LIMITATIONS OF USE OF AN INERTIAL POSITIONING SYSTEM IN A TRUCK DURING A MANEUVER OF AVOIDING A SUDDENLY APPEARING OBSTACLE

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ABSTRACT

The objective of this work is to find limitations of using MEMS-type accelerometers and gyroscopes for finding position of a vehicle in short time prospective (few seconds). Such a system could be helpful for automated vehicle driving in some situations, like bypassing a suddenly appearing obstacle. A Monte-Carlo analysis was performed to find introduced position and direction errors for various trajectories of the vehicle. Transducer noise, offset and calibration errors were taken into account as possible error sources. Also, the influence of limited data sampling rate was checked. The results are presented in form of difference statistics between real and calculated vehicle position and orientation at the end of the track as function of various parameters, including the trajectory and performance of the used sensors. The Monte-Carlo simulation accuracy was checked by bootstrap method and the errors were shown in resulting plots. Presented results show that an inertial system can be used for determining the vehicle's position with accuracy reaching centimeters. Also, it is shown that compensation of the sensor offsets, as well as knowing the initial conditions are critical for the quality of the track reconstruction.

INTRODUCTION

For a suddenly appearing obstacle partly blocking the road, an attempt to bypass it can be a more efficient maneuver than braking, at least for certain velocities and track geometry [1,2]. This maneuver can be performed automatically if the vehicle is equipped with appropriate position sensors, like laser scanners, radars and cameras. However, such kind of sensors may be vulnerable to external disturbances like flashes of light, water splashes, fog, smoke or momentary electromagnetic interference. Also, their accuracy, sampling frequency and latency may not meet the requirements for rapid movements. This makes a need to provide a system which is free of aforementioned drawbacks. It should provide vehicle position data in a time period of few seconds needed for maneuver completion, with good-enough accuracy, immunity to external interference and low latency. Modern MEMS-type inertial sensors (linear accelerometers and gyroscopes, i.e. angular speed sensors) seem to be a good candidate to be used for this purpose.
The aim of this work is to find limitations of use of these sensors due to their noise, miscalibration and generally ill-conditioned integration-based method of vehicle position reconstruction. To achieve this goal, a number of Monte-Carlo simulations were performed for different conditions, including noise of the sensors, sampling frequency, miscalibration, track geometry, initial vehicle velocity and deceleration during the maneuver.

MARKET-AVAILABLE SENSORS

The manufacturers offer a variety of MEMS-based sensors for acceleration and angular velocity. Their performance is closely related to their intended application and related customer's budget, ranging from simple orientation sensors used for mobile phones, through sensors for game-console controllers, up to professional sensors which can be used in so demanding applications as autonomous control of drones or even 'big' aviation. Several sensors (including high-performance devices) are listed in Table 1. One of them – namely LSM330DL – contains both accelerometer and gyroscope in a single chip. Its parameters were used as base values for a number of performed simulations.
At this point, it's worth noting that also chip-integrated magnetometers are available which can provide absolute information on vehicle orientation, however their use for our purpose is generally pointless. This is due to their non-

negligible latency, relatively low sampling rate and – last but not least – vulnerability to interference from external sources of magnetic fields.

Table1.
Several types of MEMS accelerometers and gyroscopes and their main parameters.

Type	Accelerometer			Gyroscope		
	Range [m/s^2]	Noise density $\left[\frac{m/s^2}{\sqrt{Hz}}\right]$	Sample rate [Hz]	Range [^{o}/s]	Noise density $\left[\frac{^o/s}{\sqrt{Hz}}\right]$	Sample rate [Hz]
LIS3DH [1]	20-160	$2.2\cdot10^{-3}$	5000	*n/a*	*n/a*	*n/a*
LIS33DE	20-80	*not specified*	400	*n/a*	*n/a*	*n/a*
LSM330DL [2]	20-160	$2.2\cdot10^{-3}$	5000	250-2000	$3.0\cdot10^{-2}$	1344
L3G4200D [3]	*n/a*	*n/a*	*n/a*	250-2000	$3.0\cdot10^{-2}$	800
CMR3000-D01	*n/a*	*n/a*	*n/a*	2000	$2.0\cdot10^{-1}$	160

MONTE CARLO SIMULATION PROCESS

The basic simulation process consisted of few steps:

- calculating the position of the vehicle along a defined track over time with dense time step (typ. 1 ms);
- calculating the data for sensors, i.e. the values of acceleration (tangential and normal component related to the vehicle trajectory) and angular velocity over the vertical axis;
- decimating the above data to get undisturbed sensor data at real sampling frequency of the sensor;
- disturbing the data to get simulated data of a real sensor;
- track reconstruction basing on disturbed data;
- finding the reconstruction errors.

Last three steps were performed multiple times (typically 1000) to get statistical information on errors. Basing on acquired data, the mean value of the error, its standard deviation and RMS (root-mean-square) value were calculated.
The whole procedure was performed for various conditions, e.g. varying noise of the sensors, vehicle speed or track length. Following further assumptions were made in order to perform the simulations:

The shape of the track

It is assumed that the vehicle moves along a straight road with a constant velocity as the maneuver begins. Then it changes its position across the road by a certain displacement (denoted as D) while moving forward. The total distance along the road during this movement (denoted as L) is generally longer than D. The track has a shape of half-cosine, according to Equation 1:

$$d(l) = \frac{1}{2} D \cdot \left(1 - \cos\frac{\pi \cdot l}{L}\right) \tag{1}$$

where l and d denote actual vehicle position along and across the road, respectively. One must note that l can not be treated as linearly changing with time, as the velocity of the vehicle is calculated along its trajectory and not along the road.
For the purpose of simulation, two short segments of straight track (parallel to the road) are added at the beginning and the end of the track. Their length is determined according to the vehicle's velocity so that their duration is about 100 ms. The aim of inserting these segments is purely technical – an amount of data is to be generated to feed digital filters for data decimation, so that no oscillations at the beginning and the end of the track occur.

It's obvious that discontinuities in acceleration and angular velocity are present at the beginning and the end of the proposed half-cosine track. Despite that such kind of track is impossible to be followed in reality, these discontinuities are not an obstacle for the track reconstruction algorithm. Thus, the assumed model of the track is acceptable for our purpose.
Last but not least, it must be noted that our model is two-dimensional. This means that possible vehicle tilting is not taken into account. The consequence of this assumption is that only two acceleration sensors among three (one for each axis) are used in the track reconstruction procedure – a sensor for vertical acceleration is not used. Accordingly, only one rotation sensor is used – this is the one to measure angular speed over the vertical axis.

Sensor models

The sensors are outputting data with a defined sample rate. It's assumed that the data acquisition time is zero (i.e. the value of the sample refers to a certain moment and is not an effect of averaging of the input value over a period of time).
It was assumed that the sensors have following errors:

- Sensor noise, which is stationary, white in spectrum and has Gaussian probability density function (PDF). During simulation, a random value of noise is added to each sample of the sensor data. The input data for the simulation is the power spectral density of the noise, which is re-calculated to variance of a single sample.
- Sensor miscalibration, which has also Gaussian PDF. Sensor miscalibration is a constant value added to the sensor data for the whole realization, i.e. single MC attempt. However, it's determined independently for each realization, giving a spectrum of different results after a number of MC loops.

Track reconstruction algorithm

The aim of this algorithm is to calculate vehicle position and orientation (the angle between the vehicle's axis and initial movement direction) basing on the sensor data. The calculation is performed with a defined timestamp, which is identical with sampling period of the sensors. Actually, two main activities are performed for each time point: calculation of the vehicle orientation (i.e. the angle between the axis of the vehicle and the axis of the road) and position.
The vehicle orientation calculation is performed using only the data from the angular velocity sensor. For a given time point t_n, the vehicle's orientation ψ is calculated as:

$$\psi(t_n) = \psi(t_{n-1}) + T_s \cdot \Omega(t_n) \tag{2}$$

where $\psi\ (t_{n-1})$ denotes vehicle orientation for the previous time point, $\Omega(t_n)$ the measured angular velocity and T_s the sampling period.
The position reconstruction requires three consecutive steps: acceleration measurement, velocity calculation and position calculation.
For the first step, the sensor data is re-calculated from vehicle coordinates to road-related *l-d* coordinates, as it's presented in Equation 3:

$$\begin{aligned} a_l &= a_{par} \cdot \cos\psi - a_{perp} \cdot \sin\psi \\ a_d &= a_{par} \cdot \sin\psi + a_{perp} \cdot \cos\psi \end{aligned} \tag{3}$$

where a_{par} and a_{perp} are acceleration values measured with respect to the vehicle's axis (parallel and perpendicular, respectively) and ψ is the calculated current vehicle orientation. The a_l and a_d denote the acceleration values in along *l* and *d* axis.
The velocity is calculated by integrating the acceleration values, basically the same way as it was done for vehicle orientation. Then, one more integration step is performed to get the position values.

Dependencies to check

The influence of the following factors on the achievable accuracy was checked:

- noise spectral density of the accelerometers and gyroscopes,
- miscalibration of the sensors (constant offset of the sensor readout),
- limited sampling rate of the sensors,
- length of the track along initial movement direction,
- initial vehicle velocity,
- vehicle deceleration during the maneuver.

Witch such a number of variables, performing simulations for all parameter combinations was virtually impossible. Thus, only 2-dimensional maps were calculated (i.e. the dependence on two selected parameters) with remaining parameters fixed at a constant value.

The basic parameter set was as follows:

- track length (L): 50 m (20 m for sample rate tests),
- track width (D): 5 m,
- initial velocity: 20 m/s
- vehicle deceleration: 0 m/s^2
- sample rate of the sensors: 100 Hz
- spectral noise density of the accelerometer: $2.2 \cdot 10^{-3}$ $m/s^2/\sqrt{Hz}$,
- spectral noise density of the gyroscope: $3.0 \cdot 10^{-2}$ $^o/s/\sqrt{Hz}$,
- accelerometer miscalibration: 0 m/s^2,
- gyroscope miscalibration: 0 $^o/s$.

Error calculation

The errors are present in each sample of the reconstructed data. However, they generally grow with time due to integration-based method of the track reconstruction – the error of any data sample is a result of the error of previous sample and new errors introduced by the sensors. Thus, the errors at the end of the track are statistically the biggest ones. For this reason, we used these 'final' errors as a gauge of the reconstruction quality.

Following errors were checked:

- misalignment in vehicle position at the end of the simulation, calculated independently in *d* and *l* axis, as well as combined position error;
- vehicle orientation error;
- the error of final movement direction.

The vehicle orientation and movement direction must be distinguished, as it is not an assumption that the vehicle is always moving along its axis. Even if we neglect small differences due to vehicle's chassis geometry, also huge discrepancies may occur if the vehicle gets into a skid. The reconstruction algorithm must take such a situation into account.

Basing on MC simulations, error statistics were gathered, giving following values:

- Error mean value. Generally, for 'input' errors with zero mean value, the mean value of the 'output' error should be also zero for a linear model. However, as our model is not linear, non-zero values may occur. It this controversial if this error can be suppressed in practice (despite it's theoretically deterministic), as its value may be strongly dependent on track parameters. Thus, we treat this error as incorrectable.
- Standard deviation of the error values. Only error spread is taken into account and not its mean value.
- Root Mean Square (RMS) value of an error. Both above components are incorporated in this value. It was used as a basic gauge during simulations.

BASIC RESULTS

In the following sections, basic results were presented in form of plots showing error RMS value as a function of various factors. Typically, each plot presents a family of curves showing the error dependence on two parameters. For each plot, 3σ error bars are plotted to show Monte-Carlo simulation accuracy.

Influence of the sensor noise

Figure 1 presents a set of plots showing the dependence of the errors on the noise of the sensors. Upper plots show the position reconstruction accuracy in two axes. Lower plots show movement direction error (left) and vehicle orientation error (right).

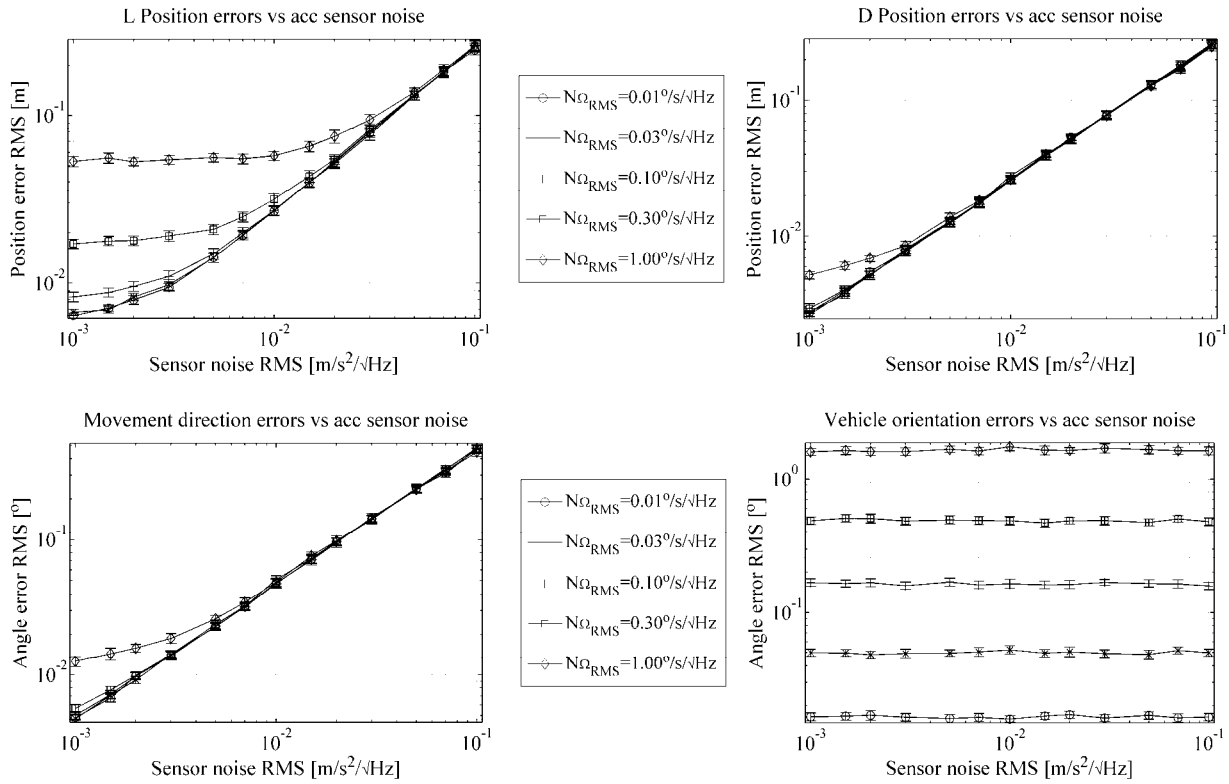

Figure 1. The influence of the sensor noise on the track reconstruction. Upper plots present position reconstruction error, while lower ones show angle reconstruction errors.

At this point, it should be noted that:

- For a given track geometry, the position reconstruction error is dependent mainly on the noise of the acceleration sensor. The influence of the gyroscope noise is visible mainly for the longitudinal component and only for high noise levels.
- The vehicle orientation reconstruction accuracy is dependent only on the noise of the angular velocity sensor, which is obvious given the reconstruction method described previously (see Equation 2).
- The accuracy of movement direction reconstruction is dependent mainly on the noise of the angular velocity sensor, but also an influence of the accelerometers can be observed for high noise amplitude.

Generally, the error values are small for expected noise levels of real sensors. For LSM330DL, the total position error should be below 1 cm for given track geometry and vehicle velocity of 20 m/s. Also, the vehicle orientation and movement direction accuracy should be well within 1°, which is more than satisfactory. Of course, these promising results should not be treated too seriously before analyzing the influence of track geometry, initial speed, sensor miscalibration etc.

Influence of the sensor miscalibration

Generally, the influence of sensor miscalibration is close (in its character) to the one of sensor noise, as Figure 2 shows. The main difference in the character of the curves is that no influence of miscalibration of the angular velocity sensor on position accuracy was observed.
If we define maximum errors as 0.1 m and 1° RMS, the allowable miscalibration values for given default conditions (see *Simulation Process, Dependencies to check*) are $3 \cdot 10^{-2}$ m/s^2 and $3 \cdot 10^{-1}$ ^{o}/s. One can see that assuring good sensor offset compensation is critical. Thus, an on-line algorithm is required to compensate slowly varying offsets of the sensors.

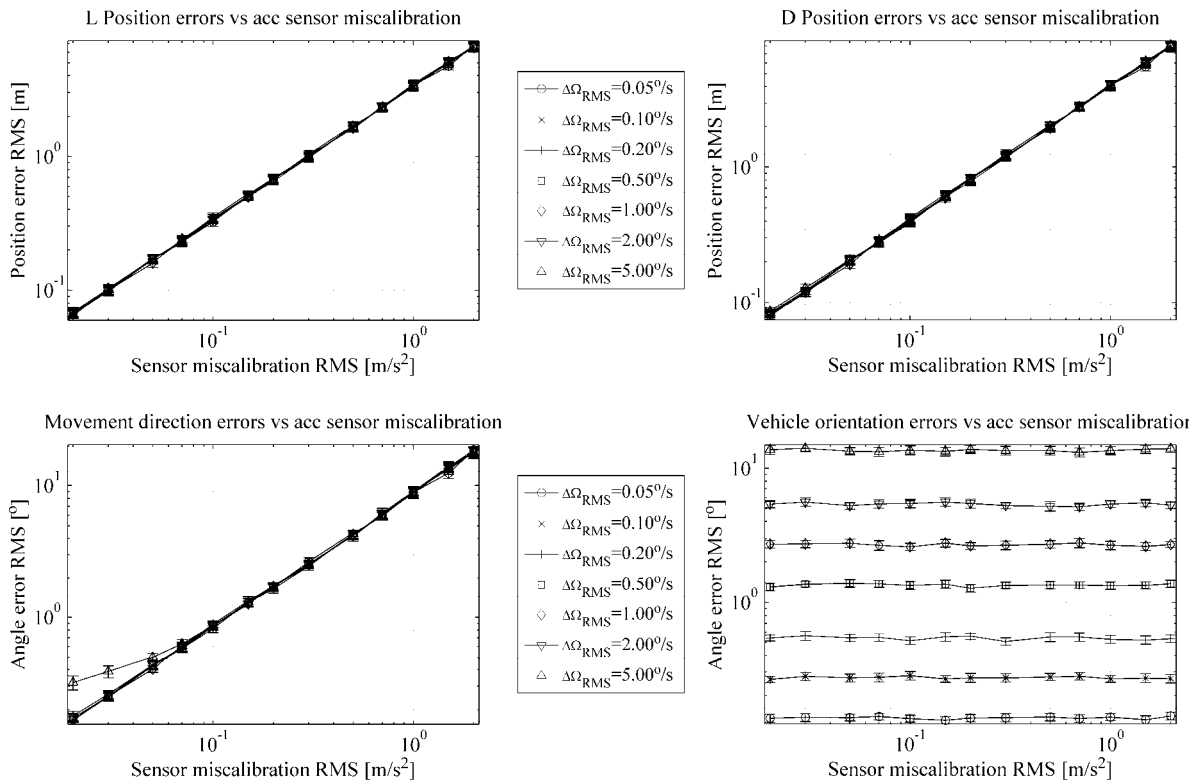

Figure 2. The influence of the sensor miscalibration on the track reconstruction.

Influence of uncertainties in initial conditions

The next possible error source is the uncertainty in initial conditions, i.e. vehicle velocity and movement direction. According to Figure 3, the simulations have shown that:

- The position reconstruction accuracy is dependent on errors both in initial velocity and movement direction. However, the influence of both parameters is different for longitudinal and perpendicular component of the displacement. As for the errors along the road, both error sources are sigificant. However, the influence on position across the road is dominated by initial direction errors.
- The accuracy of reconstruction of final movement direction and vehicle orientation is dependent only on initial direction error (it was checked that the influence of errors in initial velocity can be seen only for huge errors, which are comparable with the real value of the initial velocity).
- Achieving tolerable errors (0.1m / 1°) require that the initial velocity error is lower than ≈0.02 m/s and the initial movement direction is defined with an accuracy of 0.1^o. These requirements are very demanding, especially for the velocity measurement. However, one can see that mainly the longitudinal position is vulnerable to initial velocity (see Figure 3, upper left plot). Thus if we decrease our requirements for this

axis (it's less critical than the perpendicular component of the position), also the requirements on initial velocity requirement will become less tight.

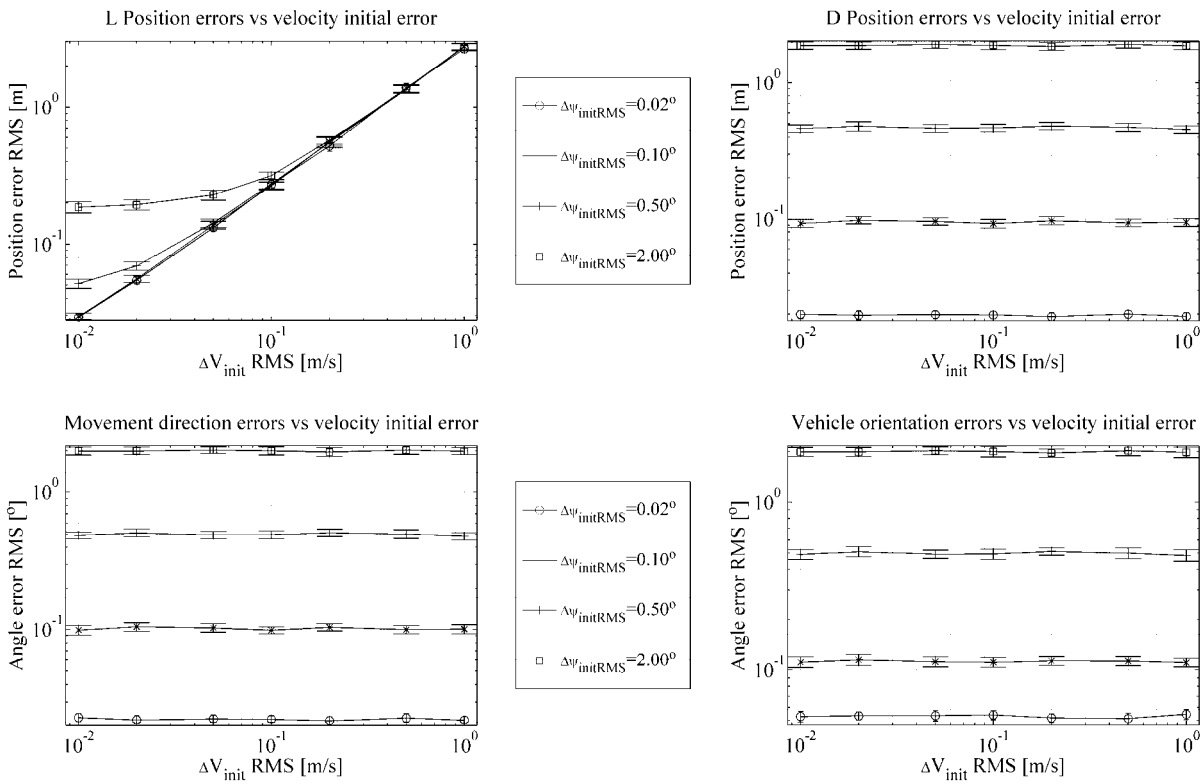

Figure 3. The influence of errors in initial velocity and angle measurement on the track reconstruction.

Influence of varying trajectory, vehicle velocity and deceleration

All presented results were obtained with a fixed track geometry (i.e. its length *L* and width *D*) and constant speed of 20 m/s. The question is, how these results change with the length of the track, initial speed and possible deceleration during the manoeuver.

For following simulations, all possible error sources were included. The simulation parameters were as follows:

- Spectral noise density of the accelerometers: $2.2\cdot10^{-3}\ \mathrm{m/s^2}/\sqrt{\mathrm{Hz}}$,
- Spectral noise density of the angular velocity sensor: $3.0\cdot10^{-3}\ {}^{\circ}\mathrm{/s}/\sqrt{\mathrm{Hz}}$,
- Miscalibration of the accelerometers: 0.01 $\mathrm{m/s^2}$ RMS
- Miscalibration of the angular velocity sensor: 0.1 °/s RMS
- Error in initial velocity: 0.01 m/s RMS
- Error in initial vehicle orienttion: 0.1 ° RMS
- Sampling frequency of the sensors: 100 Hz

The distance along the road for deceleration-dependent plots was 50 m.

The results are presented in Figure 4. One can see that a combination of all disturbing factors may cause position errors exceeding 1m, especially for long distances and small vehicle velocity. Mostly sensor miscalibration and errors in initial conditions are responsible for this value. It was checked, that the accuracy in both axes is influenced. The distinctive peaks on the deceleration-related plots (right side of Figure 4) are related to a situation where the deceleration causes the vehicle to stop at the end of the maneuver.

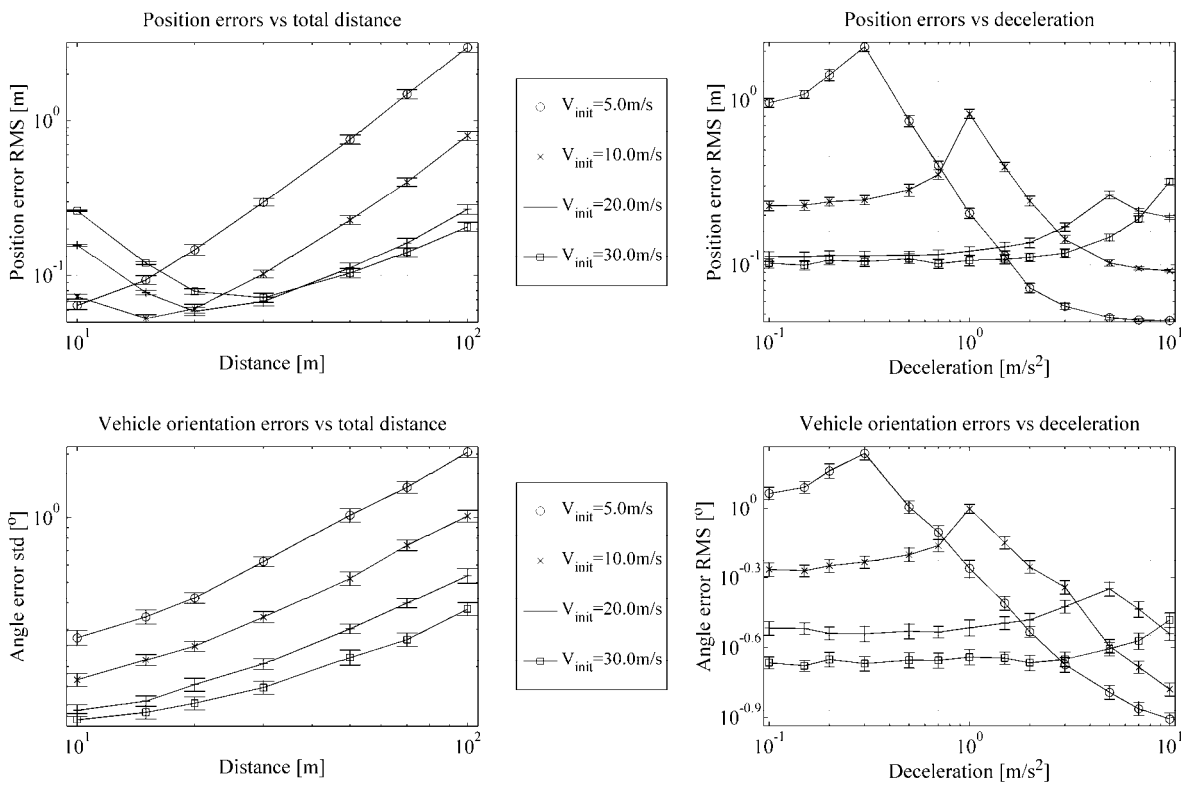

Figure 4. The influence of the track geometry, initial velocity and deceleration on the track reconstruction.

Influence of the sampling rate

The last simulation was performed to check the influence of the sampling rate of the converters on the results (Figure 5). The general outcome is that:

- the sampling frequency is more important for high velocities and narrow track shapes;
- for typical conditions, the sampling frequency in range of 100-400 Hz is sufficient.

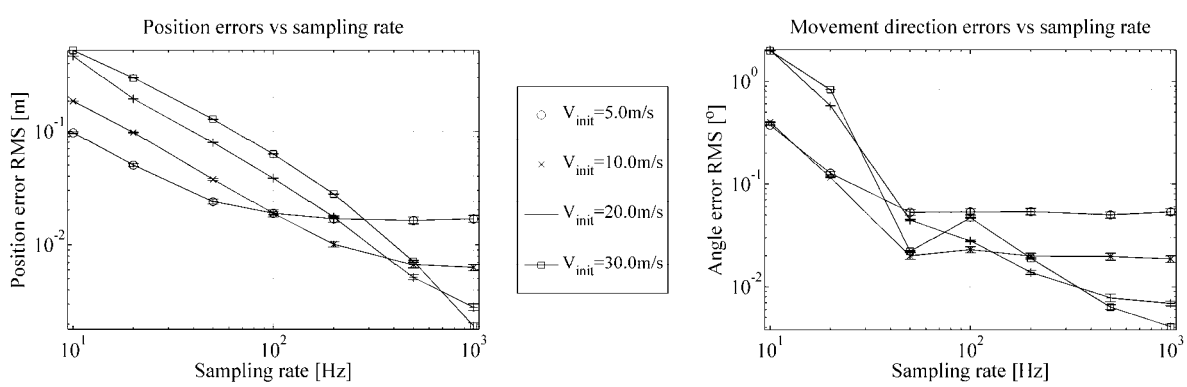

Figure 5. The influence of the sampling rate of the converters on the track reconstruction. Track length along the road is 20 m.

CONCLUSIONS AND DISCUSSION

The presented research included an analysis of achievable accuracy of a system of inertial sensors intended for automated driving of a vehicle. The results show that driving a vehicle using only inertial sensors (accelerometers and gyroscopes) is possible over short distances reaching few dozens of meters.
The crucial factors determining the accuracy of position reconstruction are good calibration of the sensors, proper offset compensation and undisturbed information on initial conditions (vehicle's velocity vector and position). It was checked that the noise of the sensors is not a foreground component determining the accuracy. The requirements regarding the noise are easy to fulfill using modern MEMS-type sensors.
The simulations have shown that lowest errors are achievable for short times, i.e. for short track lengths and high velocities. However, some issues concerning the sample rate of the sensors may influence the accuracy for very rapid movements. Proper data interpolation may partly compensate this effect, but it will never be fully eliminated.

One must take into account the limitations of the simulations. First, all of them were performed using the same track shape – half-sine. Second, the used model is only two-dimensional, while vehicle tilting may require 3-dimensional reconstruction in real applications.
The aforementioned restrictions are not an effect of limited capabilities of the developed simulation engine. They were introduced intentionally to reduce the number of possible combinations of factors influencing the results. We believe that, for such a generic research, clear representation of the results is more important that covering the full area of possible input parameters. The obtained results should be representative and easily extendable over different track geometries and switching to a 3-dimensional model should cause only moderate accuracy degradation.

The tests reported herein were carried out and their results were analysed within an authors' own research project No. N N509 568439.

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HOW IS ASTAZERO DESIGNED AND EQUIPPED FOR ACTIVE SAFETY TESTING?

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ABSTRACT

The Swedish test track AstaZero (Active Safety Test Area) is an open environment where vehicle OEMs, tier one suppliers, research institutes, and universities can come to perform development and research. AstaZero is located just outside the city of Borås in West Sweden and was inaugurated in August 2014. The initiative was taken to create an environment for innovation, testing, and research to develop new active safety functions for road vehicles. The four main environments of the facility are built especially for research and development of active safety functions. A city area for simulation of urban traffic, a multilane road, a 5.7 km long rural road, and an innovative high-speed area facilitate efficient testing. Equipment of different kinds is also at hand; test targets, position measurement and control systems, communication equipment, and driving simulators can be provided. However, the success of the AstaZero test bed is also depending on the existence of leading competence. The Swedish automotive cluster has the ability to perform research, industrial development, and rational production of road vehicles. It is essential for AstaZero to have access to strong competence in its vicinity. The organizations residing in the Gothenburg region can be reached in an hour by car. The Stockholm region is more distant but it is quite possible to travel by road in four hours. The success of AstaZero is built on the track, the competence, and all the partners supporting the facility.

INTRODUCTION

Road safety has improved during the past years, but we are still far from the zero vision that no one should be killed or seriously injured in road traffic. The European Union has set ambitious goals for road safety. According to the 2011-2020 policy the objective is that member countries must together have reduced the number of road accidents by 50 per cent by the year 2020 [1]. Active safety, as well as test facilities where new techniques can be tested, will play an important part in the contribution of making this vision reality.

Active safety functions are regarded as key components to further increase safety on our roads. Due to safety and repeatability requirements, much of the development and research of these functions must be performed in a controlled environment such as a test track. For novel active safety functions many tests cannot be made in real traffic due to the risks of prototype malfunction. In terms of infrastructure, targets and their propulsion systems, as well as measurement systems, what resources are needed to evaluate the performance of active safety functions?

The AstaZero (active safety test area) [2] located just outside the city of Borås in West Sweden was inaugurated in August 2014. The initiative was taken to create an environment for innovation, testing and research to develop new active safety functions for road vehicles. The active safety functions are under rapid development and there are presently, and in contrast to passive safety, few generally accepted testing procedures in place. Performance testing methods for active safety are necessary to improve the safety performance of new safety functions in road vehicles. Suitable test procedures are key enablers. The tests must be repeatable and the results must be relevant to the safety benefits in real traffic. There is still much development and standardisation to be done for test procedures.

AstaZero is an open environment where industry (vehicle OEMs and tier one suppliers) and academia (institutes and universities) can come and perform development and research.

TEST TRACK

The AstaZero has been designed with four main environments. (Figure 1) There is a city area for simulation of urban traffic. Highway scenarios can be simulated at the multilane road. A 5.7 km long rural road is included for monotonous driving with sudden obstacles. Dynamics and fast scenarios can be tested using the high-speed area with acceleration stretches.

