Final report: Next Generation Test Methods

Project within: Traffic Safety and Automated vehicles.

Authors: Anna Wrige Berling, Krister Wolff, Fredrik Bruzelius, John Lang, Anders Ödblom, Henrik Eriksson, Vivetha Natterjee.

Date: March 31st, 2015

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

As the active systems currently are going from research and limited implementation to broad implementation, difficulties in the processes of validation and verification of these functions have arisen. There is a lack of process – a chain of methods and tools – that can guarantee quality and safety throughout verification and validation of the next generation active safety system.

The NG-TEST METHODS project has aimed to address the research needed in order to achieve effective verification of active safety functions. The main problem to investigate has been to establish the framework for efficient active safety function verification and validation through consistent methods and tools.
Hence, the purpose of the project has been to increase efficiency in active safety testing by:

- extending the share of virtual tests and automation
- connecting virtual simulation environment with physical test environments
- finding a flexible use of various test environments
- increasing verification/validation in early phases in a simulation environment

Five main test beds have been included in the NG TEST METHODS project:

- **Virtual environment**; using different simulation software for verification.
- **Automated testing on test track**; where test vehicles and targets are driven by robots.
- **Virtual reality**; Driver of physical vehicle is in a virtual world.
- **Augmented reality**; Driver of physical vehicle sees real world that can be augmented by virtual elements.
- **Scaled test track**; Visualization and verification of functions with scaled vehicles and targets.

Figure 1 – Illustration of the five main test beds included in the NG TEST METHODS project.

The NG TEST METODS project has developed each test bed and also developed a process for how to combine the different test beds for an efficient verification framework. The project has successfully achieved the following results:

- Method for virtual simulation with high ability, accuracy and efficiency
- A method for how to take the virtual simulation results (and accuracy) to the test track.
- Developed tools necessary automated testing on the test track.
- Implementation of a first, completed version of a scaled test track
- Implementation of virtual reality as a verification tool.
- Major steps taken within augmented reality.
- Common drive file format to facilitate the use of different test beds in a comparable and consistent manner.

For detailed results see further in technical reports from the project.

2 Background

As the active systems currently are going from research and limited implementation to broad implementation, difficulties in the processes of validation and verification of these functions have arisen. Several research projects, such as Preval and eVALUE have already been conducted in the area, and developed some scenarios, methods and tools for verification of active safety systems. However, the efficiency of the methods is very limited since there is a lack of interfaces between the tools that often are stand alone. Research is needed to establish a process with a chain of methods and tools that efficiently validate and verify the system safety of these advanced active systems. Such a process is necessary to be able to verify and validate the coming generations of active systems that deals with complex situations such as on-coming traffic, crossing traffic, VRU and run-of-road accidents. The quality of today’s methods and equipment is too poor to face these challenges. It is therefore doubtful if the current tools and equipment can handle verification and validation of the next generation of active safety functions which poses a problem in development and research projects such as Non Hit Car and Truck.
There is a lack of process – a chain of methods and tools – that can guarantee quality and safety throughout verification and validation of the next generation active safety system. To be competitive, it is necessary for the Swedish companies work with active safety development to have more an efficient and advanced validation and verification process. By close coupling of the desktop simulations studies, simulators, augmented reality testing on the proving ground and the proving ground tests the verification and validation we believe that it is possible to significantly improve efficiency, quality and ability of active safety systems. We believe that most tests will be possible to perform virtually. Even more importantly, it will become possible to test the safety guarantees of future active safety systems for situations that are currently difficult or even impossible to evaluate, such as oncoming traffic scenarios.

3 Objective

The NG-TEST METHODS project has aimed to address the research needed in order to achieve effective validation and verification of active safety functions. The main problem to investigate has been to establish the framework for efficient active safety function verification and validation through consistent methods and tools.
Hence, the purpose of the project has been to increase efficiency in active safety testing by:

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4 Project realization, results and deliverables

4.1 Project overview

The NG-TEST METHODS project has targeted function verification through the development process with a focus on an effective process by linking available tools for verification. The focus can be seen in Figure 1, which describes the development process of active safety functions with help of a V-model.

