ADVANCED DRIVER ASSISTANCE SYSTEMS FOR TRUCKS – BENEFIT ESTIMATION FROM REAL-LIFE ACCIDENTS

Matthias Kuehn
Thomas Hummel
Jenoe Bende
German Insurers Accident Research
Germany
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ABSTRACT

Advanced Driver Assistance Systems (ADASs) are today becoming increasingly common in the market. This also applies to trucks, in particular. In order to quantify the effects of ADASs on truck accidents in Germany, a comprehensive study was performed, using third-party vehicle claims involving personal injury and a total claim value of at least €15,000. This study is based on a total of 443 truck accidents. Statistical methods were used to extrapolate these accidents up to 18,467 claims.

To determine the possible effects of ADASs, relevant accident scenarios were identified, and system characteristics for generic ADASs were derived. Different stages of development for some of the systems were defined and evaluated, and the theoretical safety potentials of the generic ADASs were determined by systematic case-by-case analysis.

All types of road users (cars, trucks, buses, motorcycles, bicycles, and pedestrians) were included as the other parties to the collisions involving the trucks (gross vehicle weight more than 5,000 kg); single-vehicle truck accidents were also included. The calculated theoretical safety potential of the different ADASs is based on the assumptions that 100% of the truck fleet is equipped with these systems and that the driver reacts perfectly when warned.

The conclusions of the analyses are as follows: an autonomous emergency braking system (AEBS), which is able to detect moving and stationary two-track vehicles, warn the driver and perform a braking maneuver autonomously, was able to prevent up to 12% of all truck accidents in the data sample compared to just 6% for a system that is not able to detect stationary vehicles. The safety potential of a "turning-assistant system" and an intelligent rear view camera accounts for 6% of prevented accidents in relation to all truck accidents. Detailed analysis reveals that this covers 55% of all truck accidents against vulnerable road users (VRUs). Compared to current rear-view mirror technology, these assistance systems are much more effective. The theoretical safety potential of a lane departure warning (LDW) system was found to be up to 2%. Nevertheless, this small percentage equates to about 39% of all truck accidents caused by departing the lane.

The results of the study indicate that ADASs do not achieve the same safety potential for each of the three truck categories "solo truck", "truck and drawbar trailer" and "semi-trailer truck". This should be taken into consideration for future legislation. Although some of the ADASs examined show considerable safety potential for VRUs, the current European legislation does not take this into account.

DATABASE

The UDV (German Insurers Accident Research) is a department of the German Insurance Association (Gesamtverband der Deutschen Versicherungswirtschaft e.V. – GDV) and has access to all the third-party vehicle insurance claims reported to the GDV. There were 3.4 million of these claims in 2009. For the purposes of accident research, the UDV set up a database (referred to as the UDB), taking a representative cross-section of this large data pool. The data collected is conditioned for interdisciplinary purposes for the fields of vehicle safety, transport infrastructure and road use behavior. The contents of the claim files from the insurers form the basis of the UDB. The depth of information provided by the UDB is significantly greater than that of the German federal statistics [2]. Around 700 to 800 new cases are added to the UDB each year.

Data set and representativeness

Only third-party vehicle claims involving personal injury and damage costs of at least €15,000 were taken into account in the GDV accident database. Cases involving only damage to property and less se-

rious accidents involving personal injury (damage costs < €15,000) are not included in the UDB. Each year, a random sampling method [3] is used to collect stratified random samples that take into account the type of traffic involvement, the damage sum class and the time of year as stratification variables. Case-dependent extrapolation factors allow the sample in the UDB to be extrapolated to the target population of all claims in Germany. This ensures that the statements with respect to the safety potential of driver assistance systems refer to a representative sample of all claims dealt with by German insurers.
This study is based on a total of 443 truck accidents, which were extrapolated to a total of 18,467 cases. All types of traffic involvement were taken into account as the other collision party for the truck (cars, trucks, buses, motorcycles, bicycles and pedestrians) as well as single-vehicle truck accidents. Single-vehicle truck accidents are, however, underrepresented, since cases in which there is no injury or damage to a third party are not brought to the attention of the GDV.

