was imminent.

In work package five, the project results were presented in several different ways. The activities include a number of demonstrations, presentations at conferences and universities.

The work has provided Volvo CE with a strong foundation in collision warning and avoidance research. It provides the possibility to be able to meet the customers' demand for high quality safety solutions before our competitors.

In addition to the technical progress, the project also enabled Volvo CE to expand their network and collaboration with stakeholders in road construction safety such as the major road construction contractors. Furthermore, the collaboration with sensor suppliers in the project has increased the common understanding of the requirements and possibilities on sensors for construction environments.

The project also had a successful collaboration SARPA (Safe And Robust Platform for Automated vehicles) where the GPS with communication system developed within this project was integrated on the SARPA test vehicle. Moreover, the automatic emergency brake function was integrated and tested together with SARPA.

2. Background

Roadwork and work including construction machinery often includes tasks carried out on or next to traficated roads. In this type of roadwork, accidents occur frequently. The work situation is complex with many involved actors such as construction machinery, workers on foot, and road traffic close by. This creates a highly dynamic environment where small mistakes can result in severe accidents.

The ongoing development in electronics, sensor technologies, and communication provides the potential to support the operators and workers with the aim to increase the safety and productivity. It is believed that the companies that can exploit this potential and offer technical solutions of high quality will be highly competitive in the future.

3. Objective

The main purpose of this project is to increase the safety at road-construction sites and at the same time increase the productivity. The main long-term goal is to create the possibility for Volvo to reach zero accidents and high productivity for our customers. The focus has been on identifying safety risks at construction works, to develop an electronic safety cage (active safety functions), and to implement and test those in demonstrators. The goals for this project were:

- Investigate accident data from roadside construction to increase the knowledge and understanding of the safety risks.
- Define an electronic safety cage (active safety functions) to reduce the risk for accidents between people and machinery on construction sites. The productivity of the process should be taken into consideration.
- Investigate sensor systems for absolute or relative positioning for people and machinery.
- To implement a number of safety functions (chosen based on the result of the accident analysis) in a demonstrator.
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Apart from these direct goals there are also strategic goals that the project should contribute to. Those include transferring knowledge and results to other parts within Volvo CE as well as to other parts in the Volvo Group. The project results will be part of Volvo's long term strategy for offering zero accidents in combination with high productivity. The aim is also that the results should be industrialized within the near future in safety and comfort functions for road-construction machinery. This should strengthen Volvos reputation as market leading when it comes to offering advanced technology that fulfills the customers' needs regarding safety and productivity.

4. Project realization

The project work was carried out within five work packages as described in the project proposal. In the first part, an accident investigation was made to understand what type of accidents occurs and how the can be avoided. Based on the results of the analysis, an electronic safety cage (a number of active safety functions) were chosen for implementation. The functions were developed and integrated on construction machinery. The results were demonstrated and presented. To be able to narrow down the project scope and chose machines for implementation, a specific type of road construction, asphalt paving, was chosen as the main focus area for the project. The aim was though that developed technology should be possible to transfer to other type of constructions.

Work package 1 – Accident investigation

The aim of the first work package:

- Investigate accident data from roadside construction to increase the knowledge and understanding of the safety risks.

When the investigation started, it quickly became clear that there is very limited data available about accidents within construction zones. Moreover, the available data is often

of low quality and does often not allow any deeper analysis. To get a good understanding of what types of accidents occur and how, a number of sources were used:
The aim of the first work package:

- Literature review – Available literature in Swedish and English concerning accidents in roadside construction were reviewed. From the data it was concluded that workers being struck by vehicles or mobile equipment is the main safety problem on construction sites.
- Data from Swedish insurance companies – Information was requested from AFA which had information about 70 accidents out of which 47 could be included in the analysis. The majority of the cases were less severe accidents such as tripping or slipping (24 %) or accidents during maintenance (24 %). The largest part of severe accidents was due to workers on the ground being run over (19 %).
- Data from Swedish road construction contractors – The major contractors in Sweden collect data about accidents and incidents. This data was provided to the project. Unfortunately, the descriptions were often not detailed enough to allow full understanding of the accident. The project provided recommendations on how the database could be improved to allow for better analysis with the aim of developing safety systems to decrease the accident risk.
- Interviews and focus group discussions – Eight interviews and three focus group discussions (including in total 14 persons) were conducted. The participants were people believed to have a good understanding of the safety on road-construction sites. They included workers and representatives from the road construction contractors, from the union, and machine manufacturers. The view on the safety was highly unified and all agreed that road-construction is a dangerous job with many risks. While most of the accidents are minor, more severe accidents do occur. This includes workers on foot being hit by traffic or machinery. According to the participants, outside traffic is most often involved in severe incidents and accidents.
- Visits to construction works in Sweden – During visits to asphalt paving jobs in Sweden the researchers were able to analyze the working conditions. It is clear that there is a risk for being run over by machinery or traffic. In this type of job, the traffic often passes the workers in the adjacent lane without any passive protection in between. At the same time, machinery and workers are operating close together on the same task.