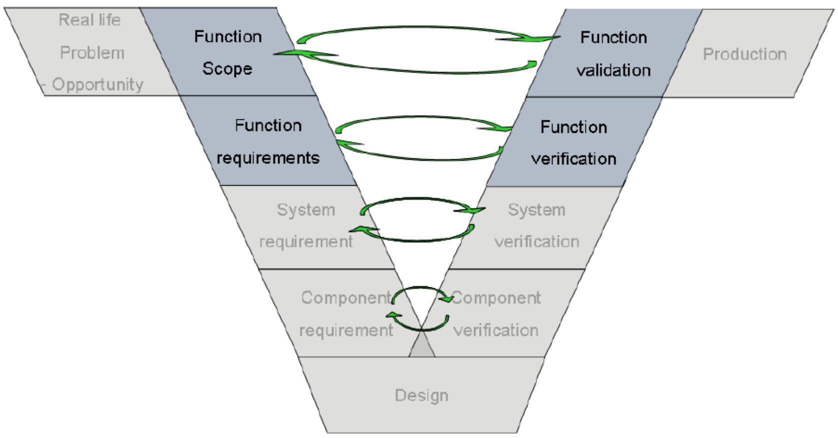

Figure 2 – Development process for active safety functions described as a V-development model, indicating that this project is focusing on function validation and verification.

The project is partitioned into nine work packages. The name of the different work packages and how they relate to each other is illustrated in this picture:

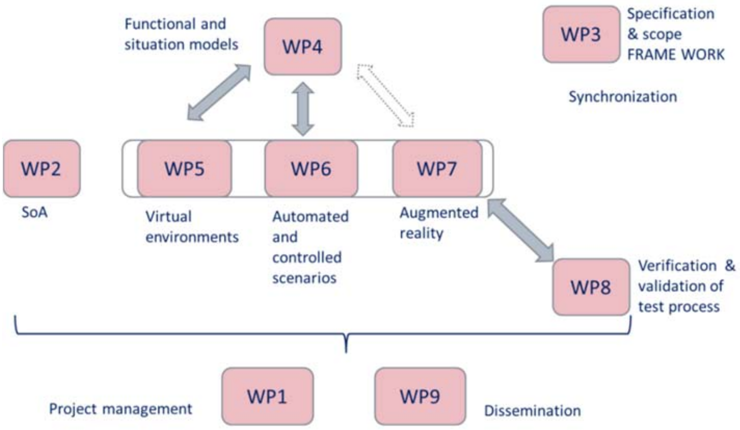

Figure 3 – NG test work package structure.

The result from the project work is described in sections 4.1.1-4.1.7. Behind each section there is a detailed report describing further the research conducted and the results. Some of these reports are publically available and some are confidential.

4.1.1 State of the art analysis

A tentative mapping of available testing tools for active safety systems into four basic development stages shows no obvious gaps, rather there are several tools available for each stage, see Table 1. A conclusion of this state-of-the-art report is therefore that the main challenge is to choose the set of tools that complement each other in the most optimal way while keeping cost down. A seamless transition of test scenarios between tools upwards and downwards the development tool chain is paramount.
While there are tools in all the development stages listed in Table 2, some areas are not as mature as other. Driver modeling is an area that is under development. Also scaled prototype systems and augmented reality testing are methods that researchers and OEMs have just recently begun to explore and apply for development of active safety systems.
Testing active safety systems in desktop simulation require vehicle dynamics models, traffic scenarios, driver models, and sensor models. Some sensors also require special solutions for presenting correct input to the sensor. In the case of cameras, a solution is to use augmented imagery to generate desired input stimuli.
When driver models are not enough, a driving simulator is a tool that allows real drivers to be included in the simulation loop. While the driver is real, the active safety system can be implemented as a model, software, or hardware, depending on development stage.
The gap from desktop simulation and driving simulators to proving ground testing is being bridged by a new method based on miniature vehicles and a scaled down traffic environment. Vehicle-in-the-loop testing with augmented reality is another promising technique that aims to combine the safe and controllable nature of desktop or lab environment with the realistic setting of real world testing on proving grounds.
Development of active safety systems puts new requirements on proving grounds. Sensors and drivers need to be presented with realistic targets. A variety of vehicle, pedestrian, and motorcycle targets have been developed. Furthermore, there is a need for robots to control vehicles up to high speeds with high precision under safe conditions.