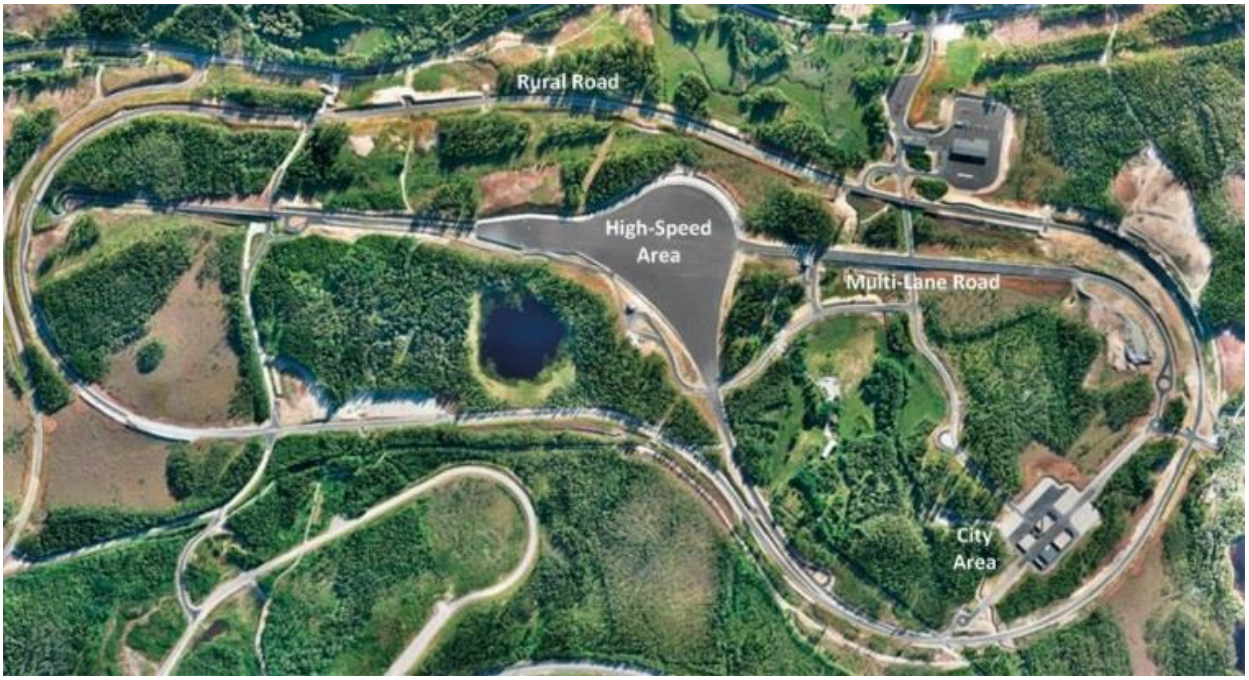

Figure 1. Overview of the AstaZero facility.

All paved surfaces are designed for 60 tons maximum vehicle weight and a 13 ton axel load. This will allow for researching scenarios where trucks with heavy load take part. A maximum vehicle length of 25.25 meters is planned. All internal roads have a width of 7 meters. They are designed for bi-directional traffic driving at the right-hand side of the road. There will be special areas for calibration made out of concrete. The calibration areas are 3 by 15 meters with flatness better than 0.1 degrees in all directions.

The Rural Road

The rural road encircles the facility. It is approximately 5.7 km long. Half of it is designed for travelling at maximum 70 km/h and to other half for maximum 90 km/h. The rural road is specially designed for different tests of driver behavior and is well-suited for the use of hidden or suddenly appearing obstacles. In several places there are scrubs or bushes growing near the road, which make it possible to conceal obstacles before they cross the road in front of the test vehicles. There are also two T-junctions and a crossroad that will be treated as real junctions changeable to suit customer requirements. The rural road will also have bus stops/lay-bys at two locations.

The road is not designed for advanced driving at high speed. It may be used for bi-directional traffic, but the normal setup is one-way traffic driving on the right-hand side of the road. There are some hills at the road, but the maximum incline is 4.5%. Initial feedback from users confirms that the rural road feels and looks like a conventional road and that “it is easy to forget that you are on a proving ground”. Communication links via optical fibers are prepared around the track, and it is ready to be populated with road-side units for ITS-applications.

Figure 2. Emergency vehicle driver and platooning research on the rural road

The High-Speed Area

The high-speed area is located at the center of the AstaZero facility. It consists of a circular area with drop-shaped entrances. The circle is 240 meters in diameter and has two acceleration roads. The main acceleration road is approximately 1 kilometer long. This will provide sufficient distance also for accelerating heavy trucks. In addition to the two acceleration roads, it is also possible to use the multilane road for acceleration. As a consequence, vehicles can enter the high-speed area from three different directions.

In this area, focus will primarily be on vehicle dynamics like avoidance maneuvers at very high speeds, but also "near misses" for active safety systems at high speeds. A large open asphalt area like the high-speed area is also useful for cases when virtual reality is combined with driving a real car.

The high-speed area slopes 1% in the lateral direction, but is completely flat in the longitudinal direction, (flatness 1.0 acc. to IRI). Asphalt is provided according to the specification SN75-80. There is a turning loop for long vehicles (25.25m) at the end of the acceleration road and halfway. It has a width of 7 meters. A calibration area is provided at the first turning loop (for gyros).

A separate control tower is overlooking the area. The tower is two stories high for good visibility, and it provides a platform on the roof for visitors. Remote control of targets, balloon cars and driving robots will be performed from the control tower.

Figure 3. Virtual reality and trailer ESC tests on the high-speed area

The City Area

The city area is located in the southern part of the facility and is connected to the rural road at two places. It consists of 4 building blocks (40 x 25 x 4 m), but there are plans to supplement it with additional five blocks. The city area will primarily be used to test the vehicle's capacity to interact with the surrounding environment. Test scenarios will include avoidance of collision with buses, cyclists, pedestrians or other road users. Streets have a 2.0% incline for good drainage into sewage drains. There are acceleration roads, longer than 150 m, before the intersection. The main street equipped with "portals" with traffic signs. The area therefore covers a number of different sub-areas, such as a town center with varying street widths and lanes, bus stops, pavements, bike lanes, street lighting and building backdrops. The city area also has a road system with different kinds of test environments such as roundabouts, T-junction, return loop and lab area (100x30 m). One block contains the control room and warehouse for dummies.

Figure 4. Aerial and entrance view of the city area

The Multilane Road

The Multilane Road is 700 meters long and consists of four lanes. These are connected to the high-speed area, and have an acceleration road that is approximately 300 meters long, 7 meters wide, and a turning loop for long vehicles. Several different scenarios can be tested on the multilane road, such as lane changes and departures, different collision scenarios, as well as crossing scenarios. For example, it will be possible to change the direction of travel in different lanes, as well as to build a temporary central barrier and different types of traffic barrier railings. The road has a 2 % lateral incline for good drainage, split between lane 1 and 2. There is a small intersection with the possibility to create intersection scenarios.

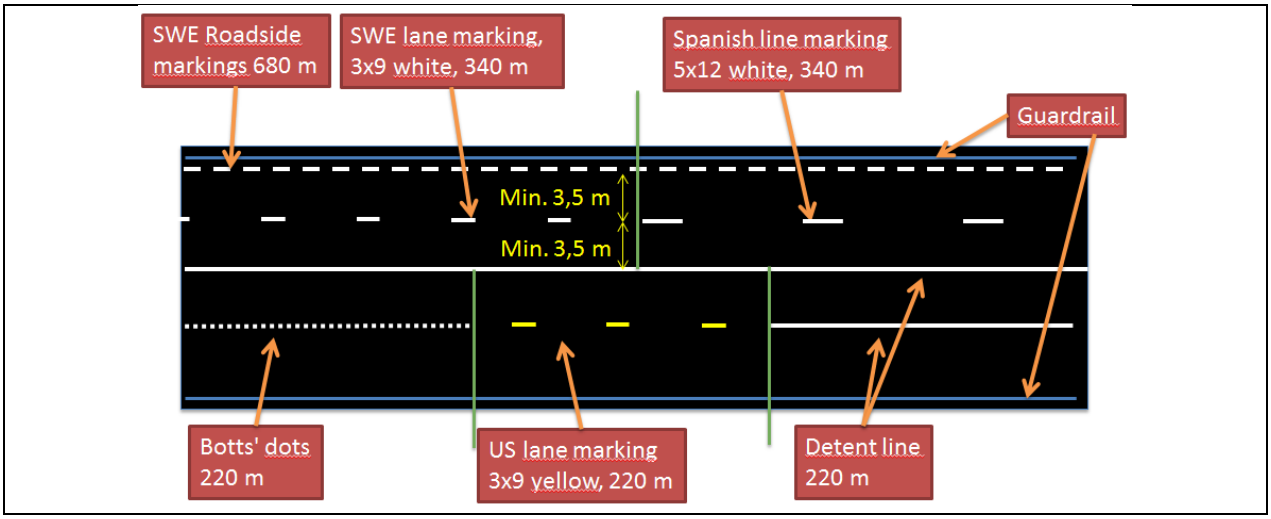

Figure 5. Lane markings available on the multi-lane road

EQUIPMENT

Equipment of different kinds is needed to successfully perform development and research at a test track. Among these are: test targets to be used in different traffic scenarios, equipment for position measurement and control, communication test equipment, data acquisition, and simulation capabilities.

Researchers and engineers visiting the AstaZero facility expect the tests to be repeatable with a high degree of accuracy and efficiency. It is expected that the equipment will be reliable enough to provide a very high availability of the test environment. There are clear requirements for productivity and through-put also at a test track.

All equipment, including the test targets, has to be properly maintained and periodically calibrated. So far, no international practice for calibration of test targets has been established.

Test Targets

The four main environments of the track are well suited to provide for many different traffic scenarios. But many traffic scenarios will also require other vehicles to be present. Safety precautions will in many scenarios require the use of test targets instead of real vehicles. Test targets are needed for cars, trucks, buses, pedestrians, bicycles and powered two-wheelers.

Test targets representing cars have been developed for rear-end collision scenarios [3,4,5]. Such a target must have a high fidelity of being perceived as a car both by the driver and by the sensor systems (radar, lidar, and/or camera) of the vehicle under test. At the same time, it must be possible to crash into without safety risks. The development of test targets for cars is towards correct representation of a car in all viewing angels, not only from the rear. Existing “balloon cars” have a three-dimensional structure, but do not provide a true 360 degree impression of the car. “360-targets” are under development and expected to be needed in future research and development.

Usually these car targets are towed or carried by a self-propelled flat platform such as the UFO [6] or LPRV [7]. However, being overrun by a heavy truck with full braking is a challenge for the platform-based solutions. It is also important to remember that the sensors on trucks could be placed in such a way that they “look down” at other road users which affect the design of targets.

Position Measurement and Control

Testing of vehicles in traffic scenarios requires the possibility to measure and control the position with high accuracy. The accuracy possible to reach varies depending on the type of scenario, especially the speed of the vehicles involved, but ±20 mm is a state-of-the-art accuracy often mentioned. AstaZero is equipped with an RTK GPS base station which covers the entire test area. State-of-the-art GPS equipment is available as well as driving robots for driverless testing [8].

With the advent of automatically driven vehicles there will be a need for more complex traffic scenarios involving many road users. Here it will be necessary with interoperability between driving robots, target platforms, and overall scenario control. Standardized open communication interfaces will thus be needed. The trajectories of all targets and the test vehicle need to be synchronized, and the positioning of each actor needs to be sufficiently accurate. This calls for cost-efficient positioning based on local anchors and/or intelligent data fusion. In areas with poor GNSS reception, it might be necessary to augment the GNSS-based systems with a ground-based one [9].

Controlling test vehicles at high speed implies both safety risks for test engineers on the test track and the risk to severely damage expensive and unique prototype vehicles. All risks must be observed and the control system must be designed to provide adequate functional safety, i.e. to reduce all risks associated with malfunctioning of the control system to an acceptable level.

Vehicle Communication Testing

Communication between vehicles (”V2V”) and communication between vehicles and the infrastructure (“V2I”) will soon be offered in cars, trucks, and buses, The wireless communication facility will help to exchange data for safety applications, autonomous driving, traffic management and other applications. Communication facilities have to be offered by AstaZero.

The ETSI G5 standard defines a Basic Set of Application (BSA) for cooperative ITS. These applications are associated to a different number of use cases. Application classes have also been defined showing the potential of cooperative ITS for active safety as well as for efficiency and mobility. Among active road safety applications, three main blocks are also being defined by ETSI which group different applications: Road Hazard Signaling, Longitudinal Collision Risk Warning and Intersection Collision Risk Warning.

Communication nodes for application at AstaZero are under development. AstaZero has to be flexible and adopt the communication units since the test track will be used by several suppliers and vehicle OEMs.

Test Data

During product development testing a lot of test data is generated, especially raw data from sensors. Large amount of video data is not uncommon. In many cases the data collection is not centralized and integrated. Instead data is collected in different devices and tiresome post processing is needed to aggregate and align test data which in the worst case is out-of-sync. A secure and centralized data repository which collects test data in almost real-time could significantly improve the efficiency of proving ground testing.

The test track is used by several research groups and many companies. All partners need to know that the data collected from their test sessions is accessible only to them. Proper measures for IT security are deployed to ensure confidentiality of the data. Also the integrity of data and the availability of recorded data can be assured.

Analysis of the executed traffic scenarios will as good as always be performed off-line when the test is completed. Test data from several data loggers is synchronized and stored. One issue to handle is when data formats differ between the loggers used.

Simulating the Test Track

The use of the test track is considered as one of the tools to develop the automotive technology of the future. Research and development may start by simulation at a computer and then continue by simulation in a driving simulator. Vehicles will be driven at the test track and later in real traffic environments. Several tools will be needed to provide efficient research and development.

AstaZero has developed a model of the track to be used in driving simulators. The researchers and engineers have the possibility to try the test scenarios in a simulator before driving at the real test track. (Figure 6.) This will make it easier to plan the tests and run the most essential test cases on the track.

There is also a high-resolution three-dimensional model of the track which has been realized by on-site scanning of the four main environments. This precision model may be used for further enhancements of the driving simulations and planning of the test.

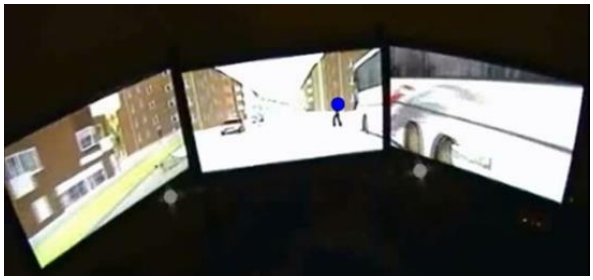

Figure 6. Ambulance drivers have trained at AstaZero both by driving on the track and in a desktop simulator

COMPETENCE AND RESEARCH

A Competence Cluster

A successful environment for automotive research and development certainly requires tools and equipment. In addition, the competence and the knowledge of the domain will be equally important. The Swedish automotive cluster has the ability to perform research, industrial development and rational production of road vehicles. The two major truck manufacturers Scania and Volvo Truck are together with the car manufacturer Volvo Cars the best known vehicle companies. There are also suppliers of world-leading reputation such as Autoliv. Research institutes offer possibilities for applied research together with all these industries, but also attract technology from small and medium sized enterprises (SMEs) in the automotive cluster. Several universities educate engineers for the automotive industry and provide automotive research together with European and international partners.

It is essential for AstaZero to have access to strong competence in its vicinity. The organizations residing in the Gothenburg region can be reached in an hour by car. The Stockholm region is more distant but it is quite possible to travel by road in four hours.

SAFER Vehicle and Traffic Safety Centre at Chalmers is a joint research unit where 30 partners from the Swedish automotive industry, academia, and authorities cooperate to make a center of excellence within the field of vehicle and traffic safety. The cooperation with authorities and local government is also essential for the development of AstaZero as a complete environment for automotive development and research.

The success of AstaZero is built on the track, the competence, and all the partners supporting the facility.

Research to Develop Testing

Test and development of novel technology requires state-of-the-art test methods and equipment. AstaZero is cooperating with research institutes, universities, and industry to develop both equipment and ways of working.

Future road transport will be different from what we are used to today. The global urbanization and the aging population are two of the main factors driving the change. Perhaps the most important factor is to mitigate the consequences of the climate change. Reduction of the emission of greenhouse gases will require a change in the way we use the roads.

AstaZero must also be prepared to work with new types of road vehicles. Electric powertrains and hybridization has influenced the types of vehicles we find on our roads. Electrification and smart charging of electric vehicles will require facilities for test and demonstration.

Automatic and autonomous driving will require a lot of development effort. All autonomous functions will have to be carefully tested; at first in a controlled environment such as AstaZero and later in real traffic. Research to facilitate testing with optimized coverage of the shifting factors of the traffic environment is

important. It is also important to understand how much of the previously performed verification and validation that has to be repeated when a design is modified.

Sweden has a long tradition of supporting national research in vehicle technology and transport. The largest Swedish program for automotive research is called FFI - Strategic Vehicle Research and Innovation. This is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to three main goals: reducing the environmental impact of transport, reducing the number killed and injured in traffic, and strengthening international competitiveness.

Standardization

The automotive industry is depending on standardization. Standardization will reduce costs by making it possible to re-use solutions from one vehicle to another vehicle. Standardized features will enable drivers to easily drive vehicles of different type and manufacture. It will also make it possible for road vehicles to interact and use the same roads.

Passive safety testing has been developing up to a point where results are comparable between different test sites and different vehicles. Crash test dummies have been developed and test procedures to represent the important crash types have been agreed. Testing of active safety and road automation is far from this goal.

AstaZero is participating in the standardization work of ISO (the International Standardisation Organisation) as convener of the working group ISO/TC 22/WG 16 for Active Safety Test Equipment. Active safety and the related standardization subjects is of interest from both an ITS and a vehicle perspective. Both perspectives have to be considered when allocating the various aspects and work items. A first step in the standardization is expected two-dimensional vehicle targets and pedestrian targets. That may be followed by targets representing bicycles and other vehicles in a more three-dimensional way.

CONCLUSIONS

The AstaZero facility has been designed and constructed according to plan. Operation started in the summer of 2014. New users of the proving ground are coming to join the competence cluster. There are already partners using AstaZero on a regular basis; vehicle manufacturers, suppliers and researchers come to AstaZero.

Equipment has been gathered and is still developing through several projects by industrial users and researchers. Also the competence network of AstaZero is under rapid development. Seminars have been held with researchers and two special “AstaZero Researchers Day” have been organized to make the research community in Sweden and internationally aware of the possibilities offered.

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VIRTUAL EXPERIMENTAL ENVIRONMENT DESIGN of CAMERA-SENSOR-BASED LANE DETECTION SYSTEM

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ABSTRACT

Based on the application of software model building, virtual experiment can be conducted with vehicle model, road environment model and sensor model building to develop camera-sensor-based lane detection system in PreScan. These three types of models are connected and the virtual experimental environment is built. Sensor-extracted data are processed by Matlab/Simulink to acquire the accurate ground truth. Meanwhile, images from camera sensor are processed with standard size for further application. The virtual experimental environment design is the foundation for the analysis and comparison of ground true and camera-detected data, as well as for accuracy evaluation in system pre-development. In conclusion, the virtual experimental environment design can be used in camera-sensor-based lane detection system development and is a supplement to traditional system development.

INTRODUCTION

In recent years, with rapid development and comprehensive application of computer vision and image processing technology, more and more products about pilotless automobiles and Advanced Driver Assistance Systems (ADAS) are coming to the market.

Camera-sensor-based vision and image processing technology are suitable for application of trajectory recognition and tracking. A lot of scientific achievements have been already applied in the real world. For example, a six-wheeled autonomous off-road vehicle (called an Argo vehicle) was equipped with various sensors at the University of Waterloo. 3D objects on the road can be dectected by the sensor on the Argo vehicle [1]. In Highway Lane Change Assistant (HLCA) system which was designed by M.Ruder from BMBF in Germany, vision and radar sensors were combined to detect dangerous objects in the neighboring lanes [2]. The system which was applied to Lane Departure Warning was connected to computers with Controller Area Network (CAN) and controlled by CAN. AutoVue System from Iteris Inc was also applied to Lane Departure Warning. The system was controlled by an integrated unit which consisted of camera and computer [3]. Currently most research focuses on application and optimization of lane detection algorithm in ADAS and pilotless automobiles [4]. There are basically two major research focuses in algorithm development. One is trajectory recognition and tracking with Hough Transform and other related algorithm. The other is based on the existing lane marker models. Parameters of the lane markers are detected by camera and matched with models [5]. The suitable lane marker model will be selected, if the information of lane markers and the model is similar or identical.

With deeper and more intensive research in development and evaluation of camera-sensor-based driver assistance system, a new method is expected to ensure the effectiveness and efficiency of system development process [6]. Meanwhile, due to high cost and long term of field experiment, virtual experiment is suggested as a good support and supplement of traditional field experiment by R&D engineers. Thus, design and development of virtual experiment is a new research focus of camera-sensor-based driver assistance system development.

1 BACKGROUND

This paper focuses on virtual experimental environment of camera-sensor-based driver assistance system, especially lane detection systems, for instance, Lane Departure Warning (LDW), Lane Keeping Assist (LKA), Lane Centering Assist (LCA) etc. Camera-sensor-based driver assistance system aims to identify various types of lanes on different roads and help cars drive in the right lane [7].

Traditional evaluation method of camera-sensor-based driver assistance system development is to apply advanced data process technology such as VBOX or TRC to extract ground truth [8]. Taking VBOX for instance, it is a GPS based data acquisition system, which can extract the real-time location and dynamic parameters of the vehicle. Extracted data will be transmitted to computers without delay [9]. Meanwhile, VBOX can process image data of lanes from the camera and output the distance between the lane markers and the vehicle. By comparing this information with data from lane detection algorithm, the accuracy of the algorithm can be evaluated.

In the course of research and development in real life, a major problem of field experiment is that the system cannot be tested and evaluated exhaustively under every operating condition. Besides, the cost of traditional field experiment is relatively high. Thus, it is quite difficult to achieve the effectiveness of experiment. Under this circumstance, virtual experiment by software is regarded as a good supplement of traditional experiment. A vehicle dynamic model is needed to calculate dynamic parameters in camera-sensor-based driver assistance system virtual experiment. A standard road environment model along with weather and traffic condition is designed in the experiment. A camera sensor and a lane marker sensor should be also included to extract real-time image data and ground truth. In total, the vehicle model, road environment model and sensor models are mutually dependent and interacting.

The PreScan Software developed by TNO provides the possibility of design of the above three kinds of models under request of different parameters and conditions. PreScan is a physics-based simulation platform that is used for development of ADAS that are based on sensor technologies such as camera and GPS [10]. Meanwhile, PreScan can be connected with Matlab/Simulink for further data processing and calculation.

2 VIRTUAL EXPERIMENT MODELS

In order to design the virtual experimental environment of camera-sensor-based lane detection system, a vehicle model, a road environment model and sensor models should be set up in the related simulation software separately. The three types of models should work together so that the model can calculate vehicle dynamic data and the sensor can receive the signal of the road environment model at the same time. The vehicle dynamic model is primarily used to simulate the vehicle motion in reality, meanwhile the sensor is equipped on the vehicle, so the motion state of the vehicles can directly influence the signal received by the sensor. The road environment model, as one of the most important parts in this virtual experiment, is the source of the information collected by the sensor. This model should contain not only the information of national standards of roads, but also the driving route and the velocity of the vehicle.

2.1 Vehicle Model

In the test experiment of lane detection system vehicle model is basically focused on vehicle dimensions and dynamic model. Vehicle dimensions can affect the location of camera, while dynamic model is to calculate dynamic parameters. Audi A8, the software built-in dimension model, is chosen for the experiment as a dimension model in this paper. A suitable vehicle dynamic model can calculate real-time dynamic parameters for development and test of lane detection system. The Two-wheeled vehicle dynamic model is selected as a dynamic model, because there is no specific requirement for more sophisticated dynamic in the lane detection

system experiment. The Two-wheeled vehicle dynamic model will calculate longitudinal and lateral velocity and acceleration, as well as yaw angle and pitch angle etc. For instance, pitch angle of the vehicle is different at different accelerations. As figure 1 shows below, the right image is in the course of acceleration, while the left one shows vehicle without acceleration. It is obvious that the horizon in the right image is higher because of the different pitch angle under conditions of different accelerations.

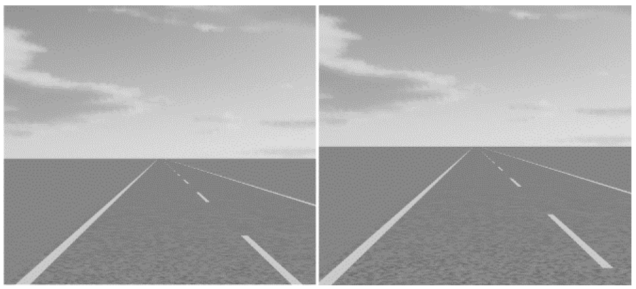

Figure1. Comparison of output images at different accelerations

It should be noted that, a customized, more sophisticated vehicle dynamic model can be called into PreScan if there is higher requirement for the virtual experimental environment.

2.2 Road Environment Model

2.2.1 Road model Lane detection systems are usually designed for expressways or other well-structured roads. Thus, the chosen road model in this paper is based on expressway model.

There are rigorous rules and regulations in Standard of Chinese Highway Route Design [11]. Direction of roads, as well as numbers and width of lanes are considered in the virtual experiment. Length, width and interval of lane markers and other related information is also important to the reality of the virtual road model.

According to the Standard of Chinese Highway Route Design, the radius of curves ranges from 250m to 1500m, and a total of 6 groups of bend road are designed. In order to test the fault tolerance of misstatement and omission of lane detection systems, missing lane markers are designed in the virtual experiment. In this paper the length of missing lane markers is 5m, 10m, 20m and 50m respectively. In addition, the color of lane markers, the luminance of lane markers, dashed/solid lane markers and bumpy/flat roads etc. can be defined as well.

2.2.2 Trajectory In the virtual experiment, the trajectory of the vehicle can be identified under specific request. However, due to the Two-wheeled vehicle dynamic model, the actual trajectories of the vehicle might be slightly different with the identified ones when vehicles change lanes or make a turn in the virtual experiment.

2.2.3 Vehicle velocity Vehicle velocity is essential to the result of virtual experiment. Since lane detection systems are mainly applied on expressways, the velocity is set at the range over 80km/h in the experiment. The performance of lane detection system is tested under different driving scenarios, including acceleration, deceleration, uniform motion and constant acceleration motion, etc.

2.3 Sensor Models

2.3.1 Camera sensor **A** camera sensor is one of the most important sensors in lane detection systems. All the extracted data are from the video images that captured by the camera sensor.

Parameters of the camera sensor can be set according to the specific sensor applied in traditional experiments, including location coordinates, range of sight, focal length, resolution of the output images, the video frames and the bit rate and so on. In this paper the frequency of the camera sensor is set as 25 Hz, that is, the video frame of the output images is 25.

2.3.2 Lane marker sensor Besides camera sensor, a lane marker sensor is quite necessary to extract accurate and real-time ground truth in the virtual experiment. The lane marker sensor is a built-in virtual sensor. It can provide the accurate information of the lane markers. The specific form of the lane marker information is the absolute coordinates of intersection between the center line of the lane marker and the sensor scanning line, as well as the distance from the intersection to the sensor. The accuracy of the data is 0.01m. According to the sensor settings, it can detect and record 3 points of the intersections at most each time. The frequency of the lane marker sensor is identical to the camera sensor, which is 25 Hz. In order to facilitate data processing and calculation afterwards, the lane marker sensor is located at the center position of the rear axle.

2.4 Build of Virtual Experiment Models

After setting the parameters of the above three types of models, different models can be connected and built in the Matlab/Simulink and the parameters of connections which are shown in Figure 2 can be further set according to specific requirements.

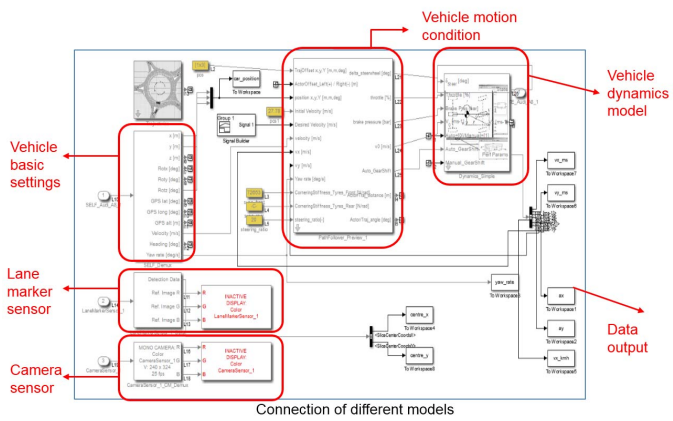

Figure2. Connections and control strategy diagram of lane detection system

3 DATA PROCESSING

In order to facilitate simulation data processing for the subsequent Software or Hardware in the Loop (SiL or HiL), the output data should be real-time data of ground truth and vehicle dynamic based on every video frame. These data can be regarded as the accurate vehicle dynamic and ground truth in the experimental environment. The results come from camera video image processing can be validated by comparing with the accurate data mentioned above.

3.1 Lane Marker Model

This paper only introduces two-dimensional lane marker models. Two-dimensional lane marker models can be divided into straight lane marker model, curve lane marker model and combined model, etc. A combined model of lane marker is chosen in this paper. At certain time, the lane marker model function below can describe the lane marker ahead [12].

$$y(x) = y_0 + \tan(\varepsilon)\,x + \frac{C_0}{2}x^2 + \frac{C_1}{6}x^3 \qquad \textbf{(1)}$$

Where,

y_0 : the distance from the center line of lane marker to the center of the rear axle

ε : the angle between travel direction of vehicle and the lane marker

C_0, C_1 : coefficients

The origin of the coordinate system is the center of the rear axle as shown in Figure 3.

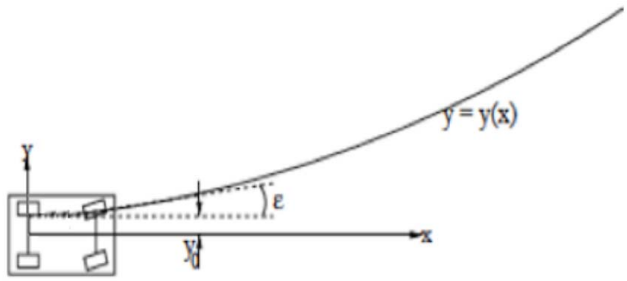

Figure3. Sketch of the lane marker model and vehicle-rear-axle-based coordinate system

3.2 Ground Truth Data Processing

In order to determine the coefficients of the lane marker model, points on the lane marker should be recorded for data fitting as many as possible at every moment. However, the lane marker sensor can detect and record only 3 points of the intersections at most each time and data are based on absolute coordinate system.

Under this circumstance, two tasks should be completed to determine the coefficients of function (1). The first task is to extract as many points as possible. The lane marker sensor is required to cover 100m lane marker ahead and extract about 1000 points in total each time, which means the points are extracted about every 0.1m on average. As a result, the vehicle should run two times in the virtual experiment.

For the first time the vehicle runs at the velocity of 2.5m/s (about 9 km/h) from the beginning of the lane to the end, by which the points on the lane marker can be extracted. The extracted data are in the absolute coordinate system. Because the frequency of the lane marker sensor is 25Hz and the velocity of the vehicle is 2.5m/s, the points can be extracted every 0.1m on the road. It can meet the requirements of data density which mentioned above.

For the second time the vehicle runs at the previous set velocity and follows the set trajectory on the road. The real-time vehicle-rear-axle-GPS data, as well as the vehicle dynamic data such as velocity, yaw rate, pitch, etc. can be extracted by PreScan. As the frequency of camera video is 25Hz, the absolute coordinate of the vehicle rear axle on each image can be known by reading the GPS data.

The second task is to transform the absolute coordinates to vehicle-rear-axle-based coordinates and determine the coefficients of function (1). The following data processing procedure is used to complete the second task:

Step 1. Coordinate transformation. The data of points on the lane marker should be transformed into the real-time vehicle-rear-axle-based coordinate system by applying the two-dimensional coordinate transformation formula.

Step 2. Data selection. All the points on the lane marker are extracted at the first time of the vehicle motion. In order to extract the points within about 100m ahead, the distance from the vehicle rear axle to the farthest points should be a little more than 100m.

Step 3. Determination of the coefficients. All the selected data should be stored by cell function. With the help of Polyfit function in data fitting tool box in Matlab, the coefficients of function (1) can be fitted. In this way, the accurate real-time ground truth can be acquired based on every frame of the camera video images.

Taking one of the lane markers on the curve road as an instance, the fitting results of these 1021 points are in the following.

$$\begin{cases} y_0 = 5.6356 \\ \varepsilon = 0.0015 \\ C_0 = -0.0044 \\ C_1 = -2.128E-05 \end{cases}$$

The fitted curve whose standard deviation is 0.0117 is shown in Figure 4.

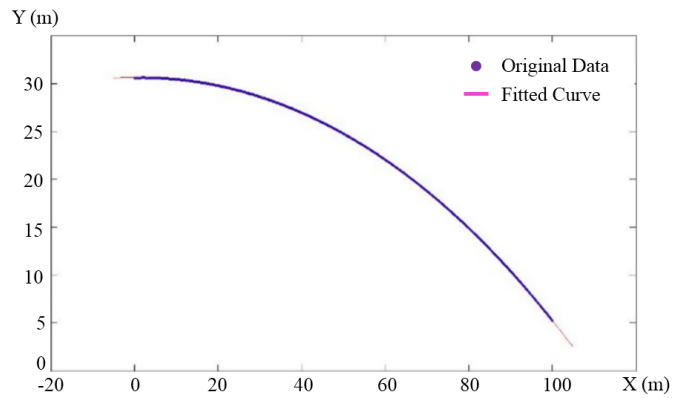

Figure4. Scatter and fitted curve of the curved lane (t=48.25s)

3.3 Video Images Output

Besides the data extracting and data processing, the video images from camera sensor should also be output and processed. In order to prepare for application of algorithm verification, the output images should be scale and processed to fitting size by batch processing in Matlab. The suitable image recognition algorithm, such as Hough Transform, is applied to extract the information of the lane markers on the image. By comparing the coefficients of function (1) determined by the image recognition algorithm with the above mentioned coefficients, the accuracy of the lane marker fitting algorithm in the virtual experimental environment can be identified.