Based on the analysis it was concluded that the main safety problems in asphalt paving construction are:

1. Workers on foot being run over by traffic inside the road-work area
2. Workers on foot being run over by traffic outside the road-work area
3. Workers on foot being run over by compactor.
4. Workers on foot being run over by construction-trucks.

Work package 2 – Design of electronic safety cage

The aim of this work package:

- Define an electronic safety cage (active safety functions) to reduce the risk for accidents between people and machinery on construction sites. The productivity of the process should be taken into consideration.

In work package 1 it was concluded what type of accidents that was most common in asphalt-paving sites. In this work package it was investigated how functions that could reduce the risk of accidents occurring might look. It was concluded that the accident risk could be reduced in a number of ways:

1. Warning functions that detects if there is risk for an accident and warns the driver if this is the case.
2. Guiding functions that actively guides, for example, car drivers on how to drive through a work zone.
3. Semi-automated functions that controls part of vehicles or machines tasks, for example, driving velocity, or brakes a machine if a collision is imminent.
4. Fully-automated functions that can control the whole driving task of, for example, a compactor or a car driving through a construction zone.
5. Functions that reduce the exposure of workers on the ground to machinery. This could be done by, for example, automating tasks that are today manually handled.

Based on the aim of the project it was decided not to aim for guiding functions or full-automation since such functionality will be very specific for different type of machinery. It will therefore not be easy to transfer to other machine types. Instead it was decided to work with warning and intervention functionality since those are believed to be transferable. Since the main problem was workers being run over, collision warning and emergency braking functions were chosen for implementation.

Work package 3 – Choosing the concept

The aims of this work package:

- Investigate sensor systems for absolute or relative positioning for people and machinery.
- To implement a number of safety functions (chosen based on the result of the accident analysis) in a demonstrator.

To be able to implement collision warning and avoidance functionality, a sensor that can detect surrounding obstacles is needed. The market was investigated to find the best sensor that fits the needs in road construction. It was concluded that the availability of sensors for this type of environment is very limited. In total, three different types of sensors were chosen for implementation and testing. None of them fulfilled all the requirements deemed necessary for optimal performance of the developed algorithms:

- GPS sensors with communication – all the machines and workers were equipped with high precision GPS sensors (DGPS with RTK) and communication units that broadcast the position of the unit at all times. The GPS antennas were bought from a supplier while the communication units were developed in-house. The machine unit and the workers unit are shown in Figure 1 and Figure 2. Since the antennas are fairly large the person units were backpack based which is of course not feasible for a production solution, however, it worked well for testing purposes in the project. Another problem with GPS based system is that they only provide good data when enough satellites are visible.

- Stereo vision – A camera based system called Blaxtair was bought from a supplier and a common interface to read data from the sensor was developed. This sensor is one of very few that is actually designed only for construction environments. The sensor performance showed very good during testing in the project. The camera was able to deliver high quality data even in challenging environments and light conditions. The main problem with the sensors is that it has very limited range. It is enough for functions in very low speeds but the range would need to be longer for the sensor to work in all driving speeds.
- Radar - A 77GHz radar system was bought from a supplier. This type of radar is normally used for Adaptive Cruise Control and Collision Mitigation for cars and trucks and the range is up to 200 meters. Radar is a proven technology that works well in different weather conditions. The main problem with the radar is that it cannot detect/distinguish people from machinery.

In addition to these three systems, a master thesis work on vision for worker detection was carried out within the project. This was mainly done to understand what performance can be expected from camera vision systems in road-construction environments in the future. The results looked promising but the developed algorithm generates too many false detections.