METHOD

Analysis of the safety approach was carried out using a multi-step procedure (Figure 1). In the first step, the accidents involving trucks were selected ("B – Data pool") from the accident data stored in the UDB ("A – UDB database"). In the second step, key aspects of the course of the accidents were identified, and groups of ADASs were defined ("C – relevance pool 1") that could be expected to have a positive effect on the key aspects of the accidents (e.g. autonomous emergency braking system). In the third step, the system characteristics were derived for generic ADASs. Different stages of development of the systems were defined and evaluated ("D – Relevance pool 2"). It is of no significance for the analysis whether it is currently already possible to implement the technical system characteristics and whether the systems under consideration are already available on the market. It was also not the intention to carry out a comparison of the products. Fourthly, the theoretical safety potentials of the defined generic ADASs were determined by systematic case-by-case analysis ("E – Calculation of the theoretical safety potential SP_{theor}").
The cases were analyzed using the "What would happen if..." method. The prerequisite for this is that none of the vehicles involved in the accidents that were analyzed were fitted with an ADAS. This approach considers the course of the accident as it happened in reality and contrasts it with the course of the accident as it would have been with an ADAS (see also [4]). This makes it possible to determine the effect an ADAS would have had on the course of the accident if all the trucks had been fitted with the ADAS considered. Although a comparison between "trucks with ADAS" and "trucks without ADAS" would have been theoretically possible, this was not done. This is because there are still too few trucks fitted with modern ADASs in the overall total (and involved in the accidents). In addition, it was not intended to compare specific products.

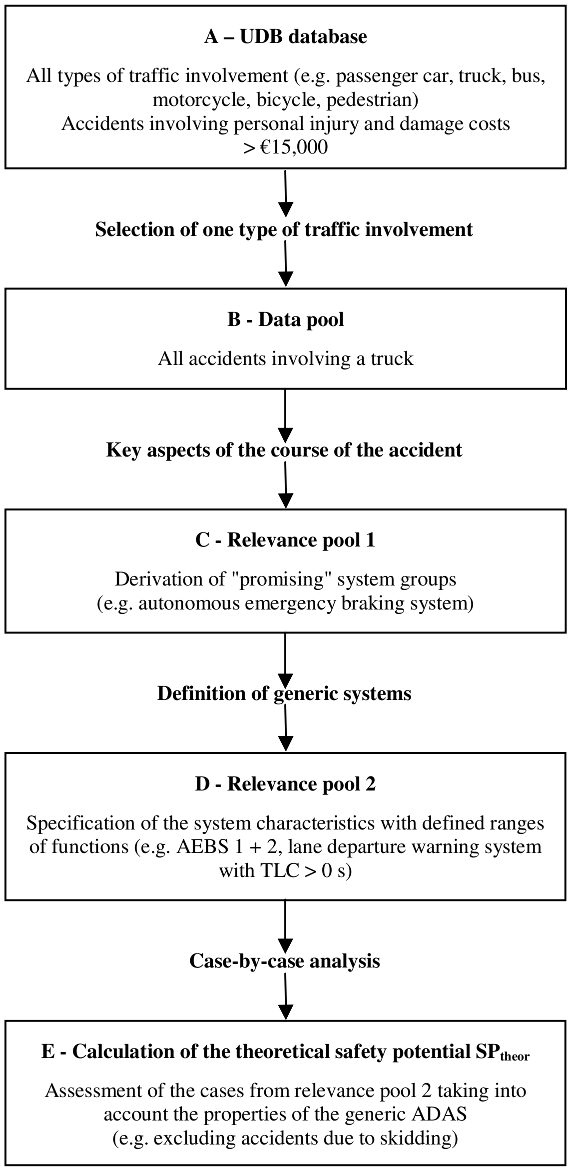


Figure 1. Multi-step approach in which A ≥ B ≥ C ≥ D ≥ E with respect to the size of the data pool.

The method of investigation selected initially assumes that a driver reacts perfectly to the warnings issued by the system, which is generally not the case in reality. This means that the theoretical safety potential calculated in step four of the method represents an upper limit that is unlikely to be achieved under real driving conditions. It is clear that this statement does not apply to completely autonomous ADASs.

RESULTS

The underlying case material here comprises 443 truck accidents from the years 2002 to 2006 involving 570 trucks. These were extrapolated to 18,467 accidents involving 22,863 trucks using the method described in [3]. Only accidents involving at least one truck with a gross vehicle weight of 5 tonnes or more were included. Pictures showing examples of such trucks are included in appendix 1.
The breakdown of the accident material with regard to the other collision parties in the accidents involving the trucks is shown in Figure 2. Only the main other collision party of the truck is shown. This is the road user with which the truck had the most serious collision involving the worst personal injuries. Cases in which trucks were indirectly involved (e.g. minor subsequent collisions between a vehicle already involved in a serious accident and the truck) are not shown in Figure 2. Truck/car collisions are the most common, accounting for 63% of the total, followed by truck/truck collisions (16%) and then collisions with cyclists (7%), motorcyclists (6%) and pedestrians (6%). Single-vehicle truck accidents account for less than 1% of the UDV's accident material and are thus clearly underrepresented in relation to the official statistics [2].