CONCLUSIONS AND DISCUSSIONS

The design of virtual experiment for lane detection system can simulate the vehicle model, road environment and camera and lane marker sensors in PreScan. With the help of virtual experiment, vehicles, roads and

sensors in different conditions can be designed and tested in short time. The cost can be much less than field experiment and the efficiency can be much higher. The accurate ground truth of the road and vehicle dynamic data can be acquired by running of the virtual experiment and the data processing.

In conclusion, the virtual experimental environment design and development can be used in camera-sensor-based lane detection system development and is a supplement to traditional system development.

However, this paper only introduces the design of basic road models of straight and curve road with a two-dimension combined lane marker model. More types of road models should be considered in further study, such as spiral road model and bumpy road model. Thus, a three-dimension lane marker model is required to acquire the accurate ground truth. In addition, complex traffic conditions, as well as different lighting conditions and weather conditions can also be added in the further study of virtual experiment design.

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PARKING CRASHES: THE RATIONALE FOR ACTION AND THE DEVELOPMENT OF TEST PROCEDURES

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Paper Number 15-0348

INTRODUCTION

During the last decade parking and manoeuvring accidents appear to be increasingly relevant in third party damage liability and first party or motor own damage claims; a trend evident in many countries around the world. At the same time, vehicle manufacturers have offered a rapidly increasing variety of advanced driver assist systems such that there is greater scope for the avoidance of collisions than ever before. The low speed nature of parking and manoeuvring crashes strongly suggests that this problem should be solvable using technologies similar to those already used in other applications. In fact, several systems directly influencing parking crashes already exist, including proximity based warning systems, systems that will detect parking spaces and park semi-automatically and automatic braking systems similar to AEB that function in reverse.

This paper aims to assess the scale of the problem with low speed manoevring crashes, identify the most common collision mechanisms, assess the potential of the different technologies to solve the problem and to describe the development of test procedures capable of characterising system performance in relation to real world crashes.

CHARACTERISING PARKING CRASHES

Objectives

The objective of this element of the work was to quantify the scale of parking crashes around the world in terms of their frequency and cost and to investigate the common crash mechanisms such that a detailed understanding could be developed of what would be required of a really effective avoidance system for such crashes.

Methods

Several Members of the RCAR network of insurance research centres analysed their individual data sets in order to answer the questions set out in the objectives. Crashes are classified differently in each data set but wherever possible the data have been compared on a consistent basis. The data sets included:

- Thatcham Research, UK: Analysis of 12,565 claims from a First Notification of Loss (FNOL) dataset involving collisions occurring in the UK in 2010. The data includes 1st and 3rd party claims, of which 7,687 (61%) are 1st party and single vehicle at fault cases. Crash categorisation was based on text analytics studies of collision descriptions.
- Allianz Centre for Technology, Germany: Analysis of 1,000 Third Party Liability (TPL) claims with material damage only and 983 Motor own Damage (MoD) claims from collisions occurring in Germany in 2011.
- German Insurers Accident Research (UDV), Germany: 345 Third Party Liability (TPL) claims with material damage and 219 Motor own Damage (MoD) claims with collisions only in Germany in 2004 to 2006 and 2012.

- Insurance Institute for Highway Safety, US: IIHS based their analysis on a retrospective analysis of data accumulated through a survey of 509 vehicles brought to drive-in insurance claims centers in the Washington D.C. metropolitan area in 2001 to 2002. The study examined the types and amounts of vehicle damage sustained in relatively minor front and rear crashes.
- Korea Insurance Development Institute, South Korea: 45,153 Third Party Liability claims (bodily injury & property damage) from 2007 to 2012 in Korea; Analysis was based on automatic extraction of parking related claims by using keywords such as 'parking' and 'reversing' etc.
- Jiken Centre, Japan: Analyses of insurance payment data from 2011.
- Insurance Australia Group, Australia: Data from in excess of 1million 1st and 3rd party insurance claims from 2010 to 2014 in Australia. Analysis was based on automatic extraction of parking related claims by using keywords such as 'parking' and 'reversing' etc.

Results

Despite the differences in data classification and analytical techniques used by the various RCAR partners in their independent analyses, the findings were remarkably consistent in the UK, Germany, US, Australia, Korea and Japan. Based on these analysis it can be confidently concluded that crashes while parking and manoeuvring at low speed:

- Represent a high proportion of all claims frequency, representing between approximately 15% and 40% of all claims;
- Are responsible for a large proportion (10% to 30%) of all motor insurance claims costs;
- Mostly (60% to 80 % of parking claims) result from reversing manoeuvres;
- Mainly involve collision with 3rd party vehicles (approximately 55% to 80%), poles and walls;
- Typically occur in car parks, and on private property and urban roads.

The findings above are valid internationally. More details were available in some of the individual national data sets. Although these cannot be strictly considered to be internationally valid, the high level of agreement where comparable data is available suggests that there is a good chance that results will be similar in other countries.

Analysis of the German data by Allianz and UDV shows that the main problem is not entering a parking space, but moving out of a parking space and manoeuvring (70% to 85%). Analysis of the UK data by Thatcham showed a comprehensive breakdown of the types of collision, as shown in **Table 1** below.

Table 1: Distribution of UK parking crashes by 1st party manoeuvre and collision object

All cases 1836 100%	Forward 382 21%	Parked vehicle 174 9%	Pole-like object 89 5%	Barrier/wall 87 5%
		Moving vehicle 6 0%	Pedestrian 0 0%	Low object 17 1%
		Motorcycle 1 0%	Cyclist 3 0%	Unknown 5 0%
	Reverse 1277 70%	Parked vehicle 828 45%	Pole-like object 199 11%	Barrier/wall 156 8%
		Moving vehicle 48 3%	Pedestrian 2 0%	Low object 26 1%
		Motorcycle 13 1%	Cyclist 0 0%	Unknown 5 0%
	Pedal misapplication 14 1%	Parked vehicle 6 0%	Pole-like object 1 0%	Barrier/wall 7 0%
	Unknown 163 9%	Parked vehicle 66 4%	Pole-like object 51 3%	Barrier/wall 39 2%
		Motorcycle 1 0%	Low object 5 0%	Unknown 1 0%

In addition to this, the Thatcham analysis was able to identify the areas of damage on the vehicle more specifically for the main crash types:

- Cases where the 1st party reverses and collides with another stationary vehicle (approx. 45% of all parking crashes)
    - 1st party damage predominantly to the rear corners (>80% of rear damage with known location)
    - 3rd party damage distributed between all corners and the sides of the vehicle
    - Central damage to the front or rear of the vehicle was infrequent for both 1st and 3rd party vehicles
- Cases where the 1st party reverses and collides with a "pole-like" object (approx 11% of all parking crashes)
    - 56% of damage is to the rear of the vehicle
    - 28% to the sides of the vehicle
    - 16% to the front of the vehicle
- Cases where the 1st party reverses and collides with a barrier or wall (8% of all parking crashes).
    - 61% of damage is to the rear of the vehicle, corner damage slightly more common than central or distributed damage
    - 16% to the sides of the vehicle
    - 16% to the front of the vehicle
    - 3% unknown

One substantial difference between the countries was in relation to reversing and collisions with pedestrians. As can be seen from **Table 1**, UK collisions where cars reversed into pedestrians were rare, representing just 0.1% of all parking crashes. The US data available does not directly quantify the total number of parking and

low speed manoeuvring crashes so it is not possible to produce a directly comparable percentage. However, it has been found (NHTSA, 2014) that on average there are 210 pedestrian fatalities as a result of "backover" accidents each year and a further 15,000 injuries. Of those killed, almost one third are children and just over a quarter are elderly adults of 70 years of age or more.

ASSESSING THE POTENTIAL EFFECTIVENESS OF PARKING SYSTEMS

Objectives

Having quantified the scale of the problem represented by parking crashes and characterised those crashes in a way that allows an understanding to be gained of what would be required to prevent them, the objective of this element of the work was to identify the different parking systems available and to try to quantify how effective they might be at preventing crashes.

Methods

A variety of different methods were used to try to provide the answers required to achieve the objectives:

- Consultation with vehicle manufacturers and a review of vehicle specification data was undertaken in order to identify available parking assistance systems. A comparison was undertaken of their specifications and functions as an initial indicator of their ability to prevent the common types of crashes identified;
- A literature search and, where possible, an analysis of RCAR members insurer data was undertaken in order to identify measurements of the effect of parking assist systems on insurance claims and these were reviewed;
- A short, subjective benchmarking study was undertaken to gain an initial overview of the capabilities of different vehicle technologies;
- A comprehensive and objective test procedure was developed and then used to assess the performance of one type of technology.

Results

Parking assistance availability and specification

The research showed that a wide variety of different driver support systems that could be classified as "parking assistance" were available. These have been grouped into the categories shown below:

- Parking sensors, or Park Distance Warning (PDW), provides proximity-based acoustic warnings to a driver during low speed manouvring and may also offer a visual display. This technology is widely available in the market and has been for many years, though it often remains an optional extra at additional cost or only available as standard on higher specification models.
- Rear view cameras: an in-vehicle screen shows the view from a camera mounted at the rear of the vehicle
- Surround view cameras: an in-vehicle screen shows a composite view derived from multiple cameras around the vehicle which shows a plan view of the vehicle and surrounding objects, sometimes combined with a direct rear view while reversing. Available on a few high specification models, such as Mercedes E and S class.
- Semi-automated parking: These systems can identify appropriate parking spaces and provide automated inputs to help manoeuver the vehicle into the space. System specification varies considerably, some will detect only parallel spaces, some both parallel and perpendicular, some will only steer and some will control steering, throttle and brake. Where systems do brake, this function is typically not active unless the semi-automated parking function is used. Many manufacturers now offer this type of system, usually as an option, including Mercedes, Volvo, Ford, and VW.

- Reverse auto-brake is similar to Autonomous Emergency Braking (AEB) for front-to-rear crashes. This technology detects potential crashes behind a reversing vehicle and automatically applies the brakes to slow or stop the vehicle thus mitigating or preventing the crash. Unlike the semi-automated parking systems, this system is always active unless de-activated by the driver. Only a small number of manufacturers offer this type of system, at the time of writing, understood to be Infinti, Mazda and Cadillac.
- Driverless parking: This is an autonomous valet parking function where the driver can leave the vehicle and use a phone app or other control to send the vehicle to find a parking space by itself and summon it again when needed. A small number of manufacturers have suggested this will become available on high specification models this year or next year.

Existing evidence of effectiveness

Although parking sensors, or Park Distance Warnings have been in production for a long time, there have been relatively few studies of their effectiveness. Since the introduction of rear view cameras there have been a few studies that have attempted to quantify the relative benefits of the different technologies experimentally by studying the responses of normal drivers with and without each technology when confronted by the unexpected presence of obstacles behind them while reversing. Kidd et al (2014) created an experiment where a child dummy was either positioned stationary, or moved into, the path of a reversing vehicle when the driver was not expecting it. It was found that when the child dummy was moving, most drivers (90%) avoided a collision even when they had no technology to support them and that there was no statistically significant difference to this when the drivers had any of the technologies available to them.

When the child dummy was stationary in the path of the vehicle, all of the drivers without technology collided with it. The addition of sensor systems giving a proximity warning reduced this very slightly to around 93% of drivers having a collision but this difference was not statistically significant. The use of a camera system reduced the incidence of collision to 56% and this was statistically significant. It was found that the effectiveness of the camera system was substantially reduced when the obstruction was in the shade. Counter intuitively, combining a sensor system with a rearview camera was found to be less effective than a camera alone. One explanation for this was that the participants looked at the in-vehicle screen less frequently when they also had the sensor system.

Although experimental studies of this are an extremely useful mechanism for predicting the potential of a system, operational factors such as the effects of shade, cited by Kidd et al (2014), as well as the possible effect of dirt on the camera lens etc., will affect the extent to which the systems are beneficial in real service. This can only really be measured by statistical comparison of collision or claims records of vehicles with and without the technology and, even then, the conclusions can be confounded by the wide range of interacting variables that affect crash frequency and severity. For example, the effect of a parking aid could be masked if parking aids were fitted only to vehicles with a very poor field of view or exaggerated if they were only selected as an option by very cautious and safe drivers. These factors can be hard to control for.

Statistical analysis of the effects on insurance claims of several parking systems has been undertaken for models of Toyota (Ydenius & Rizzi, undated) Mazda (HLDI, 2011a), Buick (HLDI, 2011b) and Mercedes (HLDI, 2012). The results of these analyses have been mixed:

- Ultrasonic parking sensors fitted to Toyota and Lexus Vehicles (model years 1999 to 2012) in Sweden were found to reduce the cost of damage while reversing by 27%;
- Ultrasonic parking sensors were found to be very effective for the Buick, reducing collision damage claims (insured vehicle) by 5% and property damage liability (typically 3rd party vehicle) claims by almost 17%. However, for the Mercedes version of the same system, the data suggested that collision claims were actually increased by 0.8% and property damage claims decreased by 1.8%, neither result being statistically significant;
- Rearview cameras fitted to Mercedes Vehicles were not found to have any statistically significant effect, while for Mazda vehicles they were found to produce a statistically significant 3.1% increase in collision claims and a non-significant 2.3% decrease in property damage liability claims;

- Semi-automated parking systems, in the form of the Mercedes Active Parking Assist system, was found to produce non-significant increases in claims frequency (6.3% collision, 5.0% PDL

It is not known whether the differences observed between experimental results and the various statistical analyses are the results of technical differences between systems, operational factors not replicated in the experimental environment, or confounding factors that could not be accounted for in the statistical analysis of claims rates. No effectiveness studies were identified that considered auto-brake systems for reversing.

Technology Benchmarking

An initial benchmarking exercise was undertaken by Thatcham in conjunction with Continental and Allianz. Three exemplary vehicles were selected, with a variety of technologies fitted, as defined below:

- Infiniti Q50
  - 360˚ Surround View
  - "Semi-guided" parking (scans for space and when driver selects a space provides the driver with instructions on movements and steering inputs required to get there)
  - Auto-brake while reversing
- Mercedes E Class
  - 360˚ Surround View
  - Semi-automated parking (steer, throttle and brake control, driver has to initiate system, initiate each movement and operate gear lever)
  - Auto-brake while semi-automated parking is in progress
- Skoda Octavia
  - Semi-automated parking (steering control automated, driver has to initiate system and operate accelerator, brake and gear lever)
  - Auto-brake while semi-automated parking is in progress

The tests undertaken were focused on the main needs identified by the data analysis rather than on a full exploration of the capabilities of different systems. As such, the test vehicle manoeuvres involved reversing in a straight line and reversing with full steering lock applied. The hazard objects considered were a stationary and moving vehicle target, a stationary and moving child pedestrian dummy, a traffic cone and a metal pole. The principle difference between the systems was that the Infiniti auto-brake system was always on, whereas for the Mercedes and Skoda it was active only when the semi-automated parking was activated. The claims data analysis reported in this paper showed that more than three-quarters of the reversing claims occurred when the vehicle was reversing out of a parking space, not reversing in. Neither of the semi-automated parking systems offer a function for reversing out of a space. While the presence of such a system may encourage more people to reverse into spaces, thus reducing the proportion that need to reverse out, the extent to which drivers will use the system in the long term is unknown. It is, therefore, likely that restricting the auto-brake function to only those times where the semi-automated parking is engaged will substantially reduce the potential benefit in the real world compared to a system that is "always on".

The main findings of the exercise have been summarized below:

- Infiniti Q50
  - Always on
  - Impressive performance with all static objects
  - Some reduced performance with moving objects, particularly a crossing pedestrian
  - No false positive with grass or small bush
  - Effective at reversing speeds of up to approximately 8 km/h
- Mercedes E class
  - Only active with semi-automated parking
  - Impressive performance with both stationary and moving targets
  - False positive tests led to additional manoeuvring and delay but final decision was always correct
  - Effective at all reversing speeds permitted by the active park assist.

- Skoda Octavia
    - Only active with semi-automated parking
    - Avoided less collisions with static objects than the other systems, smaller objects in particular
    - Further reductions in performance with moving objects
    - No false positive with grass or small bush
    - Effective at reversing speeds of up to around 4 km/h, though with some inconsistency.

Developing a parking test procedure

A comprehensive parking test procedure was designed, based on the results of the claims data analyses, the effectiveness studies and the initial benchmarking tests. The test scenarios defined were intended to cover the most frequent claims type, including a car reversing into another car and reversing into a post. In each of the scenarios, reversing straight and with full steering in either direction was considered as well as different overlaps, and different configurations of corner impact.

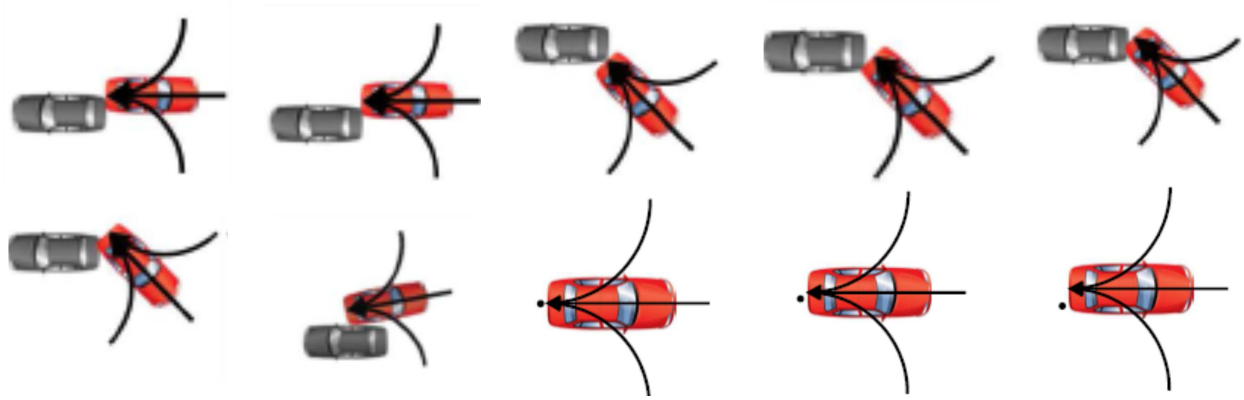


Figure 1: Illustration of the 30 different crash configurations defined.

For each of these configurations it was considered important to consider the ability of systems to detect and respond both at short range (c. 2m) and when approaches were at higher speed (c. 6 km/h). In practice, this is likely to be achieved by an approach procedure that constantly relies on moving away from rest, in reverse gear and using only engine idle speed (or small throttle in the case of hybrid/electric drivetrains). Thus the higher speed objective is achieved with the same vehicle inputs but just starting from further away from the object.

The tests were designed such that the correct impact configuration was achieved by positioning the vehicle at the impact point and applying the appropriate steering lock. The vehicle would then be moved slowly forward the prescribed distance and stopped. While maintaining the exact same steering input, the vehicle would then be reversed at engine idle speed.

For the tests, the collision objects need to be representative of real world collisions as far as the sensor systems are concerned, currently these are predominantly ultrasonic, camera or radar sensors. However, it also needs to be soft or collapsible so as not to cause damage to the test vehicle. For the initial vehicle-to-vehicle test configurations, the Euro NCAP Vehicle Target was defined. This represents the rear end of a vehicle and was designed to be representative for in-line crashes seen through the "eyes" of lidar, radar and camera sensors. It was considered likely to be effective for ultrasonic sensors, possibly OK for camera sensors but unlikely to be realistic for radar sensors when approached from an angle or with an offset. Further development of a three dimensional target is likely to be required before the test procedure could be reliably implemented in a technology neutral rating scheme.

The collisions with a "post" are actually intended to represent a broad range of collision objects found in the insurance claims data, including metal and plastic bollards, concrete posts, trees etc. A brief exercise was undertaken to measure a sample of 38 different "post-like" objects. It was found that heights ranged from 0.4m to 1m, with a median of 0.9m and the diameter ranged from 76mm to 275mm, with a median of 150mm. For

the purposes of the initial test programme a bespoke post was used, which was 110mm in diameter, 900mm tall and constructed from plastic drain fittings and ballasted with gravel.

Test results: Infiniti Q50 with Back-up Collision Intervention

The test results for the car to car scenarios are shown in **Figure 2**, below.

	Range							
Straight	1.0m	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
	2.0m	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
	3.0m	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
Left lock	10°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	No effect
	20°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
	30°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
Right lock	10°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	No effect
	20°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
	30°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	No effect

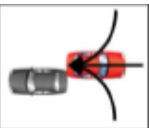
	Range							
Straight	6.0m	Avoid	Avoid	Avoid	Avoid	Mitigation	Avoid	Avoid
	8.0m	Mitigation	Avoid	Avoid	Avoid	Mitigation	Avoid	Mitigation
Left lock	60°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
	90°	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid	Avoid
Right lock	60°	Avoid	No effect	Avoid	Avoid	Mitigation	Mitigation	No effect
	90°	Avoid	No effect	Mitigation	Avoid	Mitigation	Mitigation	No effect

Figure 2: Car to Car Results of Short Range Tests (Top) and Higher Speed Tests (Bottom) for Infiniti Q50

It can be seen that performance is generally lower at the higher speeds and on the inside of the curve when turning. The performance in the tests against a bollard are shown below.

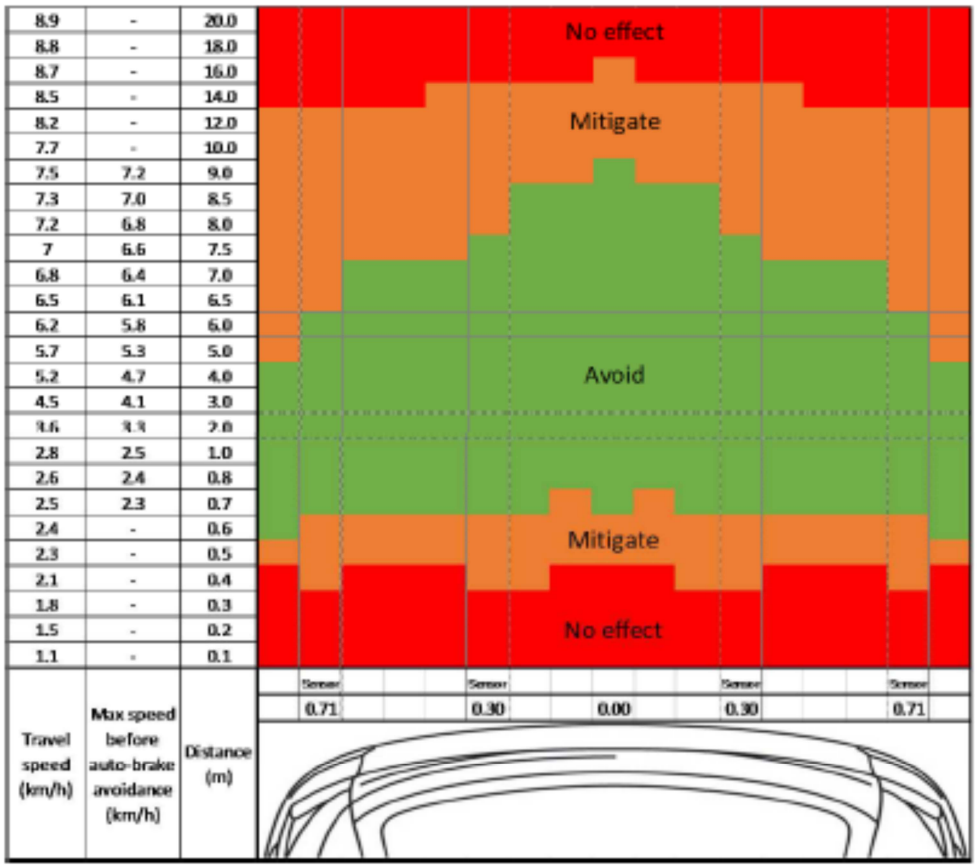


Figure 3: Results of straight line tests against a post.

It can be seen that performance was strong in the centre of the vehicle, avoiding collisions at up to around 7 km/h but that this dropped away slightly towards the corners of the vehicle (which is important because claims data shows the corners are frequently damaged). It is worth noting that the effectiveness is reduced or eliminated if starting from rest at very short distances to the collision partner.

One observational result of this range of tests was that when the auto-brake was activated and avoided a crash, the brake was only held on automatically for a period of around half a second and was then released. In the automatic vehicle to which this was fitted, this meant that the vehicle started to move backward again after a short period of time, if the driver had taken no action to brake themselves or place the vehicle in neutral. Subjectively, it was considered that some drivers, in real situations, may not react sufficiently quickly, potentially eroding some of the benefit.

DISCUSSION

The evidence shows that parking and low speed manoeuvring crashes represent a very substantial cost in terms of damage, representing up to 30% of all insurer claims cost. In some jurisdictions, they also represent a substantial cause of death and serious injury to some of the most vulnerable people in society, those aged less than 5 and more than 70. This does, therefore, represent a significant problem to solve.

A range of semi-automated parking systems are available but these are offered as a convenience feature and by focusing on assisting the driver to get into spaces, do not directly affect the mechanism (reversing out of parking spaces) that is responsible for the most claims. In addition to this, they rely on the driver deciding to use the system. It is not known how often drivers will choose to use the system in practice.

Technologies intended to more directly prevent or mitigate this type of crash have already been implemented. Simple proximity warnings have been widely available for many years and, in the US, rear view cameras have

been made mandatory for certain vehicle types. However, the evidence regarding their effectiveness is very mixed. Experimental studies suggest that camera systems will substantially reduce the incidence of reversing crashes but that proximity warnings do not (and lessen the effectiveness of cameras when used in combination). Statistical analyses of claims rates has found proximity warnings to be effective on some cars but not others and has found little evidence of the effectiveness of cameras.

There are a range of possible reasons for the mixed results, including the possibility that the effectiveness:

- relies on driver action to achieve its results;
- will be influenced by the way in which warnings are delivered;
- will be affected by the positioning and quality of screens, the cleanliness of camera lenses, and the external lighting conditions, where mixtures of light and shade can obscure objects.

Linking these detection systems automatically to the braking system such that the vehicle can be stopped without driver intervention would be expected to avoid many of these human factors difficulties and improve effectiveness. Such systems have been fitted to a very small range of vehicles and are similar to AEB systems. Although no post-hoc studies of effectiveness are yet available the analogous comparison that showed AEB systems were more effective than forward collision warning systems suggests that reverse auto-brakes should be an improvement on both cameras and sensors alone.

A comprehensive test programme has been developed to assess performance in situations that have been demonstrated to be highly relevant to real world insurance claims and it has been seen that one reverse auto-brake technology (Back-up Collision Intervention on the Infiniti Q50) proves highly effective in those tests. It is, therefore, considered that there is a compelling case for using this test programme as the basis of a scheme to incentivize the fitment of systems that perform well in situations representing real crashes. In order to achieve this, the test programme is likely to require:

- Rationalisation, to reduce the burden of testing while still promoting good performance
- Refinement to the methods to ensure accurate and repeatable results, in particular the methods for achieving consistent impact points.
- The development of a new car target providing an accurate, 3 dimensional visual and radar signature.

CONCLUSIONS

1. Parking and low speed manoeuvring crashes represent a significant cost to societies across the world, representing up to 30% of the cost of all insurance claims. Claims involving reversing out of parking spaces and colliding with other vehicles or fixed objects are the most common.
2. Existing measures to reduce the frequency of this type of crash show mixed results, with some promising signs of effectiveness but other evidence suggesting little evidence of effectiveness.
3. Many of the possible explanatory factors for the lower than expected effectiveness results are associated with human factors. These could be bypassed if the detection systems were linked to an autonomous braking function.
4. A handful of reversing auto-brake systems are already in production and tests undertaken during this research suggest they are capable of avoiding a large proportion of the the most common types of parking crash identified in the insurance data.
5. An initial test programme has been developed that is capable of assessing the performance of such systems in scenarios highly relevant to real world claims. Further refinements to this programme have been proposed to ensure it will be sufficiently robust to allow it to be implemented in suitable incentive schemes around the world.

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TECHNOLOGIES FOR THE PREVENTION OF RUN OFF ROAD AND LOW OVERLAP HEAD-ON COLLISIONS

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INTRODUCTION

A substantial number of serious collisions occur when a vehicle:

- Runs off the edge of the road way and collides with roadside furniture such as trees; and
- Crosses the centre line of the road and collides head-on with an oncoming vehicle.

A proportion of these are very likely to be caused by some form of inattention and/or distraction and several new technologies have been introduced into the market with the intention of preventing these crashes. Actions to promote the fitment of "lateral assist" systems are included within the Euro NCAP programme (Euro NCAP, 2014):

- Lane Keep Assist Test and Assesment Procedure for the 2016 rating scheme
- Advanced Lateral Support System Test and Assessment Procedure for 2018 rating scheme.

The aim of this research was to:

- Analyse the frequency and severity of relevant collisions in order to understand the potential impact of lateral control technologies
- Characterise crashes to inform the development of performance criteria that will be relevant to the real world
- Undertake initial research to explore the capability of different technologies
- Investigate the potential of candidate test procedures that could form part of future assessments.

LATERAL ASSIST TECHNOLOGIES

A wide range of lateral assist technologies have been developed and put into production since the beginning of the 21st century. These include blind spot monitoring systems but these have not been considered in-depth in this paper because they are intended to be of benefit in crashes that occur during deliberate lane changes rather than crashes that occur because of unintended departure from the lane or road. The main characteristics of the different types of technology are briefly reviewed below.

Lane Departure Warning

Lane Departure Warning (LDW) systems are now widely available on many production models, including high volume models. When the system detects that the vehicle has left the lane, or is just about to, without the activation of the direction indicator, then it provides a warning to the driver. Warning types have historically varied between different makes and models of vehicle (e.g. directional audible warnings, visual warnings on the multi-function display, steering wheel vibrations and even haptic seat vibrations) however at the time of writing warnings are generally converging to a visual multi-function display warning and/or haptic steering wheel vibration.

Lane Keep Assist

Lane Keep Assist (LKA) works on exactly the same principles as lane departure warning, except that when the system detects that the vehicle has left, or is leaving, the lane, a small heading correction is applied automatically in the form of steering torque or by differential braking in order to at least prevent further departure from the lane and, depending on exact circumstances, to re-direct the vehicle back into its lane. The intervention is deliberately kept relatively low such that it can be easily overcome by the driver, if they are deliberately changing lane and have simply forgotten to use the direction indicator.

Lane Keep Assist is now offered by many manufacturers, including Volvo, Volkswagen, Mercedes, Toyota, Subaru etc. but it tends to be offered on the higher end models.

Lane Centering Assist

Lane Centering Assist uses exactly the same technologies as a lane keeping assist. However, a lane keep assist only reacts to the vehicle passing over a road marking. Thus, in the absence of driver input it is possible that the vehicle would proceed along the road in a zig zag fashion "bouncing" from one lane boundary to the other. A lane centering system will autonomously apply steering inputs to keep the vehicle positioned as centrally in the lane as possible at all times.

This variation of the technology is less common than the systems based on crossing lane boundaries but Honda, Mercedes, Volkswagen and Infiniti have been early adopters of this strategy.

Autonomous Emergency Steer

All of the systems previously described react according to a relatively simple set of criteria, regardless of the extent of collision risk. If the speed is in excess of the threshold (typically 37 to 45 mile/h), a lane marking is detected and may be crossed, and the indicator is not activated, then the warning and/or corrective torque will be applied. Thus, the system will take the same action in normal driving with no other vehicles around, as it will in a critical incident where a head-on collision is imminent. The category of Autonomous Emergency Steer has been created to consider systems with two key differences:

- The activation criteria are combined with an assessment of the risk of collision. For example, if on a country road, in the absence of any other traffic, a driver takes a straight line path through a bend and cuts across the road centre marking, then the system may not activate at all, in other circumstances it may warn the driver but not intervene
- The range of actions available to the system is increased such that a relatively severe correctional steering input can be applied if a lane departure is detected and the sensors detect an imminent risk of collision with an overtaking or oncoming vehicle. While this could be applied via a higher steering torque, the first example of such a system used the electronic stability control system to generate the correcting moment via differential braking, with the added advantage that this also slows the vehicle down.

The aim of this system is to both reduce the chances of the system intruding on normal driving thus boosting driver acceptance and increase its effectiveness in terms of the ability to avoid critical incidents. This type of system has been introduced by Mercedes but, at the time of writing, was not known to have been introduced by other manufacturers.

Features common to different systems

Most lateral assist systems now use forward facing camera sensors to detect lane markings. It is therefore, a fundamental requirement of the system that lane markings are present and clearly visible. Effectiveness would be expected to be high on main highways and motorways where good quality markings are typically present. However, rural roads could be more challenging. For example, in the UK many rural roads may have only a centre line and not a road edge marking. Some systems can detect a road edge even without markings but the

accuracy and consistency of detection is thought to be lower, as is the level at which the system will intervene (e.g. warning only rather than corrective heading control).

In addition to this, some drivers have reported that false interventions of both warning and intervention systems. These can commonly occur where the vehicle crosses road features that appear somewhat like lane markings but are not. For example, where road works have taken place and temporary lane markings have been installed and then imperfectly removed.

The time at which warnings and interventions occur can vary considerably. For example, ISO 17361, permits a lane departure warning system to issue the warning at any point from when the vehicle remains 1.5m inside the lane boundary to a point where the vehicle is already 0.3m past the lane boundary. Given typical human reaction times, then the vehicle could be very significantly past the boundary by the time the driver reacts and the range of warning times would, therefore, be expected to substantially influence the overall effectiveness of the system.

