FFI

FORDONSSTRATEGISK
FORSKNING OCH INNOVATION

Final report, A-TEAM phase 2b

Writers: Niklas Lundin, Christian Berger, Alessia Knauss, Magdalena Lindman, Vivetha Natterjee, Per Gustafsson, Anna Wrige Berling, Mats Petersson, Håkan Andersson, Henrik Gillgren, Henrik Karlsson, Henrik Biswanger
Date: 170616
Sub program: Vehicle Safety

Innehåll

1 Executive Summary

To reach Vision Zero and maintain the competitive edge of the Swedish automotive cluster, research into active safety is crucial. The Swedish automotive cluster also has an ambition to be better than the level that laws and rating, such as EuroNCAP, require. To realize research and development of novel active safety functions to address situations far more reaching than what is required by these organizations, dedicated research activities are needed into new test methods to support the development of the new systems and functions to preserve leading market positions for the Swedish automotive industry.

A-TEAM phase 2b targeted, through research, the development of four method packages for important scenarios where research and development is needed for active safety systems. Further three work packages focused on the test system. The research about methods took place in work packages WP3, WP4, 5 and 7. WP3 performed research into scenario definition for light and heavy vehicles. WP4 focused research on light vehicles and developed methods for large animals, intersection scenarios and run-off-road. WP5 focused on heavy vehicles through research on methods for vulnerable road users. The third method related package, WP7, focused on quality and reliability analysis of the developed methods.

Concerning the test system WP2 and 6 have focused on future test system requirements, state-of-the-art assessments, and development vital test system components.

To summarize the following has been delivered by A-TEAM 2b:
Light vehicles
- Large animal   TRL2
- Run-off road   TRL2
- Method for left turn with traffic head-on TRL6

Heavy vehicles
- Heavy truck turning across VRU path   TRL6
- Straight crossing path – VRU left/right TRL6

Test system components
- Final Test system requirements   TRL2
- New target carrier   TRL6

Conference papers
- IV2017 ” Paving the Roadway for Safety of Automated Vehicles: An Empirical Study on Testing Challenges”
- FASTZero 2017 ” Proving Ground Support for Automation of Testing of Active Safety Systems and Automated Vehicles”

2 Background

Because of the rapid technical development, the number of potential active safety functions has increased at brisk pace. To be able to develop and verify these functions all the way to production-ready solutions, a host of new test methods and test systems is needed. The functions of today mainly address accidents between vehicles in the most common rear-impact situations, but accident types with a high number of injuries such as accidents with cyclists, heavy vehicles, and at intersections are not sufficiently addressed yet. Thus, methods to test these types of situations does not yet exist and thus, a test system is also missing that would fully support the complete variety of velocities, angles, and precision needed to conduct the testing contained in A-TEAM phase 1. Existing equipment is in many cases technically immature and not integrated with other sub systems, something that has been confirmed in AstaZero's and the project team's initial benchmark analysis. Because of the lacking integration, only low efficiency regarding time and resource is possible, something that is already hampering the development rate for active safety systems for the Swedish automotive industry. In A-TEAM phase 1, a pre-study mapping the overall need regarding methods, equipment, and the like was included.

The state-of-the-art for active safety testing is in many ways similar to that of passive safety testing in the 70s and it is clear that the group that first researches the test methods and test systems needed to develop and validate the next generation of active safety systems gets a great competitive advantage. A clear example is EuroNCAP where the rating for intersections and cyclists is aimed to be introduced in the 2018-2020 time frame.

Vehicle industry/academia/authorities have high goals/visions for less traffic participants being injured/killed. Intense development of activesafety (AS) functions/automated vehicles is a solution to traffic safety issue. Accidents with vulnerable road users and heavy vehicles top fatality statistics (intersection, oncoming, run-off, close-up accidents). For validation of safety functions test methods/equipment in realistic environment is needed. Commercially available test tools cover fraction of mentioned situations. For Vision Zero research/development for more methods/tools is necessary.

Test methods/equipment are developed in parallel based on requirements from accident statistics, with assurance of methods/equipment quality through experimental testing. Focus is integration of equipment wrt synchronization and usability for AS-system validation. Industry obtains a unique platform for research/development/innovation and a powerful tool for work with reducing number of injured/killed in traffic.

3 Purpose

The purpose of the project is to develop novel test methods for active safety. A-TEAM phase 2b is aimed at continuing the work started in A-team phase 1 and 2a. To be able to

do this, research into accident scenarios, test demonstrators and test methods is needed. The methods will make possible systematic research and development of a number of important new active safety functions. Thus, the project is necessary prerequisite for continued development in the active safety field.

4 Project goals

Defined relevant scenarios
Test methods for scenarios with and without driver
Demonstrate the methods and novel equipment
New knowledge, innovation, cooperation and competence

5 Project realization

The project was divided into seven work packages, WP1 to WP7. This section is an introduction to the realization of each work package.

5.1 WP1, Project management

WP1 was the project management work package. In this work package, the various other work packages were followed up on a weekly basis with respect to results, reporting, coordination, economy, and others. Reporting, planning of demonstrations, and project prioritizing were also part of the tasks of WP1.

5.2 WP2, State-of-the-art in testing of active safety systems and requirements specification for the infrastructure

The goal of phase 2 in WP2 was to identify requirements for the infrastructure to test active safety systems. For this purpose, we have conducted four project internal focus groups with 11 participants, in which we investigated the state-of-the-art of testing active safety systems and future trends on testing automated vehicles in A-TEAM phase 2a. This was a basis to derive a first draft of a requirements specification for a proving ground infrastructure. The goal for phase 2b was to iterate on improving (to further detail) the testing infrastructure as well as evaluate it.

State-of-the-art of Testing Active Safety Systems and Future Trends for Testing Automated Vehicles
We extended our study on the state-of-the-art and future trends with 15 interviews with practitioners and researchers from Sweden, Germany, the US, Netherlands, and China. The data collected is analyzed systematically [1] and the results from this are published (see results section).

<u>Updated and Evaluated Requirements specification for the infrastructure of Automated testing of active safety systems</u>
In addition to the analysis on the state-of-the-art and future trends, we have added another question during our 15 interviews that was aimed at complementing the first draft of the requirements specification for the infrastructure: *"There is an increased complexity of future testing of active safety testing. Support on proving grounds is needed to (semi-) automate the testing processes and allow for a faster and cheaper testing of active safety systems. What are your requirements for such an infrastructure, that supports the testing of active safety systems?"* This input was used to update the requirements specification with the international point of view.

In a last step, we have conducted a focus group with the project internal partners, where
1) we presented the requirements specification,
2) we asked the participants to validate the requirements, add/remove/adjust requirements,
3) we asked the participants to prioritize the requirements.
The result from this was an evaluated and prioritized requirements specification.

<u>Systematic Mapping Study on Automated Vehicles</u>
In addition to the initially planned activities for WP2, we have identified that there are only a few studies on testing of active safety systems/autonomous vehicles in the scientific literature landscape. Hence, we concluded that a systematic mapping study with a broader scope is necessary to meet scientific excellence. We have designed a systematic mapping study, using well-established guidelines of Petersen et al. [2], focusing on the entire area of autonomous vehicles. Up-to-date we have defined the research methodology for this study in a structured way (e.g., search string, data bases, research questions, filtering of papers) and have collected 11,433 papers. The results from this additional activity are currently consolidated and wrapped-up to be presented in a scientific journal.

<u>Design of Infrastructure</u>
In addition to the planned activities, we have supervised several Bachelor and Master thesis, as well as student internships on different aspects of infrastructure design. We have closely worked with John Lang and Per Gustafsson from Autoliv on the HSP and topics related to synchronization and drive file validation.

5.3 WP3, accident scenarios

The goal for WP3 was to, based on traffic accident data, identify relevant accident scenarios and also to specify these for the development of test scenarios, see figure 1.
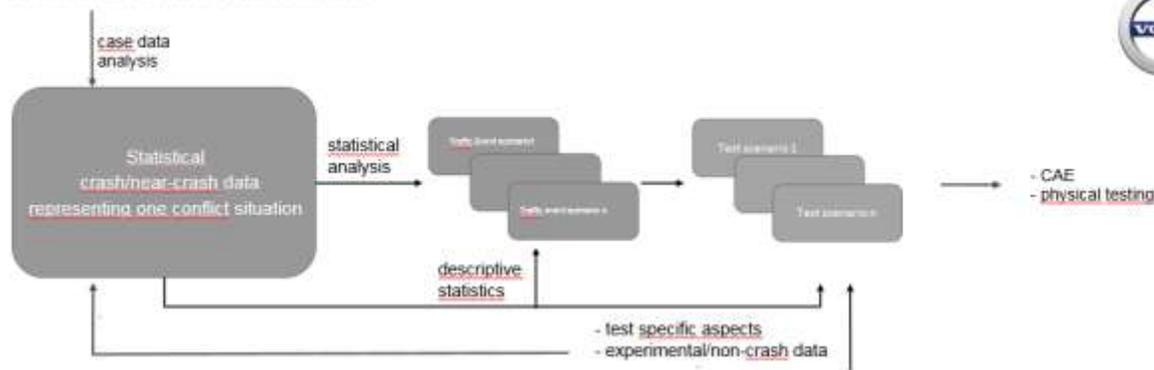
Figure 1. Illustration of substeps in WP3. Based on Statistical data, Traffic Event Scenarios is defined, in this project only crashes were considered, thus Accident Scenarios was defined in this workpackage. Next, based on these Accident Scenarios, Test Scenarios could be generated in upcoming workpackages.

In order to form the prerequisites for the Test Method development WP4 and WP5, Accident Scenarios for the following conflict situations were generated:

Light vehicle conflict situations:

- Car to Large Animal
- Car Run-off Road
- LT/OD (left turn /opposite direction), host car turning left

Heavy vehicle conflict situations:

- Same direction – heavy truck turning across VRU path
- Straight crossing path – VRU from left or right

Each Accident Scenario formed the basis for a Test Scenario. Then, each Test Scenario were defined in WP4 and WP5.

5.4 WP4, method development for light vehicles

The objective with WP4 was to develop methods for critical scenarios identified in WP3 and perform an iterative development of method together with development of targets if needed.
Based on the results from WP3 three key safety critical scenarios were identified and method development for these scenarios were carried out iteratively.

1. LTAP/OD: Method Development and Target identification
2. Large Animal: Method Development and Target Development
3. Run-off-Road: Target Identification using eLKA method

5.5 WP5, method development for heavy vehicles

WP5 is parallel to WP4, but with the difference that it targets method development for heavy vehicle scenarios.

Research of a test platform for testing without the driver in the loop has been performed, for cyclist and pedestrian scenarios ("Same direction – heavy truck turning across VRU path" and "Straight crossing path – VRU from left or right"). This included test scenarios, test methods, test objects with propulsion system, driving robots, measurement equipment etc. The work is based on input from WP3, where a number of test scenarios were identified for the relevant scenarios.