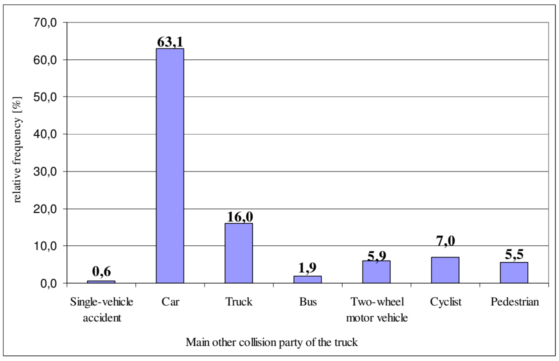


Figure 2. Single-vehicle truck accidents and main collision parties of the trucks in the accident material.

Accidents involving trucks were subdivided by " kind of accident" (see [2] for a definition) to determine the most frequent accident scenarios and rank them (Figure 3).
It is important to bear in mind here that the kind of accident only takes into account the first collision in an accident and therefore only delivers information about the constellation of the first collision, not about any further, secondary collisions. The kind of accident therefore does not necessarily indicate the collision that caused the most personal injury.
The most common accident scenario for trucks is a rear-end collision. These collisions, which account for almost 32% of the total, could be addressed by means of autonomous emergency braking systems. Scenarios (3) and (5) together account for the second largest share (23.6%). Lane departure warning systems and ESC systems could have a positive effect on this group of accidents.

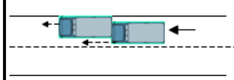
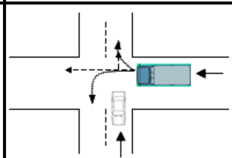
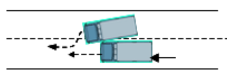
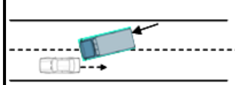
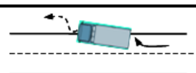
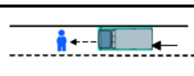
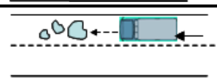
The most frequent accident scenarios $N_{data\ pool}$ **= 18,467 [100%]**		**% share**
(1) Collision with another vehicle that is: - Driving in front or waiting - Starting up, stopping or standing in stationary traffic		31.6%
(2) Collision with another vehicle that is turning into a road or crossing traffic		22.3%
(3) Collision with another vehicle that is moving laterally while traveling in the same direction		18.5%
(4) Collision with another vehicle that is traveling in the opposite direction		14.3%
(5) Vehicle leaving the road to the left or right		5.1%
(6) Collision between the vehicle and a pedestrian		4.4%
(7) Collision with an obstacle on the road		0.4%

Figure 3. Frequency of different accident scenarios in the truck data pool.

The available truck accident material was analyzed with regard to the safety potential of the following advanced driver assistance systems:

- Autonomous emergency braking system 1 and 2
- Turning assistant (for pedestrians and cyclists)
- Lane departure warning system
- Blind spot monitor
- ESC
- Reverse assist camera (for pedestrians)

The calculated safety potentials of all of these ADASs can be summed up (see “CONCLUSIONS”).

Truck autonomous emergency braking system (AEBS) – description and safety potential

In this part of the investigation, only autonomous emergency braking systems were considered that address rear-end collisions exclusively and are thus very much on the model of the autonomous emergency braking systems that are currently available on the market. Two levels of system were defined: autonomous emergency braking system 1 (Table 1) only responds to moving, double-track vehicles ahead, whereas autonomous emergency braking system 2 can also detect stationary double-track vehicles.

Table 1.
System properties and derived database attributes for the current generation of autonomous emergency braking systems (AEBS 1)

AEBS 1:	
System description	**Application to the UDB**
- Forward detection of the environment (using the radar sensors of the adaptive cruise control system)	- Rear-end collisions with double-track vehicles ahead
- Detection of moving, double-track vehicles ahead (not stationary)	
Max. achievable deceleration: 7 m/s² (dry road); 6 m/s² (wet road)	- Breakdown of accidents by road conditions (dry/wet)
- Speed range: from 15 km/h; minimum speed of the vehicle ahead: 10 km/h	All accidents in which the speed of the truck that hits the vehicle in front is known
- Inability to detect vehicles that suddenly change lane	
- Warning by the system at TTC 3.3 s	
- Partial braking at TTC 2.3 s with 30% of the maximum braking power	
- Full braking with maximum braking power at TTC 1.3 s	