CHARACTERISING LANE DEPARTURE CRASHES

The objective of this element of work was to understand the quantity of crashes that lane keeping technologies might have the potential to prevent and to characterise those crashes in order to inform the development of test procedures that would promote the design of systems with the best real-world effects. The analysis was based on:

- Analysis of 12,565 insurance claims from a First Notification of Loss (FNOL) dataset involving collisions occurring in the UK in 2010. The data includes 1st and 3rd party claims and crash categorisation was based on text analytics of collision descriptions.
- Analysis of crash data from the German In-Depth Accident Study (GIDAS).
- Review of published effectiveness studies

Analysis of the crash types found in UK insurance claims showed that in combination, single vehicle collisions and head on collision represented approximately 21% of both damage and personal injury claims (see **Figure 1**).

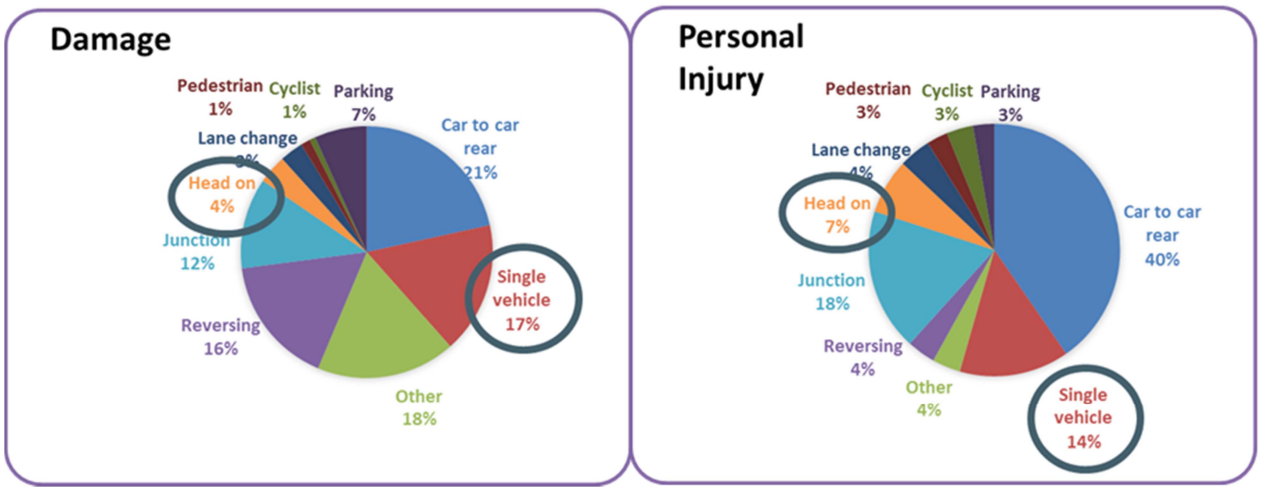

Figure 1: Crash Type Analysis, UK insurance claims 2010

Data provided to Thatcham from the GIDAS database characterised lane/road departure crashes as follows:

- Collision Mechanism
  - 44% straight road, 30% gentle left bend, 22% gentle right bend
  - 46% left departure, 40% right departure, 12% collision with other vehicle
  - Higher speeds typically 60-80km/h+

- Road Markings
  - 76% continuous white line, 12% dashed, 9% no marking
  - 72% well visible, 15% worn, 9% no marking
- Lighting & Weather conditions
  - 55% dry, 34% wet, 11% ice/snow
  - 61% daylight, 5% twilight, 34% darkness
  - 97% no fog
- Causation factors
  - Inattention
  - Fatigue
  - Failure to apply sufficient steering

It should be noted that this data is based on Germany. While this may well be representative of Europe in some respects, it may not be in all respects. Anecdotally, it would be expected that the presence, type and condition of road markings would be a feature that varied for road networks in different jurisdictions. Given that many lateral assist systems rely on cameras identifying road markings, this would be expected to have a strong influence on their overall effectiveness.

Concerns over roadmarkings notwithstanding, when combined with the data on the specification and intention of the technologies developed so far, the accident data suggests that there is strong potential for lateral assist systems to be effective. This is consistent with earlier predictive studies such as Visvikis et al (2008), which also showed strong potential (15% to 60% of lane departure crashes). However, the effects actually measured in terms of collision rates of vehicles with and without lane departure warnings have been much more ambiguous.

A US study (IIHS, 2012) found that lane departure warning systems fitted to Buick and Mercedes models were actually having a small adverse effect on claims rate for both collision (1st party) and property damage liability (3rd party) claims, although this was not statistically significant. A Volvo system appeared to be beneficial but the effect could not be separated from the fitment of a comprehensive AEB system for frontal crashes.

A more recent study (IIHS, 2014) has found that in combination a forward collision warning and lane departure warning has proved to be more effective than would have been expected based on earlier studies of both systems fitted to other vehicles. A reduction of 14% in the frequency of property damage liability claims was found, which compared to just 7% for earlier studies of forward collision warning systems. However, the effects of the FCW and LDW technologies could not be separated in the analysis of the Honda system so it remains unknown just how much the lane departure warning system has contributed to this benefit.

No studies have been identified that have yet attempted to measure the acutal claims reduction effect of a lane keeping system or other more advanced lateral assist system. Comparison of the typical results for forward collision warnings compared to autonomous braking systems suggests that the additional physical intervention should be beneficial but, as yet, this remains hypothetical.

CANDIDATE TEST PROCEDURES

Straight roads

The accident data suggests that a large proportion of lane departure crashes occur on straight roads. The type of crash most likely to be influenced by lateral assist systems is that where the driver is distracted, tired or otherwise impaired. The data suggests these crashes are characterised by relatively low lateral velocities (i.e. the vehicle leaves its lane relatively slowly.). Straight roads are thus likely to represent the simplest test procedure, and the circumstance where technology would be most capable. It is, thus considered that a straight road test would be well justified and will be the first scenario evaluated.

Any test procedure will need to define a series of standardised road markings, perhaps regionally adjusted, for which the system must be effective.

Curves

According to the data, an even larger proportion of lane departure crashes occur on gentle curves (c.52%). However, gentle bends could be interpreted as very large radius e.g. 300m plus. On these roads, the required sensor field of view and the rate of road departure (lateral velocity) may not be much greater than for straight roads. Conversely, executing tests may be more difficult because very large test areas could be required. Research tests will therefore focus on establishing whether testing on large radius curves is required by assessing whether it highlights any performance advantages or disadvantages of different lateral assist systems.

Testing on tighter bends represents a smaller proportion of all crashes, though potentially a higher proportion of severe crashes. It also represents a much greater technical challenge with much higher lateral velocities and much greater correctional steering inputs required to maintain the path. Investigation of small radius curves will therefore focus on the potential for systems to prevent this type of crash and the technical feasibility of developing appropriate tests.

Another consideration is how long lateral support should be continued for when negoatiating a curve and what mechanism should be employed to advise the driver of the support and the driving condition in which the vehicle should be left in if/when the support is terminated.

Sensitivity to hazards

One of the key factors distinghuishing between the systems described as lane keep (or lane centring) asssist and autonomous emergency steering is the ability to adapt the type or magnitude of autonomous intervention depending on the risk of collision. Thus, in order to distinghuish between such systems then tests on either straight roads or curves need to be repeated with and without the presence of a collision threat. For obvious safety and cost reasons the simulated collision risk must present minimal actual risk of equipment damage or injury.

The development of a suitable collision target for this type of testing has been the subject of much international discussion. There is an emerging concensus that the likely solution would be to define a harmonised world soft-car target which was an accurate 3D representation of a common world car in terms of radar, lidar, and visual signatures. Such a target also needs to be fully impactable at high relative speeds (100km/h+) without damaging the test vehicle. The target itself either needs to be a low cost, test consumable or it needs to be very durable such that it can be quickly re-built after impact, ready for the next test. The target could then sit on top of any low profile platform based delivery system that complied with an agreed set of performance criteria (e.g. radar signature, speed, acceleration capability etc.). Currently, a range of solutions have been proposed by various stakeholders, as illustrated in **Figure 2**, below.

Figure 2: Candidate car target and propulsion systems for testing lateral assist systems (ABD top left, 4A top right, DSD bottom left & Perrone bottom right)

INITIAL TEST RESULTS

Thatcham's initial test programme has focussed on assessing the capability of the Mercedes E Class, which is fitted with a system that corresponds with the earlier definition of Autonomous Emergency Steer (AES). The vehicle was equipped with path following robotic driving control to ensure repeatable testing. The test scenarios initially considered are based largely on the existing NHTSA standards for Lane Departure Warning confirmation on straight roads. The aim is to assess not only how the car responds to the different circumstances defined (e.g. solid lines, dashed lines, different lateral velocities etc) but also how the test procedure requires developing to allow more sophisticated systems to be fairly assessed.

For lane departure warning, the test procedure prescribes that the vehicle must simply pass through two geometrically defined "gates" that will create a lateral velocity within an acceptable range on approach to the lane boundary. The steering is applied manually and maintained as the vehicle crosses the lane boundary and the proximity to the lane boundary when the warning is isued is measured. The test procedure recommends this is achieved using a human driven open-loop steering input. The NHTSA procedure also offers a recommendation to assess lane keeping systems over a range of lateral velocities for reference purposes only where fitted, however no defined method is provided. On review of these procedures, Thatcham investigated two concerns:

- Repeatability, it was considered that the range of lateral velocities achieved in testing could possibly affect the performance of the vehicle
- If the test was controlled by robotic driving aids to improve accuracy and repeatability, a method would need to be defined to avoid the steering robot over-riding the lane keeping heading correction during the test.

Within the test procedure permitted by the NHTSA confirmation test there are a range of possible variables. If the lane boundary is to be approached at a constant lateral velocity, then the vehicle will initially travel in a straight line, be steered towards the lane boundary and then the path would be straightened. In this process, the initial steer input could be applied slowly (large radius curve) or fast (small radius curve). A range of different radii of initial turn-in were tested for the same resultant lateral velocity. Larger radii of turn required the vehicle to be initially positioned further away from the lane boundary to be crossed. Path controlled robotic steering was used to provide accurate inputs. In all cases, the steering was staightened and released by a distance 0.3m from the lane boundary and any heading control effect after that point was applied by the vehicle autonomously.

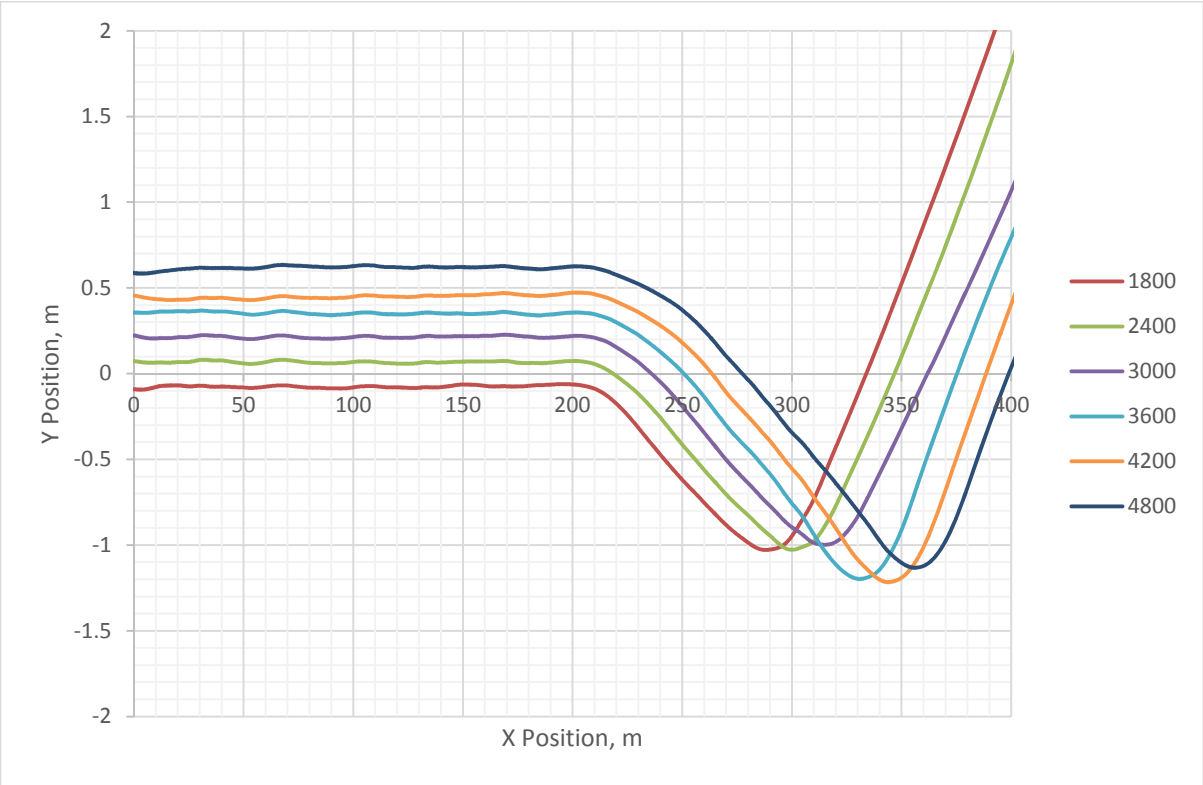

Figure 3. Effect of initial turn radius on lane keep assist function and change in vehicle heading

In this figure, the lane is centred on a y-position of zero and each trace represents the x-y position of the centre of gravity of the test vehicle. Thus, the lane boundaries would be at ± 1.75m and the edges of the vehicle will be at approximately ± 0.9m of the trace. Each trace represents the path of a test with a different radius of the initial curve. It can be seen that this variable has relatively little effect on the extent to which the edge of the vehicle crosses the lane boundary at y= – 1.75m (approximately 0.3m) or on the heading of the vehicle after the lane keep system has intervened.

It is worth noting that the lane markings during this test were such that the boundary at +1.75m was a dashed white line and the one at -1.75m was a solid white line. This graph also, therefore confirms that the Mercedes system adapts it's response according to the circumstances. Where it detected the solid white line (which in the centre of a UK road prohibits overtaking) the system intervened to correct the path. When it crossed the dashed white line it provided the driver with a lane departure waraning but did not actively steer the vehicle to correct the path. A Volvo V40 with lane keep assist tested in the same manner corrected the heading in response to both lane boundaries, such that the path of the vehicle zig-zagged from one lane boundary to the other and back again.

Subsequently, the effect of variation in the lateral velocity with which the lane boundary was approached was investigated, within a range of 0.1 to 0.6 m/s, all with the same initial radius of turn. The results are shown in **Figure 4**.

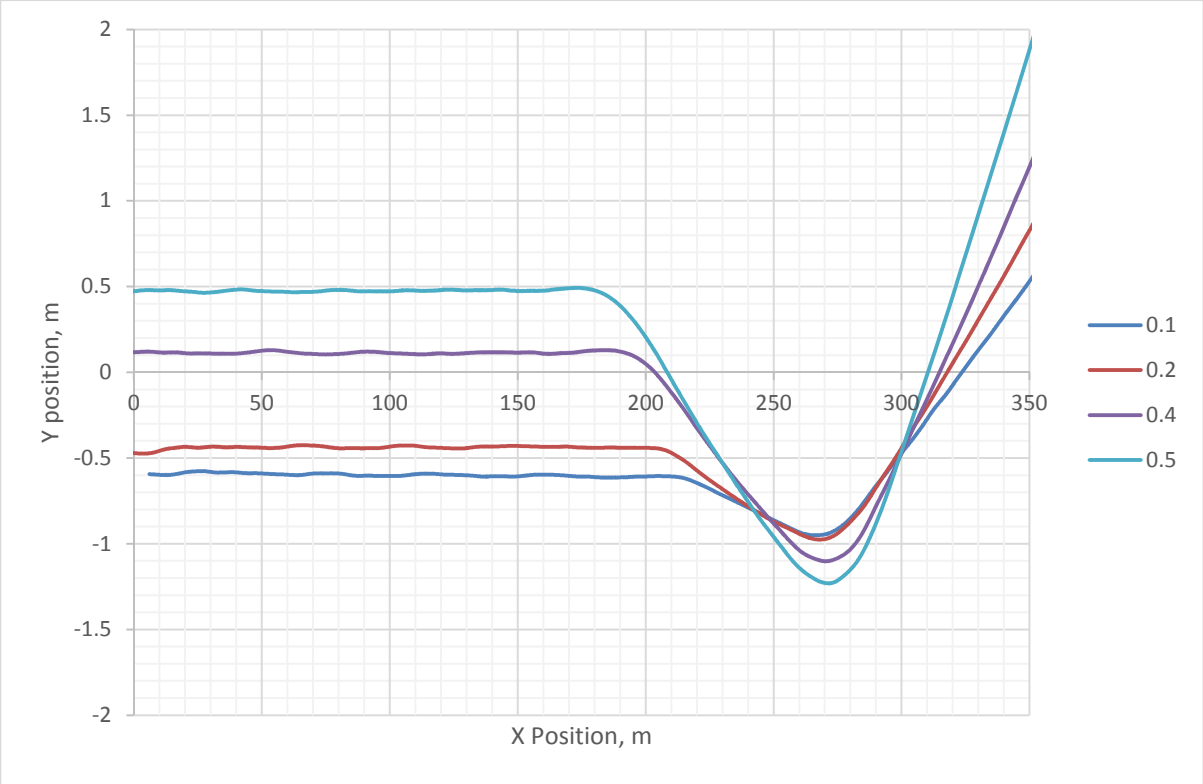

Figure 4: Effect of lateral velocity on lane keep assist function and change in vehicle heading.

It can be seen that higher lateral velocities could only be achieved by initially positioning the vehicle at the far side of the lane boundary to be crossed. However, in this case, it can also be seen that higher lateral velocities tended to result in the vehicle crossing the lane boundary by a greater margin before the active steering assist could correct the path. It also resulted in the correction of heading being applied with a greater yaw velocity, which in turn translated to the vehicle approaching the opposite lane boundary with a higher yaw velocity. The exact actions of the test inputs and vehicle response can be seen in the results of a single test at a lateral velocity of 0.6m/s.

Figure 5. Example of detailed results from a single test at a lateral velocity of 0.6m/s

DISCUSSION

It is clear that lane departures that result in run-off-road or head on collisions represent a substantial safety problems and that lateral assist systems have strong potential to prevent a substantial proportion of them. However, it is considerably less clear as to whether such systems are actually being effective in-service with some evidence suggesting that lane departure warning systems have little effect, or even an adverse effect. If forward collision warning and AEB are considered as a valid analogy, then it seems very likely that that lane keeping systems and autonomous emergency steering should be considerably more effective than a simple lane departure warning. However, further research is required to quantify the actual benefits of such systems as the available sample size increases with greater market penetration of the systems.

The capability of the lateral assist technology available is also evolving rapidly. The first lane keep assist systems only became widely available in the last few years but already the first examples of the next generation of AES is available from Mercedes. Thus performance ranges from a simple audible warning every time any kind of lane marking is crossed, to a system that varies its action in response to different situations and can provide a more abrupt correction in the heading when the threat of a collision is detected as a result of lane departure.

Test procedures already exist for the simpler systems but preliminary research has suggested that these require further development for assessing more advanced systems in a repeatable manner suitably for consumer testing. One essential requirement of a successful test programme will be the development of a lane departure test that occurs in the presence of an imminent collision threat with an oncoming vehicle. A range of different vehicle target and mobile platform systems is in existence to allow such testing. However, creating a harmonised 3-D vehicle target for use throughout the world would offer considerable benefits to both test authorities and industry and could also be used in a wide range of different test scenarios, including the existing car-to-car rear tests.

Actual testing of vehicles and the consequent refinement of test procedures remain at an early stage. However, the initial results are encouraging. They suggest that the vehicle performance offered is considerable and that accurate, representative and repeatable test procedures can be developed.

CONCLUSIONS

1. Head on and single vehicle crashes represent approximately 21% of all UK motor insurance claims and a much greater proportion of fatal collisions. There is, therefore, a substantial problem to solve.
2. Lateral Assist Systems, including lane departure warning, lane keep assist, lane centering and autonomnous emergency steering, have been developed and are on the Euro NCAP roadmap for implementation within their rating scheme.
3. While the evidence regarding the effectiveness of lane departure warning systems is ambiguous, it is expected that systems that intervene on behalf of the driver would prove more effective. AES systems would be expected to both increase effectiveness and driver acceptance of the systems in normal driving.
4. Testing the more advanced lateral assist systems also requires more sophisticated test procedures. Development of these procedures is at an early stage but shows promising results.

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Determination of Pedestrian Mannequin Clothing Color for the Evaluation of Image Recognition Performance of Pedestrian Pre-Collision Systems

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ABSTRACT

Pedestrian Pre-Collision Systems (PPCS) for helping avoid or mitigate pedestrian crashes have been equipped on many vehicles [1]. At present, there is no common standard for the performance evaluation of PPCSs. The Transportation Active Safety Institute (TASI) at Indiana University-Purdue University-Indianapolis with support from Toyota's Collaborative Safety Research Center (CSRC) has been studying the various issues to support the effort of developing such a standard. An important component in the PPCS evaluation is the development of a standard mannequin. This paper describes the approaches used to determine the color of the clothing on the mannequins based on the data obtained from the TASI 110 car one year naturalistic driving data collected in the greater Indianapolis area in USA.

1. Introduction

Pedestrian Pre-Collison System (PPCS) is an active safety system component to help avoid or mitigate the collision with pedestrians [1]. Many automotive companies have been developing PPCSs and have started to equip them in their vehicles [2]. The performance of different PPCS systems varies significantly. Many research groups and government agencies are actively studying various methods for the evaluation of PPCSs [3]. At present, there is no common evaluation standard for PPCS. The Transportation Active Safety Institute (TASI) at Indiana University-Purdue University-Indianapolis has been conducting research related to the establishment of such a standard with the support from Toyota Collaborative Safety Research Center (CSRC). Many PPCS use mono or stereo cameras for pedestrian detection which is an important part of the PPCS. One factor that may significantly affect the performance of the pedestrian detection is the color of the clothing worn by the mannequins. In order to define testing scenarios for evaluating and comparing PPCS systems, representative clothing colors for both adult and children needs to be selected to dress the dummies used in PPCS testing. This paper describes a method for determining the clothing colors for adult and child mannequins in the United States for PPCS evaluation based on pedestrian cloth color data obtained from the TASI 110 car one year naturalistic driving study.

The paper is organized as follows. Section 2 describes the process of getting the pedestrian upper and lower cloth colors. Section 3 explains the process of dividing the color space into color regions and selecting the representative color. Sections 4 and 5 are discussion and conclusion, respectively.

2. Pedestrian cloth color data collection and preprocessing

Many PPCS use mono or stereo cameras for pedestrian detection. One factor that may significantly affect the effectiveness of a PPCS is the color of the clothing worn by the pedestrians. In order to define testing scenarios for evaluating and comparing the PPCSs, representative clothing colors for both adult and children need to be selected for the performance evaluation. The color of the mannequin's clothing is one of the many variables that can affect

the performance of PPCSs. To limit the number of tests needed for PPCS performance evaluation, it is imperative to select a standard color of clothing that represents US adult pedestrians and a standard color of clothing that represents US children pedestrians. This problem involves two issues, the first is to get the data and d3escribe the pedestrians clothing color distributions, and the second is to choose specific representative colors.

From 2012 to 2013, TASI equipped 110 cars with systems capable of recording naturalistic driving data, and collected naturalistic driving data in the greater Indianapolis Indiana USA area. The purpose was to study the pedestrian behaviors in various conditions. An HD CMOS camera with GPS and G-sensor was installed on each vehicle to gather video of what the driver would see out of the front windshield. Each car collected video data for one year amounting to 100 TB of video data. 60,000 Pedestrians were identified in the video, then the clothing colors of the pedestrians were recorded by choosing one point on the pedestrian's upper body and one point at pedestrian's lower body. The RGB values at these points were recorded.

By examining the clothing colors on the pedestrian images, it was noticed that the color of the clothing is not only affected by the fabric itself, but also affected by brightness of the environment. The same clothing appears darker in a darker environment. The brightness of the environment is affected by weather, the time of the day, and the shade under a tree or building. Since these factors are controllable in the PPCS testing, only the true colors of the clothes is useful for this study. Therefore, around 8,439 pedestrian videos were manually selected from the 60,000 pedestrians such that the pedestrians in the frame were well lit by sun light during clear weather and not under any shade. Then, RGB values of the upper clothes and lower clothes were extracted.

The upper clothing colors of adult pedestrians are shown in a 3d RGB gamut space (Figure 1). The RGB gamut space is modeled as a cube with three axes Red, Blue and Green. The value range of each axis is normalized between 0 and 1. Black is at the corner of the cube that all R, G, B values are zero and white is at the opposite corner with all RGB values equal to 1. Each black dot on the diagram represents the cloth color of a pedestrian.

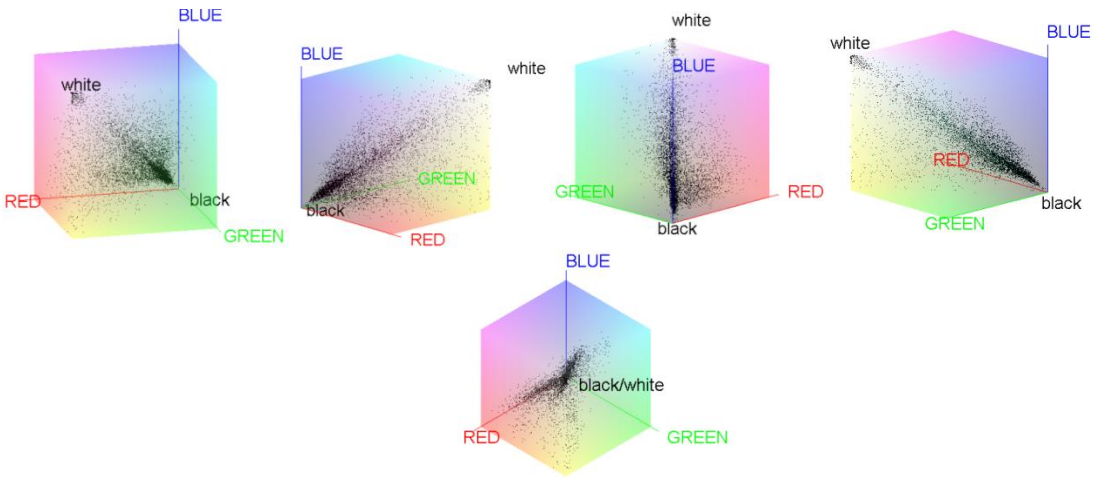


Figure 1. The colors of the top cloth of adult pedestrians plotted in five viewing angles in the RGB space.

These 3d gamut diagrams show that (1) the adult upper clothing colors are concentrated around the diagonal from the black to white axis, and (2) the colors tend to have a larger variance (span) on the axis when moving from black to white (This is reasonable due to Webber's law [4]).

3. Selection of the representative colors

The first approach for selecting the representative color is to find a color that has minimum sum of the mean square error to all the color points in the pedestrian cloth color poll. However, due to the shape of the distribution of the

pedestrian's cloth value, the resulting color is between gray and black for upper and lower cloths of both adults and children. It is concluded that this approach is not optimal.

The second approach is to divide the 3D space into seven color regions and the find which regions cover the most number of pedestrians. The seven regions are black-white, red, red-green, green, green-blue, blue, and blue-red. The boundaries of the seven color regions are determined according to the ratio of the two adjacent color values, as described as follows,

Black/White region: $(R/B \leq 1+\Delta)$ && $(B/R \leq 1+\Delta)$ && $(B/G \leq 1+\Delta)$ &&
$(G/B \leq 1+\Delta)$ && $(R/G \leq 1+\Delta)$ && $(G/R \leq 1+\Delta)$

Red region: $((R+G)/2 \geq B)$ && $((R+B)/2 \geq G)$ && $((R/G > 1+\Delta) \| (R/B > 1+\Delta))$
Blue region: $((B+R)/2 \geq G)$ && $((B+G)/2 \geq R)$ && $((B/R > 1+\Delta) \| (B/G > 1+\Delta))$
Green region: $((G+B)/2 \geq R)$ && $((G+R)/2 \geq B)$ && $((G/B > 1+\Delta) \| (G/R > 1+\Delta))$

Magenta region: $((R+G)/2 < B)$ && $((G+B)/2<R)$ && $((R/G > 1+\Delta) \| (B/G > 1+\Delta))$
Cyan region: $((B+R)/2 < G)$ && $((R+G)/2<B)$ && $((B/R > 1+\Delta) \| (G/R > 1+\Delta))$
Yellow region: $((G+B)/2 < R)$ && $((B+R)/2<G)$ && $((G/B > 1+\Delta) \| (R/B > 1+\Delta))$

Where Δ defines the boundaries of the black-white region around the black-white diagonal line. The value of Δ is chosen as between 0.1 and 0.2. These seven regions are shown in Figure 2.

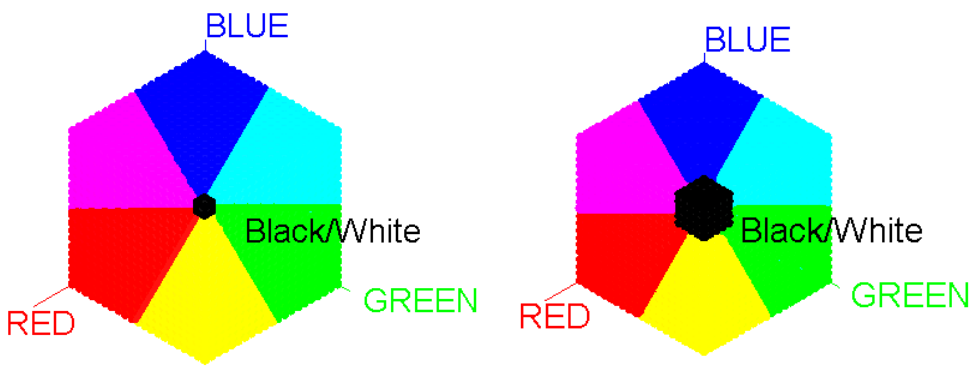


Figure 2. Seven color regions. (Left: Δ = 0.1; Right: Δ = 0.3)

To be able to distinguish the shade of the color, each of these seven regions is divided into 3 sub regions according to the color intensity. The intensity division is based on the following method,

Dark shade: $(R \leq 1/3)$ && $(G \leq 1/3)$ && $(B \leq 1/3)$
Medium shade: $(1/3 < R \leq 2/3)$ && $(1/3 < G \leq 2/3)$ && $(1/3 < G \leq 2/3)$
Light shade: $(R > 2/3)$ && $(G > 2/3)$ && $(G > 2/3)$

An example of 3 shades within the white-black region is shown in Figure 3. Therefore, a total of 21 non-overlapping regions completely cover the 3D color space is generated (Figure 4).

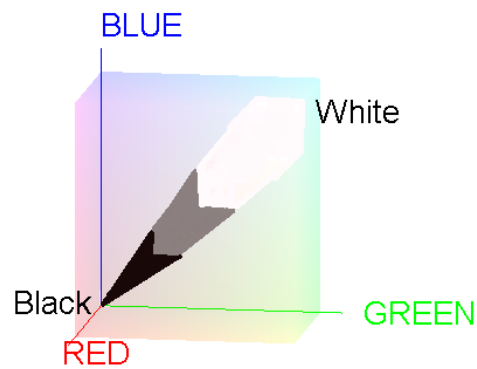


Figure 3. An example of 3 color shades in a region.

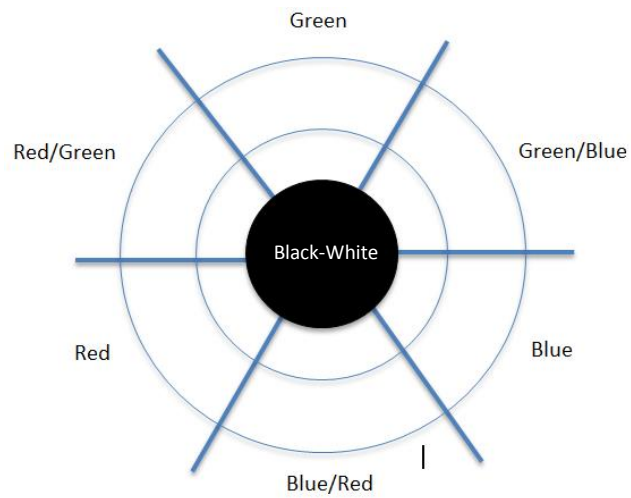


Figure 4. 21 color regions in the color space. The Black-White regions are divided in the axis perpendicular to the figure.

In order to illustrate the distribution for clothing colors in a visual friendly way, a chromaticity diagram is introduced. A chromaticity diagram can define the hue and colorfulness [5] [6] regardless of its luminance by compressing its luminance information to 2-dimentions. In this method, the luminance is less important than hue since the frame selected guarantees that colors can be interpreted correctly. The 2D chromaticity diagram source code is inspired from ECE 637 from Professor Bouman, Purdue University [7].The outer red line of the chromaticity diagram represent all the color that human can perceive [8], the CIE 1931 standard and Rec.709 standard are part of all perceivable color.