Table 1: A mapping between tool and stage of development process where the tool applies

	Function scope	Function requirement	Function verification	Function validation
Hazard & risk analysis	X	x		X
Computer desktop simulation	X	X	X	
Driving simulator	X	X	X	
Scaled prototype systems	X	X		
Augmented reality testing	X	X	X	X
Proving ground testing			x	X
Field operation testing	X	x		

4.1.2 Process and methods

The core in making verification and validation of active safety systems more virtual is to have the same representation independent of the verification environment it is run in. This gives the ability of running the exact same active safety function in the exact same scenario in different verification environments. The virtual test can with these principles be validated in a physical environment, thus the validity of the virtual verification may be guaranteed. Some of the virtual scenarios may in this manner be validated although the great number of verification scenarios is only performed virtually.
Additionally it is essential to be able to load in data from a replay environment (e.g. scenario description and log data) in a common manner between the different test environments. The ambition is to have one identical interface that feeds desktop simulations, simulators, mixed reality testing and automated test track scenarios.

Building a virtual simulation environment to be able to support in the verification and validation process is predominantly concentrating on the following objectives.

- Re-usability of real and virtual test data
- Constructing useful and real-life based scenarios
- Ability to integrate real scenarios with virtual overlays
- Modification of data in modular level

The aim with having a full scale validation requires (i) the formulation of the scenario in a virtual environment, (ii) Component level validation in a HiL facility, (iii) Test drives of the selected scenarios. It is also vital that there is an interface to and from each of the model to the other. In the NGTest setup that is to be described the steps for this integration is as follows

(i) Virtual Simulation Environment: Prescan, VCTS or any simulation tool is used to generate scenarios with details of the real environment where the vehicle will also be represented with dynamics and functions as in the real vehicle

(ii) Component level: Driving robots with the same profile as the virtual simulation environment will be able to run the same scenarios as in the virtual world in simulated tracks

(iii) Test Drives: Based on the input received from the virtual verification and validation, productive test drives will be carried out in real vehicles in targeted environments.

In order to achieve adaptability and reusability to multiple simulation and real world setup a common interface description is required. After brainstorms, implementation and re-implementation it was identified that the best way to have a robust setup is to have a ‘Greatest Common’ scenario and vehicle description which can be used to represent the scenario in multiple environments. This means that each of the tools will have the possibility to extract necessary information mandatory to the tool in order to recreate the scenario. Figure below gives a view on the commonality setup of drive files.

In order to have a ‘Greatest Common’ description there is a set of mandatory information that is needed in order to recreate a scenario from scratch. A defined format that is representative for all the tools and the minimum information needed are identified during the course of the project.

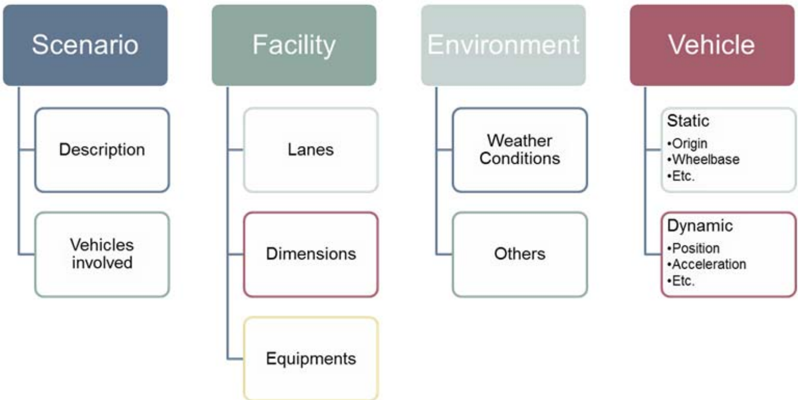

Figure 4 – Representation of NG TEST METHODS drive file format.

4.1.3 Using Rigorous Simulation to Support Hazard Analysis and Risk Assessment

The goal was to investigate if rigorous simulation could be used to support and guide the hazard analysis and risk assessment (HARA) according to the standard ISO26262.
One important activity when designing active safety functions is to determine the level of safety integrity, i.e. how trusted a system can be to not malfunction in a dangerous way. To be able to do that, hazards, hazardous events, and their associated risks have to be determined. This activity is guided by the standard ISO 26262, and the risks are quantified using three parameters: exposure, severity, and controllability.