The overall target for WP5 is to develop test methods that are as generic as possible. Therefore – the focus has not been on testing as many different traffic scenarios as possible, but rather on taking the generic method as such to a higher maturity level.

5.6 WP6, test equipment demonstrator

The development of creating a robust target carrier for active safety testing has been ongoing throughout the project. Multiple iterations of both mechanical and software changes have been performed due to different type of problems ranging from wrong selection of adhesive paste to secure nuts and bolts up to unforeseen loss of communication signal due to magnetic fields in the powertrain.

The requirements of the target carrier are still: 90mm tall, top speed of 80 km/h, withstand rain and moist, safe to run over with passenger car and handle the weight of a heavy truck. This combination of requirements requires a lot from each component. The height criterion greatly reduces the selection of available components capable of handling the rest of the criteria. The wheels have to spin with about 5000 rpm at 80km/h with the weight of the target as load. If the wheels are too soft they produce a lot of heat and wears too quickly, if the wheels are too hard they provide insufficient grip. The wheel bearings have to support the rotational speed in combination with the radial force produced by the weight of the target carrier. Components of the target carrier not being waterproof has been installed in waterproof metal boxes to assure the equipment may be used during rain and wet asphalt.

The majority of work regarding the target carrier has been performed in-house at Autoliv's facilities in Vårgårda, the exception being electronic components ordered from different suppliers in mainly Sweden. The work is continuously ongoing and the target carrier has been named High Speed Platform, derived and referred to as HSP throughout this report.

WP6 included a benchmark activity to establish the capabilities of state-of-the art, as well as development of a new target carrier.

The goal of the benchmark task has been to assess the capabilities of existing equipment for testing active safety functions. Such equipment includes driving robots, propulsion systems for target dummies, and the dummies themselves. The result is a gap analysis, i.e. an identification of a possible mismatch between current equipment and what is required from upcoming test methods and procedures. Among the parameters that have been assessed are:

- Positioning performance, i.e. the capability to be at the correct position at the correct time
- Dynamic performance, e.g. acceleration and deceleration capability, turning performance, and top speed
- Handling performance, e.g. set-up time and turnaround time
- Environmental performance, e.g. coping with adverse weather conditions and low temperatures

The following equipment has been fully or partly assessed:
- 4a pedestrian rig
- ABD SPT pedestrian rig
- ABD GST soft car platform
- EuroNCAP Vehicle Target
- ABD Driving Robot in EuroNCAP AEB/FCW
- Autoliv HSP
- DSD UFO platform
- ASTA mid-speed target carrier

5.7 WP7, quality assessment and repeatability analysis

WP7, is to develop and understand Euro NCAP 2016 then 2018. This WP has been managed and developed by AstaZero internally. During the period, one 2-weeks test containing 2 of the Euro NCAP protocols were performed as a customer test together with VCC. AstaZero got feedback regarding the present status of the development and understanding at the same time VCC got some tests done. In this WP there have also been improvements done to the measurement rig developed in A-team phase 2A as well as improvements of the scripts from phase 2A.

6   Results and deliverables

Results per work package.

6.1   WP2

Deliverable 5: Talk at AstaZero Researchers' Day spring 2016
We have presented the results from our empirical study on the state-of-the-art and future trends at the AstaZero Researchers' Day 2016-05-10. The results are based on 4 focus groups as well as an analysis of papers related to testing of active safety systems published in the proceedings of the FASTzero conference 2015.

Deliverable 6: Preliminary draft of the Requirements Specification on Infrastructure
In June 2016, we have delivered a preliminary draft of the requirements specification for the infrastructure for testing of active safety systems, with a focus on testing automated vehicles. This report was based on the four focus groups with A-TEAM project participants considering state-of-the-art of testing active safety systems and future trends for testing automated vehicles.

Deliverable 7: Updated Requirements Specification on Infrastructure
In December 2016, we have delivered an updated requirements specification for the infrastructure. We used deliverable 6 as our foundation and enriched the requirements specification with requirements elicited from 15 interviews with practitioners and researchers from Sweden, Germany, Netherlands, China and US.

Deliverable 8: Final Requirements Specification on Infrastructure
In March 2017, we have delivered an evaluated and prioritized requirements specification on the infrastructure for automated testing of active safety systems. The resulting requirements specification from deliverable 7 was used in a focus group with A-TEAM internal project partners in which requirements were evaluated and prioritized. The deliverable contains a final requirements specification as well as the requirements priorities of three groups: OEMs, suppliers, and proving ground.

Additional deliverable 1: Publication at International Conference on Software Engineering (ICSE), poster & 2 page in proceedings [3]
Authors: Alessia Knauss, Jan Schröder, Christian Berger, Henrik Eriksson
Title: Software-Related Challenges of Testing Automated Vehicles

Abstract: Automated vehicles are not supposed to fail at any time or in any situations during driving. Thus, vehicle manufactures and proving ground operators are challenged to complement existing test procedures with means to systematically evaluate automated driving. In this paper, we explore software-related challenges from testing the safety of automated vehicles. We report on findings from conducting focus groups and interviews including 26 participants (e.g., vehicle manufacturers, suppliers, and researchers) from five countries.

Additional deliverable 2: Publication at Intelligent Vehicles Symposium (IV) 2017, full technical paper [4]
Authors: Alessia Knauss, Jan Schröder, Christian Berger, Henrik Eriksson
Title: Paving the Roadway for Safety of Automated Vehicles: An Empirical Study on Testing Challenges

Abstract: More and more vehicles provide automated driving on highways where the driver is only monitoring the functionality of the system for proper functioning. Test standards for automated vehicles as well as conditionally automated vehicles (e.g.,

on highways) do not exist yet. However, we have recently seen several accidents involving such kind of conditionally automated driving. While the latest generation of active safety systems is systematically and reproducibly tested following standardized test catalogs like EuroNCAP to award stars to vehicles, these catalogs base their suggested tests on most common accidents from different countries, having the main goal to prevent future accidents. Analyzing most common accidents will not be sufficient for automated driving as the vehicle is completely in charge for the driving task and there is no driver as a back-up. Hence, automated vehicles are not supposed to fail at any time during any situations in driving. Thus, vehicle manufactures and proving ground operators are challenged to complement existing test procedures with procedures to evaluate automated driving. In this paper, we explore challenges of testing the safety of automated vehicles. We report on findings from conducting focus groups and interviews including 26 participants (e.g., vehicle manufacturers, suppliers, and researchers) from five countries with a background related to testing automotive safety-related topics. We explore state-of-practice of testing active safety features and challenges that have to be addressed in the future automated vehicles to enable safety of automated vehicles. The major challenges identified are related to 1) virtual testing and simulation, 2) safety, reliability, and quality, 3) sensors and sensor models, 4) required scenarios complexity and amount of test cases, and 5) handover of responsibility between driver/vehicle.

Comment: As the acceptance rate for this prestigious conference in the area of intelligent vehicles was remarkably low, an accompanying press release was issued:
https://www.ri.se/nyheter/svensk-fordonsforskning-pa-prestigefylld-usa-konferens

Additional deliverable 3: Accepted publication at FASTzero conference 2017 [5]
Authors: Alessia Knauss, Christian Berger, Henrik Eriksson
Title: Proving Ground Support for Automation of Testing of Active Safety Systems and Automated Vehicles

Summary: The results presented in this publication will be a summary of the evaluated requirements specification. An overview of the different clusters of topics will be given and briefly described. The goal of this publication is to share the insights on the needed proving ground support with researchers and practitioners enabling the field to advance further.

Additional deliverable 4: Publication at International Workshop on Requirements Engineering for Self-Adaptive and Cyber-Physical Systems (RESACS) [6]
Authors: Juan C. Munoz-Fernandez, Alessia Knauss, Lorena Castaneda, Mahdi Derakhshanmanesh, Robert Heinrich, Matthias Becker, and Nina Taherimakhsousi
Title: Capturing Ambiguity in Artifacts to Support Requirements Engineering for Self-Adaptive Systems

Abstract: Self-adaptive systems (SAS) automatically adjust their behavior at runtime in order to manage changes in their user requirements and operating context. To achieve this goal, a SAS needs to carry knowledge in artifacts (e.g., contextual goal models) at runtime. However, identifying, representing, and refining requirements and their context to create and maintain such artifacts at runtime is a challenging task, especially if the runtime environment is not very well known. In this short paper, we present an early concept to requirements engineering for the implementation of SAS in the context of uncertainty. Especially the wide variety of knowledge materialized in artifacts created during software engineering activities at design time is considered. We propose to start with a list of ambiguous requirements - or underspecified requirements -, leaving the ambiguity in the requirements, which will in the later steps be resolved further as more information is known. In contrast to conventional requirements engineering approaches, not all ambiguous requirements will be resolved. Instead, ambiguities serve as key input for self-adaptation. We present five steps for the resolution of the ambiguity. For each step, we describe its purpose, identified challenges, and resolution ideas.

Comment: This paper discusses a technique to tackle runtime uncertainty about e.g., the environment. This kind of technique will have implications on how testing need to be executed for autonomous/self-adaptive systems, in the sense that not all testing activities can take place at design time but need to move to runtime.

6.2   WP3

In WP3, literature reviews provided overviews of previous real world data research on the considered conflict situations. Accident Scenarios for selected conflict situations were identified in traffic accident data. Also, statistical analysis specified the scenarios for test development in WP4.

Car to Large Animal crashes

A number of studies was found that discusses environmental and driver related pre-crash factors that contribute to car to animal crashes.

In (Jakobsson et al 2015), crashes with large animals (n=446) were compared to crashes with small and medium sized animals (n=288), frontal crashes with passenger cars (n=1430) and frontal crashes with heavy vehicles (n=186).

Table 1 displays the proportion of pre-crash parameters comparing the four groups in a sample of crashes taking place on roads with posted speed limits of 70 km/h and higher and not in intersections.

A higher frequency of vehicle to animal crashes occurred in darkness, dusk or dawn as compared to vehicle to vehicle crashes.

There was also a relatively higher amount of vehicle to animal crashes on dry roads as compared to vehicle to vehicle crashes.

The proportion of drivers reporting a speed at impact higher than 60 km/h differed greatly between vehicle to animal crashes and vehicle to vehicle crashes. As Table 1 shows, 80-90% of the drivers in animal crashes while about 35% of the drivers in crashes with vehicles reported a high speed crash.

Regarding self-reported *not* braking before impact, the highest share (29%) was found among vehicle to small/medium sized animals.

With regards to self-reported distraction at impact, 10-13% of the drivers in vehicle to animal crashes reported that their attention was directed to something else than on the driving task, while the corresponding figure for drivers in vehicle to vehicle crashes was 26-28%.

