Replacing side-view mirrors in trucks with integrated digital system to improve safety (DREAMS)

Project within:	Traffic safety and automated vehicles
Author:	Habibovic, A.[1], Andersson, J.[1], Malmsten Lundgren, V.[1], Staf, H.[2], Sundberg, N.[3]
Organizations:	[1] RISE Viktoria AB, [2] Scania CV AB, [3] Stoneridge Electronics AB
Contact:	Azra Habibovic, azra.habibovic@ri.se
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Content

1 Summary

Replacing rear-view mirrors on trucks by rear-view camera monitoring systems and in-vehicle monitors is expected to increase safety and reduce fuel consumption. This project generated knowledge on how such systems operate, if truck drivers find them useful and appealing, and to what extent they can improve traffic safety. Stoneridge's camera-based rear-view mirror prototype mounted on a Scania truck served as a use case. The prototype includes cameras mounted close to the front corners of the truck cabin and in-vehicle monitors mounted in A-pillars showing videos of the surroundings to truck drivers.

An evaluation methodology has been developed and applied in tests at the test track AstaZero and on public roads. The evaluations involved both controlled and naturalistic experiments, as well as real-world use of the platform. These were conducted under various light and weather conditions and captured various traffic environments including urban, rural and highway driving.

The evaluations showed that a high-level of safety and usability could be achieved, and provided valuable insights on further improvements of the prototype, which were later implemented within the project. A majority of the drivers found the prototype desirable and easy to get used to. The major safety advantages that they identified as compared to the conventional mirrors include: a) larger field of view, especially at intersections and roundabouts, b) direct visibility significantly improved, c) dirt from windshield does not affect visibility, and d) there is no need for body and head movements to increase field of view. Some of the drivers found that objects were too small on the monitors, especially on the passenger side, and that cameras reacted differently to different light sources. Some of the drivers expressed also a general anxiety for technical failures that may occur over the lifespan of the prototype.

The project has also identified how expand the functionality of the prototype regarding driver support and automated driving. Several different concepts were suggested including: detection of vulnerable road users and other potential hazards in blind spots, free lane indication, estimation of distance to other vehicles and objects, and platoon monitoring.

Examples of future research include further improvement of the prototype in terms of e.g., monitor placement and camera adaptability to different light sources, as well as further development and evaluation of the concepts providing additional functionality.

The project was conducted by Stoneridge Electronics AB, Scania CV AB, and RISE Viktoria AB. It has increased technical maturity of Stoneridge's camera-based rear-view mirror prototype and brought it closer to the market launch that is scheduled for 2018. It has also led to a general growth in innovation capacity in Sweden, and empowered strategic R&D activities and manufacturing in the country.

2 Sammanfattning

Att ersätta konventionella backspeglar på lastbilar med motsvarande kamerabaserade system väntas leda till bättre trafiksäkerhet och minskad bränsleförbrukning. Detta projekt har genererat kunskap om hur sådana system fungerar, om lastbilsförare tycker att de är användbara och tilltalande, och i vilken utsträckning de kan förbättra trafiksäkerheten. Stoneridges digitala backspegelprototyp monterad på en Scania-lastbil användes som ett användarfall. Prototypen inkluderar kameror monterade nära de främre hörnen av lastbilens hytt och digitala bildskärmar monterade i hyttens A-pelare som visar video från omgivningen till lastbilsföraren.

En utvärderingsmetodik har utvecklats och tillämpats i utvärderingar på testanläggningen AstaZero och på allmänna vägar i Sverige. Utvärderingarna omfattade både kontrollerade och naturalistiska experiment, liksom användning av prototypen vid verkliga transporter. Dessa genomfördes under olika ljus- och väderförhållanden och i olika trafikmiljöer.

Utvärderingarna visade att en hög nivå av trafiksäkerhet och användbarhet kunde uppnås och gav värdefulla insikter om förbättringar av prototypen som senare implementerades inom ramen för projektet. En majoritet av förarna fann prototypen önskvärd och lätt att vänja sig vid. De viktigaste säkerhetsfördelarna som förarna identifierade jämfört med de konventionella backspeglarna innefattar: a) större synfält, särskilt vid korsningar och rondeller, b) direkt sikt förbättras avsevärt, c) smuts från vindrutan påverkar inte sikten och d) det finns inget behov för kropps- och huvudrörelser för att öka synfältet. Några av förarna fann att objekten var för små på bildskärmarna, särskilt på passagerarsidan, och att kamerorna reagerade annorlunda på olika ljuskällor. Några av förarna uttryckte också en generell oro för tekniska problem som skulle kunna uppstå under prototypen livslängd.

Projektet har också identifierat hur prototypens funktionalitet kan breddas med avseende på förarstöd och automatiserad körning. En rad olika koncept har föreslagits inklusive: hjälp att upptäcka oskyddade trafikanter och andra potentiellt farliga trafikanter och objekt, information om fritt körfält vid filbyte med långt ekipage, hjälp att uppskatta avstånd till andra fordon och objekt samt stöd vid kolonnkörning (platooning).