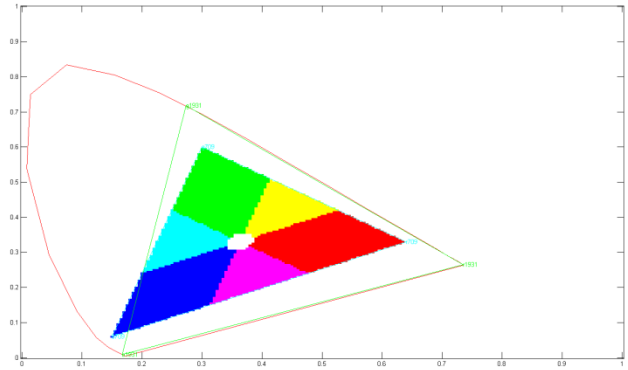
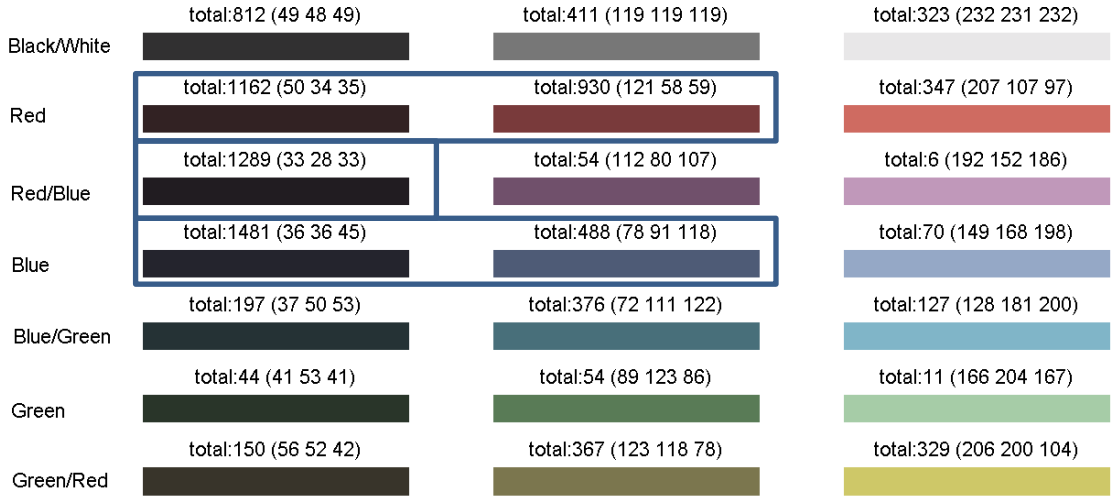


Figure 5. 2D chromaticity diagram of the color of children upper cloths.

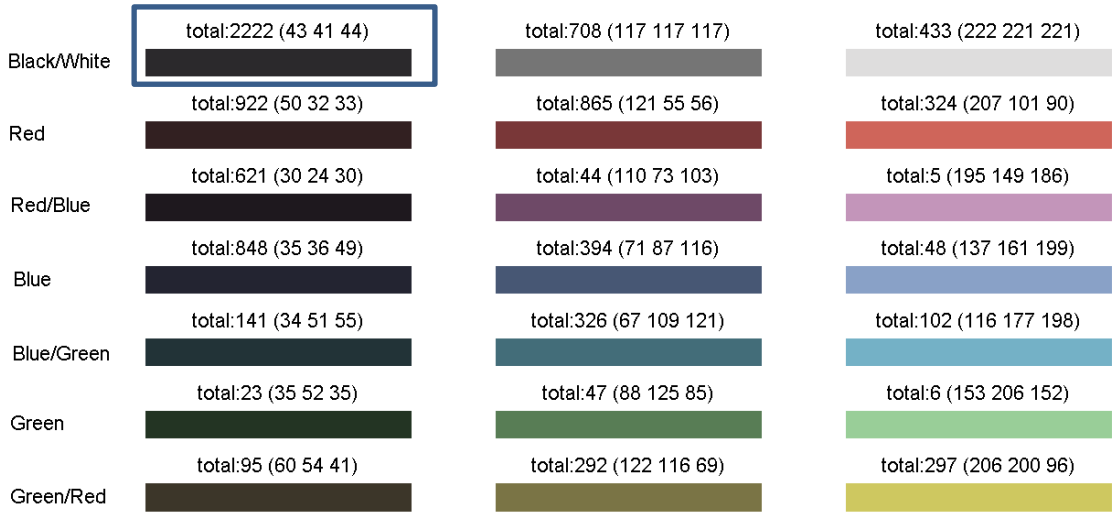
A. Adult upper cloth color

The number of the adult upper cloth and lower cloth in each color region is shown in Figure 6 and 7, respectively. The three numbers in the parentheses are the average RGB values of clothing colors in that region, respectively.

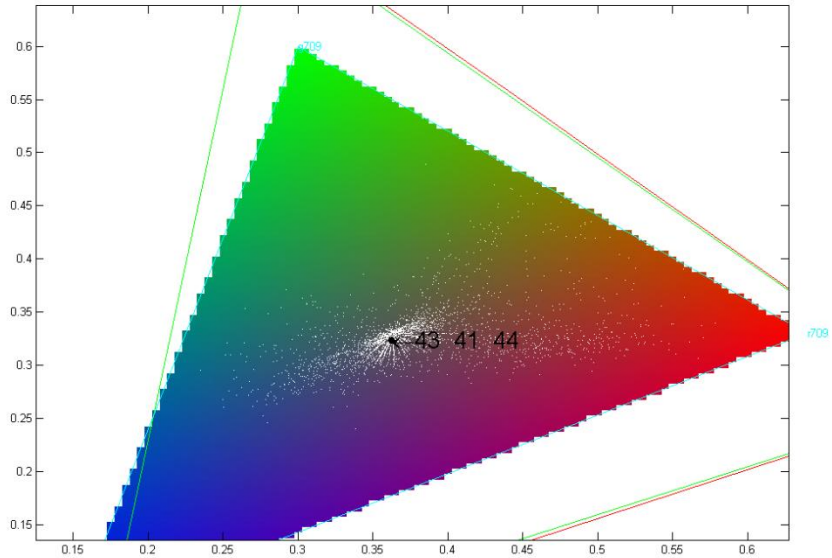
When Δ=0.1, dark/medium red, dark red/blue, and dark/medium blue are the most popular colors for adult upper cloth (see Figure 6a). Since there are more than one basic color region included, the color population in Δ=0.2 cases are checked. When Δ is increased to 0.2, a significant number of upper cloth from dark red, dark red/blue, and dark blue regions is moved to dark black-white region so that black becomes the dominate population(see Figure 6(b)). Therefore, the black color (RGB = 43, 41, 44) is selected as the adult upper cloth color. The corresponding point is shown as a black dot in Figure 6(c).



(a) Adult upper cloth. Δ = 0.1



(b) Adult upper cloth. Δ= 0.2

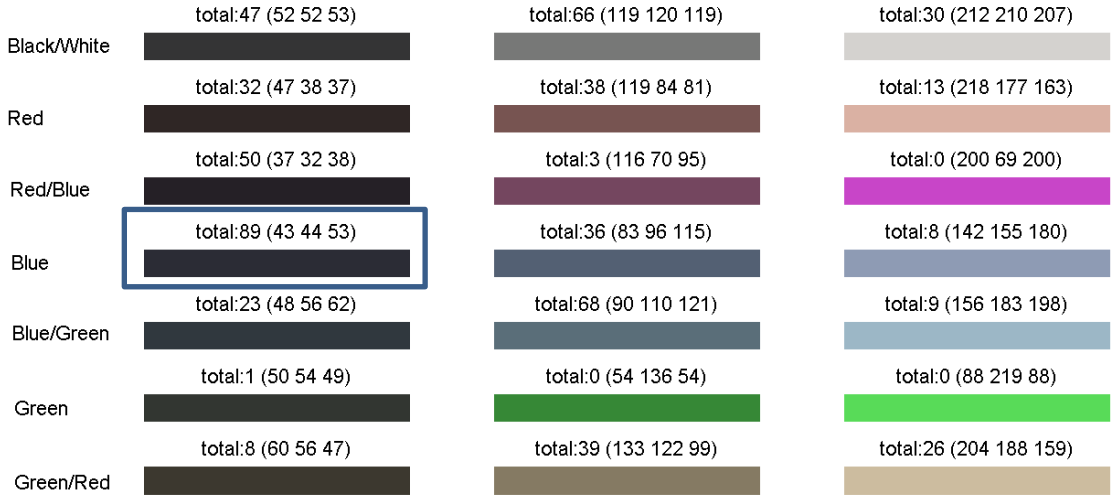


(c) 2D chromaticity diagram of the color of adult upper cloths. Black dot shows the selected color.

Figure 6. The selection of the mostly wore adult upper cloth color based on TASI 110 car naturalistic driving data.

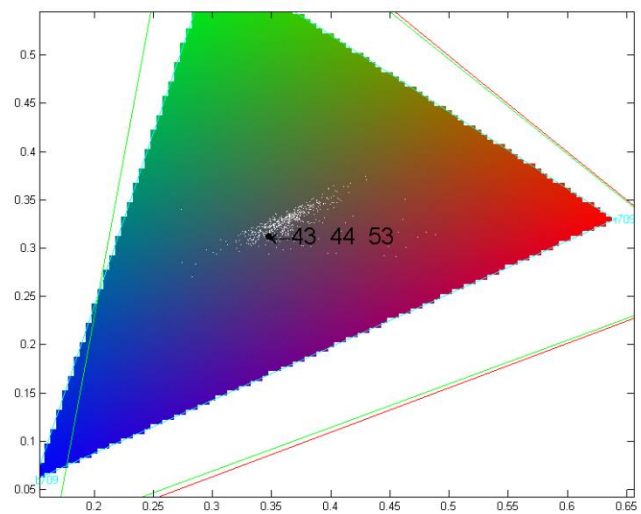
B. Adult lower cloth color

The number of adult lower clothing colors in each color region is shown in Figure 7. When Δ=0.1, dark blue (43, 44, 53) is significantly more favorable than other colors. Therefore, dark blue color (RGB= 43, 44, 53) is selected for adult lower cloth color. The corresponding point is shown as a black dot in Figure 7(c).



(a) Adult lower part Δ= 0.1

(b) Adult lower part Δ= 0.2

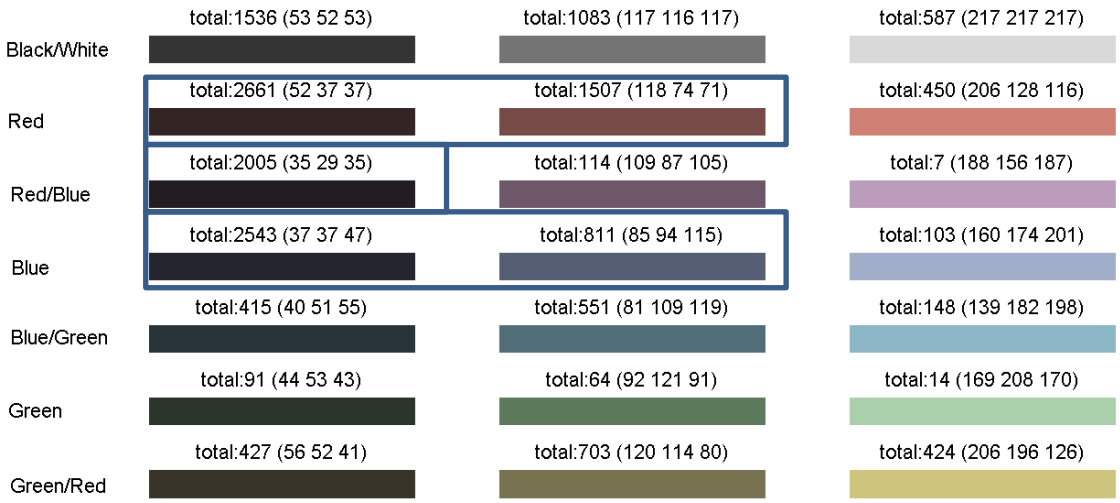


(c) 2D chromaticity diagram of the color of adult lower cloths. Black dot shows the selected color.

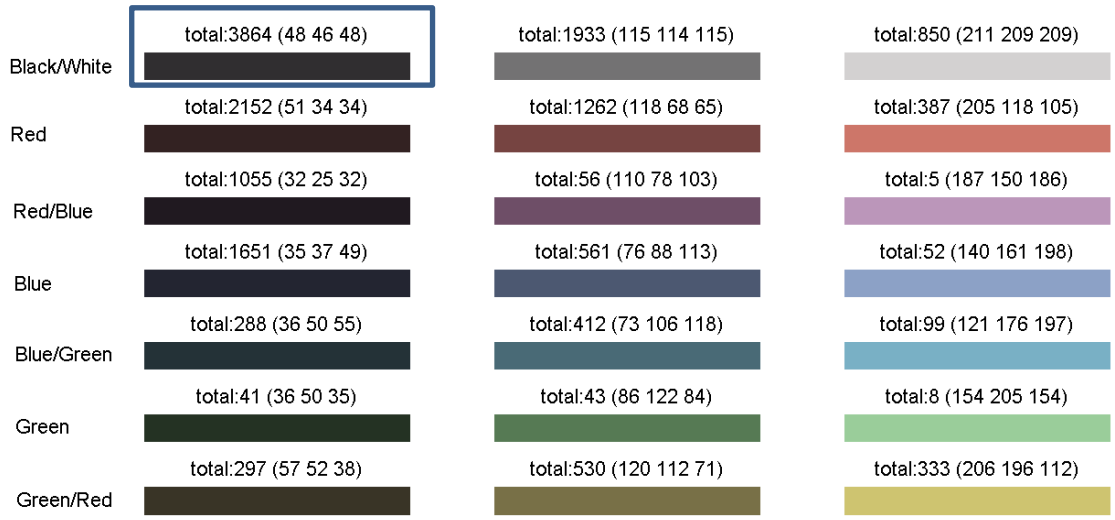
Figure 7. The selection of the mostly wore adult lower cloth color based on TASI 110 car naturalistic driving data.

C. Child upper cloth color

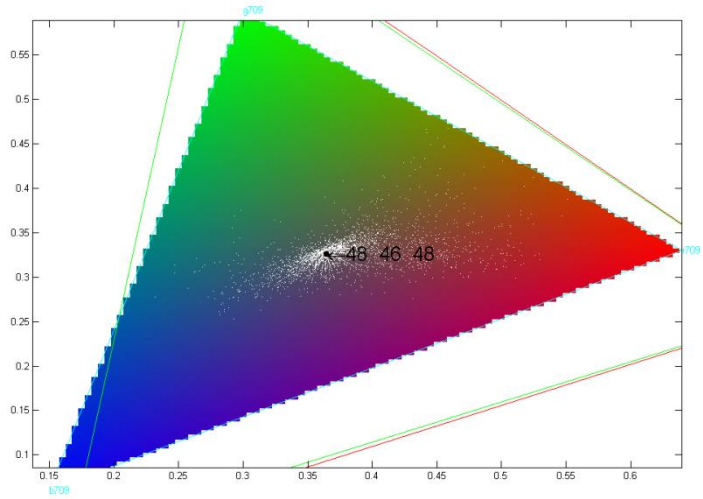
The number of the child upper cloth colors in each color region is shown in Figures 8. When Δ=0.1, dark/medium red, dark red/blue, and dark/medium blue were the most popular colors for adult upper clothing. Since there is more than one pure color region having high population, the color population in Δ=0.2 cases is checked. When Δ is increased to 0.2, a significant number of the population from dark red, dark red/blue, and dark blue regions are moved to dark black-white region so that black becomes the dominate population. Therefore, the black color (RGB = 48, 46, 48) is selected as the child upper clothing color. The corresponding point is shown as a black dot in Figure 8(c).



(a) Children upper cloth. part $\Delta = 0.1$



(b) Children upper cloth. $\Delta = 0.2$

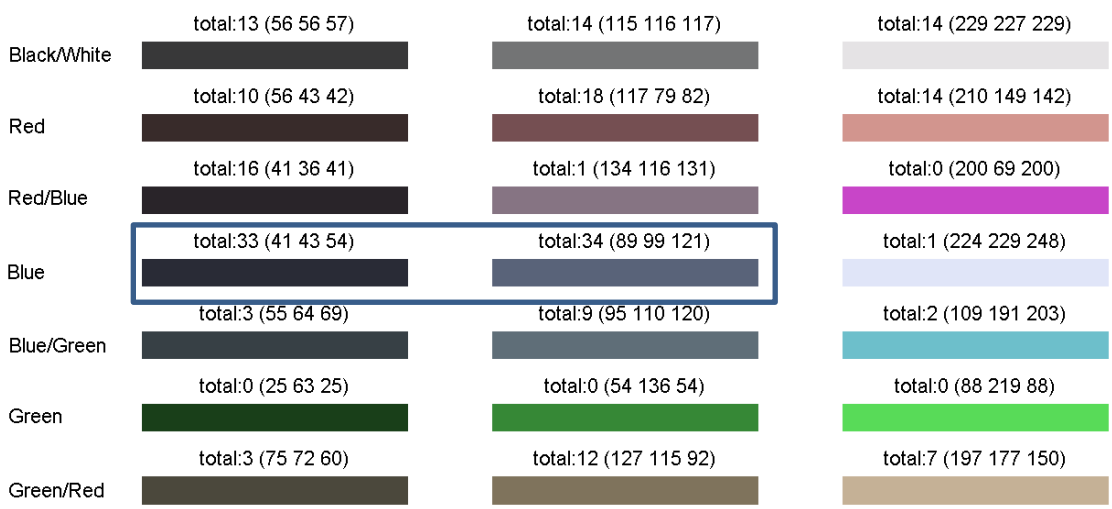


(c) 2D chromaticity diagram of the color of child upper cloths. Black dot shows the selected color.

Figure 8. The selection of the mostly wore children upper cloth color based on TASI 110 car naturalistic driving data.

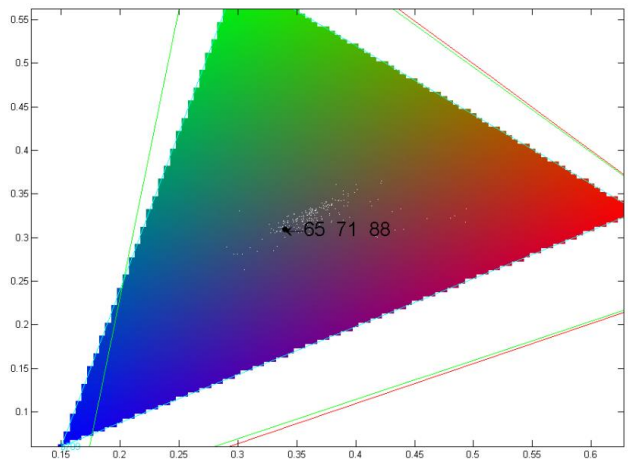
D. Chile lower cloth color

The number of the child lower clothing colors in each color region is shown in Figure 9. Since there are close counts in the dark blue and medium blue regions, the average color (65, 71, 88) of these two blue shades is selected to represent the child lower cloth color. The corresponding point is shown as a black dot in Figure 9(c).



(a) Children lower part Δ= 0.1

(b) Children lower part Δ= 0.2



(c) 2D chromaticity diagram of the color of child lower cloths. Black dot shows the selected color.

Figure 10. The selection of the mostly representative child lower cloth color based on TASI 110 car naturalistic driving data

Summary of cloth colors

The representative the upper cloth color for adult is black (RGB=43, 41, 44)
The representative the lower cloth color for adult is deep dark blue (RGB=43, 44, 53)
The representative the upper cloth color for children is black (RGB=48, 46, 48)
The representative of the lower cloth color for children is medium blue. (RGB=65, 71, 88)

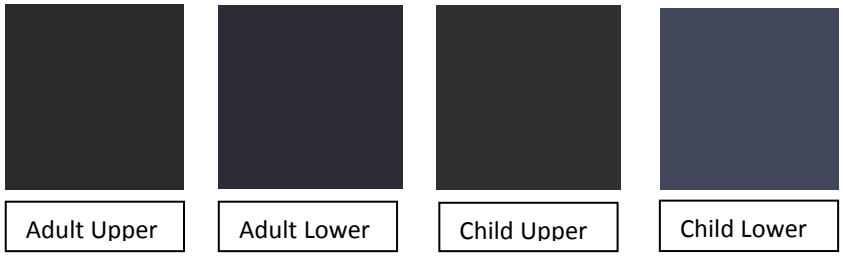


Figure 11. The representation of upper/lower adult and upper/lower children cloth color from left to right.

4. Discussion

The goal in this paper is to select one set of colors for dressing the mannequins for PPCS evaluation. The proposed method is to determine the color based on the popularity of the colors seen from video cameras. It is well known that lighting affects the perceived color. Even through the data preparation tried to remove the lighting influences, the color seen in the image are still darker than the original color. There are other possible ways to consider the clothing color, such as contrast to the background. Contrast base study is currently ongoing and will be reported in the future.

5. Conclusion

A method for finding the representing upper and lower clothing colors for both child and adult mannequins is described in this paper. The paper is based on the pedestrian data collected from TASI 110 car one year naturalistic driving in Greater Indianapolis area in USA. This data can be considered as an accurate representation for the whole Midwest region in USA. The method can be applied to additional pedestrian clothing color data from other naturalistic driving studies.

Acknowledgments

This project is sponsored by Toyota's Collaborative Safety Research Center

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EVALUATION OF MOTORCYCLE ANTILOCK BRAKING SYSTEMS

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Paper Number 15-0256

ABSTRACT

Objective: Previous studies have found lower crash rates for motorcycles equipped with antilock braking systems (ABS). Although prior studies controlled for a variety of personal factors related to motorcycle crashes, they did not control for the possibility that riders with similar demographics still can differ in the likelihood that they buy optional safety equipment and that this difference might be related to their crash likelihood. Specifically, motorcyclists who purchase ABS might be more likely to behave in a manner that makes them less likely to crash. The purpose of the current analysis was to examine the influence of individual crash risk on the frequency of insurance claims under collision coverage for ABS-equipped motorcycles. Auto collision claim histories were used as a proxy for the crash risk of individual riders, independent of the motorcycles they ride.

Methods: Coverage and loss data on nearly 2 million motorcycles by their unique vehicle identification numbers (VIN) were supplied by 13 insurers for model years 2003-14. The VINs were used to determine the ABS status of each motorcycle. Demographic characteristics including gender, marital status, date of birth, zip code, and insurance company were used to match the riders of these motorcycles to their auto insurance histories. Riders without any auto insurance history were excluded. Regression analysis was used to quantify the effect of ABS while controlling for auto claim frequency and other covariates including rider age and gender, garaging state, and collision deductible.

Results: Motorcycle riders with higher auto collision claim frequencies were associated with higher motorcycle collision claim frequencies. Riders with high auto claim frequencies (an average of more than two auto claims per 5 years insured) were associated with motorcycle claim frequencies that were 64 percent higher than those for riders with a history of zero auto claims. The percentage of motorcycles with ABS optionally equipped increased with the riders' auto claim frequencies. After controlling for auto claim frequency, motorcycles equipped with optional ABS were associated with a 21 percent reduction in claim frequency compared with similar motorcycles without ABS. Further analysis indicated that the reduction in motorcycle claim frequency associated with motorcycles equipped with ABS did not vary significantly depending on the auto claim frequency of the rider.

Discussion: Among motorcyclists with both auto and motorcycle collision insurance coverage, there was a strong relationship between motorcycle and auto claims experience. However, there was no evidence that safer riders, as measured by auto claim frequency, were more likely to purchase motorcycles with optional ABS. Rather, riders with higher auto claim frequencies were more likely to ride motorcycles with ABS. Most important, controlling for a rider's auto claim frequency did not substantively change the observed ABS effect, and the 21 percent estimated reduction in motorcycle collision claim frequency was consistent with prior research.

Conclusion: This analysis evaluated the real-world safety benefits of motorcycle ABS while also addressing the potential influence of self-selection by safer riders. Results indicate that all riders may be expected to benefit from ABS technology on their motorcycles. This study also confirms that auto crash risk is a reasonable proxy for a safety profile that may be applied to future research on other optional safety technologies.

INTRODUCTION

According to the National Highway Traffic Safety Administration (NHTSA), motorcycle registrations more than doubled between 1997 and 2010 (NHTSA, 2012). Analysis by the Insurance Institute for Highway Safety of data from the Fatality Analysis Reporting System shows that, during the same time period, fatalities in motorcycle crashes increased by 110 percent. Motorcyclist deaths began to increase in 1998 and continued to increase and peaked in 2008. Motorcyclist deaths decreased by 16 percent in 2009 compared with 2008 and increased only slightly from 2010 through 2012. Motorcyclist deaths decreased again slightly in 2013. It is not known to what extent the overall decrease from 2008 is related to improvements in highway safety or due to the significant drop in new motorcycle sales from more than 1.1 million in 2008 to only 560,000 in 2010 (Motorcycle Industry Council, 2011). Compared with automobiles, motorcycles offer much less occupant protection in the event of a crash. Only 20 percent of automobile crashes result in injury or death, whereas 80 percent of motorcycle crashes do (NHTSA, 2005). Therefore, any countermeasure aimed at reducing the likelihood of motorcycle crashes should significantly reduce the risk of injury or death.

Improper braking was identified as a significant factor in causes of motorcycle crashes (Association of European Motorcycle Manufacturers, 2004; Hurt et al., 1981). Braking too hard and locking a wheel on a motorcycle can lead to loss of control resulting in a crash. Riders concerned with wheel lock may avoid applying full force to the brakes resulting in insufficient braking power to avoid or mitigate an impact. Antilock braking systems (ABS) were developed to help riders solve this dilemma by automatically adjusting braking pressure to avoid wheel lock. These systems allow a rider to brake with full force without fear of the wheels locking.

Evaluations of ABS have shown strong benefits for motorcyclists. Closed test track studies have shown that ABS improves the braking performance for both novice and experienced riders (Green, 2006; Vavryn and Winkelbauer, 2004). Other studies reconstructed real-world crashes to determine if ABS may have prevented the crash. Gwehenberger et al. (2006) estimated that approximately half of the crashes studied were relevant to ABS and, of those, between 17 and 38 percent could have been avoided if the motorcycle was equipped with ABS. Rizzi et al. (2009) and Roll et al. (2009) estimated that ABS had the potential to prevent 38 to 50 percent of motorcycle crashes. Teoh (2011, 2013) examined the motorcycle fatal crash rate per registrations for motorcycles with ABS compared with the rate for the same models without ABS. The author's most recent study estimated a statistically significant 31 percent reduction in the fatal crash rate for ABS-equipped motorcycles.

NHTSA (2010) conducted a study of motorcycle ABS effectiveness by defining a group of crashes likely to be affected by ABS. A comparison group comprised of crash types deemed not relevant to ABS was used as an alternative measure of exposure. The agency found that ABS had no statistically significant effect on motorcycle crash risk. However, the agency acknowledged the difficulty in identifying types of crashes for which ABS would not be relevant. Behavioral differences between the ABS and non-ABS groups of riders could also result in differing distributions of crash types causing selection bias.

The Highway Loss Data Institute (HLDI, 2009, 2013) examined the effects of ABS on insurance claim frequency. Its most recent results showed that ABS-equipped motorcycles were associated with a statistically significant 20 percent reduction in collision claims per insured vehicle year compared with the same model motorcycles without ABS. Another HLDI (2012) study found that ABS was more effective during the first 3 months of collision insurance policies. A new policy could represent a first time rider, an experienced rider on a new motorcycle, or a rider who changed their insurance company. Motorcycles with ABS were associated with a 30 percent reduction in collision claim frequency versus the non-ABS versions of the same motorcycle during the first 90 days of the policy. For policies in effect 91-720 days, ABS motorcycles were associated with a 19 percent reduction in collision claim frequency compared with the non-ABS versions.

Although the HLDI studies controlled for rated rider characteristics such as age, gender, marital status, and insurance risk group, one criticism is that there may still be a self-selection bias. People who place a greater value on safety may be more likely to purchase an optional safety feature and to ride in a manner that makes them less likely to crash. If primarily safer riders are the ones purchasing ABS-equipped motorcycles, then it is possible that a portion of the ABS benefit observed in prior research was attributable to safer crash risk.

The purpose of this study was to examine the relationship between ABS and insurance losses under collision coverage while controlling for self-selection. This study controls for the safer rider effect by using a motorcycle rider's available auto claim history as a measure of their crash risk. Doing so separates the effect on motorcycle collision claim frequency due to the ABS technology from that attributable to crash risk.

METHODS

Insurance Data

Automobile insurance covers damage to vehicles and property as well as injuries to people involved in crashes. Different insurance coverages pay for vehicle damage versus injuries, and different coverages may apply depending on who is at fault. The current study is based on collision coverage. Collision coverage insures against vehicle damage to an at-fault driver's vehicle sustained in a crash with an object or other vehicle; this coverage is common to all 50 states. HLDI has data on the vehicles insured by its member companies including the length of time those vehicles were insured as well as any claims filed for that vehicle under collision coverage. Using this information, HLDI calculates collision claim frequency as the number of collision claims divided by exposure, where exposure is defined as the number of insured vehicle years. One insured vehicle year can represent one motorcycle insured for 1 year, two motorcycles insured for 6 months, etc. HLDI also receives the vehicle identification numbers (VINs) of the vehicles on the insurance policy. The VIN for a motorcycle contains information about the manufacturer, model year, and model type. In some instances, the ABS status of a motorcycle may also be determined from the VIN.

Information about the garaging zip code of the vehicle, deductible amount, and rated rider are also provided. Rated rider characteristics include age, gender, marital status, and insurance risk group. Insurance risk group is a binary variable indicating whether the rated rider is considered to have standard or non-standard insurance risk. The rated rider is the one who typically is considered to represent the greatest loss potential for the insured vehicle. In a household with multiple vehicles and/or riders, the assignment of riders to vehicles can vary by insurance company and by state. The actual rider operating the motorcycle at the time of the claim is unknown.

Motorcycle and Auto Loss Data

The HLDI database does not include a direct link between a given person's auto and motorcycle insurance policies. Therefore, it was necessary to match motorcycle and auto loss data using rated driver characteristics. The following multi-step process was used:

1. Rated rider/driver demographic data was used to create a mapping of a rated motorcycle rider's policy with their corresponding auto policy. An individual rated rider/driver was identified by their insurance company, gender, marital status, year of birth, date of birth, zip code, and state. Full date of birth data for some companies first became available to HLDI beginning in 2011.

2. In total, 505,864 unique combinations of insurance company, gender, marital status, year of birth, date of birth, zip code, and state existed in both auto and motorcycle databases concurrently. Approximately 13 percent of these combinations were associated with multiple auto or multiple motorcycle policies or both and were therefore excluded from the analysis. The remaining 87 percent had a one-to-one mapping of motorcycle and auto policies.

3. Once the mapping of policies was established, the motorcycle and auto loss data associated with the rated rider/driver were linked. Although a rider/driver's full date of birth was initially used to create the policy mappings, full date of birth data were only available beginning in 2011. Therefore, after motorcycle and auto policies were matched, year of birth was used as a substitute to track a rated rider/driver's motorcycle and auto loss data through years preceding 2011.

This procedure resulted in 949,551 years of motorcycle collision exposure and 16,605 motorcycle claims for model years 2003 to 2014, and calendar years 2006 to 2013. This was matched to 1,204,271 years of auto collision exposure and 62,742 auto claims.

Analysis Methods

The observed auto claim frequency for each rider, based on their total available matched auto history, was calculated as the total number of auto claims divided by the total years insured times 100. For example, a rider with one auto claim over 5 years with auto insurance would have an observed auto claim frequency of 1/5 * 100 = 20. The total years insured is the number of years the rider/driver had auto insurance. The observed auto claim frequencies were then categorized, as shown in Table 1.

Table 1.
Categorization of auto claim frequencies.

Category	Auto claim frequency	Description
Zero	0	No auto claims
Low	0-20	An average of between 0 and 1 claims per 5 years insured
Medium	20-40	An average of between 1 and 2 claims per 5 years insured
High	40+	An average of more than 2 claims per 5 years insured

Regression analysis was used to quantify the effect of ABS and/or auto claim frequency on motorcycle collision claim frequency while controlling for other covariates. Covariates included calendar year, vehicle age, garaging state, vehicle density (number of registered vehicles per square mile), rated driver age group, rated driver gender, rated driver marital status, deductible range, and insurance risk group. For analysis including only optional ABS vehicles, make and model was included as a covariate. For analysis including vehicles where ABS is standard or not available, motorcycle class and engine displacement were included as covariates. Claim frequency was modeled using a Poisson distribution using a logarithmic link function.

This study consisted of two main analyses to examine the effect of ABS on motorcycle crashes. The first compared the collision claim frequency of motorcycles with optional ABS to the same year\make\models without. For comparative purposes, the same study vehicles from the HLDI (2013) ABS-only study were chosen for this portion of the analysis. For a motorcycle to be included, its VIN had to have an ABS indicator. Only motorcycles with optional ABS and with loss data for both ABS and non-ABS versions were included. It should be noted that some motorcycles in this study population were also equipped with combined control braking systems (CCBS). However, both the ABS and non-ABS motorcycles had CCBS. Since CCBS was present in both the control and study group for those motorcycles, the estimated effect was for ABS only. Table 2 shows the exposure and percentage of exposure with and without ABS for the 17 models included in this portion of the analysis. In total there were 38,838 years of motorcycle exposure and 622 motorcycle claims, matched with 56,707 years of auto insurance with 2,638 auto claims. The effect of ABS with and without controlling for auto claim frequency was estimated and the results compared.

The second analysis examined a much broader range of motorcycles and included models where ABS was standard or not available, as well as motorcycles where ABS was optional and the presence of ABS was indicated by the VIN. The motorcycles were divided into two groups: with ABS and without ABS. Motorcycles where the ABS status

Table 2.
Distribution of exposure of antilock braking systems for April 2013 study vehicles.