Table 1. Proportions of pre-crash parameters per crash category, restricted sample of crashes on roads with posted speed limit of 70 km/h and above and not in intersection. (Jakobsson et al 2015)

	Collision with large animal	Collision with small-/ medium-sized animal	Frontal collision with passenger car	Frontal collision with heavy vehicles
Lighting condition = darkness/dusk/dawn	81.6	74.6	35.7	34.3
Road condition=dry	64.5	72.0	56.3	54.3
Self-reported driver distraction	13.2	10.2	28.0	25.7
Self-reported speed at collision >60 km/h	79.1	89.0	34.9	35.7
Self-reported driver's braking=no	16.2	28.8	8.4	20.0

In (Olsson, 2008), effects of highway fencing to wildlife road crossings in roads with posted speed limit of 90-110 km/h are analysed. As expected, moose-vehicle accidents within the study area decreased after the construction.

Vägverket, 2007 investigated contributing factors to the change in moose-vehicle accidents in the years 1970-2006. The snow depth, related to the early snow fall 2006 was found influencing the moving pattern of moose and thus the car to moose crash rate.

FHA, 2012 examined if rates and/or frequencies of animal crashes are higher for certain types of roads in years 1985-1991 in Illinois, Maine, Minnesota, Utah and Michigan, As can be seen in Figure 2, the animal crash rate is highest on two-lane rural roads.
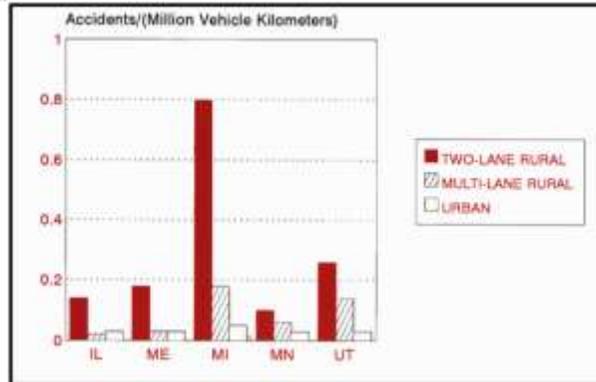
Figure 2. Average animal crash rate by road type. (FHA, 2012)

Sullivan, 2009 suggested, based on analysis of fatal crashes in the United States and injury and property-damage-only (PDO) crashes from Michigan where an animal was the first harmful event, that crash occurrence broadly mirror the activity patterns of the animals. Greatest activity coincides with dawn and dusk and peak crash levels follow this pattern: highest collision risk occurs about an hour after sunset. Top seasonal activity occurs during breeding season, declines in winter, and increases again in the spring.

The relative risk of crashes in darkness versus daylight appears to be associated with posted speed limit. Also, higher posted speeds result in proportionally greater crash risks in darkness. Thus, limited forward preview time results in higher crash risk.

Likewise, a study on Australian crash data (Rowden 2008), found that night-time travel is a notable risk factor.

A statistical analysis of data from the accident years 2002-2013 on 257 car to large animal accidents with modern cars in the Volvo Cars Accident Database (VCTAD) was performed.

In a hierarchical cluster analysis, Accident Scenarios were defined that show the association of crash circumstances. The variables selected for the analysis, were chosen in the context of their relevance to Test Scenario generation for the A-Team project

- Visibility range wrt obstructions such as vegetation, buildings and traffic elements
- Road curvature
- Car speed
- Crash configuration; impact location on car and animal
- Animal moving direction

Two clusters, see Table 2, representing 83% of the crashes was suggested to form the A-Team Accident Scenarios. From these cluster, a comprehensive range of basic properties can be combined for Test Scenario suggestions. For example, for Cluster 1,

3x3x3x4x2=216 different Test Scenario setups could be considered if all levels of the selected variables in the crash data is taken into account.

In the upcoming WP4 for Test Method development, a selection process defines the final Test Scenarios for the A-Team project with regard to this information and to the findings from the literature review, but also with reference to test specific aspects.

Table 2. Clusters for car to large animal Accident Scenarios.

	Visibility range	Road curvature (radius)	Car speed	Crash configuration	Animal moving direction
	<7,5 m	0 m	<70 km/h	Car Front - Animal Front	Left
	7,5-20 m	1-750 m	70 km/h		Right
	>20m	751-2000m	>70km/h	Car Front – Animal Side	Same/Oncoming Direction
				Car Side – Animal Front	
				Car Side – Animal Side	
Cluster 1					
Cluster 2					

Car run-off road crashes

Several studies on real-world data has been performed that investigates pre-crash factors that contribute to run-off road crashes.

Crashes during 2002-2012 (car model years 1999-2012) were selected for an analysis of 1721 run off road crashes that were compared to 4698 on-road crashes, i.e. without initial roadway departure (Jakobsson et al, 2014). For pre-crash parameters, descriptive analysis

and chi-square tests were used to assess the differences in percentages of the two groups of crashes.

Table 3 displays categorical environment, driver and vehicle state parameters for with significant differences in percentages when associating run off road crashes to on-road crashes.

75% of run off road crashes occurred at rural roads including highways.

Road departures took place more often in curves than on-road crashes. Almost one third of the run off road crashes happened in darkness while 23% of the on-road crashes did so.

21% of the run off road crashes occurred during adverse weather conditions (rain or snow), which is almost relatively twice as many as in on-road crashes.

Information on driver fatigue and inattention was investigated for a subsample including accident years 2005-2011. Fatigue was reported in 12% and inattention in 33% of the run off road cases, as compared to 4% and 22%, respectively, of the on-road crashes.

Young drivers aged 18 to 25 years, were overrepresented in run off road crashes.

A major part (55%) of the run off road crashes was preceded by a loss of control event, this is almost a five times higher percentage of skidding than in on-road crashes.

71% of the drivers reported a higher speed than 40 km/h in run off road crashes. This can be compared to slightly more than 40% in on-road crashes.

In Sweden, winter and summer seasons can appear very different in terms of road status. Use of winter tires is prescribed during winter season when the roads are snowy or icy. In 51% of run off road crashes and 40% of on-road crashes, ordinary tires were used in situations when the roadway was covered with snow/ice.

Table 3. Percentage of pre-crash parameters in run off road- and on-road crashes, respectively, together with p-values for Pearson chi-square statistics of association. (Jakobsson et al 2014)

precrash factor	run-off-road crashes (%)	on-road crashes (%)	P-value
driver fatigue	11.63	3.59	<.0001
driver inattention	32.68	21.78	<.0001
rural road or highway	74.97	58.4	<.0001
curve	43.43	14.67	<.0001
darkness	30.26	23.09	<.0001
rain or snow	21.08	11.75	<.0001
drivers age <26 years	14.47	6.92	<.0001
summer tires on road with snow/ice	50.94	40.21	0.0058
skidding	54.58	11.31	<.0001
speed at impact >40 km/h	71.27	42.64	<.0001

Tomasch et al, 2010, investigated Single vehicle accidents in Austria and Table 4 provides the distribution of different subgroups of crashes per injury severity level.

Leaving the road to the right are dominant with 81% of fatal accidents. 75.8% of fatal run-off-road accidents are on straight road sections. Only a small portion of fatal run-off-road accidents take place at bends.

Table 4. Distribution of injury severity in SVA on Autobahn between 2002 and 2009 (Tomasch et al 2010)

Single vehicle accident subgroups			fatal	severe	minor	unknown	Total
leaving the road to the right side	straight road		229	1.012	3.445	1.006	5.692
			75.8%	68.0%	59.5%	64.2%	62.3%
			4.0%	17.8%	60.5%	17.7%	100.0%
	right bend		6	26	97	18	147
			2.0%	1.7%	1.7%	1.1%	1.6%
			4.1%	17.7%	66.0%	12.2%	100.0%
	left bend		9	43	142	38	232
			3.0%	2.9%	2.5%	2.4%	2.5%
			3.9%	18.5%	61.2%	16.4%	100.0%
leaving the road to the right side	Σ		244	1081	3684	1062	6071
			80.8%	72.6%	63.7%	67.8%	66.4%
			4.0%	17.8%	60.7%	17.5%	100.0%
leaving the road to the left side	straight road		43	332	1665	420	2460
			14.2%	22.3%	28.8%	26.8%	26.9%
			1.7%	13.5%	67.7%	17.1%	100.0%
	right bend		7	19	127	30	183
			2.3%	1.3%	2.2%	1.9%	2.0%
			3.8%	10.4%	69.4%	16.4%	100.0%
	left bend		1	6	64	7	78
			0.3%	0.4%	1.1%	0.4%	0.9%
			1.3%	7.7%	82.1%	9.0%	100.0%
leaving the road to the left side	Σ		51	357	1856	457	2721
			16.9%	24.0%	32.1%	29.2%	29.8%
			1.9%	13.1%	68.2%	16.8%	100.0%
leaving the road in the area of an exit or junction, applied to all types of junctions			5	19	68	12	104
			1.7%	1.3%	1.2%	0.8%	1.1%
			4.8%	18.3%	65.4%	11.5%	100.0%
other single vehicle accidents			2	31	179	35	247
			0.7%	2.1%	3.1%	2.2%	2.7%
			0.8%	12.6%	72.5%	14.2%	100.0%
Total	Σ		302	1.488	5.787	1.566	9.143
			100.0%	100.0%	100.0%	100.0%	100.0%
			3.3%	16.3%	63.3%	17.1%	100.0%

Lane markings are sometimes considered important for crash avoidance technologies, and lane markings in road departure crashes were investigated in US data (Kusano and Gabler, 2010). 11% of crashes occurred on roads with no markings on either side of the lane (Table 5) and 24% of crashes had no marking on one or both sides of the initial travel lane.

Table 5. Distribution of Lane Marking Style in Road Departure Crashes from NCHRP 17-22 (n=851). (Kusano and Gabler, 2010).