Exempel på framtida forskningsaktiviteter inkluderar förbättring av prototypen med avseende på exempelvis placering av bildskärmar och kamerans anpassningsförmåga till olika ljuskällor, samt vidareutveckling och utvärdering av koncepten som breddar prototypens funktionalitet.

Projektet har genomförts av Stoneridge Electronics AB, Scania CV AB och RISE Viktoria AB. Det har ökat mognadsgraden hos Stoneridges kamerabaserade backspegelprototyp för lastbilar och fört den närmare marknadslansering som är planerad till 2018. Det har också lett till ökad innovationskraft i Sverige och bidragit till strategisk FoU-verksamhet och tillverkning i landet.

3 Background

Today, trucks are equipped with various types of mirrors, including rear-view mirrors. Such mirrors are used to improve visibility of the surrounding environment and facilitate a safer maneuvering. Still, truck drivers have limited visibility and there are large blind spot areas around their trucks (Figure 1) [1]. There is a premise that camera-based monitoring systems (CMS) can reduce blind spots, add views that are difficult for drivers to obtain, or to replace existing mirrors. In addition to having the potential of making trucks safer, such systems are also expected to reduce airodynamic drag and improve fuel economy (by up to 3% [2]) as well as to make trucks quieter.

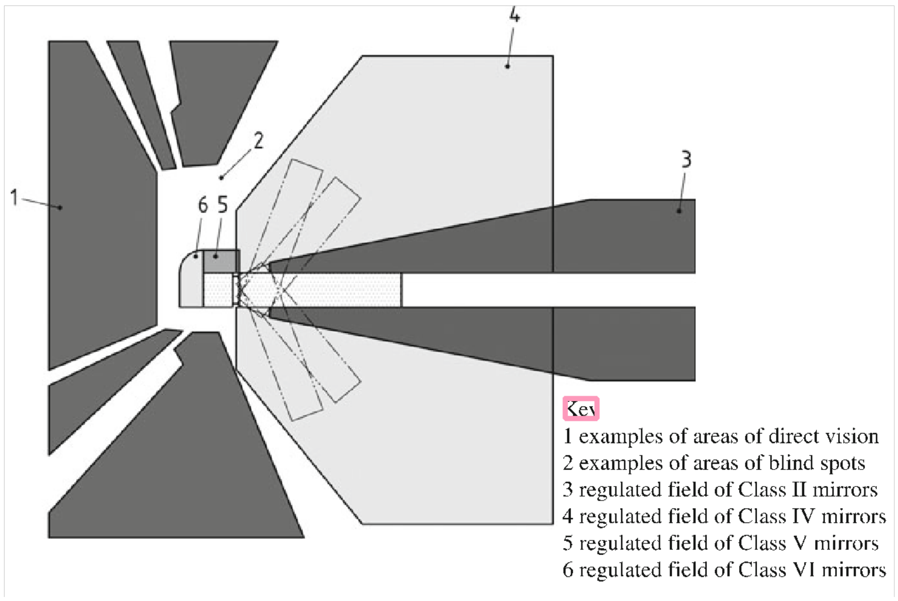

Figure 1. Different classes of mirrors on trucks as specified by UN R.46 and illustration of blind spots areas for different positions of the trailer.

The introduction of cameras in vehicles has been going on for some time. Passenger vehicle manufacturers such as Volvo Cars, BMW, Mercedes to name a few, use cameras facing forward to detect traffic signs, lane markings and objects for active safety systems that assist drivers in controlling the vehicle. Also, night vision systems with infrared cameras are common today. The installation of such driver assistance systems is, however, not required by current vehicle regulations and the camera systems are as such not legally required in vehicles except in the US where all new passenger cars and light trucks (under 4500 kg) built from May 1, 2018 should have a rear-view camera [3]. The normative framework of the standard ISO 16505:2015 on ergonomic and performance aspects of CMS [1] in combination with the latest version of UN Regulation No. 46 (UN R.46 [4]) enable also replacement of mandatory rear-view mirrors by CMS for both passenger cars and trucks in series production.

In their passenger car prototype, Volkswagen has demonstrated how side-view mirrors can be replaced by cameras [5]. BMW showed its system in which small cameras replace mirrors and offer an electronic display, allowing drivers to get three separate images or a single panoramic view. This means a driver can look ahead and do not need to turn his or her head to see side mirrors. French equipment maker Valeo has also demonstrated a system which uses cameras as well but maintains electronic displays on each side of the car [6]. General Motors announced that the inside mirror in its Bolt electric car will be able to connect to a camera, eliminating the problem of a view blocked by passengers or tall objects in the back seat [7].

Several truck manufacturers have also envisioned a future with similar systems for trucks (Figure 3, [12-17]), as well as suppliers such as Continental [8] and Bosch [11]. Continental has presented a CMS, named ProViu®Mirror, consisting of two camera arms mounted on each side of the truck and 12.3" monitors integrated in each of the A-pillars of the vehicle. Each camera arm contains two cameras, mounted at different angles to attain the proper fields of vision. Bosch's CMS named Mirror Cam System has similar characteristics; however, it contains situation-specific displays which enable the driver to see further behind the truck when driving on highways, while in urban areas the angle of view is enlarged to enable better detection of objects near the truck.

a) b) c)

d) e) f)

Figure 2. Various truck manufacturers have shown prototypes that include CMS: Volvo Trucks (a), Renault (b), Mercedes-Benz (c), Peterbilt (d), Iveco (e), MAN (f).