Hazards due to a malfunctioning item together with an operational situation form a hazardous event. In order to avoid unreasonable risk, safety goals are formulated. The integrity of a safety goal (ASIL) is determined by analyzing the impact factors severity, exposure, and controllability. The result of the HARA is a number of safety goals and their associated ASILs.

A modeling language called Acumen was selected for this task. Acumen is a domain specific language design to represent the specifications and concepts of cyber physical systems. A key characteristic of modeling and simulation languages for robotic systems is supporting hybrid (continuous/discrete) mathematical models. Modelica and SimScape are widely used examples of such type of languages.
It appears that a lightweight language like Acumen with just few features can be helpful in addressing interdisciplinary challenges. Using a lightweight language can help highlight the connections between mechanical, electrical and computer science concepts precisely and avoid the introduction of artificial distinctions between manifestations of the same concept in different contexts. These observations inspired us to look into the utility of the tool into automotive design process especially at early conceptual phases.

A rear-end advanced emergency braking (AEB) scenario was the intended use case and it was modelled in Acumen. Brake omission failures were simulated and the resulting collision delta-velocities used to determine the severity levels useful for the HARA.

4.1.4 Virtual environments

The project aimed to develop virtual tools with sufficient ability, accuracy and efficiency to reduce physical testing. For an efficient way of working we need a strong chain of tools which integrate seamlessly with each other from in-computer to in-vehicle based testing.
Since a wide range of active safety technologies are needed to reduce traffic accidents, and the subsequent injuries, we need a wide range of Computer Aided Engineering (CAE) tools. Below follows a summary of the results in WP5.
The contributors to this work package are Volvo Car Corporation and AB Volvo. Volvo Cars has primary focus on in-house developed tools as summarized below, whereas AB Volvo has been investigating what can be accomplished with the commercial tool Prescan.
Specifically, we have developed the following capabilities to increase the virtual ability:

1. Import and replay of test track scenarios in CAE
2. CAE design, export and physical replay at test track of CAE scenarios
3. Scalable traffic simulator with equivalent treatment of all traffic objects
4. Electronic Horizon simulator
5. Automatic parking simulator
6. ITS cloud simulator
7. Worst case simulator
8. Road network generation from map and road databases
9. Arbitrary driving path generator
10. Interacting driver models for testing of autonomous functions
11. Traffic Jam Assist / Adaptive Cruise Control simulations
12. Lane Keeping Aid evaluation method
13. Replay environment development

14. Hardware-in-the-loop 3D worlds
15. Vehicle dynamics control simulations
16. Evaluation of commercial tool Prescan for active safety testing

We have worked on the virtual accuracy in the following areas:

A. Final vehicle positions relative surrounding objects and road for automatic parking functionality
B. Accuracy of robotically controlled physical vehicles on test track
C. Positioning accuracy in real traffic environments
D. Accuracy of sensor models

In terms of virtual efficiency we have worked on the following subjects:

- Compiled traffic simulator that runs on cluster computers
- Automatic search for worst case errors
- Robotic data collection for efficient physical testing
- Automatic extraction of all driving paths in arbitrary macro-intersection
- Automatic Hardware-in-the-Loop analysis

Example of automatic parking simulator is shown in the figure below.

Figure 5 – Simulated vehicle that parks autonomously between two cars.

4.1.5 Automated test track scenarios and equipment

Active safety system are in the automotive industry are becoming more prevalent. The complexity of the scenarios that the active safety systems are helping to avoid or mitigate accidents are increasing as the technology matures. Thus the need to test these active safety systems in a safe and controlled manner is also increasing. The goal of WP6 was to investigate and develop test tools and methods to meet the needs of the next generation of active safety testing.

The first step of this process was to analyze the current test tools and targets to determine their strengths, weaknesses, and limitations. Crash tests were performed on the balloon targets to determine the max collision speed of the target and to see if there was any damage to the subject vehicle. Existing driving robots and target platforms were also tested running simple scenarios to measure their performance.