	Right Side Marking				
Left Side Marking	Solid	Single Dashed	None	Other	Total
Solid	4%	12%	2%	0.1%	18%
Single Dashed	25%	2%	6%	0.1%	34%
Double Solid	20%	0.1%	4%	0%	24%
Dashed Solid	10%	0.02%	1%	0%	12%
None	0.6%	0.1%	11%	0%	12%
Other	0.6%	0.01%	0.1%	0%	0.7%
Total	63%	13%	24%	0.3%	100%

All cells and row/column percentages are rounded

Four datasets that covered events - from lane departures during normal driving, to nearcrashes, to crashes - were compared in (Kusano et al, 2015). Overall, the results indicates that in the design of test track experiments, crash and near-crash events should be used over less severe NDS departure events. Especially inteersting were the EDR crash data results for speed and brake application, see Figure 3 and Table 6. In the sample of lane departures with EDRs, 109 had valid pre-crash speed data. Time for vehicle departure is not known and maximum pre-crash speed was used as a proxy and is plotted using national weighting factors. In 60% of crashes with EDRs, there was braking during the pre-crash.
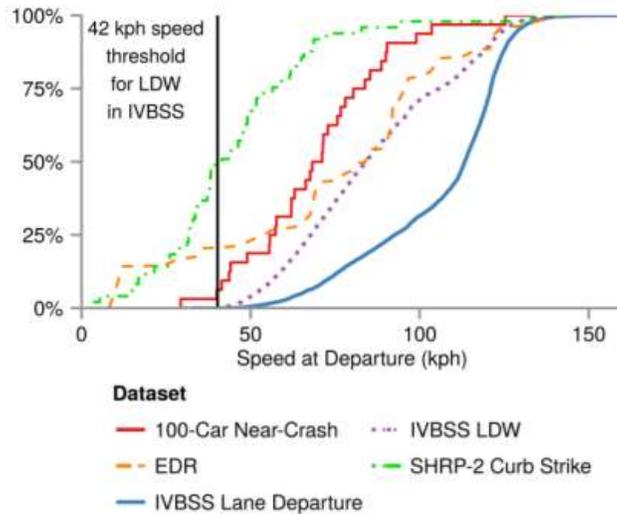
Figure 3. Cumulative Distribution of Vehicle Speed in Lane Departure Events. (Kusano et al, 2015)

Table 6. Percentage of pre-crash parameters in run off road- and on-road crashes, respectively, together with p-values for Pearson chi-square statistics of association. (Kusano et al, 2015)

Group	Brake Application	No Brake Application
EDR (Any Braking)	60%	40%
EDR (Any Braking 1 second before crash)	52%	48%
IVBSS Lane Departure*	0%	100%
IVBSS LDW	4.2%	95.8%
100-Car Near-Crashes	37.5%	62.5%
SHRP-2 Curb Strike	32.7%	67.4%

* Lack of brake application was a condition of selection for LDW lane departure events

Test Scenarios for active safety testing has been proposed by different studies. In (Najm and Smith, 2006) the General Estimates System database was queried to distinguish pre-crash situations. Five single-vehicle, run-off-road scenarios represented 63 percent of light vehicle crashes and 83 percent of heavy-truck crashes, not taking into account crashes caused by vehicle failure or evasive maneuver, see Table 7.
(Kuehn et al, 2015) used the in-depth database of the German Insurers five accident scenarios were realized that make up 68% of the crashes and 66% of the fatalities, see Table 8.

Table 7. Run-Off-Road Crash Imminent Base Test Scenarios for Light Vehicles and Heavy Trucks, In (Najm and Smith, 2006)

No.	Light Vehicle (Host Vehicle)	Heavy Truck (Host Vehicle)	Schematic
1	Light vehicle is going straight at 25-55 mph and departs road edge to the right in daylight or darkness, clear weather, on straight and level road.	Heavy truck is going straight at 25-55 mph and departs road edge to the right in daylight, clear weather, on straight and level road.	
2	Light vehicle is going straight at 30-60 mph and departs road edge to the left in daylight or darkness, clear weather, on straight and level road.	Heavy truck is going straight at 25-55 mph and departs road edge to the left in daylight/ darkness, clear weather, on straight and level road.	
3	Light vehicle is negotiating a curve at 30-55 mph and departs road edge to the right in daylight or darkness, clear weather, on sloping road.	Heavy truck is negotiating a curve at 30-55 mph and departs road edge to the right in daylight, clear weather, on sloping road.	
4	Light vehicle is negotiating a curve at 40-60 mph and loses control in daylight, clear or adverse (i.e., slippery surface) weather, on sloping road.	Heavy truck is negotiating a curve at 35-55 mph and loses control in daylight, clear weather, on sloping road.	
5	Light vehicle is turning left at 25-45 mph and departs road edge to the right in daylight, clear weather, on straight and level road.	Heavy truck is turning left at 20-40 mph and departs road edge to the right in daylight, clear weather, on straight and level road.	

Departing right road edge   Departing left road edge   Control loss

Table 8. Accident scenarios for inadvertent lane departures, (Kuehn et al, 2015).

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Relevance and brief description						
		Filter criteria for assignment to a scenario				
Road surface		Dry	Dry	Damp/wet	Damp/wet	Damp/wet
Course of the road		Bend	Straight	Straight	Straight	Bend
Radius of the bend		< 200 m	-	-	-	< 200 m
Light conditions		Daylight	Daylight	Daylight	Dawn/darkness	Daylight
Severe weather conditions		None	None	None	Heavy rain	None
		Additional information				
Relevance in relation to all accidents (n=100)	n	27	23	7	6	5
	%	27	23	7	6	5
Relevance in relation to all fatalities (n=32)	n	12	2	3	3	1
	%	38	6	9	9	3
Average speed of the case car		85 km/h	90 km/h	75 km/h	Unknown	70 km/h

A statistical analysis of data from the accident years 2002-2013 on run-off road accidents with modern cars in the Volvo Cars Accident Database (VCTAD) was performed. For the

analysis, crashes with traction occurring on straight roads, n=275, representing ~30% of all run-off road crashes, were selected.

In a hierarchical cluster analysis, Accident Scenarios were defined. The variables selected for the analysis, were chosen in the context of their relevance to Test Scenario generation for the A-Team project:

- Car speed (km/h)
- Initial distance car center to road edge (m), DE in Figure 4
- Road edge departure angle (∘), A in Figure 4
- Shoulder width (m), S in Figure 4
- Initial distance car center to closest lane marking (m), DL in Figure 4
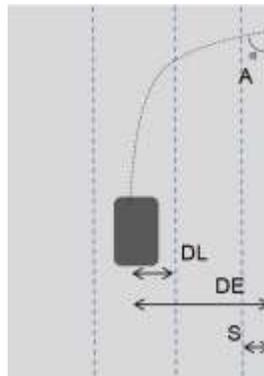
Figure 4. Variables for Accident Scenario generation.

Two clusters, see Table 9, representing 75% of the crashes was suggested to form the A-Team Accident Scenarios. From these clusters, a comprehensive range of basic properties can be combined for Test Scenario suggestions, where Table 2 displays the most obvious choices.

Table 9. Car Run-off Road Accident Scenarios for crashes with traction and on straight roads.

	RoR1	RoR2
Car speed (km/h)	90	110
Initial distance car center to road edge (m)	5,6	2,7
Road edge departure angle (∘)	12,5	3,3
Shoulder width (m)	0,5	0,7
Initial distance car center to closest lane marking (m)	1,7	2

In the upcoming WP4 for Test Method development, the final Test Scenarios will be defined for the A-Team project with regard to this information and to the findings from the literature review, but also with reference to test specific aspects.

LT/OD, host car turning left

24 published reports that studied LT/OD accidents or LT/OD situations in driving data in real traffic were compiled per geographical region (North America, Asia, Sweden and the rest of EU) and selection criteria (accidents reported by police, fatal accidents etc.). Results from the reports were organized in categories: velocity-related measures, posted speed limits, traffic control, state of the road surface, precipitation, driving lanes and road geometry, lighting conditions, obscured view, counterpart/other, traffic elements, collision, and driver-related pre-crash parameters. This was shared with all partners of the A-Team project in 2014. Examples of relevant information for the project were: variety in intersection geometries, counterpart types in serious accidents and details such as travel and turn speed in driving data.

A statistical analysis of data from the accident years 2007-2013 on LT/OD crashes with modern cars in the Volvo Cars Accident Database (VCTAD) was performed.

In a hierarchical cluster analysis, Accident Scenarios were defined. The variables selected for the analysis, were chosen in the context of their relevance to Test Scenario generation for the A-Team project:

- Main deformation side of turning car (kollisionstyp LT-bilen in Table 10)
- Initial lateral offset (Y in Table 10)
- Width of the crossing road (B in Table 10)
- Combination of speeds for each vehicle (hastigheter in Table 10)

Table 10. Accident Scenarios *for LT/OD*

kollisionstyp LTAP-bilen	sida	front	sida
Y (se fig)	7 m	4 m	18 m
B (se fig)	14 m	8 m	25 m
hastigheter (LTAP-bilen vs OD-bilen)	10-20 km/h vs 21-40 km/h	10-20 km/h vs 41-60 km/h	41-60 km/h vs 41-60 km/h

Based on these Accident Scenarios, the Test Scenarios were subsequently developed.

Heavy vehicle accident scenarios

Studies presenting accident data analysis of heavy truck accidents involving pedestrians or bicyclists were compiled.

C1	Truck- VRU, truck front vs. VRU when taking off		6%	C5	Truck- VRU collision, truck side vs. VRU, lane driving		12%	
C2	Truck- VRU collision, truck vs. VRU when reversing		4%	C6	Truck- VRU collision, meeting accident		7%	
C3	Truck- VRU collision, VRU that suddenly cross the direction of truck, e.g at cross road		30%	C7	Truck- VRU collision, VRU drives into truck		5%	
C4	Truck- VRU collision, truck side vs. VRU when turning		20%	C8	Truck-VRU collision, Truck drives into VRU from the rear.		6%	
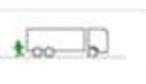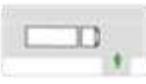
Figure 5. Overall accident type distribution for serious and fatal heavy truck - VRU accidents [8]
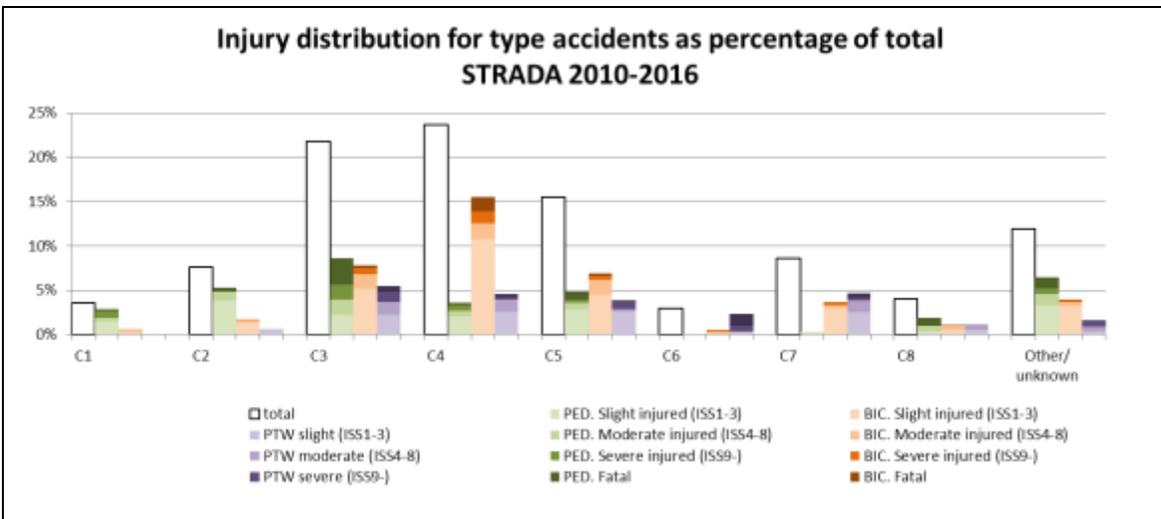
Figure 6. Type of VRU and injury severity. STRADA accidents mapped to type accidents C1-C8.[8]