4 Objective and research questions

The *aim* of the project was to investigate the potential of camera-based rear-view mirror replacement systems to improve safety using Stoneridge's platform mounted on a Scania-truck as a case study at AstaZero and on public roads. The platform is herein referred to as DREAMS-platform (as short for Digital REAr-view Mirror Systems).

The *objective* of the project was two-fold:

- To identify and investigate the necessary requirements to achieve a safe and user-friendly camera-based rear-view mirror replacement system.
- To propose and evaluate concepts of extended functionality of a rear-view camera system regarding active safety, automated driving and connectivity.

The project addressed the following *research questions*:

R1. What are the performance requirements of the self-calibrating camera system to ensure safe operation while adapting to different lightning, weather and road conditions?

R2. Can a rear-view camera system give drivers a better awareness of their surroundings than side-view mirrors?

R3. Do drivers who learned to drive with conventional rear-view mirrors need education and/or training on how to use camera-based information in the best way?

R4. What new functionality can be added to a rear-view camera system to increase its application area?

5 Project realization

The project was divided into four work packages *(WPs)*:

1. Project management
2. Platform development
3. Extended functionality of the platform
4. Evaluation of the platform

These WPs were to a large extent interrelated and carried out in a parallel manner (Figure 3). The focus has been on further developing the DREAMS-platform and evaluating it in realistic settings with truck drivers (many of which were recruited by Scania). Three different evaluations were carried out giving direct input to further development of the platform, both in the near- and long-term (i.e. identification of additional functionality). The long-term evaluation was not included in the original project plan.

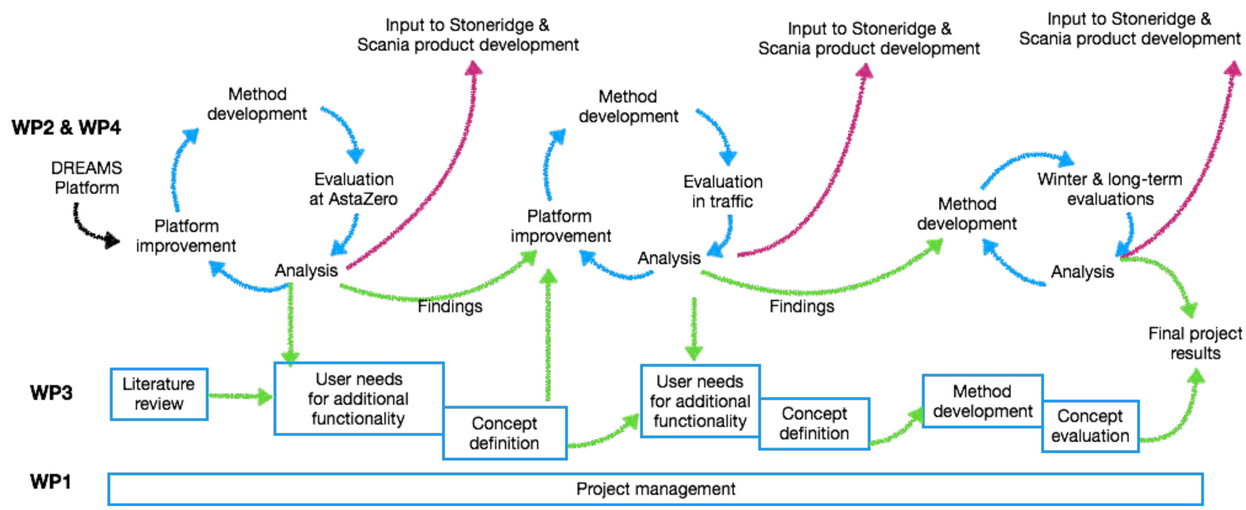

Figure 3. Overall realization process in the project where activities were conducted in parallel.

5.1 Further development of the platform (WP2)

The platform that Stoneridge brought into the project captures the view from two mirror types: Class II and Class IV (Figure 1).

The DREAMS-platform consists of two modules:

- A camera module consisting of a video processor, video channel transceiver with bidirectional communication, heater, bracket, covers and folding mechanism. Such a module is placed on the top of the truck cabin, one on each side (Figure 4).
- A monitor module consisting of a 12.3" display, video channel receiver with bidirectional communication, display processor, state machine, diagnostics, CAN communication with vehicle, housing and bracket. Such a module is placed on the A-pillar inside the truck cabin, one on each side (Figure 5).

Figure 4. DREAMS camera module is mounted close to the front corners of the cabin, one on each side.

Figure 5. DREAMS monitor module is placed on the A-pillar in the track cabin, one on each side.

The DREAMS-platform operates in three different light modes: day, dusk and night. It is activated/deactivated via a button integrated in the dashboard. The driver can adjust some system settings via a control device placed to the right of driver.