As the test scenarios become more complex it was decided that automation was necessary to provide a repeatable and accurate testing environment. A driving robot was developed to allow for the full control of the lateral and longitudinal direction of the vehicle. Actuators were used to control the acceleration pedal, brake pedal, and steering wheel, and a combination of high precision GPS and IMU were used to provide accurate position feedback for the system. The system was controlled by creating a “path” file for it to follow which describes the timing, position, speed, and acceleration at points along the path. Also developed was an automated target platform that would allow itself to be run over by a vehicle. This was deemed necessary to handle the testing needs where on-coming or crossing traffic scenarios were involved. This platform provides and same functionality as the driving robot in terms of lateral and longitudinal control and also uses high precision GPS and IMU data for accurate positioning. The platform was also designed to follow the same driving “path” as the driving robot. Another method for automating the vehicle that was investigated during the project was to use a driving robot and control the vehicle through a CAN interface, using the existing actuators in the vehicle. This method provides good results for certain test scenarios, and provided for a quicker and cleaner installation.

A scenario tool was developed to help assist in the creation and adjustment of test scenarios. Multiple vehicles could be added to the simulation and the vehicle paths could be created by adding line segments to describe the motion paths of the vehicles. Four possible line segment types could be chosen: straight-line, arc, clothoid, and cosinus, and the speed during the segments could be chosen as well. The view angle of active safety sensors could be displayed and digital maps could be overlaid in the background. The output files generated from the tool could then be directly loaded by the driving robots.

To test the tools four scenarios of varying complexity were selected to be tested during the course of the project. Scenario #1 was a true-positive rear-end scenario where the subject vehicle approaches a target vehicle that is moving at a slower speed directly in the path of the subject vehicle. Scenario #2 was a false-positive scenario involving a cut-in maneuver. The scenario involved the subject vehicle driving in a straight line and a target vehicle running at the same speed cutting into the path of the subject vehicle from another lane. Scenario #3 was another false-positive scenario which involved a subject vehicle and a slower moving target vehicle driving in the same path, and the target vehicle would turn off on an off-ramp before an impact could occur. Finally scenario #4 was a true-positive intersection scenario, which involved the target vehicle making a right turn into the path of the subject vehicle. The subject’s vehicles lateral position was also adjusted to test various overlaps of the target vehicle.

Finally, two accuracy and repeatability studies were performed using robots to automated testing process. It was shown that good synchronization, accuracy, and repeatability could be achieved by automating the scenarios and that test cycle times of 3-4 minutes could be achieved.

Figure 6 – Automated testing on the test track. Cut-in scenario where the truck approaches an intersection where the balloon car suddenly drives out in front of the truck. Truck and balloon car driven by robots. Complete scenario controlled from the control room. (AstaZero Multilane test track).

4.1.6 Scaled test track

A novel methodology and test bed, primarily for research and development in connection with active safety systems for cars and trucks, but also for research about autonomous car driving. The scaled test track (STT) laboratory is based on modified radio-controlled scale model vehicles. The scaled test track is a high impact embodied simulation, visualization, and user experience tool, intended for rapid prototyping and debugging of test scenarios in connection with development of active safety systems. The main result consists of an implementation of a first, completed version of the scaled test track. It has been demonstrated to be useful in five different test cases, see below, and the accuracy and repeatability have been investigated. Specifically, the first version of the subject vehicle is completed, and a working version of the first target vehicle has been completed. The subject vehicle can be controlled (speed, brake and steering angle) from the driver's interface, via the wireless network, using a standard gaming wheel. Furthermore, an on–board video camera has been installed and connected with the data communication software. The data communication framework has been implemented, including all necessary backbone functionality, e.g. streaming video, transmitting control signals, and logging functionality. In addition, a local positioning system has been investigated and integrated with the overall system. Thus, closed-loop control of the vehicles has been achieved, as well as motion logging. Six test cases have been performed in the scaled test track, in order to demonstrate and verify the functionality. The ensemble of test cases comprise the following six items:

- DLC: Human driver double lane change test (Sect. 3.1).
- BDF: Basic drive file test (Sect. 3.2).
- BTI: Basic T intersection scenario (Sect. 3.3).
- ATI: Advanced T intersection scenario (Sect. 3.4).
- DAB: Dynamic avoidance behaviour (Sect. 3.5).
- REP: Repeatability test (Sect. 3.6).

The scaled test track is primarily intended for use in connection with development and rapid prototyping. It is not meant to replace any of the current tools and methods, such as computer simulations, driving simulators, or full–scale proving ground tests. It should be seen as a novel, complementary tool, which could provide new insights to the field. Furthermore, an essential role of a university is to spread knowledge to the public, society and industry. Therefore, efforts have been undertaken in order to involve Chalmers students in the work with the STT lab. The STT lab has been shown at two NG-Test external demonstration events, with invited guests from the industry and academia. Finally, a scientific paper about the scaled test track has been published within the project.