Same direction - heavy truck turning across VRU path:
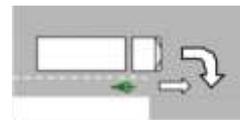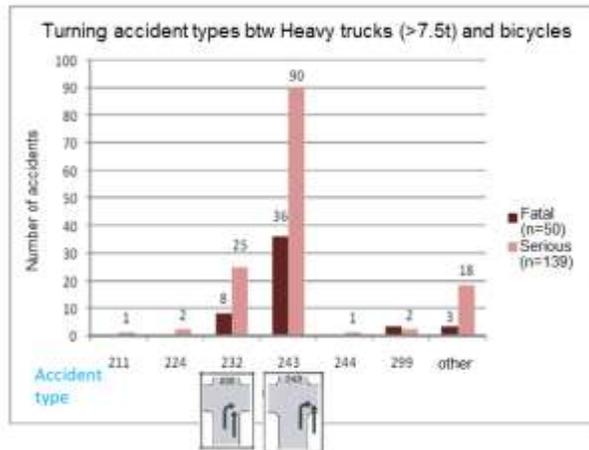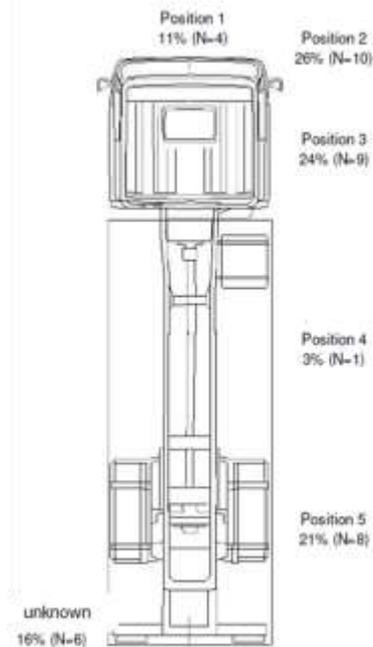
Accident type distribution   *Impact point on truck*

Figure 7. Accident type distribution and impact point on truck in turning accidents with bicycles based on German accident data, ref Schrek et al, 2014 [6].

Summary of accident conditions [6]:

- Urban area
- Daylight
- Dry weather
- Both with and without traffic light signaling
- Initial speed of heavy truck is below 30 km/h (in 90 % of cases)
- Initial speed of bike is below 20 km/h (in 85% of cases)
- In 40% of cases, initial speed of bike is larger than speed of the heavy truck, partly caused through truck starting from stationary and cyclist catching up from behind.
- Bike does not brake in 65% of cases
- Heavy truck does not brake in 70% of cases
- Driver did not see cyclist in 90% of cases

Based on this, the following preliminary test scenario characteristics were defined for WP5:

- Assume truck movement to be first straight, then turning with constant radius
- Daylight and dry weather
- Parameters:
  - Speed heavy truck: 10, 20, 30, 40 km/h
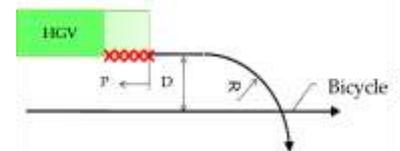
- Speed bicycle: 10-25 km/h
- Lateral separation of truck and bicycle before turning: 1.5 to 4,5 m
- Curve radius: 5m, 10m and 25m (radius of inner front wheel of heavy truck)
- Point of impact at truck, distance behind truck front: 0 – 6 m
- For "Same direction – host vehicle turning" scenarios involving pedestrians, the only parameter that will be changed is the speed of the VRU.
  - Speed pedestrian: 1-10 km/h

Straight crossing path – VRU from left or right:
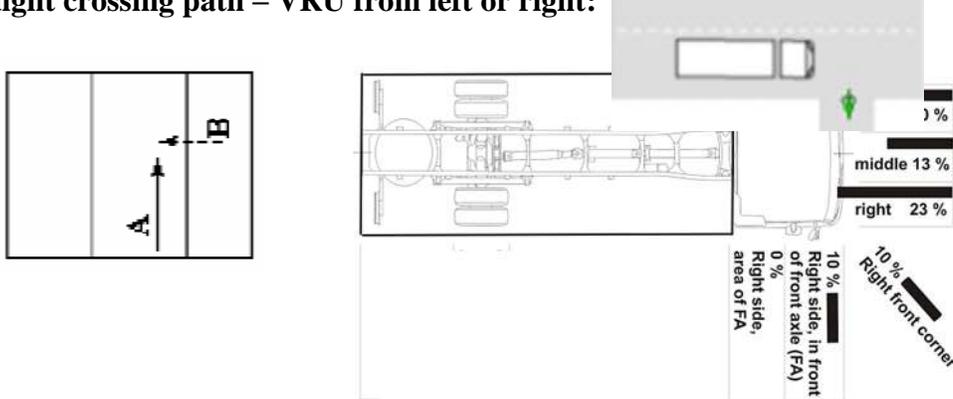
Figure 8. Accident type and impact point on truck based on German accident data, ref Desfontaines et al, 2008 [7].

Summary of accident conditions [7]:
- Urban area
- Daylight
- Dry weather
- Both with pedestrian crossings and without
- Speed of heavy truck is below 50 km/h (in >90 % of cases)

Based on this, the following preliminary test scenario characteristics were defined for WP5:
- Truck movement straight
- Daylight and dry weather
- Parameters:
  - Speed heavy truck: 10, 20, 30, 40, 50 km/h
  - Speed pedestrian: 1-10 km/h
  - Speed bicycle: 10-25 km/h

6.3   WP4

The purpose of WP4 was to develop a test method and look into test equipment need for performing and analyzing LTAP/OD, Large Animals & Run-Off-Road scenarios within the A-Team project. Thereby to find out what demands and requirements were needed. The key players within this work package were Volvo Cars and AstaZero.

6.3.1.1 LTAP/OD

We looked into finding a solution which gives the possibility to use a driverless target carrier platform together with an ABD robot which controlled the VUT. For this UFO platform was chosen and within the project gained experience of ABD robot together with the UFO (Driverless Platform)

In order to have and accurate and repeatable collision behavior, the possibility to not collide in each test by changing the reference point to left front wheel on both VUT and UFO target was identified. This presented with multiple benefits like reduced number of collision during test and hence less repair and rebuild. This is presumed as the fastest way to test and overall much more flexibility.

Based on the results from a clinic conducted within the project the curvature profile was identified from actual driver behavior. This behavior was used to model the trajectory for VUT while taking a turn for the LTAP/OD scenarios.

We altered different collision points and looked into the accuracy. In order to avoid to avoid collision, we moved the reference point to behind the CT (Car Target).

 The accuracy and result we obtain were satisfying for this use.

6.3.1.2 Large Animal

Based on the studies conducted within WP3 a need for Large Animal collision avoidance method development was identified and both Large Animal Target and a method to test Large animal crash avoidance was developed within WP4.

6.3.1.2.1 IDENTIFIED SCENARIOS
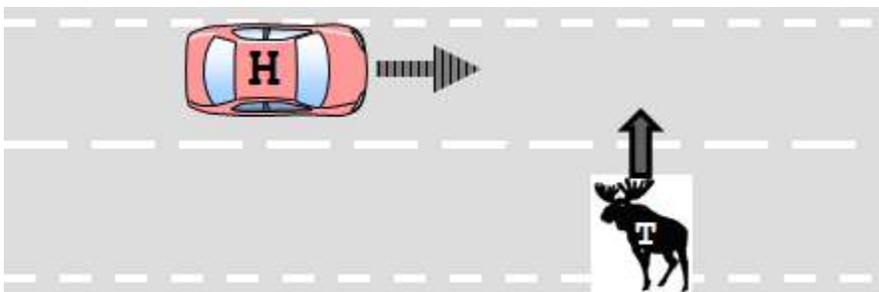
Host Velocity	Elk Velocity	Impact Offset	Impact Angle
		Percentage (Both	
km/h	km/h	direction)	Degree
30	5	120%	
40	5	120%	
60	5	120%	
80	5	120%	
100	5	120%	
70	5		75
70	5		105
70	10		75
70	10		105

Figure 9: Identified scenarios

6.3.1.2.2 LARGE ANIMAL TARGET DEVELOPMENT (MOOSE TARGET)

We had taken out a plastic Moose that we put faux fur on. The straw on this coat was quite long: which meant that Elk's appearance was a little fluffy. Mainly it was noticed at the Elk's head that almost looked like a dog. Fluffiness was the reason we chose to paint the other copy of the plastic-Moose: Brown.

We ran an unofficial test against both the Moose: i.e. fur Moose & Brown plast Älg. The work was carried out together with the supplier who reviewed the logs for us.
We can also mention that the test was in Twilight: just when it began to get dark: i.e. so we drove with the driving of the car.
It also blew pretty heavy side wind during the test (approx: 8 m/s)

6.3.1.2.3 TEST SETUP
The test was setup at High Speed Area of ASTA
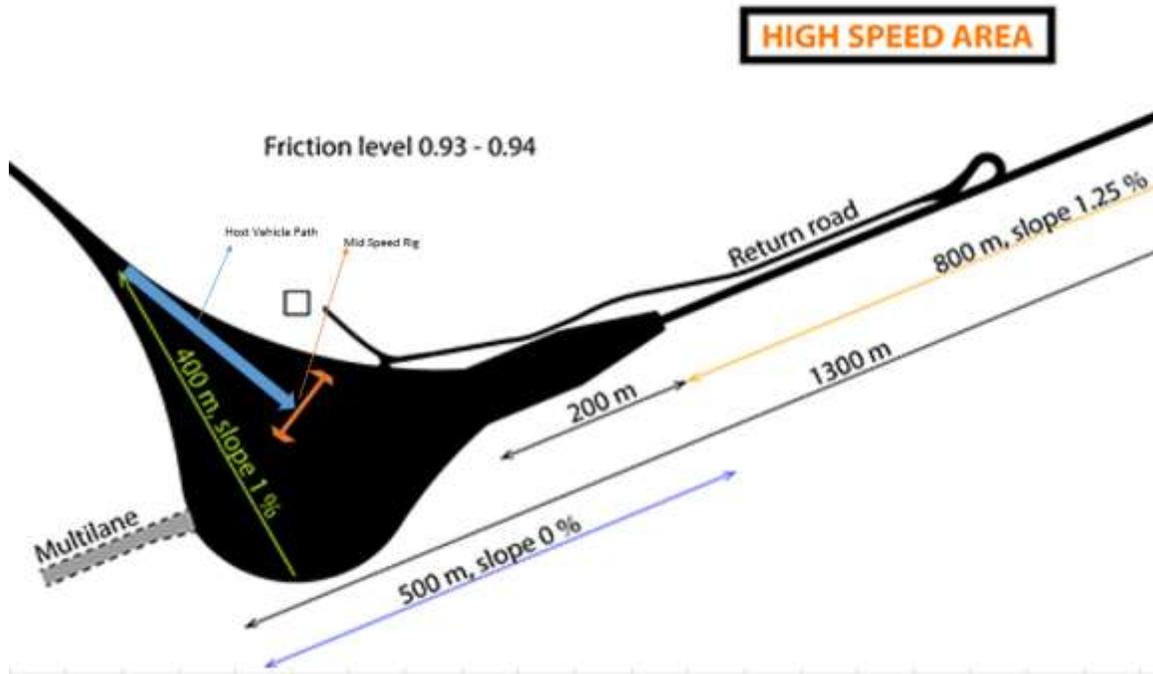
Figure 10: Test set up

6.3.1.2.4 TEST EQUIPMENT

A Volvo XC90 was equipped with ABD robots to act as vehicle under test. The robot was calibrated and tuned and all necessary drive files for the test matrix were prepared for the robot.