In the project, the focus was on the improvement of the DREAMS-platform, both regarding hardware and software. The aim was to fulfill the ISO 16505 standard [1] and UN R.46 [4] and meet needs of the stakeholders (OEMs and end users), and thereby achieve a system performance that is at least as good as the performance of the conventional mirrors. As illustrated in Figure 3, the improvements were carried out in an iterative manner. The first major improvement took place prior to the evaluation with the truck drivers at the test track AstaZero, while the second major improvement was based on the results from that evaluation and was carried out prior to the evaluations with the truck drivers on public roads.

The software properties that were improved included latency, dynamic range, and resolution. Hardware improvements focused on ensuring that the cameras a) can perform self-calibration and quickly adapt to different light, weather, and road conditions, b) are redundant in the event of a hardware or software failure, and c) are easy to maintain. On the HMI side, the focus was on ensuring that the monitors are reliable and robust towards light, weather, and road conditions, as well as ensuring that important settings are adjustable to fit needs of different truck drivers. Examples of such settings include:

- Horizontal and vertical adjustments are controlled with a door module in the same way as on electrical mirrors.
- Panning for following trailer end is done automatically. This means that the Class II view is panned so the end of the trailer is in the middle of the image. It can also be manually controlled.

- There is a zoom function that is manually activated and works differently depending on driving situation.
- Camera heating and cleaning are activated automatically, but can also be manually controlled.
- Night mode with IR-leds is automated automatically, but can also be manually controlled.
- Illumination of the displays is automatic, but can also be manually controlled.

5.2 Evaluation methodology (WP 4)

To evaluate performance of the DREAMS-platform in terms of safety and usability, three evaluation approaches have been developed:

A. Evaluation at the test track AstaZero: Controlled experiments;
B. Short-term evaluation on public roads: Naturalistic experiments; and
C. Long-term evaluation in various environments: Real use.

In the first two cases (A and B), the DREAMS-platform has been installed in a Scania rigid truck with trailer with a total length of 24 meters (Figure 6). In case C, the DREAMS-platform was installed on the same truck, however, it was sometimes operated with the trailer and sometimes without the trailer.

Figure 6. Truck with trailer at the test track AstaZero.

5.2.1 Evaluation at the test track AstaZero: Controlled experiments

The focus has been on developing a methodology for a controlled experiment that enables evaluation of:

- Drivers' understanding of the depth perception and distances to other road users and objects in different light conditions and in different traffic situations;

- Drivers' assessment of speed of other road users in different light conditions and in different traffic situations; and
- Drivers' assessment of the truck's position on the road.

To start with, test scenarios were defined based on a focus group study with truck drivers, literature review and the ISO-standard 16505. The scenarios included city driving (encounters with pedestrians and bicyclists, tight intersections, roundabouts, reversing) and highway driving (various overtaking maneuvers and interactions with passenger cars, lane change, road work, onramp). The execution of these scenarios at the test track AstaZero is illustrated in Figure 7.

The experiment was then designed as a within subject study, meaning that each truck driver experienced two conditions: a) with conventional mirrors and b) with DREAMS-platform. These conditions were experienced in a random order. When condition a) was experienced, the DREAMS-platform was turned off and the monitors were concealed. When condition b) was experienced, the conventional mirrors were removed. Further, the experiment was designed to allow repetitive data collection (e.g., for each condition, the drivers drove two laps around the test track where one lap corresponds to ca 7 km). The data collected included both subjective and objective metrics such as:

- Distance and speed perception of other road users and objects.
- DGPS-based measurement of distance between the truck and other road users and objects;
- Estimation of the truck and trailer position on the road.
- Perceived minimum safe distance to change lane when being overtaken.
- Distance estimation at standstill.
- Eye behavior.
- Subjective ratings of the visibility performance.
- Overall experience of the platform.

Each experiment took approximately 90 minutes. It started with a short introduction where the driver completed a background questionnaire and filled in a consent form. After, the driver got introduction to the truck (and DREAMS-platform, if it was to be experienced first) and his/her task. The experiment started in the city and the driver's task was to drive to the highway and follow instructions of the test leader who was sitting in the passenger seat. The DREAMS-condition included a training session on road of ca 10 minutes to ensure that the drivers get used to the platform. The test leader gave various task to the driver such as "Please, tell me when it feels unsafe to change lane". After maneuvering between buildings in the city environment and performing a reversing exercise, the experiment ended in the city where the driver was asked to fill a post-questionnaire about his/her experience and perceived visibility of DREAMS-platform or conventional mirrors. When both conditions were completed, the driver was asked to fill in a questionnaire comparing these two types of mirrors and to answer a few questions in an openend interview. Some of the experiments were carried out under daylight conditions, while some others were carried out in dusk or in darkness. This to explore performance of the DREAMS platform under various light conditions.

In total, 18 truck drivers participated in the experiment. All of them were working in the Borås-area (the nearest big city). The drivers were recruited for the study by direct contact with them or their employers. The pre-condition for participating in the study was that each driver should have a driver's license for heavy trucks and be operating a truck on daily basis.