It was decided that both a warning function and an emergency braking function should be developed within the project. While the emergency braking function has higher potential to increase the safety, it is also more complicated to implement in a safe and reliable way. Possible false interventions will also affect the productivity negatively. It was shown in the project that it is complicated to warn operators in low speed scenarios when machinery is operating close to workers on the ground. Since the velocity is low, the operator can stop the machine very quickly if in control of the situation. However, in the warning design, the operator’s reaction time must be taken into account, and therefore warnings are likely to trigger too early and disturb the operator during normal operation. However, warning functions will still work in certain types of construction works, especially those where machines and workers are normally not working to close to each other.

The implemented warning function is zone based and dynamic safety zones are created around machines and workers. These zones are dependent on many factors, such as, velocity, steering angle, driving direction, and predicted driver performance.

The implemented emergency brake function is using the same strategy as state of the art functions in the automotive industry. The algorithm is not allowed to apply the brakes as long as the driver can avoid the obstacle. To decide if this is the case, it is predicted in every time step if the operator can avoid an obstacle by braking, steering or acceleration.

Figure 1: Two vehicle units mounted on a passenger car during the initial testing.

Figure 2: Two worker units in backpacks.

If the obstacle cannot be avoided in by any type of intervention, the brakes are automatically applied to bring the machine to a full stop. The algorithm is model based and therefore possible to use with different type of machinery by updating the model or model parameters. Within the project, it has been successfully tested on both compactors and haulers.

Work package 4 – Implementation on demonstrator

The aims of this work package:

- To implement a number of safety functions (chosen based on the result of the accident analysis) in a demonstrator.
- Present the results using the demonstrator and presentations as well as dissemination of research results.

The functions developed within the previous work package were implemented on machinery for testing and demonstration. For the majority of all tests and demonstrations in the project, the GPS system with communication was used as the obstacle sensor. It was used since it best fulfilled the needs of the project and could detect obstacles on long range and distinguish between workers and machinery. The hardware diagrams for the machine and worker units are shown in Figure 3. To achieve the highest quality of the position data it is necessary to use a base station with the GPS system.

The machine unit consists of the rapid prototyping control unit where the collision warning or emergency braking function is executed. The control unit is connected to the machine and receives data about velocity, etc. and can control the brakes. It is also connected to a unit which can provide visible and audible warnings to the operator. The position of the machine is received from the GPS unit which also broadcasts the position to all other equipped entities. The machine unit can also send warnings to the worker units.

The worker unit consists of the GPS unit which broadcasts the position of the workers and receives warnings from the machine communication units. It is connected to a device which can provide haptic warnings to the worker on the ground.

Figure 4 shows a hauler and an obstacle equipped with the system during testing and demonstration on a hauler in Eskilstuna. This test was performed together with SARPA.

When the stereo camera and radar were evaluated, they were integrated in a similar way to the machine units on the machinery. In those two cases, the control unit received the obstacle position data from the respective sensor instead of from the GPS unit. In this setup, the workers on the ground did not need any equipment. Hence, it was not possible to provide any warnings to the workers when using those sensor systems.

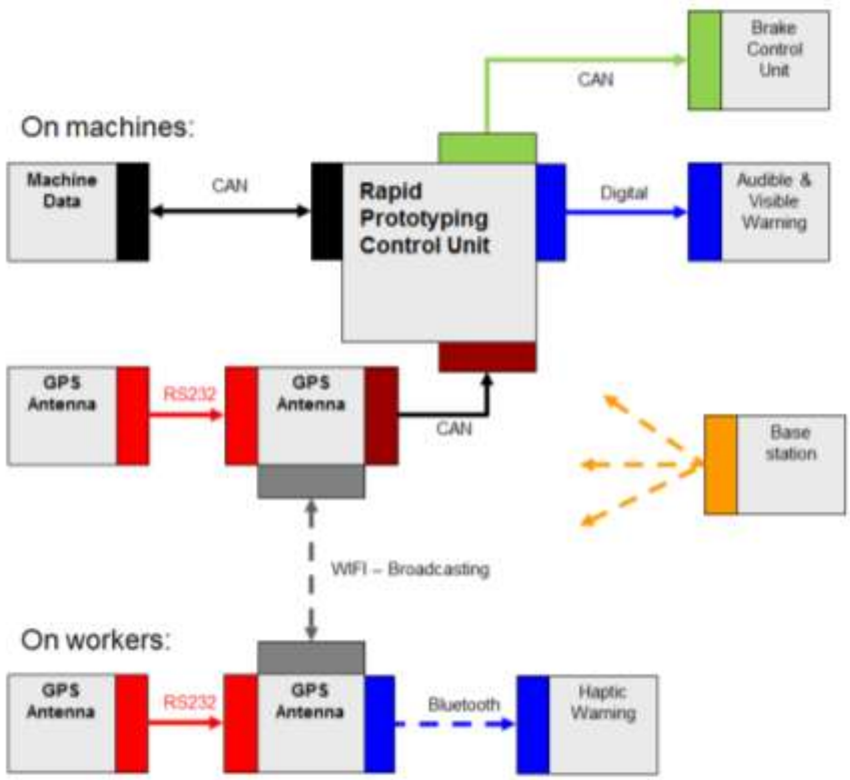

Figure 3: Hardware diagram for the GPS system including communication.