The Elk target was integrated with the Mid-Speed Carrier for dynamic elk tests. The Elk target was mounted in a moving platform connected to the belt of Mid-Speed carrier. A light trigger was used as start trigger for the Elk corresponding to the vehicle.

Figure 21: Elk test

6.3.1.3 Run-off-Road

6.3.1.3.1 SCENARIOS
The current Euro NCAP LSS 2016 Rating the car will drift in a straight line with a fix relative lateral velocity. Se image below.
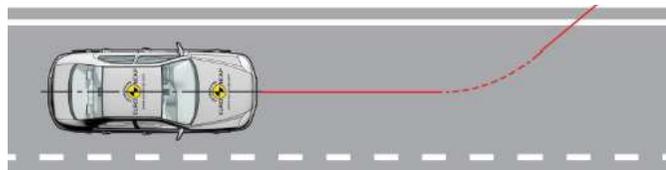
Figure 12: Test scenario

The car will drive straight and parallel to the lane making it possible for the car to register the lane. After a fixed distance the car will turn with a given radius until a given angle, corresponding to a given relative lateral velocity, is reached. The whole maneuver is performed with a steering robot in order to have high repeatability and accuracy. The robot shall not intervene with the LSS, this is prevented by release/deactivate the steering

FORDONSSTRATEGISK
FORSKNING OCH INNOVATION

robot before the LSS activation. To locate when the steering robot need to be released/deactivated following steps are used.

1. Perform the test without LSS functionality and no release/deactivate on steering robot
2. Perform the test again with LSS functionality and no release/deactivate on steering robot
3. Plot measured Torque VS Distance Travelled from the two tests. Locate when the LSS function by a Torque deviation in the plots.
4. Program the robot to be released before the Torque deviation
5. Perform the test with LSS Functionality and release the robot before LSS activates.

6.3.1.3.2 RUN-OFF-ROAD TARGET DEVELOPMENT

Road edge equipment

Couple of different types of artificial grass material were bought and verified against the sensor detection. The material varied in height, colour and hue. However, the artificial grass material was not sturdy enough to give a repeatable performance for the sensors. The angle of the grass strings, the reflectivity of the material with sun direction affected the detection of the road edge like material. In the picture below two of the different plastic grass material with varying heights is shown.

Considering that height of the material could be an issue the edges were ramped using wooden planks to give a variation in height. However this wasn't enough to get a repeatable performance as well. The findings were presented at IDIADA and other OEM suggestions were also investigated.

Figure 13: Example of road edge equipment

Target on Road / Road Line Markings
The test requires use of two different types of lane markings.
1. Dashed line with a width between 0.10 and 0.25m
2. Solid line with a width between 0.10 and 0.25m.

Length of dashed lines can either be short, medium or long: 0.3, 6.0 or 9.0 m
Distance between dashed lines can either be short, medium or long: 0.3, 6.0 or 9.0 m
Distance between lines and the road edge can either be short, medium or long: 0.25, 1.0 or 2 m

Target on Road / Road without Markings
The test requires a road without lane markings. No defined marks along the roadside: i.e. the road edge is the target.

6.4   WP5

Target development:
In A-TEAM 2b the mid-speed target carrier (which is being developed within the project) was used for the heavy truck – VRU scenarios.

A standard bicycle was mounted on the carrier plate. A few different mountings were explored and the final choice was mounting of the bicycle in such a way that both wheels rotated when the carrier plate moved.

The 4D dummy was mounted on the bicycle.

Figure 14. Mid-speed target carrier with bicycle target mounted.

A major improvement from target carriers used in A-TEAM 2a was that this set-up was far less sensitive to being hit or run-over by a heavy truck.

Scenario generation
As in A-TEAM 1 and 2a, all test scenarios were created in PreScan to generate drive files for the driving robot and the mid-speed target carrier.

Test method set-up
Since the mid-speed target carrier is still under development, there was during the course of this project not possible to synchronize the rig with the ABD robot and thereby the test object. To achieve repeatability and accuracy in the test scenarios, a light gate was used to set the starting time of the drive file for the mid-speed target carrier.

With a little additional work the light gate could be made even more precise, but up until now it was simply placed at the side of the truck path and hence triggered by the front left corner of the truck. However, already without working more on the preciseness of the light gate, good enough accuracy and repeatability was achieved for the low speeds used in the VRU scenarios.
The light gate was kept in the same place for all scenarios – and only the drive file adjusted to achieve correct timing of the bicycle target towards the test vehicle and collision point/time.

Figure 15. Picture showing the position of the light gate relative to the truck path and target carrier.

The efficiency of the tests was improved compared to A-TEAM 2a status by changing from starting the test truck from standstill to manually accelerating the truck up to the starting velocity of the test scenario.
A starting area (in the shape of a large cone) was allowed by the ABD software and the test scenario was started from inside the truck, when the truck was driving inside the cone area at a speed close to the starting speed of the test scenario. The ABD robot then steered the truck so that the point of the cone was passed at the right time and speed.

The previous method – where the test scenario was started with the truck in standstill required an unpractically long acceleration stretch, since it is very difficult and requires a lot of tuning to get the ABD robot to accelerate a truck in a good way. To minimize the need for tuning and to avoid specific drive files for different truck configurations the drive files were created with a very slow acceleration – and consequently required a very long test track stretch to reach the scenario speed.
Since the targeted scenarios are to be conducted with a test driver in the driver seat for the foreseen future this does not affect the feasibility of the test method at all.

The analysis of test data has also been improved by working out a method to read out the ABD robot data through the test vehicle's CAN. This way the test scenario data and function data are automatically synchronized.

Same direction - heavy truck turning across VRU path
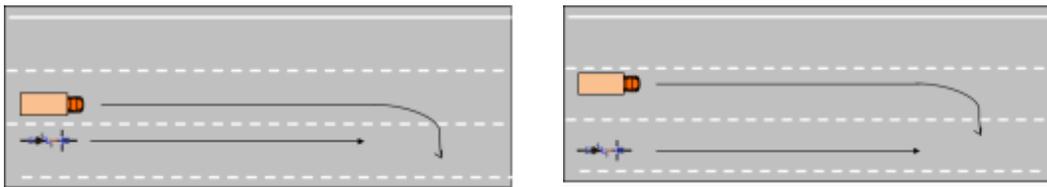
Figure 16. Illustration of same direction – heavy truck turning across bicyclist path.

Several different scenarios for Same direction – heavy truck turning across VRU path were run through – with high precision, efficiency and repeatability.

In most scenarios the test truck runs at constant speed throughout the scenario, but there were also tests made with a scenario that includes the truck stopping at a traffic light and then taking off again. The method allows also for this types of scenarios so what has been developed here is a generic method that can be varied in many more ways than what has been tested so far.

Figure 17. Illustration of same direction – heavy truck stopping at traffic light and then turning across bicyclist path.

The test method developed in A-TEAM 2b has been successfully verified with real targeted cases and hence, reached TRL6 with a test vehicle equipped with an ABD SR30 robot and the mid-speed target carrier with a bicyclist target.

Straight crossing path – VRU from left or right

Figure 18. Illustration of straight crossing path – bicyclist from right.

Also for this scenario the change of target carrier has enabled the reach of higher TRL. So far in A-TEAM 2 only bicyclist target has been used and with good results. TRL6 has been reached.

To achieve also TRL6 for a pedestrian target the only thing remaining is to actually mount a pedestrian on the target carrier – something that is solved in the development of the actual rig.

6.5   WP6

6.5.1.1 Issues
One issue has been durability of components (motor controllers, batteries, propulsion motors, drive shafts and brakes) during regulator tuning and testing of software changes. During prototype testing the different components has been pushed beyond their limits which has resulted in standstill due to long delivery time of special components. After regulation tuning the physical components have shown higher level of durability and the problems have shifted towards software and communication issues.

The second issue has been on antenna integration in the HSP and antenna coverage. The antennas are still not fully integrated in the equipment resulting in when a test vehicle runs over the HSP there is a risk of destroying antennas. The performance of the antennas gets greatly reduce while the DRI SoftCar 360 target is mounted. Solutions has been to temporarily mount the antennas higher inside the target but this has resulted in damage to antenna cables when running into the SoftCar target. Four antennas are currently needed to run the HSP: GPS Antenna, GPS correction data antenna, emergency stop receiver antenna and WiFi/3G antenna for setting up drive paths and controlling the equipment. The GPS antenna has been integrated into the chassis of the HSP allowing it to sink into the chassis in the event of a run-over. The other antennas has however shown great degradation of performance when being mounted too close to the ground, i.e. directly atop the HSP.

Another issue has been unnecessary wear of the tires when communication fails or any other safety mechanism which causes the HSP to emergency brake and creating a flat spot on the wheels. This has resulted in long downtime due to change of wheels. The solution has been to create a new type of brake which does not brake using the wheels but instead uses a rubber pad which is pressed down onto the ground in case of an emergency brake activation. The brake is depicted in Figure 19.

Figure 19 shows the first version of the pad brake while being activated.

The first primary issue is that current battery technology being too low in energy density which results in a temporary design deviation in terms of HSP height at the battery compartment; even though the HSP uses the latest battery technology with highest available energy-to-weight ratio on the market the height at the battery compartment is 120mm instead of 90mm.

The second main issue is the propulsion motors. Due to the design height limitation of 90mm the range of available motors producing enough power becomes extremely small. Due to the size of the motors and the torque required to propel the HSP, the current through the motors has caused them to melt down on multiple occasions. The solution was to restrict the current through the motors which also impacted the acceleration

performance and, to some extent, the top speed of the HSP. Another type of motor was tested and it proved to be superior that of the old motor. The new motor is however 100mm in diameter which resulted in a design deviation: the height of the HSP at the propulsion motors is 120mm instead of 90mm.

The design deviations will be solved when available technology for propulsion and energy storage further develops or when more time is prioritized towards restacking battery modules inside the HSP.