Make/Series	Exposure	Percent ABS	Percent no ABS
Aprilia Scarabeo 500	174	32%	68%
Honda Gold Wing	25,581	23%	77%
Honda Interceptor 800	1,005	29%	71%
Honda Reflex	856	16%	84%
Honda Silver Wing	1,221	20%	80%
Honda ST1300	2,448	31%	69%
Kawasaki Ninja 650	90	36%	64%
Kawasaki Ninja ZX-10R	119	40%	60%
Suzuki Bandit 1250	503	27%	73%
Suzuki Burgman 400	181	42%	58%
Suzuki Burgman 650	1,447	20%	80%
Suzuki V-Strom 650	1,672	30%	70%
Triumph Sprint ST	587	41%	59%
Triumph Thunderbird	477	58%	42%
Triumph Tiger	672	34%	66%
Triumph Tiger 800	310	89%	11%
Yamaha FJR1300	1,496	48%	52%
Total	38,838	26%	74%

was unknown were excluded. Unlike the first analysis, the motorcycle models in the with-ABS and without-ABS groups were not the same. Therefore, in order to control for differences between models, motorcycle class and engine displacement were included as covariates. In addition, while only motorcycles with known ABS status are included in this analysis, the CCBS status is not always known. In the HLDI (2013) study of ABS with CCBS, an extensive review of publically available documentation was conducted on all motorcycles included in the analysis. However, information about the presence of CCBS for some motorcycles is not always available from public sources. This analysis includes more than 630 different motorcycle series over 12 model years. As a result, the effect of ABS in this study may be confounded with CCBS since some of the study motorcycles have ABS only while others may have both ABS and CCBS. Therefore the effect being measured may be attributable to "ABS and ABS/CCBS" as opposed to solely ABS. In addition, some of the motorcycles without ABS may have CCBS. However, this analysis assumes that CCBS in non-ABS motorcycles is a small part of the overall exposure.

Therefore, the second analysis is a less focused examination of the ABS effects but has the advantage of involving much more exposure. The addition of motorcycles with standard and not available ABS resulted in 842,487 years of motorcycle exposure and 14,311 motorcycle claims matched with 1,093,225 years of auto exposure and 57,193 auto claims. This was an increase of more than 21 times the motorcycle exposure of the optional ABS analysis. The effect of ABS and ABS/CCBS is estimated with and without controlling for auto claim frequency and the results compared. Finally, the interaction effect of ABS and ABS/CCBS with auto claim frequency category is also estimated.

RESULTS

Full regression results for the second analysis are shown in the Appendix. To further simplify the presentation here, the exponent of the parameter estimate was calculated, 1 was subtracted, and the result multiplied by 100. The resulting number corresponds to the effect of the feature on that loss measure. For example, the estimate of the effect for ABS and ABS/CCBS on motorcycle collision claim frequency was (-0.3268); thus, collision claim frequency for motorcycles with ABS and ABS/CCBS is expected to be 28 percent lower than for motorcycles without ABS ((exp(-0.3268) -1)*100 = -28).

Figure 1 shows the relationship between auto claim frequency category and motorcycle claim frequency. Riders with higher auto claim frequencies were associated with higher motorcycle claim frequency. The black bars correspond to the 95 percent confidence intervals. Riders in the high auto claim frequency category were associated with a statistically significant 64 percent increase in motorcycle collision claim frequency compared with riders with no history of auto claims. Riders in the medium auto claim frequency category were associated with a statistically significant 18 percent increase, while those categorized as having low auto claim frequency were associated with a 4 percent increase.

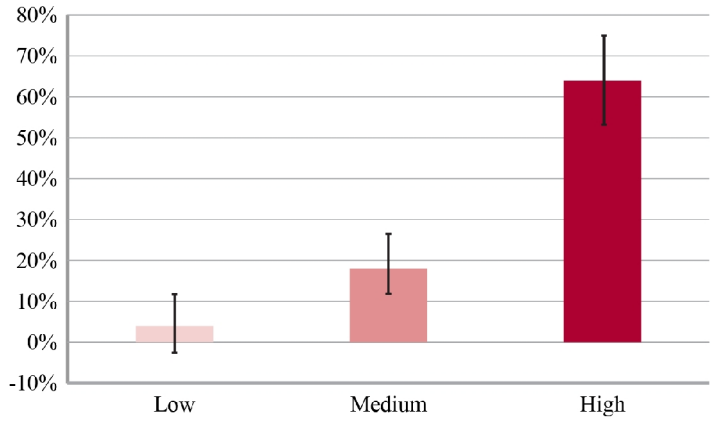

Figure 1. Motorcycle collision claim frequency by auto claim frequency category relative to rider/drivers with no auto claims.

Figures 2 and 3 show the results of the first analysis examining collision claim frequencies for motorcycles equipped with optional ABS relative to the same models without ABS. Figure 2 compares the estimated ABS effect in the present dataset, without controlling for auto claim frequency, with results from the full dataset used in the 2013 HLDI study. The ABS effect is essentially the same in both datasets — a 20 percent reduction in collision claim frequency compared with motorcycles not equipped with ABS.

Given that the ABS effect is present in the matched data set, the effect of additionally controlling for auto claim frequency was then analyzed. Table 3 shows the breakdown of motorcycle exposure with and without ABS by auto claim frequency category. Although the amount of the exposure is small, the percentage of exposure with ABS increases with auto claim frequency; 26 percent of the motorcycle exposure with zero auto claim frequency was for motorcycles with ABS compared with 32 percent of the exposure with high auto claim frequency.

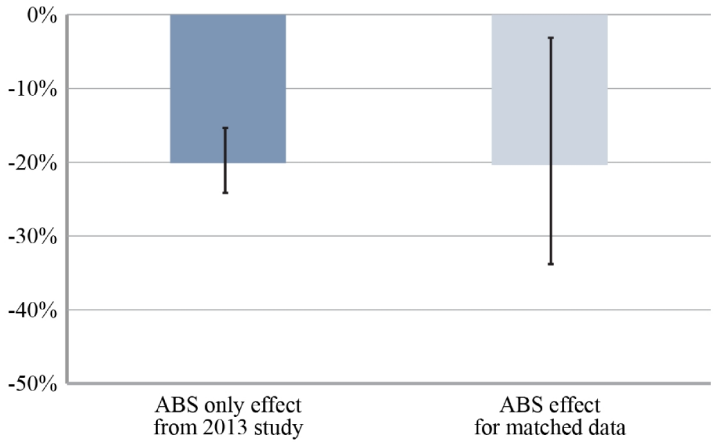

Figure 2. Effect of optional ABS on motorcycle collision claim frequency without regard to auto claim frequency, HLDI (2013) study vehicles

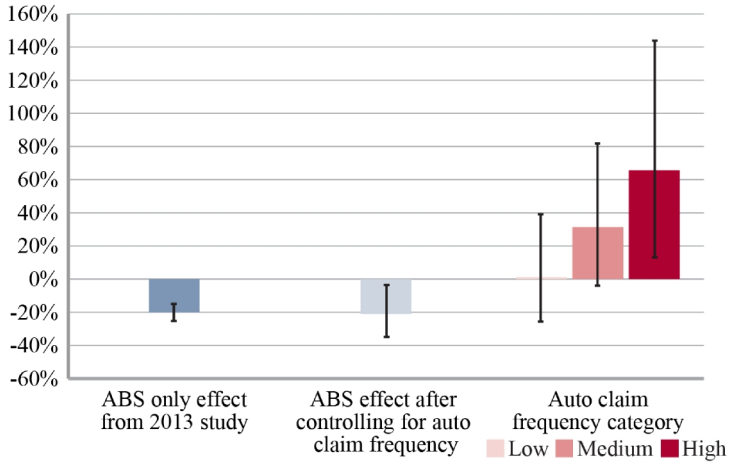

Figure 3. Effect of optional ABS and auto collision claim frequency on motorcycle collision claim frequency, HLDI (2013) study vehicles

Table 3.
Distribution of exposure by auto claim frequency category for April 2013 study vehicles.

Auto claim frequency category	Exposure	Percent ABS	Percent no ABS
Zero	33,279	26%	74%
Low	2,590	28%	72%
Medium	1,949	29%	71%
High	1,021	32%	68%

Figure 3 shows the results when both ABS status and the auto claim frequency categories are added as variables in the regression model. After controlling for auto claim frequency, the reduction in motorcycle collision claim frequency for ABS-equipped motorcycles increases slightly from 20 to 21 percent. Also shown in Figure 3 is the relationship between auto claim frequency category and motorcycle claim frequency using this subset of data. The results are consistent with Figure 1, although the confidence bounds are larger due to the reduced size of the dataset.

Figures 4 and 5 show the results of the second analysis that examines the effect of ABS and ABS/CCBS on motorcycles where ABS is standard or equipped with optional ABS versus motorcycles without ABS. Figure 4 compares the estimated ABS and ABS/CCBS effect in the present dataset, without controlling for auto claim frequency, with results from the 2013 HLDI study. The observed effect of 28 percent for ABS and ABS/CCBS falls between the 2013 study results of 20 percent for ABS only and 31 percent for ABS/CCBS.

Figure 5 shows that after controlling for auto claim frequency, the effect of ABS and ABS/CCBS was also a statistically significant 28 percent. The relationship between auto claim frequency category and motorcycle claim frequency using this subset of data is also shown. Again, the results for auto claim frequency are consistent with Figure 1. Full regression results for this model are shown in the Appendix.

Figure 6 shows the effect of ABS and ABS/CCBS by auto claim frequency category. The effect by auto claim frequency category is fairly consistent. Motorcycles with ABS and ABS/CCBS are associated with a 29 percent reduction in motorcycle claim frequency compared with motorcycles without ABS for riders with no history of auto claims. ABS and ABS/CCBS for riders categorized with a low auto claim frequency was associated with a 24 percent reduction. ABS and ABS/CCBS for riders categorized with medium or high auto claim frequencies was associated with 26 and 25 percent reductions, respectively. The differences between the effects of ABS and ABS/CCBS by rider auto claim frequency was not statistically significant.

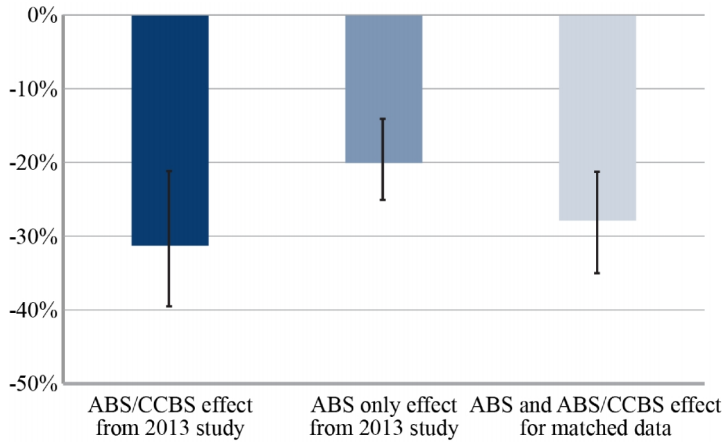

Figure 4. Effect of ABS and ABS/CCBS on motorcycle collision claim frequency, no auto claim frequency

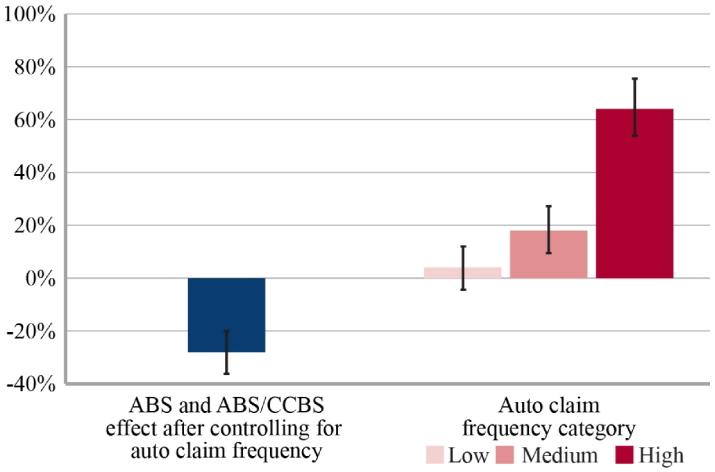

Figure 5. Effect of ABS and ABS/CCBS and auto collision claim frequency on motorcycle collision claim frequency

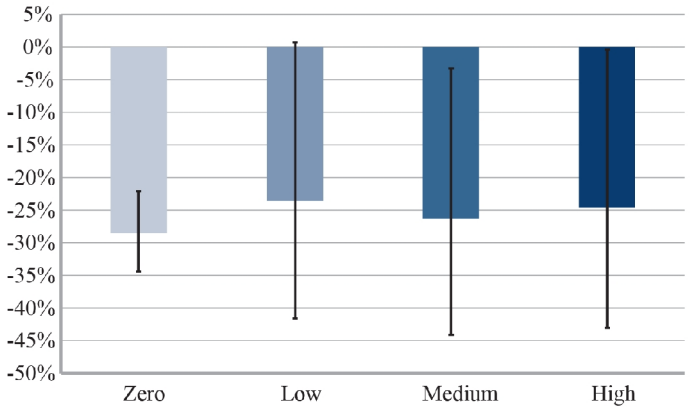

Figure 6. Effect of ABS and ABS/CCBS by auto claim frequency category

DISCUSSION

Prior HLDI studies have shown that ABS on motorcycles is effective in reducing collision losses by 20 percent, and others have shown motorcycle ABS reduces fatal crashes by 31 percent (HLDI, 2013; Teoh, 2013). These studies were criticized because they did not control for the possibility that the crash reductions attributed to ABS were not instead the result of safer riders choosing ABS. The present study addresses this concern by using a rider's auto claim frequency as an independent measure of their crash risk. Regression analysis showed that riders with higher auto claim frequencies were associated with higher motorcycle collision claim frequencies and, after taking this into account, the ABS benefit persists.

European regulators have acted on the strong evidence of the benefits of ABS for motorcycles, Beginning in 2016 in the European Union, ABS will be mandatory for motorcycles that have an engine displacement greater than 125 cc. In contrast, motorcycle ABS is not required in the United States. Despite the lack of a requirement, manufacturers have taken the initiative to increase the availability of ABS on new motorcycles in the United States during the past few years.

Figure 7 shows the increase in ABS availability by model year as indicated in motorcycle VINs process by HLDI, which represents a large sample of the registered fleet. More than 90 percent of 2002 model year bikes were not available with ABS. In contrast, more than two-thirds of new bikes in the 2013 model year have either standard (22 percent) or optional (46 percent) ABS. Moreover, manufacturers such as BMW, KTM, and Ducati have begun fitting stability controls systems that promise to prevent even more loss of control crashes among motorcycles (Bosch, 2014)

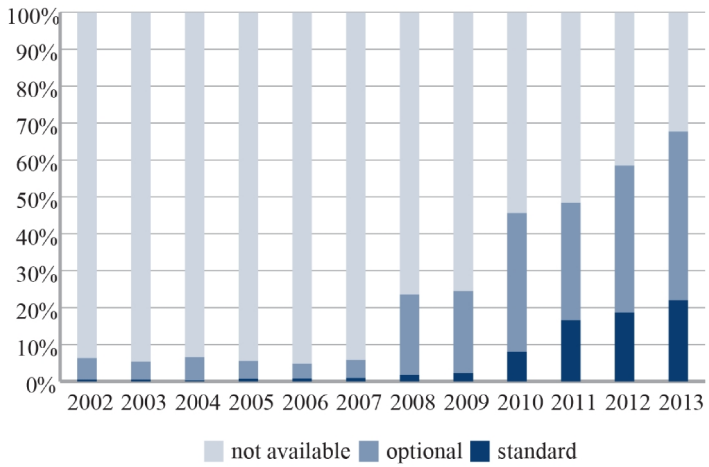

Figure 7. Motorcycle ABS availability by model year

Limitations

There are limitations on the data used in this analysis. Using auto claim frequency as a covariate in the regression required matching data from two separate databases using demographic data. Although there is no way to be absolutely certain that a matched rider/driver is the same person, using the full date of birth, zip code, gender, and marital status limit the likelihood of erroneous matches. It is also possible that a particular person would have their auto and motorcycle policies with different companies. These individuals would be excluded from the analysis. In addition, motorcycle riders who do not have an auto policy would also be excluded from this analysis. It is unknown whether there are significant differences between riders who also have an auto policy and those with just a motorcycle policy.

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APPENDIX

Table A1
Illustrative regression results: Collision claim frequency for motorcycles with and without ABS or ABS/CCBS.

Parameter	Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	p-value
Intercept	1	-9.2916		0.4588	-10.1908	-8.3925	410.22	<0.0001
Calendar Year								
2006	1	-0.3742	-31.2%	0.0961	-0.5626	-0.1857	15.15	<0.0001
2007	1	-0.4147	-33.9%	0.0571	-0.5266	-0.3029	52.83	<0.0001
2008	1	-0.4572	-36.7%	0.0428	-0.5412	-0.3732	113.87	<0.0001
2009	1	-0.5816	-44.1%	0.0389	-0.6578	-0.5053	223.49	<0.0001
2010	1	-0.5634	-43.1%	0.0332	-0.6285	-0.4982	287.54	<0.0001
2011	1	-0.3190	-27.3%	0.0249	-0.3679	-0.2701	163.45	<0.0001
2012	1	-0.2549	-22.5%	0.0230	-0.3001	-0.2098	122.37	<0.0001
2013	0	0	0	0	0	0		
Vehicle age	1	-0.1087	-10.3%	0.0038	-0.1161	-0.1013	825.01	<0.0001
Rated driver age								
14-24	1	0.9486	158.2%	0.0545	0.8417	1.0554	302.84	<0.0001
25-39	1	0.3173	37.3%	0.0383	0.2422	0.3923	68.65	<0.0001
40-64	1	0.0105	1.1%	0.0347	-0.0575	0.0784	0.09	0.7629
65+	0	0	0	0	0	0		
Gender								
Female	1	-0.1211	-11.4%	0.0266	-0.1732	-0.0691	20.79	<0.0001
Male	0	0	0	0	0	0		
Marital status								
Married	1	-0.1211	-11.4%	0.0978	-0.3128	0.0706	1.53	0.2158
Single	1	0.0231	2.3%	0.0988	-0.1706	0.2168	0.05	0.8152
Unknown	0	0	0	0	0	0		
State								
Alabama	1	0.3570	42.9%	0.1816	0.0011	0.7130	3.86	0.0493
Arizona	1	0.4653	59.2%	0.1771	0.1182	0.8125	6.90	0.0086
Arkansas	1	0.2089	23.2%	0.1995	-0.1820	0.5999	1.10	0.2949
California	1	0.4862	62.6%	0.1724	0.1484	0.8240	7.96	0.0048
Colorado	1	0.2029	22.5%	0.1782	-0.1463	0.5521	1.30	0.2548
Connecticut	1	0.2198	24.6%	0.1846	-0.1420	0.5817	1.42	0.2337
Delaware	1	0.8593	136.2%	0.3354	0.2018	1.5167	6.56	0.0104
District of Columbia	1	0.6508	91.7%	0.2285	0.2031	1.0986	8.12	0.0044
Florida	1	0.1984	21.9%	0.1726	-0.1398	0.5366	1.32	0.2502
Georgia	1	0.3296	39.0%	0.1762	-0.0157	0.6748	3.50	0.0614
Hawaii	1	0.2810	32.4%	0.2000	-0.1111	0.6730	1.97	0.1601
Idaho	1	0.1199	12.7%	0.2018	-0.2757	0.5155	0.35	0.5525
Illinois	1	0.0813	8.5%	0.1768	-0.2653	0.4279	0.21	0.6457
Indiana	1	0.2783	32.1%	0.1842	-0.0829	0.6394	2.28	0.1310
Iowa	1	-0.0066	-0.7%	0.1868	-0.3727	0.3594	0.00	0.9717
Kansas	1	0.1217	12.9%	0.1895	-0.2498	0.4931	0.41	0.5209
Kentucky	1	0.3797	46.2%	0.1978	-0.0080	0.7674	3.68	0.0549
Louisiana	1	0.4134	51.2%	0.1817	0.0573	0.7695	5.18	0.0229
Maine	1	0.3473	41.5%	0.2226	-0.0890	0.7836	2.43	0.1187

Parameter	Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	p-value
Maryland	1	0.3205	37.8%	0.1769	-0.0262	0.6673	3.28	0.0700
Michigan	1	0.3058	35.8%	0.1845	-0.0558	0.6674	2.75	0.0974
Minnesota	1	0.0431	4.4%	0.1875	-0.3243	0.4105	0.05	0.8181
Mississippi	1	0.2709	31.1%	0.2041	-0.1292	0.6710	1.76	0.1845
Missouri	1	0.2400	27.1%	0.1890	-0.1304	0.6105	1.61	0.2040
Montana	1	-0.1582	-14.6%	0.3089	-0.7637	0.4472	0.26	0.6085
Nebraska	1	0.0666	6.9%	0.1946	-0.3147	0.4479	0.12	0.7322
Nevada	1	0.6364	89.0%	0.1901	0.2639	1.0090	11.21	0.0008
New Hampshire	1	0.2025	22.4%	0.2255	-0.2395	0.6446	0.81	0.3691
New Jersey	1	0.1643	17.9%	0.1879	-0.2039	0.5325	0.76	0.3818
New Mexico	1	0.2884	33.4%	0.1846	-0.0735	0.6502	2.44	0.1183
New York	1	0.3641	43.9%	0.1733	0.0243	0.7038	4.41	0.0357
North Carolina	1	0.2203	24.6%	0.1785	-0.1295	0.5701	1.52	0.2171
North Dakota	1	0.1481	16.0%	0.3090	-0.4575	0.7536	0.23	0.6318
Ohio	1	0.0211	2.1%	0.1763	-0.3245	0.3667	0.01	0.9046
Oklahoma	1	0.2389	27.0%	0.1851	-0.1238	0.6016	1.67	0.1968
Oregon	1	0.3714	45.0%	0.1877	0.0035	0.7394	3.92	0.0478
Pennsylvania	1	0.2132	23.8%	0.1760	-0.1318	0.5582	1.47	0.2258
Rhode Island	1	0.1529	16.5%	0.2267	-0.2914	0.5973	0.46	0.4999
South Carolina	1	0.2064	22.9%	0.1838	-0.1538	0.5667	1.26	0.2614
South Dakota	1	0.0033	0.3%	0.2620	-0.5102	0.5169	0.00	0.9898
Tennessee	1	0.3529	42.3%	0.1738	0.0122	0.6935	4.12	0.0423
Texas	1	0.3324	39.4%	0.1729	-0.0064	0.6713	3.70	0.0545
Utah	1	-0.0321	-3.2%	0.1852	-0.3951	0.3309	0.03	0.8623
Vermont	1	-0.0052	-0.5%	0.2690	-0.5324	0.5220	0.00	0.9845
Virginia	1	0.2582	29.5%	0.1750	-0.0847	0.6012	2.18	0.1400
Washington	1	0.3058	35.8%	0.1786	-0.0443	0.6558	2.93	0.0869
West Virginia	1	-0.0597	-5.8%	0.2119	-0.4749	0.3556	0.08	0.7781
Wisconsin	1	0.0623	6.4%	0.1917	-0.3135	0.4380	0.11	0.7453
Wyoming	1	0.2364	26.7%	0.2433	-0.2404	0.7132	0.94	0.3313
Alaska	0	0	0	0	0	0		
Density								
<50	1	-0.4348	-35.3%	0.0380	-0.5092	-0.3603	130.95	<0.0001
50-99	1	-0.3254	-27.8%	0.0322	-0.3884	-0.2624	102.39	<0.0001
100-249	1	-0.2349	-20.9%	0.0277	-0.2892	-0.1806	71.87	<0.0001
250-499	1	-0.2269	-20.3%	0.0274	-0.2806	-0.1732	68.59	<0.0001
599-999	1	-0.1463	-13.6%	0.0277	-0.2006	-0.0920	27.86	<0.0001
>999	0	0	0	0	0	0		
Risk								
Nonstandard	1	0.0509	5.2%	0.0202	0.0112	0.0905	6.32	0.0119
Standard	0	0	0	0	0	0		
Deductible range								
0	1	-0.2403	-21.4%	0.4516	-1.1254	0.6447	0.28	0.5946
1-50	1	0.6109	84.2%	0.4142	-0.2009	1.4228	2.18	0.1402
51-100	1	-0.2555	-22.5%	0.4096	-1.0583	0.5472	0.39	0.5327
101-200	1	-0.1534	-14.2%	0.4106	-0.9581	0.6513	0.14	0.7087
201-250	1	-0.0151	-1.5%	0.4090	-0.8167	0.7865	0.00	0.9706

Parameter	Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	p-value
251-500	1	-0.1875	-17.1%	0.4087	-0.9884	0.6135	0.21	0.6464
501-1000	1	-0.5987	-45.0%	0.4102	-1.4028	0.2053	2.13	0.1444
>1000	0	0	0	0	0	0		
Motorcycle class								
Chopper	1	-0.8309	-56.4%	0.1007	-1.0283	-0.6335	68.07	<0.0001
Cruiser	1	-0.5776	-43.9%	0.0505	-0.6765	-0.4786	130.85	<0.0001
Dual purpose	1	-1.0269	-64.2%	0.0777	-1.1792	-0.8747	174.73	<0.0001
Scooter	1	-0.2698	-23.6%	0.0674	-0.4018	-0.1377	16.03	<0.0001
Sport	1	0.2885	33.4%	0.0584	0.1740	0.4030	24.39	<0.0001
Sport touring	1	-0.1931	-17.6%	0.0759	-0.3419	-0.0442	6.46	0.0110
Standard	1	-0.2881	-25.0%	0.0841	-0.4529	-0.1233	11.74	0.0006
Super sport	1	0.5819	78.9%	0.0535	0.4771	0.6868	118.31	<0.0001
Touring	1	-0.4736	-37.7%	0.0553	-0.5820	-0.3651	73.27	<0.0001
Unclad sport	0	0	0	0	0	0		
Engine displacement	1	0.0004	0.0%	0.0000	0.0004	0.0005	235.58	<0.0001
Auto claim frequency category								
Low	1	0.0358	3.6%	0.0377	-0.0381	0.1098	0.90	0.3422
Medium	1	0.1661	18.1%	0.0349	0.0976	0.2345	22.63	<0.0001
High	1	0.4975	64.5%	0.0358	0.4272	0.5677	192.65	<0.0001
Zero	0	0	0	0	0	0		
ABS and ABS/CCBS								
Equipped	1	-0.3268	-27.9%	0.0421	-0.4092	-0.2444	60.38	<0.0001
Not equipped	0	0	0	0	0	0		

ANALYSIS OF CAR ACCIDENTS CAUSED BY UNINTENTIONAL RUN OFF ROAD

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ABSTRACT

Car accidents caused by unintentional run off road (in this paper the term "inadvertent lane departure" is used) have become an important topic within world wide accident research activities. These accidents can be addressed by lateral support systems (e.g. Lane Departure Warning) which are considered by experts to be the second most important active safety countermeasures after forward collision intervention systems.

There is no common understanding for "run off road" yet. This term is being used both for the event of a departure from the own driving lane and for the event of a departure from the road. But it is known that when a driver leaves its driving lane unintentionally, it mostly results in a severe crash involving an oncoming vehicle or an obstacle (e.g. tree).

The importance of this topic is also visible as efforts have already been made in order to adopt this issue in current and future testing procedures (eg. NHTSA, IIHS, Euro NCAP).

In Germany, the relevance of unintentional run off road accidents can hardly be estimated when using only official numbers. Official statistics categorize accidents by the parameter "leaving the carriageway" without any differentiation between intentional or unintentional lane departure. However, in the year 2013, these accidents made up 14% of all accidents with personal injury involving all kinds of road users but 30% of all fatalities and 23% seriously injured persons. A more accurate view on the accidents that match the definition "unintentional run off road" was given by UDV in an earlier study (paper-09-0317).

This paper presents now the results of a second more detailed analysis which was carried out with up-to-date accident data. For the analysis, the In-depth database of the German Insurers (UDB) was used. It contains a representative cross section of all third party insurance claims reported between 2002 and 2011. The group of car accidents analyzed was defined as "unintentional run off road accidents" and implies only cases where a car had left his driving lane unintentionally. The aim of the analysis was to get a better understanding of the circumstances at which these incidents occur and to derive key accident scenarios.

From a total of 118 relevant cases in the database, which account for 5% of all accidents caused by a car, five accident scenarios were deduced. These make up 68% of the accidents and 66% of the fatalities in the datapool. Some of the main results were: A lane departure to the left occurred more frequently than a lane departure to the right. Generally, the lane departure was followed by a collision with an oncoming vehicle (in 70% passenger car) rather than by a run off from the road. Regarding behavioral issues, health problems of the driver were found to be twice as frequent as distractions of any kind.

INTRODUCTION

Car accidents caused by inadvertent lane departure now feature significantly in accident research around the world. Systems for lateral support (or lane departure warning systems) can have a positive effect on these accidents and are seen by experts as being the second most important active safety measure that can be taken, right after advanced emergency braking systems. Accidents caused by inadvertent lane departure are generally very serious because they often result in collisions with oncoming traffic or roadside obstacles such as trees at relatively high speeds. The significance of these accidents is also evident from the level of attention now being given to them by international

test institutes (e.g. NHTSA, IIHS, Euro NCAP). At the European level, Euro NCAP has already made progress toward including systems for lateral support in its test program in future. Euro NCAP's current roadmap [1] includes the objective of providing a test procedure for lane departure warning systems from 2016. From 2018, a procedure will also be available for active lane keeping systems, which constitute a further development of lane departure warning systems.

The relevance of accidents caused by inadvertent lane departure has not yet been extensively investigated in Germany. The official accident statistics do not allow concrete statements to be made about these kinds of accidents. The reason for this is that the road accident reports on which the official statistics [2] are based do not contain any information on inadvertent lane departure because this is not recorded in police accident records.

A previous UDV study [3] provided an initial overview of car accidents caused by inadvertent lane departure. The aim of the present study is to describe these accidents in more detail and identify the main accident scenarios in order to assist with the development of realistic future test procedures. The study also describes the complex methodology that is required for the identification of the relevant accidents and underlines the priority and challenge of this important part of the analyses.

CASE MATERIAL

The accident material on which the study is based covers the years 2002 to 2011 and comprises 4,245 car accidents, in which 339 people were killed, 2,756 sustained serious injuries, and 4,592 sustained minor injuries. A total of 6,822 cars (not including vans) were involved in these accidents, and 41% of them were the main causer of the accident. All types of road users were taken into account as the other parties in the collisions (cars, vans, trucks, buses, two-wheel motor vehicles, bicycles and pedestrians). Single-vehicle accidents were also included. However, single-vehicle accidents are underrepresented in this case material because, for methodological reasons, cases not involving injury or damage to a third party are not included in the UDV's accident database (UDB).

TERMINOLOGY AND FORMULATIONS

It is best to begin by explaining some of the terminology and formulations used in this study:

- **Accident type**: Designated by a code of up to three digits. Describes the initial conflict between two road users that led to the accident [4].
- **Kind of accident**: Designated by a single-digit code. Indicates the position of the parties to the collision in relation to each other immediately before the impact [2].
- **Person-related misbehavior** (cause 01-69): This term is taken from the translation of the official accident statistics and essentially refers to a personal error. It is assessed and assigned to the relevant road user by the police officer recording the accident on the basis of a list of accident causes [2].
- **Lane and carriageway**: The carriageway (roadway) consists of at least two lanes, which separate it into two directions of travel; the borders of a lane are generally indicated by markings (Figure 1).
- **Case car**: This is the car that leaves its lane, without the driver intending to do so, and thus causes the accident. In this study, the case car is always the main causer of the accident. In the course of the accident, other road users may leave their lanes either intentionally (to get out of the way) or inadvertently (following a collision), but they are not considered to be the case car.
- **Lane departure**: This is when at least one wheel of the case car leaves its lane. This can be either to the left, which means it crosses the center line, or to the right, in which case it crosses over the border of the carriageway.
- **Leaving the carriageway**: This happens when the case car leaves not just its lane but the entire carriageway (roadway). Leaving the carriageway thus always involves lane departure.

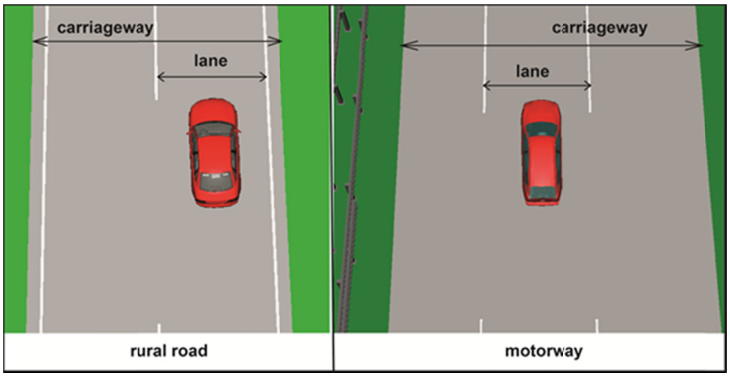


Figure 1. Illustration of the terms "lane" and "carriageway"

METHODOLOGICAL APPROACH

The methodology used in the study involves the following steps:

a. Pre-analysis of a random sample of cases in order to ascertain the defining factors for identifying accidents caused by inadvertent lane departure
b. Selection of factors that indicate inadvertent lane departure and identification of the relevant case material by means of a database query
c. Case-by-case analysis of the relevant case material with descriptions of the accidents and identification of the main accident scenarios.

a: Pre-analysis

Information on inadvertent lane departure is not recorded in police accident records and thus does not exist in this form in the accident database. It was possible to obtain this information subsequently by utilizing expert knowledge and by taking into account relevant factors that made it possible to conclude from the course of an accident that inadvertent lane departure had occurred. To begin with, the defining factors were ascertained by means of a brief analysis of a random sample of cases. The ten kinds of accident were selected here as the filter criterion, and ten cases were then randomly selected for each kind of accident. The kind of accident [2] has the advantage that it describes the collision position of the vehicles at the time of the accident and thus reveals a key aspect of the accident. In addition, by taking into account all kinds of accident, we ensured that the random sample covered all the accident constellations contained in the database. In the pre-analysis of individual cases, we investigated whether any cases of each kind of accident were caused by inadvertent lane departure, and we examined which factors indicated this.

The pre- analysis resulted in two important findings: Firstly, a combination of different factors and their refinements was required in order to properly identify the cases we were looking for. Secondly, it became clear that a vehicle that causes an accident as a result of inadvertent lane departure is almost always the main causer of an accident. It was thus possible to clearly identify the case car in the subsequent analyses.

b: Selection of factors that indicate inadvertent lane departure

The relevant cases were selected by using expert knowledge on the basis of the following factors:

- Kind of accident
- Accident type (three-digit code)
- General accident cause
- Person-related misbehavior (cause per road user involved)
- Location

- Soft shoulder
- Single-vehicle accident (yes/no)
- Party with which the car collides.