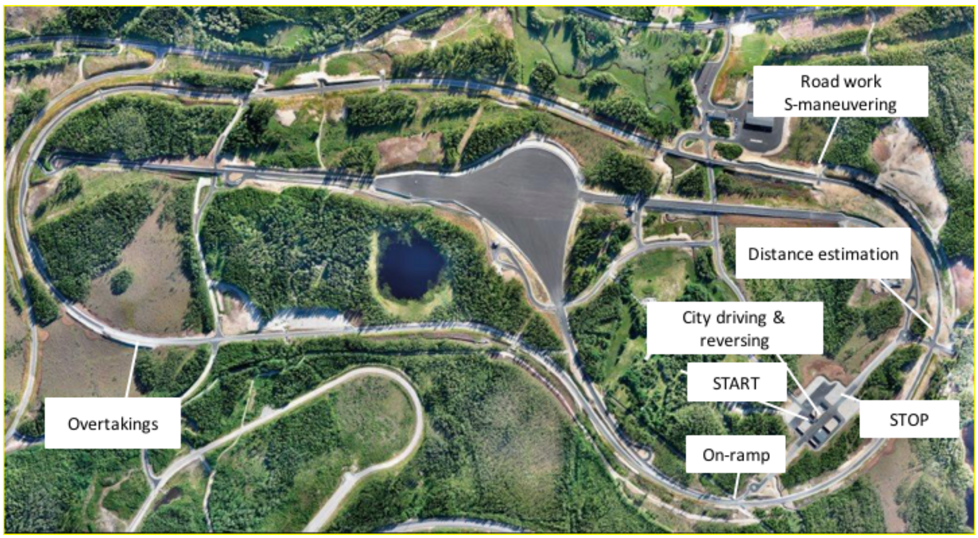

Figure 7. Scenarios that were carried out at the test track AstaZero.

5.2.2 Short-term evaluations on public roads: Naturalistic experiments

The short-term evaluation on public roads was carried out as an uncontrolled within subject experiment. This means that the route was pre-selected and that each driver experienced both conventional mirrors and DREAMS-platform (in a random order). To test the DREAMS-platform without corresponding conventional mirrors on public roads, an exemption from the Swedish Vehicle Ordinance was obtained from the Swedish Transport Agency.

The experiment was carried out in Södertälje-area and was divided in two sub-experiments. One that took ca 1.5h to complete (Sub-experiment A), and one that took ca 4h to complete (Sub-experiment B). The drivers in Sub-experiment A, experienced only daylight conditions, while the drivers in Sub-experiment B experienced daylight, dusk and darkness. Furthermore, a part of the route in Sub-experiment B corresponded the route in Sub-experiment A. However, Sub-experiment B involved also some other routes. The total number of drivers in Sub-experiment A was 22, and the total number of drivers in Sub-experiment B was 8.

The pre-selected routes reflected the scenarios that were previously tested at the test track AstaZero. The procedure was also similar the one at the AstaZero. The focus was mainly on subjective metrics. The overall task of the driver was to drive the truck as usually and to think aloud while driving and comment on special events, as well as to answer the test leader's questions. The test leader accompanied the driver in the truck to guide him/her and ask predefined (short) questions during the journey. To ensure that the drivers are comfortable to drive with the DREAMS-platform on public roads, each driver started at Scania's test track. The drivers were asked to inform the test leader if they feel ready to drive on public roads. The test-participants were Scania drivers.

5.2.3 Long-term evaluation in various environments: Real use

To evaluate long-term effects of the DREAMS-platform a group of 4 Scania drivers were using DREAMS-platform in their daily work in ca 2.5 months during spring 2017. The first 2 months, the platform was used without the conventional mirrors, while it was used in combination with conventional mirrors for the rest of the evaluation period. This, to enable a direct comparison of these two different types of mirrors. The truck was used for tasks such as trailer relocation and goods transportation between different facilities in Södertälje. The drivers have also driven it to different venues on several occasions. They have been driving in different traffic environments from urban environment to highways and rural roads. In addition, it has been used extensively in industrial areas where it was required to drive or reverse into narrow spaces with trailers.

The drivers got an introduction to the platform prior to the evaluation period. At the end of the evaluation period, the drivers participated in a focus group study where they discussed their experiences. The discussion was moderated by two moderators. The drivers were also asked to compare performance of the camera-based mirror with the performance of the conventional mirrors in different driving scenarios (e.g., overtaking, reversing, driving in darkness).

5.3 Extended functionality of the platform (WP 3)

The project explored additional functionality aiming at improving the self-awareness of the driver and the vehicle. It investigated which functions could be executed on the DREAMS-platform in the future. The goal has been to derive recommendations and high-level concepts rather than to implement and integrate such functions in trucks. This included a thorough investigation of the requirements on hardware and software as well as human-machine interaction (HMI). A special attention was given to the functions related to automated and connected vehicles. The project also investigated what requirements that the use of the DREAMS-platform for such applications may pose on in-vehicle communication networks in terms of e.g., bandwidth and latency.

To start with, truck drivers' support needs were identified via literature review, focus group studies and evaluations of the DREAMS-platform at the test track AstaZero and on public roads. Based on that and the current technology trends, several concepts were derived. The concepts were evaluated in walkthrough study with 9 drivers. One of the concepts (Vulnerable Road User

Detection) has also been initially implemented on the DREAMS-platform. Overall, the evaluation with drivers showed that all suggested concepts are desirable and have potential to improve traffic safety and contribute to a positive driver experience in trucks. One of the major requirements is that the concepts can rapidly convey status of the situation such as “safe” or “not safe”. That is, the information provided by the concepts should be easy to notice and perceive by drivers, without occluding other relevant information or causing mental workload.