Figure 7 – Photo of the scaled test track for the double lane change demonstration. There are two lanes in the track, defined by the red cones shown in the picture.

4.1.7 Augmented/virtual reality testing with driver in the loop

Testing of active safety systems using real vehicles on a test track can be resource intensive, dangerous to both man and machine and also have poor reproducibility and repeatability. Driving simulators offer a remedy to some of these issues but suffer from their own disadvantages; e.g. driver behavior adaptation, motion sickness, and questionable validity. An alternative to driving simulators is to use virtual or augmented reality and perform experimental scenarios in a real vehicle at a test track. This provides an efficient way of testing that inherits many of the advantages of driving simulators, while retaining some of the advantages of physical testing.
The augmented/virtual reality system performance and usability is defined by main characteristics, such as the latency of the visual presentation, the field of view, and the tracking accuracy of the user’s head motion. Correct tracking of the user’s head relative to the vehicle and the road is essential to correctly orient synthetic objects, such as other vehicles or obstacles. The aim of the present work was to investigate the feasibility to use augmented/virtual reality in vehicle and vehicle system testing.
The need for flexibility to investigate various characteristics imposed a development of a system rather than acquiring an off-the-shelf product. A system consistent of a head mounted display, two cameras and a tracking system was developed and algorithms and software were produced to achieve the desired function. Design considerations and component chooses and their consequences were explored.

Two major studies were conducted during the work, where the first one was designed to measure the human sensitivity of photon-to-photon latency in the system, i.e. the time elapsed before an object is presented in the display system. Latency is believed to be one of the key factors that determine the usability of the technique. The study, with 24 test subjects driving a simple driving task when exposed to pre-defined latencies, suggest that human drivers are well capable to compensate for fixed time latencies with only minor changes in the driving behavior. However, the level of discomfort and motion sickness of the test subjects appears to increase radically with increased latency.
A second study was set up to compare the driving behavior when using augmented reality, virtual reality and just use the head mounted display. The general conclusion is that drivers appear to easier accept virtual reality and the perceived level of difficulty is higher for augmented reality. However, all drivers manage to complete the task in all three environments and the self-perceived performance of the conducted task were almost similar.
Further tests needs to be conducted in these matters and further improvements needs to be implemented to the system, such as tracking performance to cope with fast head motions, improved depth cues of the computer graphics and reduced latencies to increase the comfort and realism. However, as a concept it has great potential to be a competitive tool in testing vehicle active safety systems and none of our conclusions here suggest otherwise.

Figure 8 – Left: a participant in the study wearing the helmet. Right: the test vehicle driving in the cone track.

4.2 Delivery to FFI-goals

The Next Generation Active Safety Test project can be directly related to the areas Intelligent Safety Systems, Crash Safety, development methods and Human cognition and tolerances defined by FFI. It also relates to the area of vehicle development with embedded system and software.
Measurable contribution of the Next Generation Active Safety Test project to the program:

- Ability to verify and validate system safety for next generation active safety applications which target severe traffic situations with significant overall traffic fatalities today. These methods will allow for deployment of active safety systems that otherwise would not be possible to introduce.

- Increased efficiency and effectiveness in validation and testing by virtual methods that ties with physical testing – leading to earlier introduction of active safety functions and room for development of more functions as well as strengthening of Swedish competiveness within the area.
- Ability to perform automatic tests on the test track – giving the opportunity for exact description of test scenarios and ability to repeat them
- Ability to determine driver response in real vehicles for fatal collision scenarios to set requirements for and validate active safety function design
- Increased number of research projects leading to the development of new and improved products.
- Use of the verification and validation process with its methods and tools in new active safety development projects

5 Dissemination and publications

5.1 Knowledge and results dissemination

During the project 2 demonstration activities were organized. The first one was held during the fall of 2013 and the second one was the final demonstration which was organized as the “Researchers’ Day” at AstaZero in October 2014 – a half day event with over 100 participants. Projects presentations as well as desktop and test track demonstrations.