Taking into account the above factors, the methodology involved combining the ten kinds of accident with the following three-digit accident types [4]:

- "Other accident" (761-763; 771-775; 799)
- All "driving accidents" (in which the driver loses control over the vehicle), filtered by the criteria "rural road" and "soft shoulder".

After preselecting the accidents with the car as the main causer of the accident (n=2,475), a new set of case material was formed by means of a database query using the factors specified above (n=118 cases). This contained only cases that could be attributed to the inadvertent departure of the car from the lane. In other words, it was the case material we were looking for.

Description of the methodology by means of an example

In the following example the methodology is explained with respect to the identification of the relevant cases:

The case material involving accidents in which the car was the main causer of the accident was filtered on the basis of the fourth kind of accident, "collision with another oncoming vehicle". This kind of accident provides important information on the accident, such as that it was not a single-vehicle accident and that it was a collision with oncoming traffic in which none of the road users involved intended to turn off across the lane of the oncoming traffic. In order to establish the relevance of the case material conclusively, the following questions also had to be answered:

- Which of the road users left their lane?
- Was this road user a car (case car)?
- Did the driver of the car leave the lane intentionally (e.g. in order to overtake) or inadvertently?

In addition to the kind of accident, accident type 7 ("other accident") was included as a further factor. For this accident type, the refinement "sudden physical incapacity" (two-digit code 76) was set as the filter criterion, for example, together with the additional refinement "asleep at the wheel" (three-digit code 761). This three-digit accident type indicates that the accident was caused by a driver who lost control of his or her vehicle as a result of falling asleep. Together with the information "collision with another oncoming vehicle" and the pre-selected criteria "car driver was the main causer of the accident", it was possible to conclude that the accident occurred because the driver left his or her lane inadvertently as a result of falling asleep. Further factors such as "person-related accident cause" (with the refinement "overfatigue") and "location" (with the refinement "rural road without motorway") confirmed this picture.

RESULTS OF THE ANALYSES

The following chapters give a first general description of accidents caused by inadvertent lane departure and they then present the results of the analyses with respect to the main accident scenarios.

Relevance of accidents caused by inadvertent lane departure

From the case material of n=2,475 accidents in which the car was the main causer, a total of n=118 relevant cases were identified by means of the methodology described. In these cases, 33 people were killed, 153 people sustained serious injuries, and 148 sustained minor injuries. Accidents caused by inadvertent lane departure thus made up only 3% of all car accidents and 5% of all accidents caused by cars. However, they accounted for almost 10% of the total of 339 fatalities involved in all car accidents, and are thus highly relevant in terms of accident severity.

Causes of the lane departure

In order to obtain a better understanding of the course of these accidents, the causes of the departure from the lane were examined in relation to the case car.

It was possible to clearly identify the causes in half of the cases (n=50). In descending order of importance, these were:

a. Physical problems and health problems such as overfatigue and faintness or loss of consciousness (66%)
b. Distraction/inattentiveness, e.g. caused by adjusting the navigation system or radio or engaging in some other activity in the car (26%)
c. Alcohol/drugs (6%)
d. Weather conditions, such as heavy rain or fog (2%).

The causes were almost exclusively driver related. The comparatively low number of usable cases was due to the fact that a rather conservative approach was taken to analyzing them. In other words, only cases in which at least one clear cause was ascertained were included. These accident causes were ascertained on the basis of police inquiries, witness statements and medical reports (of low blood sugar or pre-existing medical conditions, for example).

The analyses revealed that physical and health problems were the cause of the inadvertent lane departure in two-thirds of the cases. This cause was twice as common as inattentiveness/distraction (26%). Drugs and/or alcohol (three cases) and severe weather conditions (one case) were found to be the cause far less often.

The distractions involved in the inattentiveness/distraction category originated almost exclusively in the vehicle itself. Examples included adjusting the navigation system, conversations with passengers and searching for things. In a few cases, nothing more was known than that the driver of the case car left the lane due to inattention. These cases were also included in the subsequent analyses.

a: Collision events caused by "physical and health problems": For the above mentioned "physical and health related causes", the collisions that occurred after the lane departure were investigated. The results were as follows:

a. Collision with oncoming traffic on a rural road (n=19)
b. Subsequent collisions on the motorway (n=6)
c. Single-vehicle accident including a collision with an obstacle such as a tree (n=3)
d. "Other", such as a collision with a pedestrian at the side of the road (n=2)

In over half of the cases caused by physical problems, the case car collided with oncoming traffic on a rural road (n=19 cases). It is worth noting here that the underlying case material originated from third-party claims, which means that collisions with oncoming traffic (i.e. with third parties) may be overrepresented, just as single-vehicle accidents are underrepresented, as already mentioned.

The second most common collisions were motorway accidents in which the case car and/or further road users collided with each other (n=6 cases). The accidents often took the following course: The case car left its lane, hit the crash barrier and came to a standstill on the carriageway. Subsequent collisions then occurred between the case car and other road users or between other vehicles without any direct involvement of the case car.

b: Collision events caused by "distraction/inattentiveness": Collisions with oncoming traffic on rural roads were also clearly the most common accidents caused by "distraction/inattentiveness" (nine out of twelve cases).

It was noticeable in five of the nine cases that the case car first went onto the soft shoulder at the side of the road before ending up in the lane for oncoming traffic as a result of the driver overcorrecting. Despite the low number of cases, this result is worthy of note in that the soft shoulder did not play a role in any of the accidents caused by the driver experiencing physical or health problems. One possible explanation for the high proportion of cases in which the car departed from its lane on the right-hand side is that the distracting activities described above generally took

place on the driver's right-hand side. In consequence, the driver unintentionally moved the steering wheel to the right while moving to the right.

Main accident scenarios

In the subsequent analyses, the 118 accidents were subdivided into predefined categories in order to identify the main accident scenarios. For these analyses, vehicle-specific and infrastructure-related aspects were taken into account in order to form these categories. The following factors and their refinements were taken into account and applied in terms of an "analysis path":

- State of the road surface (dry, wet/damp)
- Course of the road (straight road, bend)
- Radius of the bend (greater or less than 200 m)
- Light conditions (daylight, dawn/darkness)
- Severe weather conditions (heavy rain, fog)

Due to a lack of information, 18 cases could not be allocated to any category. This reduced the case material to be analyzed to n=100 cases with n=32 fatalities.

Relevance of the main accident scenarios: A total of five scenarios were identified. These are shown in figure 2 together with the factors described. The five main accident scenarios together account for 68% of the accidents and 66% of the fatalities in the case material of 100 cases.

It has to be mentioned that other combinations of these "analysis paths", resulting in other scenarios, are also possible. Against the background of the planned test procedures for lateral support systems and the use of accident data to support them, this approach was considered to be reasonable. This ensures that the scenarios also address those aspects that describe the characteristics of the sensors of lateral support systems and can also be tested in future.

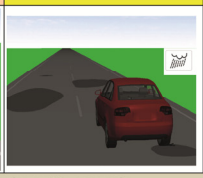
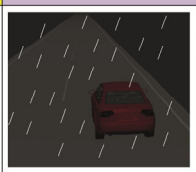
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Relevance and brief description						
Filter criteria for assignment to a scenario						
Road surface		Dry	Dry	Damp/wet	Damp/wet	Damp/wet
Course of the road		Bend	Straight	Straight	Straight	Bend
Radius of the bend		≥ 200 m	-		-	≥ 200 m
Light conditions		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

Figure 2. Main accident scenarios for accidents caused by inadvertent lane departure

For example, according to figure 2 all accidents that met the following criteria were allocated to Scenario 1:

- Dry road surface
- Daylight
- Accident in the vicinity of a bend with a radius of at least 200 m
- No severe weather conditions such as heavy rain or fog.

In-depth analysis of the main accident scenarios

In the course of a more in-depth analysis, the following aspects were examined more closely, allowing the scenarios to be described in greater detail in relation to the test procedures mentioned:

- Location
- Lane width
- Type and location of the road markings
- Speed of the case car
- Typical collision opponent of the case car
- Direction of the lane change before the collision
- Driver-related causes
- Age of the driver.

The results are shown in Table 1.

Scenario	Percentage (n=100)	Location	Typical lane width	Typical speeds	Lowest speed	Highest speed	Type and location of the road markings		Typical collision opponent and direction of the lane change before the collision		Average age of the drivers (only cases with a known cause)	Typical driver-related causes for inadvertent lane departure	Average age of drivers with health problems
S1	27	Rural roads	2-3 m	86 km/h	45 km/h	160 km/h	Left	Broken	Car	To the left	59	Health problems (45%), distraction/inattention (36%), overfatigue (9%), drugs (9%)	72
							Right	Continuous					
S2	23	Rural roads	2-3 m	91 km/h	50 km/h	140 km/h	Left	Broken			51	Health problems (38%), overfatigue (23%), distraction/inattention (38%)	61
							Right	Continuous					
S3	7	Rural roads	3-4 m	68 km/h	40 km/h	90 km/h	Left	Both			55	Health problems (50%), overfatigue (25%), alcohol/drugs (25%)	52
							Right	Both					
S4	6	Both urban and rural roads	2-3 m	100 km/h (one case)			Left	Broken			22	Overfatigue (75%), alcohol/drugs (25%)	-
							Right	Continuous					
S5	5	Rural roads	2-3 m	67 km/h	50 km/h	90 km/h	Left	Broken			48	Health problems (25%), overfatigue (25%), distraction/inattention (25%), severe weather conditions (25%)	25
							Right	Continuous					

Table 1. Descriptive details of the five main accident scenarios

The in-depth analysis revealed following results:

- With only a few exceptions, all accidents took place on rural roads with typical lane widths of 2 to 3 meters.
- There was at least one road marking present in all cases.
- The most frequent collision opponent of the case car was another car (in 70% of the cases). The case car always departed from its lane on the left-hand side before colliding with the other car.
- The average age of the drivers who had inadvertently left their lane due to health problems was 67 in the two most common scenarios (S1 and S2, which accounted for 50% of the case material).
- The most common health-related cause was faintness (as a result of low blood sugar, for example).
- Falling asleep at the wheel was specified most often in connection with the cause “overfatigue”.

- The following ranking was obtained for driver-related causes:

  - Health problems: e.g. faitness (36%)
  - Distraction/inattention (27%)
  - Physical problems: e.g. overfatigue (25%)
  - Alcohol/drugs (8%).

Main accident scenarios under the consideration of test procedures

As a result of the finding that over a third of the cases were attributable to health problems of the driver, and that these were thus cases in which the driver's reaction and acting were significantly impaired, the scenarios had to be adjusted. In the cases described, it is highly unlikely that the accidents could have been prevented by lateral support systems, and the scenarios would thus not be suitable for the planned test procedures.

Figure 3 therefore shows what the structure of the scenarios would look like if only cases with known causes were used, and cases caused by health problems were excluded. For this new structure the analysis revealed that the five scenarios would remain the same but their ranking would change. Within the individual scenarios marginal changes in the average driven speeds of the case car could be observed.

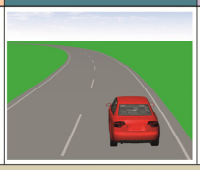
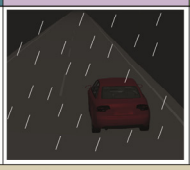
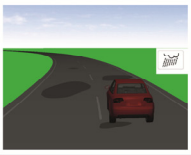
Relevance and brief description (only cases with a known cause, excluding the cause "health problems") n=23 accidents; n=4 fatalities		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
						
Filter criteria for assignment to a scenario						
Road surface		Dry	Dry	Damp/wet	Damp/wet	Damp/wet
Course of the road		Straight	Bend	Straight	Bend	Straight
Radius of the bend		-	≥ 200 m	-	≥ 200 m	-
Light conditions		Daylight	Daylight	Dawn/darnkess	Daylight	Daylight
Severe weather conditions		None	None	Heavy rain	None	None
Additional information						
Number of accidents	n	8	6	4	3	2
Number of fatalities	n	1	2	0	0	1
Average speed of the case car		71 km/h	77 km/h	Unknown	70 km/h	80 km/h

Figure 3. Rearrangement of the main accident scenarios with the following constraint: only cases with a known cause of the inadvertent lane departure and excluding cases caused by health problems

CONCLUSIONS

The analysis of car accidents caused by inadvertent lane departure showed that, although these accidents only occur rarely (accounting for 3% of all car accidents), they have serious consequences (accounting for 10% of all fatalities in car accidents). The most common reasons for inadvertent lane departure were physical and health problems and distraction/inattention. The main accident scenarios that were deduced from the analyses account together for 68% of the accidents and 66% of the fatalities in the case material (n=100 cases).

It was found that, in the main accident scenarios, most drivers inadvertently left their lane on a straight road, in daylight and on a dry road surface (i.e. in nearly ideal driving conditions). However, it was also found that over a third of these cases could be attributed to health problems of the driver and that over half of the drivers affected were over 60 years old. In view of the high percentage of accidents caused by health problems (36%), it is clear that there are limits on how effective current lateral support systems can be. The systems are not capable of preventing these

accidents. For the future there is a need to consider systems that are effective regardless of the location (on rural roads or on motorways) and that bring the vehicle to a standstill safely when the driver is no longer in a fit state to drive. Consequently, for the scenarios identified for the purpose of testing the features of lateral support systems, only those cases that are not attributable to health problems should be taken into account.

The following findings were also obtained in relation to these scenarios:

- 75% of the accidents occurred on a dry road surface, with 25% thus taking place on a wet road surface.
- Most case cars initially left their lane on the left-hand side.
- They then collided with an oncoming vehicle.
- At the point at which they left their lane, the case cars were generally traveling at over 70 km/h.
- At least one road marking was present in all cases. In cases where the case car left the lane on the left-hand side, there were both broken and continuous markings (to indicate that overtaking was prohibited, for example).
- Dawn/darkness and severe weather conditions (heavy rain, fog) were not significant factors in lane departure.

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SAFETY ASSESSMENT PROCEDURE FOR ADVANCED EMERGENCY BRAKING SYSTEM

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ABSTRACT

This paper suggests a safety assessment procedure for evaluation of enhanced longitudinal safety by Advanced Emergency Braking (AEB) system in Korea. The objective of project is to suggest safety evaluation procedure of the AEB system with the consideration of Korean road condition and physically meaningful situation.
To develop the impact assessment procedure of the AEB system, the AEB test vehicle as well as the test scenario should be designed. Before the development of the test procedure, this paper reviews the international regulation of AEB system and traffic accident statistics, and develops domestic safety standards and evaluation requirements. Test scenario has been developed to assess the safety performance of AEB systems for the reductions in collision frequency and severity by using the Korea's traffic accident statistics. Also, the test scenario is designed to represent the real driving condition and to evaluate the safety performance of AEB system in various situations. The AEB test vehicle comprises of a millimeter wave radar sensor, CCD camera and pre-developed AEB algorithm of which are processed to judge the collision risk. To evaluate the collision avoidance performance of the AEB test vehicle, pre-performance test was conducted by using the NCAP-AEBS draft test procedure and proposed test scenario.
From the traffic accident statistics and the field test result, it is shown that proposed AEBS test scenario represents not only the frequently occurred collision case but also physically meaningful situation in terms of expected control performance of the AEB system. Also, it has been shown that AEB system of prior study can reduce the collision velocity and provide the greatest real world benefits. Because of the limitation of test equipment and safety, test scenario about Cut-in vehicle could not be included in the test results of the proposed test procedure. However, by using the analysis methods and simulation test, the safety effect for enhanced longitudinal safety of the AEBS with respect to Cut-in case has been assessed scientifically.
In this paper, the safety assessment procedure for AEB system has been described to evaluate the safety performance of the AEB system. The test procedure according to AEB system provides objective safety performance level of each AEB system. Also, these tests are expected to be a strong driver of improved safety in the real world.

INTRODUCTION

Since the passive safety systems, such as seat belts, airbags or active head-rest, etc., became part of almost every vehicle, the demands of vehicle active safety system had been also getting larger. Therefore, many automakers are trying to help drivers to avoid or mitigate collision using active safety system. Several systems are already commercialized including Adaptive Cruise Control (ACC), Traffic Jam Assist (TJA), Lane Keeping Support (LKS), Lane Change Assist (LCA), Blind Spot Detection (BSD), Automated Parking Assist (APA) and Forward Collision Warning System (FCWS). [1]~[6] Especially, Advanced Emergency Braking (AEB) system is one of the active safety system which is supposed to be able to significantly contribute to reduce the number of road fatalities.
After AEB system was developed and commercialized, the number of vehicles with AEB system have been increased and is predicted to be increased more. Also, as AEB system became one of the most interesting topic for researchers and automakers, there have been many studies to improve the performance of AEB system. Therefore, each of AEB systems developed in different ways which means it is difficult to compare the performance between

each AEB systems. Hence, the studies to evaluate the performance of these AEB systems are required. Governments and research centers of many countries such as Euro NCAP and International Organization for Standardization (ISO) have been studied about the regulation of AEB system and some of them already announce a standard regulation. The regulation of ISO is already using as a standard of safety performance for the commercialization of AEB system. Euro NCAP provides objective standards about the safety performance of AEB system. [7] However, these regulations are still not perfect to guarantee the safety by AEB system in various situation.
In the case of Korea, there is no specific regulation about the performance of AEB system. According to the National Policy statistics in Korea, the total number of deaths in 2010 caused by traffic accidents in Korea was 5,505 which means about 2.6 per 10,000 cars experianced the fatal accident. It was the twice the OECD average of 1.3. [8] In 2009, Traffic Accident Analysis Center of Korea reports that almost 60 percent of traffic accident was longitudinal accident. Hence, the regulation which is based on the Korean road condition is required to reduce the collision frequency and severity.
In this paper, the international regulation of AEB system and the traffic accident statistics are reviewed. The typical factors which should be considered for the development of AEB test scenario are summarized.Then, we present the AEB test scenario which contains the characteristics of traffic accident of Korea and represents not only the frequently occurred collision case but also physically meaningful situation. Last of all, the proposed test scenario is verified via computer simulation and vehicle test.

TRAFFIC ACCIDENT STATISTICS AND THE STATUS OF REGULATION OF AEB

In this chapter, traffic accident statistics and the international regulations of AEB are reviewed.

Traffic Accident Statistics

To develop the test scenario for the evaluation of the performance of AEB systems which is appropriate to the case of Korea, traffic accident statistics of Korea should be studied. In this section, the type of traffic accident of Korea is reviewed based on the reports of Traffic Accident Analysis Center of Korea. Also, to determine the specific ratio of each type of collision which was not exists in the case of Korea, international traffic accident statistics is also reviewed.

Korea Lee analyzed the traffic accident of Korea from 2005 to 2009 based on the reports of Traffic Accident Analysis Center of Korea. [9], [10] He analyzes and classifies the traffic accident statistics based on the two topics: violation of law and human factor. Based on the case of violation of law, almost 50 percent of all traffic accident was caused by the violation of the duty to drive safely. Signal violation and safe distance violation was followed. Safe distance violation which is closely related with the longitudinal safety was 13.7 percent of traffic accident. According to the classification based on the human factors, almost 60 percent of traffic accident was caused by the negligence in forward-looking which is also closely related with the longitudinal safety.

International NHTSA reports about the situation and driving condition of traffic accident. [11] According to the report of NHTSA, traffic accident which occurred in America can be classified into 7 categories, and 39 percent of total traffic accidents were longitudinal collision. Also, in order to analyze the situation of traffic accident, NHTSA classify the traffic accident into 45 kinds of typical scenarios. Five of them were closely related with the longitudinal safety, which are about 28.9 percent of total traffic accidents.

Regulation of AEB system

Research centers of many countries have been studied about AEB system for the announcement of regulation of AEB system. In this section, the regulation of Euro NCAP and ISO are introduced.

Euro NCAP Euro NCAP classifies the AEB test procedure into 2 cases: City and Inter-Urban test procedure. [12] For AEB City test scenario, they evaluate the performance of AEB in low speed region while

the preceding vehicle is at standstill. For AEB Inter-Urban test scenario, they evaluate the performance of AEB in low and high speed region for the cases of which the preceding vehicle is stationary, slowly moving and braking with constant deceleration. The scoring of each test procedure was developed based on the statistical data about the frequency and severity of traffic accident at each speed region. However, they only regulate the performance of AEB in the case of straight road and simple target condition. Hence, the performance of AEB in curve or other driving situation cannot be guaranteed. Also, they focused only on the avoidance and mitigation of the collision which means the excessive control of AEB system cannot be verified through their regulation.

ISO ISO also announce the regulation of AEB system. They evaluate the performance AEB with the vehicle speed from 15 km/h to the maximum available speed. They suggest that the AEB system should be able to reduce the impact speed more than 20 km/h for the stationary target, and to avoid the collision for the moving target with the speed of 12 km/h. Also, they regulate about the warning timing of AEB system. However, they also regulate the performance of AEB only in simple cases: straight road and single target condition.

REPRESENTATIVE FACTORS OF AEB TEST SCENARIO

For the evaluation of the performance of AEB system, test scenario should represent not only the frequently occurred collision case but also physically meaningful situation. Hence, many factors such as driving mode, road type, environment, and AEB system element should be considered to evaluate the performance of AEB system. The typical factors are summarized in fig. 1. The AEB test scenario should contains these factors to varify the performance of AEB in various situation.

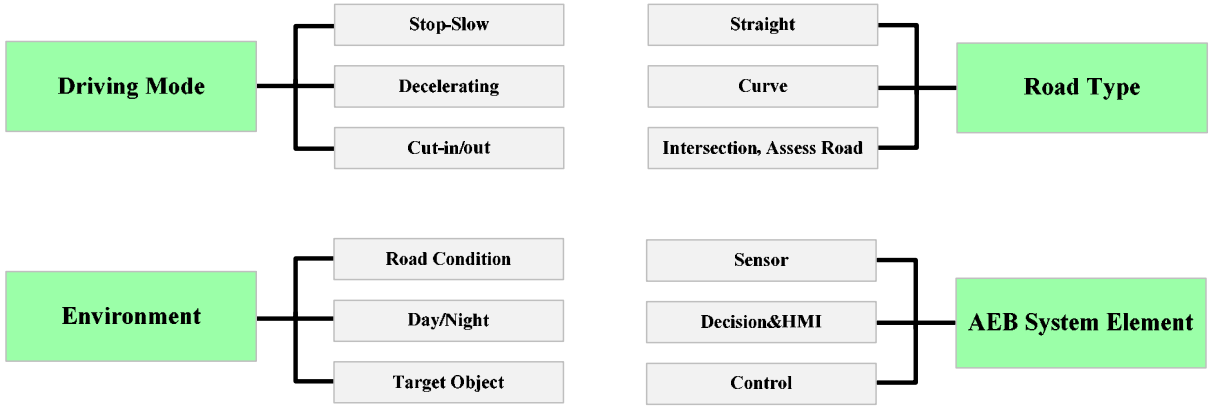


Figure1. Representative factors of AEB scenario.

Driving Mode

The performance of AEB should be guaranteed in various kinds of driving condition especially about the behavior of preceding vehicle. To evaluate the performance of AEB, the vehicle with AEB should be tested in both normal and severe conditions. The typical examples of these driving modes are introduced in this section.

Preceding Stop-Slow Vehicle In city-driving condition, lots of crashes occur between the stationary or stop preceding vehicle and following vehicle. Hence, the response of AEB about the slow or stop preceding vehicle should be evaluated.

Preceding Decelerating Vehicle Many drivers do not use large deceleration in normal driving condition. However, dangerous situation makes driver to use large deceleration which can make a secondary accident with the following vehicle. If the preceding vehicle is decelerating with large deceleration in some reasons, it is difficult to react quickly for the driver of following vehicle. Hence, AEB should indicate the danger to the driver and should determine to decelerate the vehicle automatically in proper moment unless the driver reacts about the dangerous situation. Although the AEB cannot prevent the crash perfectly, it should decrease the severity of the accident. Hence, the performance of AEB about the preceding decelerating vehicle should be verified.

Preceding Cut-in/out Vehicle Sudden Cut-in or Cut-out situation can be a risk to the following vehicle. In this situation, the flexible reactions about each case are very important. If the Cut-in or Cut-out situation makes the situation dangerously, the proper reaction of the driver is required. In this situation, AEB should indicate the danger to the driver and determine to decelerate the vehicle in proper moment to avoid the crash or decrease the severity of the crash unless the driver reacts about the danger. Hence, the performance of AEB in Cut-in or Cut-out situation should be also evaluated. Also, if the Cut-in/out situation is not dangerous to the following vehicle, AEB should not be activated. The undesired and unnecessary reaction of AEB could disturb the driver. Hence, the deactivation of AEB in safe Cut-in/out situation should be verified.

Road Type

In City road condition, various types of road are exists which could effect on the performance of the AEB. Including the straight road condition, AEB should guarantees the performance on curve or other road types.

Straight Road According to the NHTSA's report, for about 40 percent of the collision was longitudinal collision. [11] Hence, the performance of AEB in longitudinal collision situation should be evaluated importantly

Curve In slow speed condition, dangerous situation is occurred when the distance between the vehicles is relatively small. In this situation, the effect of curvature of the road is small because the lateral offset of the preceding vehicle at dangerous situation is relatively small. However, in high speed region, the effect of curvature of the road is not negligible. AEB system should classify the vehicles which are on the same lane and which are not. If AEB system is failed to recognize the preceding vehicle on the same lane in curve, AEB could not response about the danger at proper moment which can lead to an accident. If AEB response about the vehicle on other lane and decelerate the vehicle, it can disturb the driver. Hence, deactivation of the AEB by the vehicle on other lanes should be also verified as well as the activation by the vehicle on same lane.

Other Road (Intersection, Access Road) Various types of road condition including the mentioned situation are exists in normal city driving condition. Although the straight and curve road condition are more frequent, complex road conditions such as intersection and assess road is more dangerous. However, the performance of AEB cannot be guaranteed perfectly in these complex situations due to the limitation of the perception range of AEB system. Hence, the evaluation of the performance of AEB in complex driving mode such as intersection and assess road is not considered in this paper. However, these topics are suggested to be considered on the evaluation of the performance of advanced active safety system or advanced driver assistance systems (ADAS).

Environment

AEB should also guarantee the performance in unusual environment. Although the performance of AEB on unusual environment cannot be perfect, AEB should guarantee a certain level of safety performance. Hence, AEB performance on unusual environment condition should be evaluated.

Road Condition Braking distance of the vehicle became longer in wet road condition. In this situation, AEB should response about the danger quickly than usual situation. Even if AEB cannot estimate the road condition, it should guarantee a certain level of safety performance on the wet road condition.

Day/Night Condition In night-time driving condition, driver's sight became narrow which makes the required time to recognition and decision became larger. Hence, AEB system should indicate the danger to the driver and response about the danger properly in night-time driving condition. However, some kind of sensors such as vision sensors are vulnerable to a night condition. Also, although vehicles are visible at night due to the headlight and taillight of the vehicle, pedestrian or other kind of obstacles are not visible. Hence, the performance of AEB in night-time driving condition is suggested to be evaluated.

Target Object In city-driving condition, pedestrian or other obstacles on the road can lead to an accident. Hence, AEB should perceive the pedestrian or other obstacles as well as the preceding vehicles. Especially, AEB should be able to perceive the pedestrian and response about the danger because car to pedestrian accident can lead to a fatal accident. Hence, the performance of AEB about the pedestrian target should be verified.

AEB System Element

AEB system should contain four parts: sensor part, decision and Human Machine Interface (HMI), control, and actuator. The characteristics and general requirements of each part are explained in this section.

Sensor Sensor part perceives the target in the range. It should classify the target type such as preceding vehicle, pedestrian and other kind of obstacles and it also should be able to classify the two-wheeled vehicle or other specific targets. It should provide the target information including the type of target, target position, and preceding vehicle relative velocity. Multi-target perception and tracking should be available. The longitudinal and lateral perception range of sensors should satisfy the range requirement for the operation of AEB. Certain level of accuracy in unusual driving condition should be also guaranteed as well as in normal driving condition.

Decision & Human Machine Interface (HMI) Decision part selects the proper target between the perceived multi targets and recognizes the risk. Decision part should be able to track the multi-target simultaneously and select the proper target to response in dangerous situation. Hence, this target selecting ability should be also guaranteed in multi-vehicle condition and curve or other complex driving conditions. Also, tracking ability including the tracking delay about new target should be evaluated. In order to evaluate the safety performance of AEB, warning and decelerating timing can be a standard of evaluation.
HMI is the part which indicates the danger to the driver and responses about the drivers input. HMI should indicate to the driver visually, acoustically, or in other ways to make driver react about the danger. In this situation, HMI should perceive the change of driver's behavior. If driver react about the danger, HMI should hand over the control authority to the driver. This change of control authority should be evaluated as well as the safety performance of AEB with and without driver's braking input: for example, if the amount of brake of the driver is not enough, AEB should make the vehicle to decelerate more.

Control Control part decelerate the vehicle in proper amount of deceleration for each situation. Although a small amount of deceleration can be lead to an accident, large amount of deceleration can disturb the driver and make driver inconvenient. The appropriate range of deceleration which doesn't make driver inconvenient

is difficult to be determined theoretically. Hence, driving data based determination is usually suggested to guarantee the comfort of driver as well as the safety performance of AEB.

Actuator In order to guarantee the performance in real driving condition, the actuator part should be durable. Hence, the durability about vibration, repetitive decelerating condition, and environmental change should be guaranteed.

AEB TEST SCENARIO

Based on the international AEB regulation and the typical factors of AEB test scenario which are mentioned in previous chapters, the required AEB test scenario for the evaluation of the performance of AEB system can be determined. However, although the exact performance of AEB system in various situation can be evaluated through a great number of test scenarios, limited test is available due to the limitations. Hence, significant and necessary test scenario should be selected. The summarized test scenario for the evaluation of the performance of AEB system is described in table 1. In this chapter, only three cases of test scenario is explained.

Table1.
AEB test scenario.

<table>
<tr><th>Item</th><th>Preceding Vehicle</th><th colspan="2">Specifics</th><th>Test No.</th></tr>
<tr><td rowspan="6">Test No. 1
Straight</td><td rowspan="3">Stop Vehicle</td><td rowspan="2">Vehicle Target</td><td>Dry Asphalt</td><td>1-1D</td></tr>
<tr><td>Wet Asphalt</td><td>1-1W</td></tr>
<tr><td colspan="2">Pedestrian Target</td><td>1-1P</td></tr>
<tr><td colspan="3">Slow Vehicle</td><td>1-2</td></tr>
<tr><td colspan="3">Decelerating Vehicle</td><td>1-3</td></tr>
<tr><td colspan="3">Cut-in Vehicle</td><td>1-4</td></tr>
<tr><td>Test No. 2
Curve</td><td colspan="3">Stop Vehicle</td><td>2-1</td></tr>
</table>

Straight Road Preceding Decelerating Vehicle

The main purpose of AEB system is avoidance or mitigation of the collision in longitudinal direction. Preceding deceleration vehicle is one of the typical scenario of longitudinal traffic accident.

Scenario In straight road, the large deceleration of preceding vehicle can cause an accident. Especially, if the driver of subject vehicle fails to recognize the deceleration of the preceding vehicle, it can lead to a fatal accident. Hence, warning and braking of the AEB system in this situation should be evaluated.

Performance evaluation In straight road preceding vehicle decelerating situation, AEB should indicate the danger to the driver. Also, unless the driver reacts about the danger, AEB should determine to decelerate the vehicle automatically to avoid or mitigate the danger. For this, AEB should be able to perceive the target in proper range and recognize the danger. Hence, the warning and decelerating timing of the AEB system should be evaluated. Also, the relative speed of the impact and the reduction of the subject vehicle speed should be in safe region.

Straight Road Preceding Cut-in Vehicle

AEB system should be able to response about sudden change of traffic condition such as cut-in case.

Scenario The test scenarios of the Euro-NCAP and ISO already include the preceding stop, slow, and decelerating vehicle. However, these three scenarios cannot evaluate the response about an unexpected obstacle or vehicle. Preceding cut-in vehicle situation is one of the representative situations of the danger caused by unexpected obstacles or vehicles. However, in normal driving condition, cut-in vehicle with similar speed does not always lead to an accident. In this situation, the response of AEB system could disturb the driver and make the driver inconvenient. Hence, the response of AEB system about both safe and dangerous Cut-in cases should be verified.

Performance evaluation When the preceding vehicle cuts in with deceleration, AEB should be able to recognize the danger and indicate the danger to the driver. Unless the driver reacts about the danger, AEB system should determine to decelerate the vehicle automatically to avoid or mitigate the collision. However, if the cut-in of preceding vehicle doesn't cause a danger, AEB system should not be activated. Hence, the deactivation of AEB system in safe Cut-in situation should be evaluated as well as the activation of AEB system in dangerous Cut-in situation. In the case of cut-in with decelerating situation, the warning and decelerating timing should be checked as well as the collision avoidance or reduction of the impact speed. Also, in the case of safe cut-in situation, the deactivation of AEB should be verified.

Curve Road Preceding Stop Vehicle

Regulation of Euro-NCAP and ISO evaluate the performance of AEB only in straight road condition. However, in city and inter-urban case, the driver should meet lots of curves. Hence, AEB performance in curve road also should be evaluated.

Scenario City and Inter-Urban condition contains lots of curve road situation. Hence, AEB system should guarantee the safety performance in curve road condition to guarantee the safety in city or inter-urban driving condition. For this, AEB system performance in curve road condition should be evaluated. In curve road situation, target perception and decision part is the most important part while other performance of AEB can be also evaluated in the case of straight road condition. Curve road stop vehicle situation is the most typical and simple scenario between the curve road situation.