6.5.1.2 Programming and Testing

The GUI's (Graphical User Interface) appearance for controlling the HSP is still in the development phase and is not very intuitive but works well for a person who have received some training. The user may create drive paths and send start and stop commands. The user may also save log files of all the onboard data at this point the log file contains 41 parameters. The regulation system to control the position of the HSP includes 32 regulation parameters: 6 parameters for the lateral positioning/steering system, 8 parameters for the longitudinal positioning and 18 parameters for others including geometrical properties of the HSP.

6.5.1.3 Creating drive files

Creating drive files are done by using the GUI and writing lines stating what the HSP should execute. The first line contains the starting point and the start heading. The second line and onwards contains velocity change, heading change and time duration to perform the wanted maneuver. One example is shown below in Figure 20 and *Table 1*1.

Table 11 Shows the structure of the drive file. Columns are time, velocity change, heading change

Drivefile
267,213,-146
1,0,0
3,6,0
2,0,0
2,4,0
1,0,0
4,-4,0
2,0,0
10,0,-100
13,0,0
14,0,-170
1,0,0
3,8,0
1,0,0
4,-10,0
2,0,0
12,0,180
6,0,-90
2,-2,0
4,0,0
26.5,0,-180
2,-1.5,0
1,-0.5,0
3,0,0
20,0,0

Figure 10 Shows the resulting drive file in the GUI.

6.5.1.4 Test results

Multiple tests to set up the regulation parameters and to test the performance of the HSP has been performed. Testing with the DRI SoftCar 360 top mounted has only been tested at a few occasions due to the decrease in communication signal coverage when the target is mounted.

Figure 21 shows the logged data from a test where top speed without target mounted was tested. The HSP reached a top speed of 87 km/h. The red line corresponds to actual throttle command, the green line corresponds to target velocity and the blue line corresponds to actual velocity. The acceleration performance did not quite reach the preprogrammed path, i.e. the blue line is below the green line at the beginning. The top speed was however enough and the actual speed reached above the target speed. The main reason for the actual speed being behind the target speed is the inertia of the system during start, once the HSP has started moving the slope of the target and actual speed matches up to 50km/h where the acceleration performance of the equipment becomes insufficient. The overshoot of the actual speed is due to regulation not being quick enough at this stage to decrease the throttle. *Figure* 22 shows the current through the system during the top speed test. It shows that the current reaches a maximum of approximately 400A during the acceleration phase and decreases to 150A during steady state at 87km/h. This shows that the battery need to have a current drain capacity of 400A and the motor controllers need 200A to perform this kind of test.

The same type of test was performed with the DRI SoftCar 360 target mounted. Figure 23 and Figure 24 shows the logged data when the target is mounted. Figure 23 shows that the actual velocity does not reach the target velocity, this is probably due to the larger frontal area and thereby increased wind resistance. Another reason is that the throttle (PWM) signal was not adjusted when mounting the target, i.e. the HSP should have put out more power when the target is mounted than when it is not. Figure 24 shows that the current drain during acceleration is increase to about 600A and during steady state driving at 74km/h the current stays at 240A. This test shows that the battery need to handle 600A and the motor controllers 300A to perform the same test with the target mounted.

The HSP did not reach 80km/h with the top mounted but one conclusion is that the HSP probably cannot handle 3m/s^2 acceleration all the way up to 80km/h, at least not with the currently mounted motors, new motors are however being tested. The powertrain batteries have not shown any sign of degradation and seems to be stable at these load levels.
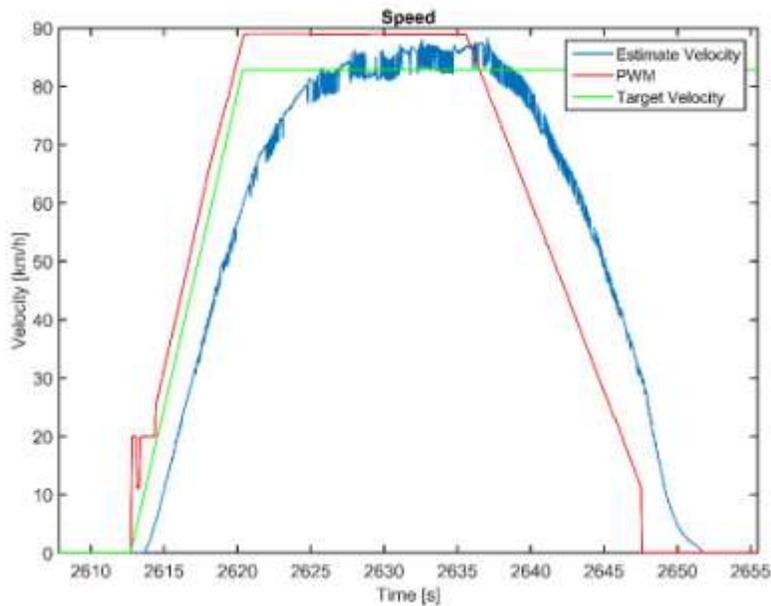
Figure 21 depicts the logged data from the HSP during a high speed regulation test. The DRI target was not mounted.
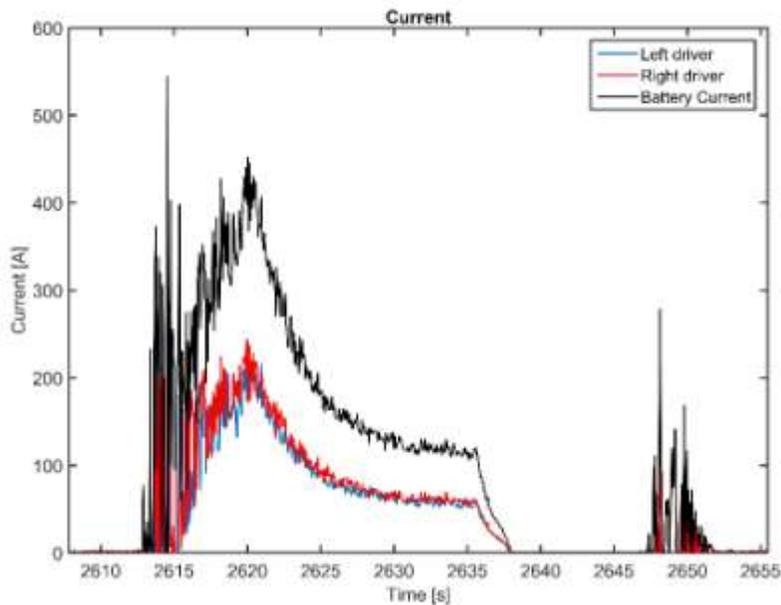
Figure 22 shows the current through the left and right motor controller and the total current from the battery.
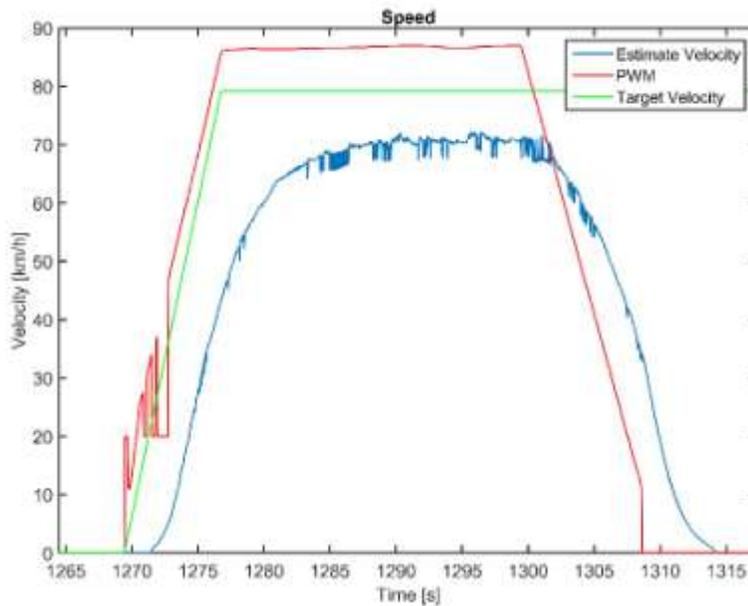
Figure 23 shows the top speed measured when the DRI SoftCar 360 top was mounted.
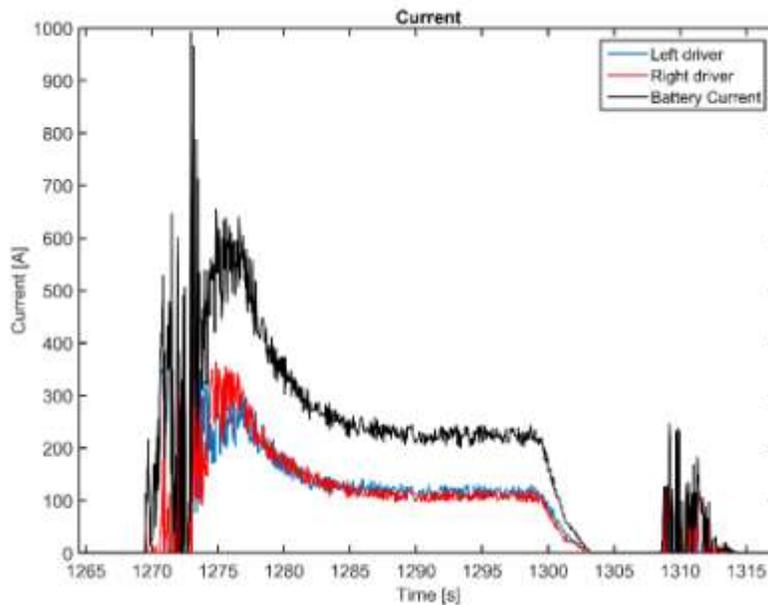
Figure 24 shows the current through the system when the DRI SoftCar 360 top was mounted.

Two videos are attached which shows the two tests performed. "TopSpeed.mp4" shows the video corresponding to Figure 21 and Figure 22. "TopSpeedTargetOn.mp4" shows the video corresponding to Figure 23 and Figure 24. These two tests were performed at the airfield in Vårgårda.

The 14th September there was a demonstration planned where the aim was to show the HSP in action. The HSP was fully functional before the demonstration but at the time of

demonstration the equipment had a malfunction: the antenna for the e-stop had a bad connection which led to emergency stopping at certain vibration frequencies. The planned demonstration was however recorded before the malfunction and the video "Demo hsp20160914" is attached in this report.

6.5.1.5 Results summary

Many requirements of the HSP has been fulfilled. It can withstand multiple overruns by a heavy truck at velocities up to 80km/h while standing still. A driver in a passenger vehicle can run over the HSP at speeds up to 100km/h while HSP is standing still without inducing harm to the driver. The HSP suffers from the similar issue in terms of crash safety as the other over runnable target carriers: it is unsafe if the HSP crashes into the side of a test vehicle. The HSP has experienced multiple crashes, the worst crash being 50km/h into a concrete barrier with a mass of 250kg, the worst damage was some chipping at the corners of the side ramps. The HSP has not showed any signs of degrading due to water and all functions are operational during bad weather conditions (the HSP has been used during rain, during wet asphalt and during temperatures below 0 degrees Celsius). The HSP has reached a top speed of 87km/h without any top mounted. And a top speed of 76km/h with the DRI - Soft Car 360 mounted. The HSP can follow a preprogrammed path (drive file). The HSP is under constant development to make it compatible with future trends in active safety testing.