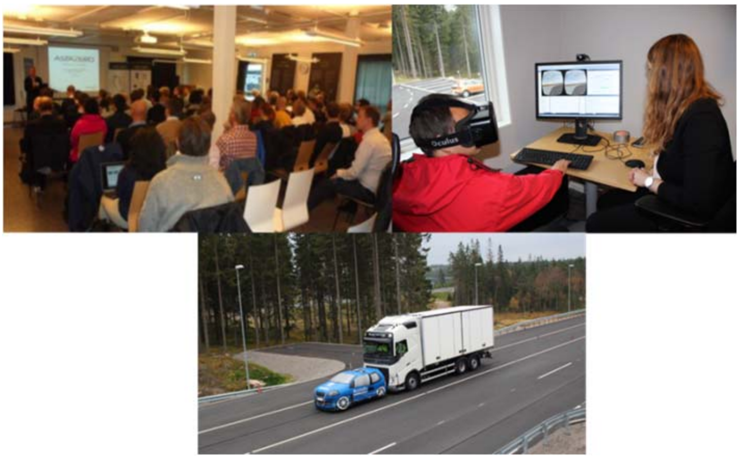

Figure 9 – Photos from the final demonstration of the project.

Also, the project has been presented at various venues, such as FFI resultatkonferens; Transportforum, SAFER International Scientific Advisory Board review.

The project has connections to several other research projects. Two projects that can help speed up the introduction of the NG test methods and results are the A-TEAM I & II and Asta zero Sim projects.

5.2 Publications

Augmented and Mixed Reality as a tool for evaluation of Vehicle Active Safety Systems
Proceedings of the International Conference Road Safety and Simulation, Italy 2013.
B. Blissing F. Bruzelius, J. Ölvander

Abstract:
Even though the realism of driving simulators increases constantly, there is a potential issue with how representative the test is compared to a real life scenario. An alternative to simulators is to present a mixture of real and simulated environment to the driver and perform the scenario at a test track when driving a real vehicle. This enables an efficient way of testing that inherits many of the advantages of driving simulators as well as some of the advantages of physical testing in prototype vehicles. The present paper is a compilation of previous research in augmented reality in vehicle driving situations, focusing on technical limitations of Head-Mounted-Displays.

Scaled test track: A novel approach for active safety system development, testing, and validation
Krister Wolff, Ola Benderius, Mattias Wahde
Department of Applied Mechanics, Chalmers University of Technology

Abstract:
This paper provides a summary of the work performed in the first iteration in the development of a scaled test track lab, which currently is under development in the Adaptive systems research group at Chalmers University of Technology. It is mainly intended as a tool for research, development and testing of active safety systems for cars and trucks. The scaled test track is based on modified R/C scale model cars, which have been modified with on-board computers and cameras. A local positioning system, which is based on IR cameras, is used for tracking of vehicle motions, and the execution of the test scenarios is handled from a central server node. Furthermore, a wireless computer network is used for sharing data and control signals within the system. Apart from the physical vehicles, an arbitrary number of virtual cars can be simulated.
So far, two relevant test scenarios have been executed in the scaled test track, in order to demonstrate and verify the functionality.

Further publications are planned for after the end of the project, primarily by Högskolan i Halmstad (Using Rigorous Simulation to Support Hazard Analysis and Risk Assessment), VTI (Augmented reality) and Chalmers (Scaled Test track).

6 Conclusions and future research

The detailed conclusions can be found in the technical reports.
The overall conclusion from the project is that many important steps have been taken on the way to a verification framework – with a large share of virtual verification – to achieve efficient and accurate verification of active safety functions.
Future research is needed to take all methods and test beds to a mature enough level to be used extensively in product development.
Also, more research is needed to define in full detail all parts of the framework and how different test beds should relate to each other in the development process.

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7 Participating parties and contact person

Part		Kontaktperson
VOLVO	Volvo Technology AB	Anna Wrige Berling anna.wrige@volvo.com
VOLVO	Volvo Car Corporation	Anders Ödblom anders.odblom@volvocars.com
Autoliv	Autoliv Development AB	John Lang john.lang@autoliv.com
CHALMERS	Chalmers University of Technology	Krister Wolff krister.wolff@chalmers.se
	Högskolan i Halmstad	Tony Larsson tony.larsson@hh.se
vti	The Swedish National Road and Transport Research Institute	Fredrik Bruzelius fredrik.bruzelius@vti.se
SP	Sveriges Tekniska Forskningsinstitut	Henrik Eriksson henrik.eriksson@sp.se