Figure 4: Hauler and obstacle equipped with the system during testing and demonstration together with SARPA in Eskilstuna 2014.

Work package 5 – Presenting the results

The aims of this work package:

- Present the results using the demonstrator and presentations as well as dissemination of research results.
- Appoint an industrial Ph.D. student within this area who will write a licentiate thesis within the project.

The project results have been presented internally and externally on a number of occasions. In the beginning of the project he aim was to gather information which was done internally in workshops and externally in meetings with different entities working with road construction such as contractors, the road administration, the union, etc.

As the project progressed, the focus was on presenting the results which has been done internally in a number of demonstrations and presentations. Externally, a number of presentations have been given on conferences and on other universities.

An industrial Ph.D. student was appointed early in the project. The licentiate thesis degree planned to be completed in the project has been delayed since the industrial Ph.D. student has been working in other related projects. Volvo will continue to fund the Ph.D. work and the aim is that the thesis should be finalized during 2015.

5. Results and deliverables

5.1 Delivery to FFI-goals

The project has contributed to advance Volvo position in research on safety in roadside construction and other type of construction works compared to the competitors. If this advantage can be exploited and active safety technology can be industrialized in the near future, Volvo will have a competitive advantage, especially since the customers' interest in safety has increased greatly over the last few years. The continued development will be decided based on demonstration results after the project end date. The response to the earlier project demonstrations has been positive and the possibilities for continuing the development look promising. If the developed technology can reach the market it has the potential to contribute to the aim of reducing the number of fatalities and injuries in the traffic.

During the project, Volvo CE has increased its network in several areas. There have been several stakeholders that have contributed to the project. Some examples are the union for road workers and the major road construction contractors in Sweden. They have all provided their view and data on accidents and risks on construction sites. They have also allowed the project crew to visit worksites for observation and data collection. The common activities have led to increased collaboration and have the potential to lead to new collaborations in the future. Volvo has also increased the collaboration with sensor providers with the aim to find feasible sensor solutions to be used in construction environments.

The Ph.D. student has during the project been able to establish international connections when visiting or meeting with other universities: Vrije Universiteit Brussels, Penn State University, and UC Berkeley. Common research interests were identified with UC Berkeley researchers and as a result, the Ph.D. student will spend 15 months in Berkeley during the next 3 years. This collaboration has been realized thanks to a Vinnova Vinnmer project grant. The collaboration gives Volvo the opportunity to collaborate with world leading researchers.

The project moreover successfully managed to support the SARPA project and provide a sensor system to be used on their automated test vehicle. In addition to the sensor system, the automatic emergency braking function was integrated on the machine as a safety backup system to avoid collisions in case the automated functionality failed. This provided the opportunity to make sure that the developed algorithms were possible to transfer to other type of machines with only minor modifications.

6. Dissemination and publications

The project has been presented at several occasions both internally and externally. The dissemination activities include demonstrations with machines, presentations at conferences and universities, and exhibiting on FFI program conference. Figure 5 shows two pictures from a demonstration together with SARPA during 2014. A movie from the demonstration was part of the exhibition on the FFI Program Conference in 2014.

Figure 5: Pictures from the movie recorded during the demonstration of automatic emergency braking in Eskilstuna, 2014. The picture to the left shows a close call when the machine has stopped just before hitting the dummy. The picture to the right shows how the machine can drive around close to the dummy without the algorithm generating any false intervention.