The project suggested the following concepts that could extend the functionality of the DREAMS-platform.

- *Vulnerable Road User Detection*. Accidents with vulnerable road users (VRUs), such as pedestrians and cyclists, account for 15-25% of all accidents related to trucks and in majority of the cases accidents happen in low speeds. Compared to conventional mirrors, camera-based rear-view mirror systems are capable to analyze the situation and potentially warn drivers for actions, especially when drivers are inattentive or distracted. With the context of autonomous driving, the information can also be used to trigger control functions such as automatic brake. In the project, VRU detection has been evaluated and tested on the DREAMS-platform. It is performed by a system built on neural networks. They are very power consuming, but this approach is needed to reach the required accuracy. These nets need to be very fast and need to be able to run on at least 10 fps. Scheduler/OS has been tailor-made to suit the network. And the system has been trained on several hundred thousand images. The preliminary findings suggest that the camera covering Class V area is the most suitable for VRU detection since this is an area which is most difficult for the driver to monitor regarding both direct and indirect vision. However, VRU detection is also useful in the Class II and Class IV areas. In addition, the project suggested several HMI solutions which were evaluated in a walkthrough study together with truck drivers.
- *Blind Spot Detection.* Blind spots are one of the most challenging obstacles while driving. To facilitate detection of vehicles and other occluded objects, devices such as blind spot information systems and indirect vision systems are implemented in vehicles. In the project, it was investigated if DREAMS-platform could be utilized to detect potential hazards around the truck and to inform drivers about them. The focus was mainly on highway driving (e.g., overtaking, lane change), but the ideas could be extended to other speeds and traffic environments.
- *Free Lane Indicator*. The project explored also the effect of a function that aims at continuously informing truck drivers about the occupancy of the adjacent lanes. Instead of informing the driver about the potential hazards as suggested in *Blind Spot Detection* this function would inform the driver when the adjacent lanes are free from other vehicles. The evaluation with the truck drivers showed that such a function would provide extra confidence in situation assessments to the drivers, especially in situations

such as lane merging and highway onramp. The concept shows also the end of the truck/trailer, which was highly appreciated by the truck drivers since estimating the end of the trailer in relationship to the road outline is often a challenging task.

- *Distance Support*. A concept that facilitates easier distance estimation to (potentially hazardous) objects (e.g., vehicles, motorcyclists, buildings) in the vicinity of the truck was also explored for both high speed and low speed scenarios such as reversing. The evaluation with the truck drivers showed that the function would improve distance estimation and facilitate maneuvering of the trailer attached to the truck. For high speed applications, the concept was implemented in the VICTA simulator [9]. However, it has not been evaluated with truck drivers yet.
- *Platooning Support.* Platooning is one of the most promising applications for truck-based road transport for improving road capacity, fuel efficiency, as well as safety. The functionality is based on many different sensors including radar, camera, and vehicle-to-vehicle communications. Today, platooning uses dedicated displays or nothing for driver awareness. As shown in the European Truck Platooning Challenge [10], there is a clear gap on how to deliver platooning information to driver without distraction (e.g., without causing "eyes off the road" behavior). In such cases, the monitor module in the DREAMS-platform is a natural and potentially the best solution to increase situation awareness between platoon drivers. In addition, video streaming between vehicles in a platoon has also been suggested as a way to increase situation awareness. In this project, we have investigated the potential of video streaming from the camera module in DREAMS-platform and what requirements it may pose on communication networks, both in-vehicle and intra-vehicle.
- *Automation indicator*. Road vehicle automation is under fast development and vehicles that do not require input from a human driver under certain conditions are expected to arrive on our roads in a few years, and some manufacturers foresee even a future without any human drivers at all. One potential application of the DREAMS monitor module is to show to the truck driver which of the vehicles in the vicinity are operated by automation. This would support truck drivers in create expectations regarding behavior of the other vehicles/drivers.
- *Security Support.* There is a strong demand for temporarily remote monitoring of trucks when drivers are not at the spot such as during short breaks, especially when the trucks carry valuable goods. DREAMS-platform could potentially be used for surveillance purposes. The concept involves monitoring via a smartphone.

6 Results and deliverables

The DREAMS project has developed knowledge on how digital rear-view camera systems operate, if truck drivers find them useful and appealing, and to what extent they can improve traffic safety. It has increased technical maturity of Stoneridge's platform and developed evaluation methodologies that can be transferred to other projects in the area. The project has as such developed knowledge on both HMI and technical perspectives that has directly been fed into the product development at Scania and Stoneridge.

The specific results from the project include:

- A methodology for evaluating performance of rear-view camera systems in trucks from safety and usability perspectives in various traffic environments.
- Understanding of performance requirements for rear-view camera systems in trucks;
- Knowledge about the potential of rear-view camera systems regarding active safety, automated driving and connectivity.
- An improved prototype of Stoneridge's rear-view camera system.
- A demonstration and proof-of-concept evaluation on AstaZero and on public roads.