Performance evaluation factor In the case of curve road stop vehicle scenario, the most important part is perception and recognition of the target on same lane. For this, activation by the preceding vehicle on same lane and deactivation by the obstacle on other lanes should be assessed. The effect of curvature became larger at high speed region. Hence, the performance of AEB system should be evaluated in high speed region. For the same lane stationary obstacle, perception and recognition of the AEB system should be evaluated as well as warning and decelerating timing. Since the test should be proceeded in high speed region, impact speed and relative impact speed also should be verified. For the stationary obstacle on other lanes, failure of the perception or recognition should be verified.

SIMULATION AND VEHICLE TEST RESULT

In this chapter, the simulation and field test result of the proposed AEB test scenario is proposed. For this, AEB algorithm which is presented in previous research is introduced in the first section. Using this AEB algorithm, computer simulation was conducted using simulation toll Carsim and MATLAB/Simulink. Also, vehicle test was also conducted. However, cut-in and curve test scenario couldn't be included due to the limitation of test equipment and safety.

AEB Algorithm

In the study of Lee, AEB algorithm based on a new safety index was proposed. [Lee 2015] The new safety index was developed by using time to collision (TTC) and warning index (x). TTC and warning index is defined as:

$$TTC = \frac{C}{v_{rel}} \qquad \textbf{(1)}$$

$$x = \frac{C - d_{br}}{d_w - d_{br}} \qquad \textbf{(2)}$$

where C is clearance, v_{rel} is relative velocity, and d_{br}, d_w are braking-critical and warning-critical distances which are defined as follows. [13]

$$\begin{aligned} d_{br} &= v_{rel} \cdot t_{brake} - \frac{{v_{rel}}^2}{2a_{\max}} \\ d_w &= v_{rel} \cdot t_{thinking} + v_{rel} \cdot t_{brake} - \frac{{v_{rel}}^2}{2a_{partial}} \end{aligned} \qquad \textbf{(3)}$$

where t_{brake} is system delay, which is given by the brake-system hardware, $a_{\max}$ is the maximum deceleration of the vehicle under driving conditions, $t_{thinking}$ is the delay in human response between recognition and manipulation. [14] Using these indices, new longitudinal safety index can be defined as follows. [7]

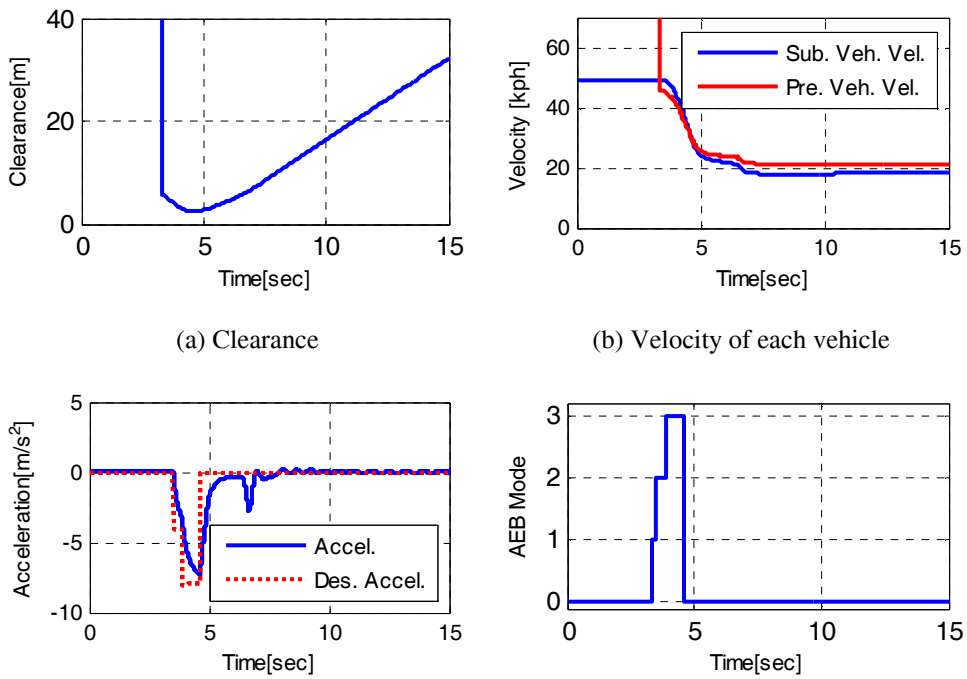
$$S_{Longi} = \sqrt{\left(\frac{TTC - TTC_{Partial}}{TTC_{Emergency} - TTC_{Partial}}\right)^2 + \left(\frac{x - x_{Partial}}{x_{Emergency} - x_{Partial}}\right)^2} \qquad \textbf{(4)}$$

where $TTC_{Partial}$, $TTC_{Emergency}$, $x_{Partial}$, and $x_{Emergency}$ are the thresholds for the control mode selection of AEB system which can be determined physically:Warning mode, Partial braking mode and Emergency braking mode.
Based on this new longitudinal safety index, AEB algorithm select the control mode: warning mode determines to indicate the danger to the driver, partial braking mode determines to decelerates the vehicle with small deceleration, and emergency braking mode determines to decelerate the vehicle with the maximum deceleration.

Simulation Result

Computer simulation was conducted using simulation tool Carsim and MATLAB/Simulink. In this paper, the simulation result of Cut-in with decelerating vehicle scenario is presented.

Simulation Case: Cut in with Decelerating Vehicle The simulation result of Cut-in with decelerating vehicle scenario is shown in fig.2. Initially, radar sensor of subject vehicle failed to detect the preceding vehicle due to the lateral offset of preceding vehicle. After the preceding vehicle started to cut in, lateral offset decreased and radar based target perception became possible. However, since the preceding vehicle was decelerating during the cut-in, clearance between the preceding vehicle and subject vehicle is smaller than 10 m when the preceding vehicle started to be detected. Hence, as described in fig.2 (d), AEB started to indicate the danger, and started to decelerate the vehicle due to the assumption that driver didn't look forward at that moment. As described in fig.2 (a), collision was avoided and the velocity of subject vehicle was successfully decelerated. This result shows that the proposed AEB system performs well in the Cut-in with decelerating vehicle scenario.



(a) Clearance

(b) Velocity of each vehicle

(c) Acceleration

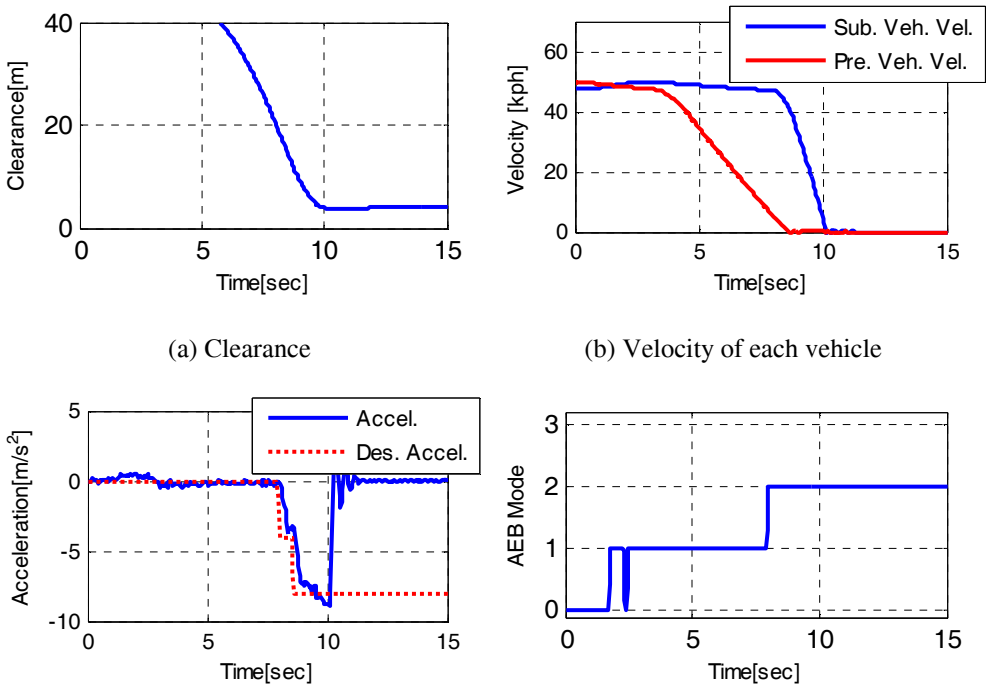
(d) AEB Control Mode

Figure2. Simulation result of AEB system in preceding cut-in with decelerating vehicle scenario.

Vehicle Test

To confirm that the proposed AEB test scenario is realistic and physically meaningful, vehicle test have been conducted. The proposed AEB algorithm is implemented on vehicle. A millimeter wave radar sensor and carge-coupled device (CCD) camera are equipped to detect the preceding tret, pedestrian, and obstacles. The Euro-NCAP vehicle target which is physically linked with another vehicle was used as a preceding vehicle target for the preceding moving target cases. In this section, test result of the straight road decelerating vehicle scenario which is also included in the regulation of Euro NCAP is presented.

Test Case: Straight Road Decelerating Vehicle The test result of the straight road decelerating vehicle scenario is shown in fig.3. The initial speed of subject and preceding vehicle was 50 km/h and initial clearance was about 50m. As shown in fig.3, after the preceding vehicle started to be decelerated with constant deceleration of 0.2g, clearance between the preceding vehicle and subject vehicle was also decreased. However, the subject vehicle maintained the initial speed according to the assumption that there was no reaction of driver about the danger. Therefore, AEB system indicates the danger to the driver which is expressed as AEB Mode 1, and AEB system started to decelerate the vehicle automatically which is expressed as AEB Mode 2. Fig.3 shows that proposed AEB algorithm performed well in the straight road preceding decelerating vehicle situation.



(a) Clearance

(b) Velocity of each vehicle

(c) Acceleration

(d) AEB Control Mode

Figure3. Test result of AEB system in preceding decelerating vehicle scenario.

CONCLUSIONS

In this paper, a safety assessment procedure for evaluation of enhanced longitudinal safety by Advanced Emergency Braking (AEB) system has been developed. The proposed AEB test scenario consists of 7 cases which include straight road cut-in vehicle scenario and curve road stop vehicle scenario. In order to determine the AEB test scenario which represents the real driving condition, the typical factors such as driving mode, road type, environment, and AEB system element should be considered to guarantee that the proposed AEB test scenario represent not only the frequently occurred situation but also physically meaningful situation.
The proposed AEB test scenario has been validated based on the investigation on international regulation of AEB system and traffic accident statistics. In order to verify the proposed AEB test scenario, AEB algorithm of prior study was conducted via computer simulation and vehicle test. The simulation and vehicle test results show that the proposed AEB test scenario was realistic and physically meaningful.
In order to develop the specific regulation such as rating criteria and detail procedure of each test scenario, additional experimental test should be conducted with various AEB systems.

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THE DEVELOPMENT OF ASSESSMENT TECHNOLOGIES FOR ADVANCED SAFETY VEHICLES

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ABSTRACT

Like many industrialized countries, the Republic of Korea (ROK) has implemented policy and research aimed at reducing the number of casualties caused by traffic accidents. For example, ROK launched the project titled "Reduce traffic casualties by half in 10 years" in 2008, Sweden introduced the Vision Zero Policy in the late 1990s, and other European Union members have launched similar projects aimed at reducing traffic accident fatalities by between 30 to 50 percent.

To reduce the number of casualties from road accidents requires improvements to vehicles, road and traffic managements systems. To expedite this process Intelligent Transport System has been adapted and implemented to the vehicles and road systems.

Vehicles with advanced safety features will be expected to reduce or prevent accidents which drivers cannot not respond to or perceive.

To date, there has been insignificant research into the effective performance of vehicles with advanced safety features. The lack of assessment procedures has impeded the public acceptance of vehicles with advanced safety features.

The Development of Assessment Technologies for Advanced Safety Vehicles has been introduced for the promotion of advanced safety vehicles. The project involves the development of assessment technologies for advanced safety vehicles.

This paper shows the development of assessment methods for passive and active safety technologies. These technologies primarily address active protection for pedestrians, rear passenger safety, lane keeping assistance system, and automatic emergency braking system.

INTRODUCTION

Industrialized countries around the world, including the Republic of Korea (ROK), have implemented policies and research aimed at reducing traffic casualties. The goal has been to reduce traffic casualties by between 30 to 50 percent within ten years through policies that include ROK's "Reduce Traffic Casualties by Half" campaign and Europe's "Vision Zero" policy.

To attain such goals, it is necessary to complement and improve road and traffic systems including automobiles. Technologies utilizing Intelligent Transport System (ITS) in automobiles and road systems are actively being studied and disseminated as a way to expedite such improvements to road and traffic systems.

It is expected that the prevention of traffic accidents and improvements to traffic flow can be achieved by strengthening traffic infrastructure on roads that will enable communication between a vehicle and a road or between vehicles. In addition, vehicles themselves can be fitted with advanced safety features through convergence with IT technology, which can contribute to reducing traffic accidents through avoiding or preventing possible accidents by perceiving, assessing and responding to accident situations or by minimizing damage in the event of an unavoidable accident.

These state-of-the-art safety features can help prevent or reduce accidents by effectively responding to traffic situations to which a driver is unable to respond or perceive. For this reason, it is critical to develop and disseminate advanced safety features to reduce the number and severity of road traffic accidents.

However, it is not easy to disseminate and promote either advanced safety features or automobiles with advanced safety vehicles. This is because there has been insufficient research into the effective safety performance of those cutting-edge safety features and no technology has yet been developed to assess their safety performance.

Accordingly, this paper will assess the Advanced Safety Vehicle Project (hereinafter referred to as ASV Project), which aims to secure the safety performance of advanced safety vehicles. This research is thus designed to encourage the dissemination of advanced safety vehicles by providing independent justification for the development and application of advanced vehicle safety technologies.

ABOUT THE PROJECT

Implementation System

The ASV Project is a project funded by the Ministry of Land, Infrastructure and Transport and the Korea Agency for Infrastructure Technology Advancement. The lead research institute of the project is the Korea Automobile Testing and Research Institute under the Korea Transportation Safety Authority, and thirteen co-research institutes include Hyundai MOBIS and Seoul National University (Figure1).

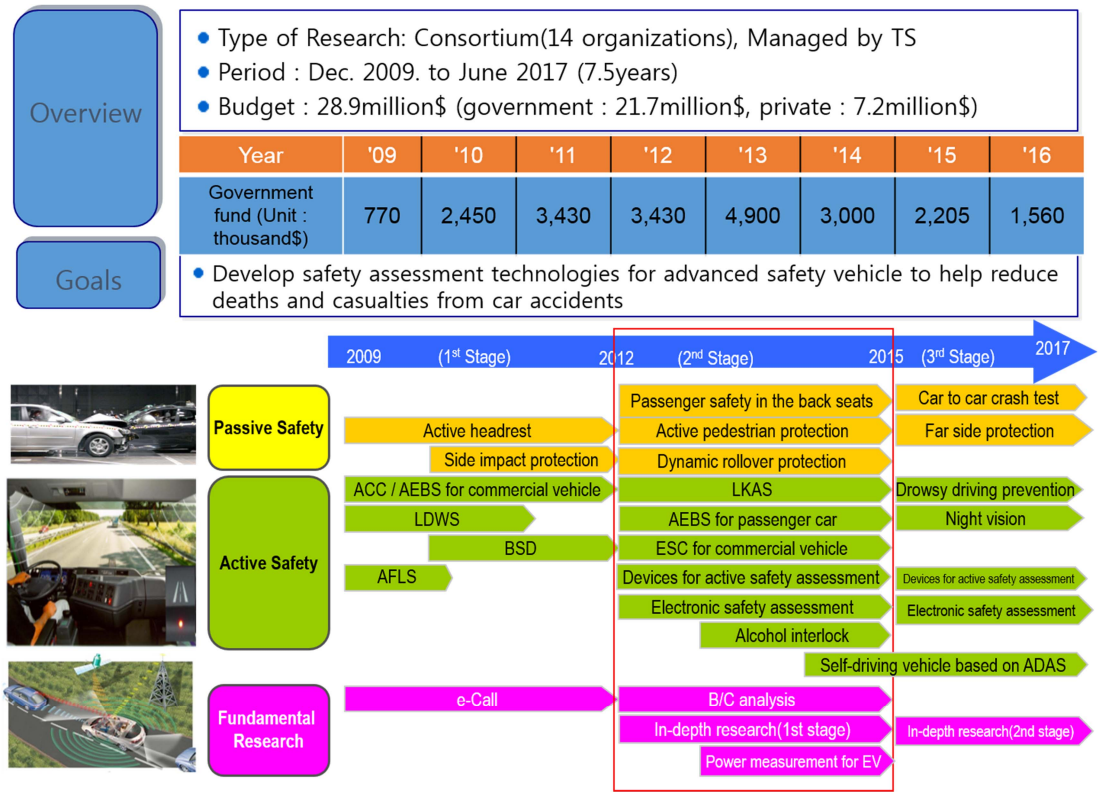


Figure1. Roadmap for the development of assessment technologies for advanced safety vehicles

The total project duration is eight years from December 2009 to July 2017 and consists of three phases (Phase I - 3 years, Phase II - 3 years, and Phase III - 2 years). The total research budget is 28.9 billion dollars. At present, the project is in the third year of Phase II, and Phase II research is scheduled to end in June, 2015.

Research Roadmap

The research area of the ASV Project is largely divided into three parts: crash safety technology, preventive safety technology and base technology. Research on crash safety technology is dedicated to examining the technologies required to improve the safety performance of passive safety technologies for pedestrians, as well as vehicle occupants in the event of a road traffic accident. By contrast, research into preventive safety technology is designed to develop the assessment technologies required to verify the safety performance of advanced safety features equipped with various active safety technologies to prevent traffic accidents. Lastly, research into base technology is designed to conduct research on the technologies required to support the development of passive and active safety technologies.

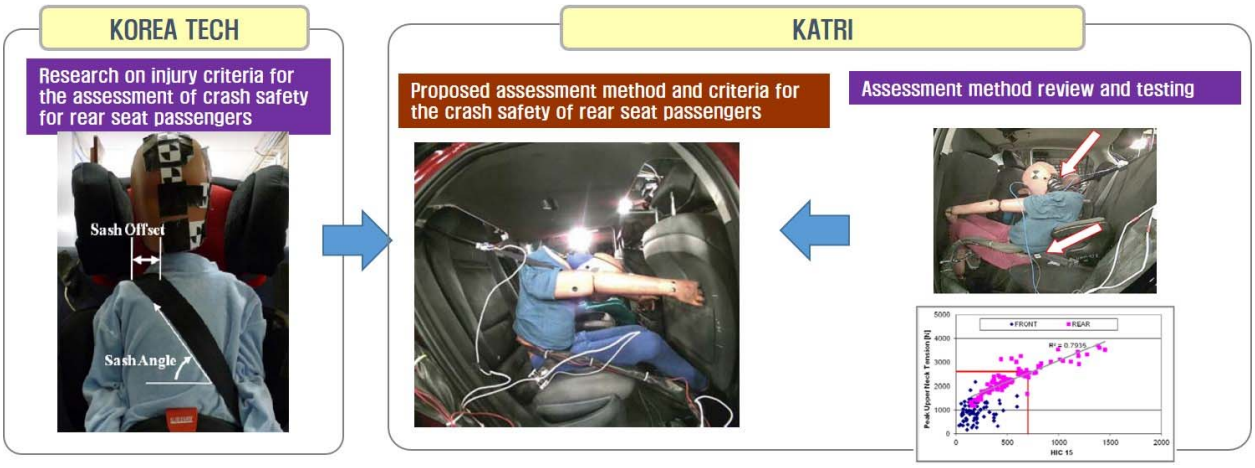
The following is a brief introduction to the main assessment technologies, starting with the Phase II research currently in progress.

SPECIFIC SAFETY ASSESSMENT TECHNOLOGIES

Protection of Rear Seat Passengers

The development of technologies for rear seat passenger protection involves the development of assessment technologies designed to improve the performance of crash safety for rear seat passengers, regardless of whether children or adults, in the event of a road traffic accident.

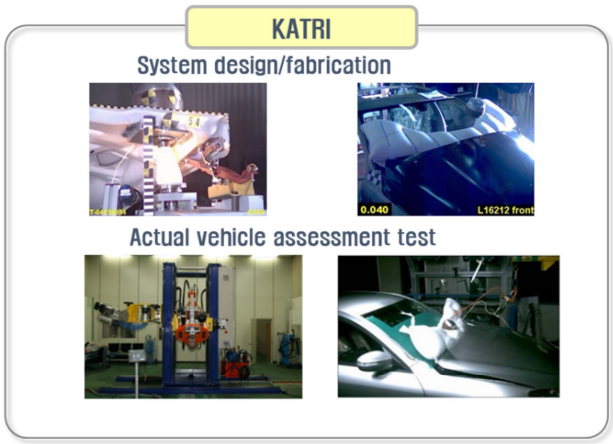
To this end, research is ongoing into the impact on rear seat passengers of road traffic accidents, through data analysis of the mechanism of injuries on children and adult passengers in the rear seats and the strengthening of rear seat passenger crash safety assessment methodology. The proposed criteria for assessment of crash safety for rear seat passengers are based on this analysis.

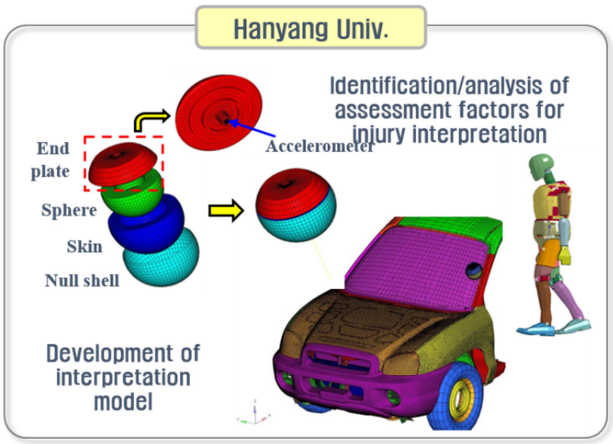


Active Pedestrian Protection

The development of technologies for active pedestrian protection assessment involves the development of assessment technologies for active hoods and pedestrian airbags, as well as technologies designed to reduce the casualties caused by traffic accidents, particularly given the relatively high frequency of pedestrian injuries in Korea that are caused by road traffic accidents.

To this end, there is ongoing design and fabrication work for safety systems that can be fitted to passenger cars and SUVs, with testing carried out using actual vehicles. Related interpretation models have been developed to support the establishment of proposed criteria for the assessment of crash safety for pedestrians.

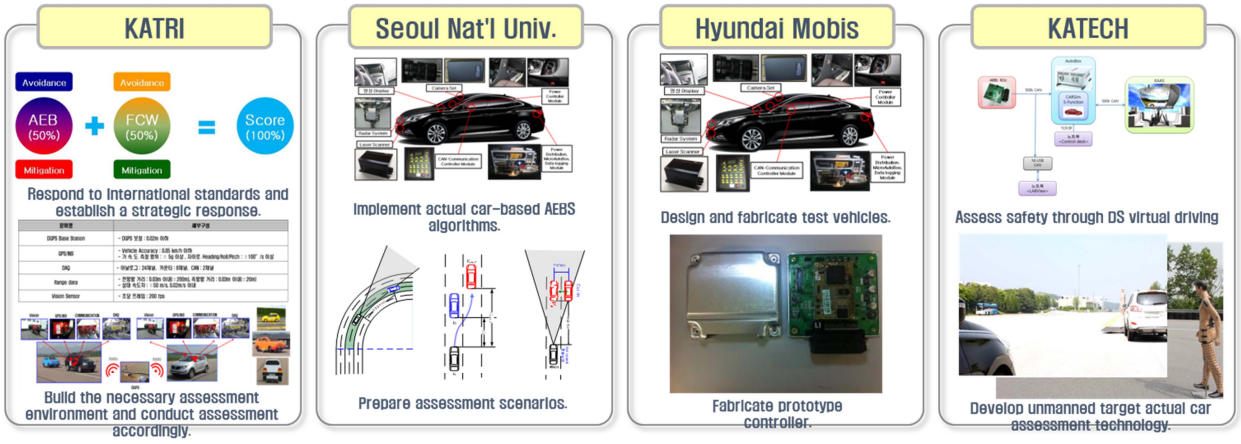




AEBS for Passenger Cars

Development of Advanced Emergency Braking System (AEBS) for passenger cars aims to develop technologies for safety assessment of AEBS, a technology designed to prevent or minimize traffic accidents when a driver is unable to perceive front traffic situations or properly brake the vehicle in emergency.

For this, this research develops assessment technologies for AEBS for passenger cars by studying international automotive criteria, implementing AEBS algorithm based on actual vehicles, developing assessment scenarios and fabricating vehicles for AEBS assessment and prototypes.

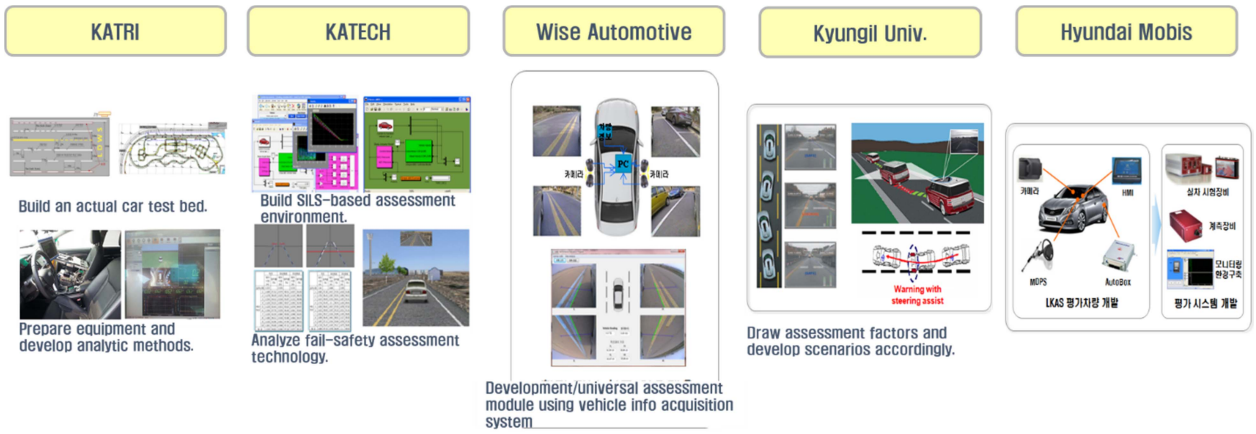


Development of Assessment Technologies for the Safety Performance of LKAS for Passenger Cars

The development of Lane Keeping Assistance System (LKAS) for passenger cars involves the development of technologies to assess the Lane Keeping Assistance System. LKAS is used to prevent possible accidents by

automatically operating the vehicle's steering system to keep the vehicle in the correct lane in the event of possible driver error or carelessness causing it to otherwise veer into another lane or off the road.

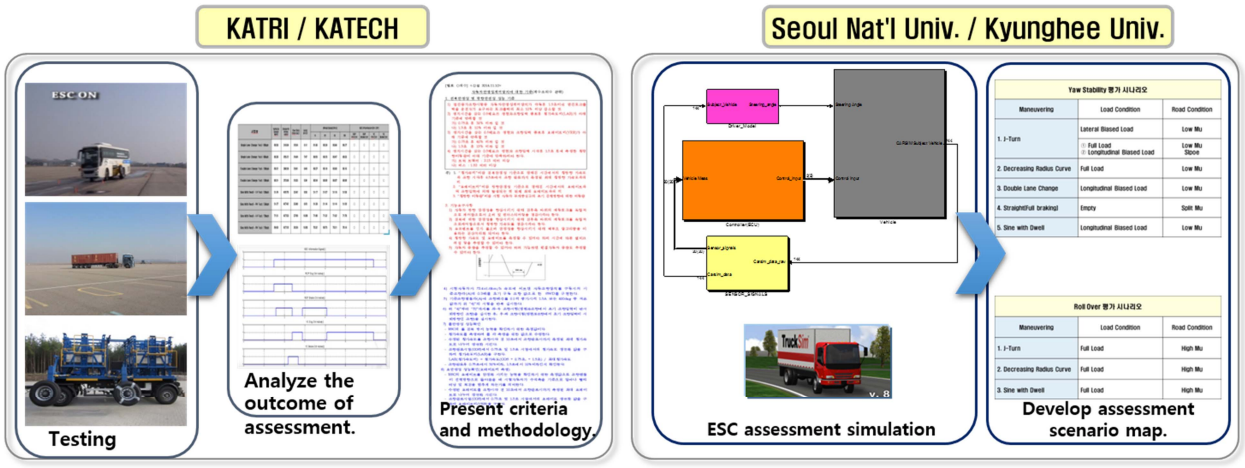
This research includes establishing a proper environment for LKAS assessment, analyzing and developing technologies for fail-safety assessment, developing universal LKAS assessment modules, identifying LKAS assessment factors and developing assessment scenarios.



Development of Assessment Technologies for the Safety Performance of ESC for Commercial Vehicles

The development of assessment technologies for the safety performance of ESC for commercial vehicles involves the development of assessment technologies for the safety performance of Electronic Stability Control (ESC) equipped to vans and trucks to prevent rollover or slipping accidents.

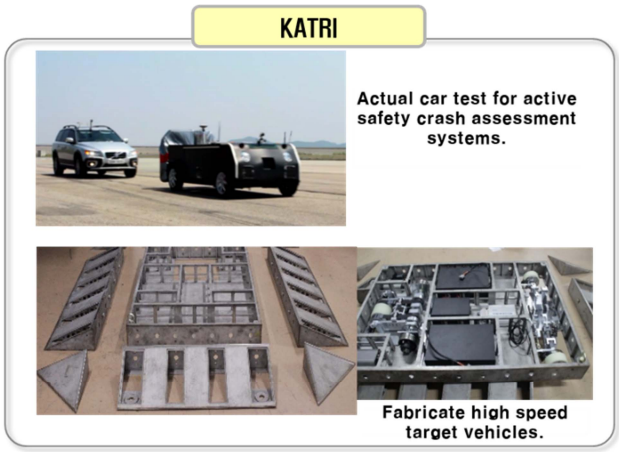
This research includes verifying the assessment of the safety performance of the ESC of commercial vehicles (vans and trucks), developing simulation models and algorithms, analyzing assessment technologies for the performance of ESC and developing technologies for fail-safe assessment.

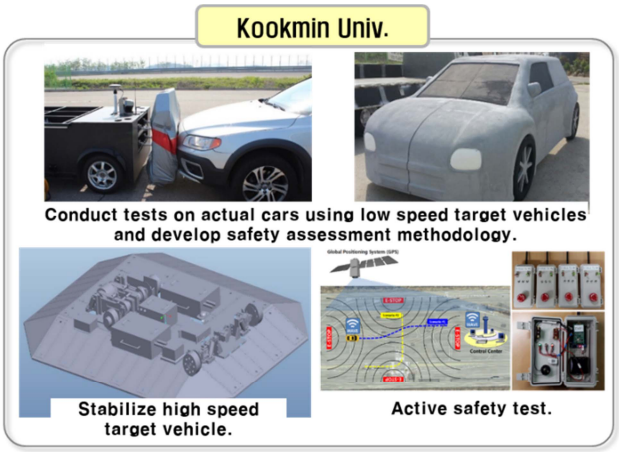


Development of Active Safety Crash Assessment Systems

This involves the development of systems for assessing the safety of vehicles equipped with advanced safety features such as Advanced Emergency Braking System (AEBS) and Electronic Stability Control (ESC).

This includes fabricating target vehicles for low/high speed driving, stabilizing them, and developing operating software.





Self-driving Vehicles

The development of assessment technologies for the safety performance of self-driving vehicles involves the development of technologies for assessing the safety performance of self-driving vehicles equipped with sensor-based Advanced Driver Assistance System (ADAS).

This includes building self-driving assessment systems and test beds by integrating ADAS element technologies, developing algorithms for self-driving assessment systems, and conducting studies on the assessment criteria for the structural safety and driving safety of self-driving vehicles equipped with ADAS.

KATRI

- Conduct research on international technologies and standards (selection of items requiring establishment/amendment of safety standards)
- Decide assessment factors for safety assessment (proposed structure and criteria)
- Define test bed and assessment system (assessment procedures)

Seoul Nat'l Univ.

- Establish criteria for the safety assessment of self-driving systems (motorway)
- Develop algorithms for the control of self-driving system.

MOBIS

- Define specifications of ADAS-based self-driving vehicles.
- Configure ADAS-based self-driving vehicles for assessment.
- Configure control logic and systems by ADAS element.

Wise Automotive

- Build actual car-based test bed for V2V integrated system safety.
- Conduct actual car assessment based on V2V scenarios.
- Improve V2V assessment scenarios.

CONCLUSIONS

This paper presented an introduction to the project for the Development of Assessment Technologies for Advanced Technology Vehicles, which is funded by the Ministry of Land, Infrastructure and Transport and the Korea Agency for Infrastructure Technology Advancement and conducted by the Korea Automobile Testing and Research Institute under the Korea Transportation Safety Authority and other partner research institutes.

The goal of this research is to develop the assessment technologies required to verify the safety performance of both advanced safety features utilizing IT convergence technology as well as advanced safety vehicles utilizing such features to reduce casualties from traffic accidents. More specifically, it involves the development of assessment technologies for the fields of crash safety technologies, preventive safety technologies and relevant supporting technologies.

The subjects for each phase of the project were selected by comprehensively taking into account the technology level, market environment and accident reduction effects of element technologies. Research on them is currently being conducted in three different phases.

This paper has introduced the high-level outline and detailed contents of the research on specific safety assessment technologies conducted in the Phase II research project (2012-2015).

The safety performance of vehicles around the world can be improved if automotive safety standards and New Car Assessment Program (NCAP) are updated to reflect the safety assessment technologies developed by the ASV Project. This research project, by contributing to the establishment and amendment of international vehicle safety standards, will also help to raise the prestige of Korea.
Moreover, it is expected that the international technical and market competitiveness of carmakers and parts makers can be improved through the more rigorous assessment of both advanced safety features and the vehicles equipped with such features.

ACKNOWLEDMENTS

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