6.1 Knowledge and results dissemination

A list of dissemination activities is given below:

Demonstrations

Demonstration of warning function for machine - worker and machine - machine collision, Gothenburg, 2014. This demonstration was carried out with a passenger car and people on foot. All units were equipped with positioning units and warnings were issued when there was a risk for collision.
Demonstration of emergency braking algorithm on hauler, Eskilstuna 2014. This demonstration was carried out on the A25 hauler used in the SARPA project. The machine was driven towards worker and vehicle dummies equipped with positioning equipment. The brakes were automatically applied to avoid collision with the obstacles.
Demonstration of warning functions for machine to worker and machine to machine collision, Shippensburg, 2014. This demonstration was carried out with a paver, a compactor and in presence of people on foot to simulate a construction work. All involved units were equipped with positioning units and warnings were issued to the machine operators and the workers on foot when there was a risk for collision
Planned: Demonstration of machine - machine collision warning functionality, Shippensburg, 2015. A demonstration using paver and compactor on a simulated road work is planned in Shippensburg for April, 2015.

Presentations

Conference presentation at the International Symposium of Automation and Robotics in Mining and Construction, *Automation for improved safety for roadside construction,* Montreal, 2013.
Presentation at Department of Fundamental Electricity and Instrumentation, Vrije Universiteit Brussel, *Towards Zero Accidents in Roadside Construction,* Brussels, 2013. Presentation regarding active safety function design for collision avoidance.
Presentation at Department of Mechanical Engineering, Penn State University, *Warning design for collision avoidance functionality,* State College, PA, 2014. Presentation regarding warning design in low-speed scenarios for collision avoidance.
Presentation to in connection to Volvo dagarna, *Projektuppdatering: Nollvision vid vägarbeten*, Eskilstuna, 2014. Presentation about the project status to stakeholders.
FFI program conference, ”Fordonsstrategisk Forskning och Innovation – Vision, trender och internationell utblick, Gothenburg, November, 2014. The project presented the emergency braking functionality which was tested on a Volvo A25 hauler together with SARPA. The presentation contained posters, a movie, and a working installation of the vision sensor used in the project with human detection and tracking.
Planned: Conference presentation at the Intelligent Vehicles Symposium, *On threat assessment and collision avoidance for articulated machinery in low-speed scenarios*, Seoul, 2015. A paper has been submitted to the conference and notice of acceptance will be given in April 2015. The paper investigates how algorithms developed for the automotive sector performs in construction machinery and low-speed scenarios.
Planned: FFI conference on project results, 2015. The project has been proposed for presentation on the conference. The presentation would include a broad overview of the results achieved within the project.

6.2 Publications

S. Bergquist, C. Grante, J. Fredriksson, J. Sjöberg. Automation for improved safety in roadside construction, International Symposium on Automation and Robotics in Mining and Construction, Montreal, 2013.

S. Bergquist, J. Sjöberg, C. Grante. On threat assessment and collision avoidance for articulated machinery in low-speed scenarios, submitted to The Intelligent Vehicles Symposium, Seoul, 2015.

Arash Akbarinia, Real-time 2D detection and tracking of construction workers, Erasmus Mundus in Vision and Robotics, 2013.

Vignesh Radhakrishnan, Machine movement prediction for collision avoidance, Delft Center for Systems and Control, 2014.

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7. Conclusions and future research

In this project, the focus has been on increasing the safety in roadside construction. It has been shown that these are risky workplaces where accidents often occur. The most common type of serious accidents is workers on foot being struck by vehicles or machines. Within the project, a number of potential safety increasing functions, ranging from warnings systems to full automation, have been identified. Systems that can warn the operator or automatically brake the machine to avoid an imminent accident were implemented. The potential of these systems were shown in tests and demonstrations.

At the same time, the project has identified a number of problematic areas where more research and work is needed. One major problem is the lack of sensors for this type of environment. Here, an increased cooperation with sensor suppliers is needed. Another area is warnings in low speeds where more research is needed to decide in what type of works and for what type of machines warnings can be used efficiently.

The work has provided Volvo CE with great knowledge about collision avoidance systems and their performance in roadwork environments. This provides the possibility to be able to meet the customers' demand for high quality safety solutions before our competitors.

Furthermore, the project has contributed to establishing contacts between Volvo CE and a number of other actors working with, or interested in safety in road works. Such examples are the major road construction contractors and sensor suppliers. These contacts have the potential to speed up the introduction of active safety systems in road work environments and reduce the number of killed and injured in traffic.

8. Participating parties and contact person

Volvo Construction Equipment
Peter Wallin
peter.wallin.2@consultant.volvo.com
016 541 6316

Chalmers Tekniska Högskola
Jonas Sjöberg
jonas.sjoberg@chalmers.se
031 772 1855

Volvo Advanced Technology & Research
Stefan Bergquist
stefan.bergqvist@volvo.com
031 322 9254