6.5.1.6 Benchmark

Below some brief observations with respect to the benchmark assessments are presented:
- 4a pedestrian rig
  - Fairly easy to set-up, short turnaround time as long as the target is not hit
  - Have severe problems during wet conditions: some tests are aborted and stated top speed is not reached
  - Acceleration and deceleration can be set in scenario program but do not affect the acceleration or deceleration in the actual test
- ABD SPT pedestrian rig
  - Fairly easy to set-up, short turnaround time as long as the target is not hit
  - Controller believes it follows the desired speed profile. However measurements show that this is not the case.
  - Does not reach its stated top speed of the platform
- ABD GST soft car platform
  - First assessment was severely hampered by the GST capability to cope with wet and cold conditions
  - Does not fulfil stated acceleration values
  - Fulfils stated top speed and lateral acceleration.
- EuroNCAP Vehicle Target
  - Positioning and dynamic performance limited by the driving robot in the tow vehicle

- Damping effect of the tow ladder must be further investigated. The target lags compared to the tow vehicle speed profile.
- ABD Driving Robot
  - Assessment was performed using EuroNCAP AEB speed profiles
  - Given enough lead-in, the robot can perform tests with the speed, yaw, etc. accuracy stated by the EuroNCAP test method
- Autoliv HSP
  - The HSP is still in a premature state and its drivetrain needs tuning
  - The HSP does not fulfil required top speed or max acceleration
  - The HSP has successfully been overrun by a truck without experiencing damage
  - The HSP has an interesting solution for an emergency brake which can save time and cost related to the ordinary wheels
- DSD UFO platform
  - Does not fulfil stated acceleration values
  - Fulfils stated top speed and deceleration.
  - Seems to be user friendly and battery swapping takes "no time"
  - The DSD had the best availability of the tested vehicle platforms
- ASTA mid-speed target carrier
  - The MSTC seems to fulfil its specification w.r.t. positioning and dynamic performance
  - However, positioning could be significantly affected by wind
  - No GNSS-based synchronization between MTSC and VUT is available at the moment.

As a general conclusion one can observe that, in principle, almost all test equipment has more or less trouble fulfilling their specifications. Equipment which are well-tried, such as the ABD driving robot, the one which best manage to fulfil its specification. A majority of the test equipment seems to have problems with Swedish weather (snow, rain, low temperature) and other conditions (salted roads). In many cases a few test cases, or even no test cases, could be performed due to failing equipment. For more detailed information on the conducted benchmark tests please consult the ATEAM Benchmark Report.

6.6 WP7

The main achievement within the Euro NCAP 2016 is that local instructions based on the Euro NCAP protocols have been created. The instructions are the main foundation for a synchronized implementation between the test engineers with the present equipment and tracks at AstaZero. The instructions in combination with a checklist have also made the start-up procedure for each test more standardized and helped to reduce the time before the VUT is ready for the tracks and the actual tests.

The instructions clearly state what equipment to use and where to find further guidelines for help if needed. Furthermore, the instructions have set-up a standardized way of working from a new car arrives to finished test. In addition to the instructions several more documents covering checklist, drive files, coordinate systems and installation/verification documents have been created so common things between different tests does not need to be re-created.

Verification test of the installation of equipment in the VUT has been developed and tested with good results to secure the measurements of the VUT for the up-coming tests.

Another improvement is the measurement rig developed in phase 2A, all measurements needed in the four Euro NCAP protocols AstaZero is about to perform, are now included in one chart. The measurement gage has been improved so measurements can be performed single handed and time has been decreased.

The evaluation scripts which were also developed in phase 2A have been modified and improved a great deal. The scripts are now running automatically after a few setups in the computer in the VUT, the script makes the evaluation after each run automatically with only a few check questions to be answered by the driver and a full report with OK or Not OK for the run is presented.

These single reports from each run can later easily be combined and implemented in the final report to the customer. Further development of the scripts is possible to get more information out from each run and to get the basic implementation of information into the final report automated so more time can be spend on the analysis and total evaluation of the test.

The level of the test engineers and comfort zone of practical doing the Euro NCAP test has increased significantly for the test engineer. A good help here was the mid-term 2-weeks test with VCC to evaluate the present stand-point.

Some of the work done can also benefit other kind of tests and preparations of other VUT. The measurement rig together with the checklist and verification test are also very helpful to secure the upcoming test, no matter what the test is about.

6.7 Delivery to the FFI goals

The combination of a proving ground and the new tools and methods that this project aimed at developing contributes to many of the general FFI goals. Swedish industry has, thanks to the test methods, a unique platform for research and innovation and thus access to new tools in the work to remove accidents resulting in serious injuries and deaths. These test methods are needed also to support the development of autonomous vehicles since autonomous vehicles must be able to handle these situations.

The methods and test system addressed four out of six research areas in the strategic roadmap for the vehicle and traffic safety:
- Vehicle and traffic safety analysis including other facilitating technologies and knowledge

- Basic safety attributes of vehicles
- Driver support and related interfaces between driver and vehicle
- Intelligent collision-avoiding systems and vehicles

Through the mapping of the potential future method and test equipment steps, a plan was indirectly created for further contribute to the roadmap in many steps. Swedish vehicle industry is in the absolute cutting edge of active-safety development and the new possibilities in the new methods combined with the testing efficiency improvements will allow the industry to maintain and increase the leadership. Accidents in intersections are already mentioned as a domain where active safety can contribute [10]. Within this scope, cooperating systems based on vehicle to vehicle and vehicle to infrastructure is contained. As shown by Lefévre [11], the number of involved parties in combination with their various types is increasing the dynamics and complexity of the traffic model. By using suitable warnings- or other active safety systems that e.g. informs parties in intersections in time, the associated risk for this traffic type can be lowered. The decision by EuroNCAP to develop a rating method for the scenario type further shows the focus dedicated to this traffic environment.

The increased method and equipment competence will allow the Swedish companies, institutes and universities to play a greater role in the EU Horizon 2020 programs.

Within the SAFER framework, there is already a strong cluster that now has gotten more nourishment to further strengthen the cooperation between the triple helix parties.

Swedish vehicle industry has gotten new possibilities to develop new vehicle based active safety systems that supports the driver in taking the right actions in situations involving various cognitive driver loading and possibility to strengthen driver initiated actions such as braking.

Similar scenarios will be designed for driving simulators and this will create a need to validate simulator tests using proving ground testing. The knowledge is used to develop driver models to CAE tools utilizing the potential of shorter development times of technology.

7 Dissemination and publications

From WP2, several talks and papers.. Further, demonstrations have been performed at AstaZero Researchers' Day.

Conference papers
- ICSE poster 2017 "Software-Related Challenges of Testing Automated Vehicles"
- IV2017 "Paving the Roadway for Safety of Automated Vehicles: An Empirical Study on Testing Challenges"
- FASTZero 2017 "Proving Ground Support for Automation of Testing of Active Safety Systems and Automated Vehicles"

Workshop papers

- RESACS workshop 2017 "Capturing Ambiguity in Artifacts to upport Requirements Engineering för Self-Adaptive Systems"

8   Conclusions and future research

A-Team phase 2b has delivered validated test methods, scenarios, test equipment prototypes and demonstrated them in test systems with performance levels necessary for validation of the methods.

ATLAS will be a continuation of A-team with required modifications to handle autonomous functionality, specifically new techniques to identify scenarios, more advanced test equipment and technology to allow autonomous functionality to accept the test track and a real traffic environment. AstaZero is coordinator for A-team and for CHRONOS (test platform for complex scenarios) which will facilitate a smooth start of ATLAS and tight cooperation with CHRONOS.

9   Participating parties and contact persons

Peter Janevik, peter.janevik@astazero.com, 010-5166143

Contact persons:

VCC: Anders Axelson, anders.axelson.ii@volvocars.com

AB Volvo: Anna Wrige Berling, anna.wrige@volvo.com

Autoliv: Per Gustafsson, per.gustafsson@autoliv.com

RISE: Henrik Eriksson, henrik.eriksson@rise.se

Chalmers: Christian Berger, christian.berger@chalmers.se

AstaZero: Niklas Lundin, niklas.lundin@astazero.com, Håkan Andersson, hakan.andersson@astazero.com

10 References

[1]   F. Shull, J. Singer, and D. I. K. Sjøberg, Eds., *Guide to Advanced Empirical Software Engineering.* London: Springer London, 2008.

[2]   K. Petersen, R. Feldt, S. Mujtaba, and M. Mattsson: *Systematic Mapping Studies in Software Engineering*. In Proceedings of the International Conference on Evaluation and Assessment in Software Engineering (EASE'08), pp. 68-77, 2008.

[3]   Alessia Knauss, Jan Schroeder, Christian Berger, and Henrik Eriksson. *Software-Related Challenges of Testing Automated Vehicles.* In Proceedings of the International Conference on Software Engineering (ICSE), 2017.

[4]   Alessia Knauss, Jan Schroeder, Christian Berger, and Henrik Eriksson. *Paving the Roadway for Safety of Automated Vehicles: An Empirical Study on Testing Challenges.* In Proceedings of Intelligent Vehicle Symposium (IV), 2017.

[5]   Alessia Knauss, Christian Berger, and Henrik Eriksson. Proving Ground Support for Automation of Testing of Active Safety Systems and Automated Vehicles. In International Symposium on Future Active Safety Technology Toward zero traffic accidents (FASTzero), 2017.

[6]   Juan C. Muñoz-Fernández, Alessia Knauss, Lorena Castañeda, Mahdi Derakhshanmanesh, Robert Heinrich, Matthias Becker, and Nina Taherimakhsousi. *Capturing Ambiguity in Artifacts to Support Requirements Engineering for Self-Adaptive Systems*. In Proceedings of International Workshop on Requirements Engineering for Self-Adaptive and Cyber Physical Systems (RESACS), 2017.

[7]   Abbiege-Assistenzsystem für Lkw - Grundlagen für ein Testverfahren Benjamin Schreck, Dr. Patrick Seiniger 2014

[8]   PRUDENT-VI Project - PRotection of vulnerable road Users in case of acciDENT against an Industrial Vehicle, H. Desfontaines, P. Beillas 2008

[9]   Volvo GTT European Truck Accident Report 2017, P Wells et.al. 2017

[10]   U.S. Department of Transportation, National Highway Traffic Safety Administration: "The New Car Assessment Program Suggested Approaches for Future Program Enhancements", http://www.safercar.gov/staticfiles/DOT/safercar/pdf/810698.pdf.

[11]   S. Lefèvre: "Risk Estimation at Road Intersections for Connected Vehicle Applications", PhD Thesis, Université de Grenoble, October 2012