6.1 Delivery to FFI-goals

The project has led to a general increase in the capacity of innovation in Sweden. It increased technical maturity of Stoneridge's prototype and helped Stoneridge to continue their strategic R&D activities and manufacturing in Sweden. It has also helped Stoneridge industrializing the prototype and bringing it to the market (launch planned for 2018). Furthermore, a strategic cooperation between Stoneridge (supplier), Scania (OEM) and RISE Viktoria (research institute) has been established and the research network of each organization has been enhanced. Worth noting is also that Stoneridge got opportunity for the first time to participate in a research project together with a research institute and a vehicle manufacturer. As such, the project has contributed mainly to the following overall FFI-goals:

- Increased research- and innovation capacity in Sweden;
- Promoted participation of suppliers in research projects; and
- Promoted cooperation between industry and research institutes.

The project has developed and evaluated safety and usability aspects of camera-based systems that replace rear-view mirrors in trucks. It has demonstrated that such systems may in long term outperform conventional mirrors and improve overall awareness of the driver (e.g., by informing and warning drivers about potential threats). The project has thus addressed two areas of the FFI collaboration program *Traffic safety and automated vehicles*:

- Effect analysis and evaluation of vehicle safety and use of safety systems.
- Driver support and interfaces between the driver and vehicle.

7 Dissemination and publications

7.1 Dissemination

Several seminars and workshops have been organized among the project partners for discussions, knowledge transfer, as well as concept and study ideation. The results from the project have been passed on to the product development at Scania and Stoneridge. The results have also brought

Stoneridge's rear-view mirror replacement system prototype closer to the market launch that is planned for 2018. The project has also collaborated with other projects such as *Automated Vehicle Interaction Principles* (AVIP), *Glass Reality*, and *VICTA Lab* (a project within competence and innovation node VEHILE ICT ARENA). In addition, it has led to a new use-case in the project *Real-time support for heterogeneous networks in automotive applications* (RETINA) and *Ethernet Communication for Real-time Automotive* (ECRA) where implications of video-data communication on network structure and capacity are investigated. The experiences and knowledge from the project have also inspired two recently completed projects within the Drive Sweden program: *Metoder och mått för utvärdering av ett automatiserat transportsystem* and *Studie av kommunikationsbehov vid interaktion mellan lastbilar och omgivande trafik vid konvojkörning*.

Table 1. Overview of the application and dissemination of the project results.

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	All project parties have increased knowledge in the field.
Be passed on to other advanced technological development projects	X	The project has been collaborating with other R&D projects. The evaluation methodologies developed here can be reused in other similar projects.
Be passed on to product development projects	X	The knowledge and results gained in the project have been passed on to the product development at Scania and Stoneridge.
Introduced on the market	X	In 2018, Stoneridge plans to introduce a rear-view mirror replacement system on the market that is partly based on the results from this project.
Used in investigations / regulatory / licensing / political decisions		

Furthermore, the following *conferences and seminars* involving external parties have been conducted:

- Andersson, J., Habibovic, A., 2017. Automated vehicles. Transportstyrelsen, Rättvik.
- Andersson, J., 2017. Ongoing Research in Sweden. ISO Workshop on Ergonomics, Göteborg.
- Andersson, J., 2017. Ongoing research at RISE. Presentation at CEVT, Göteborg.
- Habibovic, A., Andersson J., 2017. Evaluation Methodologies. Knowledge exchange seminar at Stanford University, Stanford, California.
- Habibovic, A., Andersson, J., 2017. Ongoing research on truck safety and automation. Seminar at Peloton Technology, Mountain View, California.
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- Habibovic, A., 2015. Digital rear-view mirrors on trucks. Seminar at SAFER, Göteborg.

7.2 Publications

The project has generated the following *reports and papers*:

- Habibovic, A., Andersson, J., Malmsten Lundgren, V., Staf, H., Sundberg, N., 2015. Methodology for evaluation of digital rear-view mirror systems on trucks at test tracks. Internal project report.
- Habibovic, A., Andersson, J., Malmsten Lundgren, V., Staf, H., 2015. Evaluation results from the test track AstaZero: Summary. Internal project report.
- Habibovic, A., Malmsten Lundgren, V., Andersson, J., Staf, H., Sundberg, N., 2016. Methodology for evaluation of digital rear-view mirror systems on trucks on public roads. Internal project report.
- Habibovic, A., Malmsten Lundgren, V., Andersson, J., Staf, H., 2016. Evaluation results from public roads: Summary. Internal project report.
- Habibovic, A., Malmsten Lundgren, V., Andersson, J., Staf, H., Sundberg, N., 2017. Methodology for long-term evaluation of digital rear-view mirror systems on trucks. Internal project report.
- Habibovic, A., Malmsten Lundgren, V., Andersson, J., Staf, H., 2017. Evaluation results from long-term evaluation: Summary. Internal project report.
- Bengtsson, H., Chen, L., Habibovic, A., 2017. In-vehicle communication requirements to support video signal processing applications for rear-view mirror replacement. Internal project report.

- Habibovic, A., Andersson J., Staf, H., Malmsten Lundgren, V., Sundberg, N., To be submitted. Methodology for evaluation of digital rear-view mirrors on trucks in a test track setting.
- Habibovic, A., Malmsten Lundgren, V., Andersson J., Staf, H., to be submitted. Methodology for evaluation of digital rear-view mirrors on trucks on public roads.
- Andersson, J., Habibovic, A., Malmsten Lundgren, V., Staf, H., to be submitted. Distance estimation with digital rear-view mirrors: User testing and experience.
- Habibovic, A., Malmsten Lundgren, V., Staf, H., to be submitted. Digital or conventional rear-view mirrors on trucks? Driver experiences on public roads.
- Habibovic, A., Andersson, J., Staf, H., to be submitted. Short and long-term evaluations of DREAMS: Methodological aspects.
- Chen, L., Habibovic, A., Malmsten Lundgren, V., to be submitted. Platooning in realistic traffic: driver interactions with digital rear-view cameras.
- Malmsten Lundgren, V., Habibovic, A., Chen, L., to be submitted. How can a digital rear-view camera system be used to provide driving assistance to truck drivers?

8 Conclusions and future research

The objective of this project has been to explore camera-based rear-view mirror systems on trucks, and to generate knowledge on how such systems operate, if truck drivers find them useful and appealing, and to what extent they can improve traffic safety.

The first step in the project was to further develop the DREAMS-platform that Stoneridge brought into the project. The focus was mainly on obtaining a performance comparable to, or better than, the conventional mirrors (*Research question 1*). The standard ISO 16505 and the UN R.46 were used as guidelines to specify the minimum requirements on hardware and software (e.g., latency, bandwidth, dynamic range, resolution). The evaluations on the test track AstaZero, and later on public roads, showed that fulfilling the minimum requirements is not always sufficient to warrant safety and positive user experience. For example, the minimum requirement for the monitor size on the driver side is 10’’, and on the passenger side 12,3’’. In the project, a monitor of size 12,3’’ was used on both sides. However, some of the drivers experienced objects too small, especially on the passenger side and under adverse weather and light conditions. This issue was especially emphasized if the driver had some vision impairment. This suggests that a larger monitor may be needed on the passenger side, or that the monitor may need to be placed closer to the driver. This is a complex topic with several challenges and requires in-depth investigation. A recommendation is to conduct long-term evaluations where drivers use the platform in their daily work, allowing exploration under various conditions and scenarios.

Overall, the studies conducted suggest that camera-based rear-view mirrors have a great potential to outperform the conventional rear-view mirrors on trucks in terms of providing truck drivers with views of their surroundings (*Research question 2*). Many of the drivers were from the beginning suspicious and stated that they believed that such a mirror replacement would not be appealing to them. However, a majority of them were positively surprised and stated after completing the evaluation that they would like to use such a system in future. They found that the images viewed on the monitors were generally easy to perceive and that the entire system was attractive to use. A major precondition is, however, that the technology is reliable and redundant, and that they have ability to adjust some parameters (e.g., height of the monitors). It is also important that the cameras automatically adjust to different light sources; flickering was identified by some drivers as a potential issue depending on the light source captured by the cameras. The major safety advantages that were identified as compared to the conventional mirrors include: a) larger field of view, especially at intersections and roundabouts, b) direct visibility significantly improved, c) dirt from windshield does not affect visibility, and d) there is no need for body and head movements to increase the field of view.

An additional conclusion from the project is that drivers who learned to drive with conventional rear-view mirrors do not need education and/or training on how to use camera-based information in the best way (*Research question 3*). Most the drivers found it easy to get used to the DREAMS-platform, and after using the platform for 5-10 minutes in a closed area all of them felt ready to proceed further to the real-world traffic.

The project showed also that replacing conventional rear-view mirrors with camera-based systems offers new possibilities for vision enhancements and supplementary information that could facilitate driving (*Research question 4*). It identified several areas where camera-based rear-view mirror systems could be used to provide additional support to truck drivers including detection of vulnerable road users such as pedestrians and cyclists, distance information, and warning for other vehicles and objects in blind spots around the truck. Several high-level concepts were developed utilizing the monitors to provide drivers with information. The evaluations showed that the information should be easy to perceive without requiring drivers to focus on the monitors. Given that in-vehicle support systems and information could contribute to increased mental workload of the driver and lead to distraction and impaired driving, it is crucial to further explore applicability of additional functionality in real-world settings.

Examples of future research include further development of the current platform in terms of e.g., monitor placement and image flickering, as well as further development and evaluation of the concepts suggested in the project. Also, more extensive long-term evaluations of the current platform could be performed to gather deeper understanding of its performance in adverse conditions and with a larger sample of truck drivers. The evaluation methodologies suggested in the project could be applied, and if needed further developed.

9 Participating parties and contact persons

Stoneridge Electronics AB
Box 3133
SE-169 03 Solna
Contact: Nicolas Sundberg (Development manager)
nicolas.sundberg@stoneridge.com

Scania CV AB
SE-151 87 Södertälje
Contact: Hanna Staf (Vehicle ergonomist)
hanna.staf@scania.com

RISE Viktoria AB
Lindholmspiren 3A
417 56 Göteborg
Contact: Azra Habibovic (Senior researcher)
azra.habibovic@ri.se

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