<u>**Truck autonomous emergency braking system 1 (AEBS 1)**</u> Taking the truck data pool as a basis (18,467 accidents), all rear-end collisions were selected in which the vehicle that hit the one in front was a truck and had not been in a collision with another road user beforehand (relevance pool 1). This pool was then further restricted to obtain rear-end collisions with moving, double-track vehicles (relevance pool 2). These were then subjected to a case-by-case analysis to examine the effect of AEBS 1. This system is an autonomous emergency braking system of the current generation. It is a fully automatic system that issues a warning when it detects acute danger, initiates partial braking and finally, if the driver does not react, maximum braking until the vehicle comes to a stop. It only responds to moving vehicles. The system properties of AEBS 1 are shown in Table 1.
The case-by-case analysis was carried out based on a simplified, conservative calculation that assumes the driver would not have reacted to the system’s warning in any of the cases. Each case was then recalculated and only categorized as preventable if, taking into account a warning period of a second, a partial braking period of a second and possibly full braking, the speed of the truck would have been reduced to the speed of the vehicle in front of it without a collision. This calculation was thus purely theoretical and carried out, moreover, on the premise that the adaptive cruise control (ACC) system was switched off, because the ACC system generally uses the same sensors as the autonomous emergency braking system and would normally intervene first and initiate partial braking. For this reason and because it is assumed that the driver does not react, the figures given below represent the lower limit of the maximum prevention potential that can be expected for AEBS 1.
With an adjusted data pool of 12,273 cases (only accidents in which the truck’s speed is known), the safety potential calculated for AEBS 1 is 6% of preventable accidents (Table 2) and 4% of both preventable fatalities and serious injuries (Table 3). When applied to all truck rear-end collisions (relevance pool 1: 2,815 cases), as many as 26.5% of these accidents could be prevented.
In Tables 2 and 3 as well as the subsequent tables, the

95% confidence interval [7] is specified in addition to the calculated safety potential. Due to these confidence intervals, SP_{theor} can – in some cases – decrease to "zero", especially if the number of (prevented) accidents and/or fatalities and injuries is small.

Table 2.
Accidents that could be prevented by AEBS 1

Truck accidents that could be prevented by	**Data pool** **[100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
AEBS 1	12,273	2,815	1,239	746 **6% ± 2.7%**

Table 3.
Fatalities and injuries that could be prevented by AEBS 1

Fatalities and injuries that could be prevented by **AEBS 1**	Number of fatalities and injuries in the data pool (all truck accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	2,509	88	**3.5 ± 4.8**
Serious injuries	8,635	345	**4.0 ± 2.5**
Minor injuries	14,927	1,112	**7.4 ± 2.6**

Truck autonomous emergency braking system 2 (AEBS 2) A glance at relevance pools 1 and 2 in Table 2 reveals that collisions with stationary vehicles (the difference between the figures for the two pools, amounting to 56%) are of particular relevance as far as truck collisions with the vehicle in front are concerned. A new relevance pool 2 (of 1,576 cases) was therefore formed from the existing relevance pool 1. This consists of all the cases in which a truck has driven into a stationary, double-track vehicle. It was then examined to determine the effect of an enhanced autonomous emergency braking system (AEBS 2).

In addition to having the functionality of AEBS 1, AEBS 2 can also detect stationary vehicles. The method used to calculate the potential benefits of AEBS 1 was therefore adjusted in such a way that the theoretical prevention of an accident required braking that would bring the truck to a standstill without having a collision with the vehicle in front.

The accident prevention potential of AEBS 2 is considerably higher than that of AEBS 1 because it can detect stationary vehicles. It has a safety potential of 12%, which is almost twice that of AEBS 1 (Table 4). The potential for preventing fatalities is 4.9% (Table 5), while the potential for preventing serious injuries is 8.4%. AEBS 2 has the greatest effect on minor injuries, which are reduced by 17.5%. Over half of all collisions in which trucks collide with the rear end of another vehicle (52.3%) could be prevented by AEBS 2.

Table 4.
Accidents that could be prevented by AEBS 2, taking AEBS 1 as a basis

Truck accidents that could be prevented by	**Data pool** **[100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
AEBS 1	12,273	2,815	1,239	746 6%
AEBS 2	12,273	2,815	1,576	725 (5.9%) **11.9% ± 3.8%**

Table 5.
Fatalities and injuries that could be prevented by AEBS 2, taking AEBS 1 as a basis

Fatalities and injuries that could be prevented by **AEBS 2**	Number of fatalities and injuries in the data pool (all truck accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	2,509	123	**4.9 ± 5.6**
Serious injuries	8,635	723	**8.4 ± 3.6**
Minor injuries	14,927	2,614	**17.5 ± 3.8**

Turning assistance system – description and safety potential

A further analysis of the accident material (18,467 cases) revealed that approximately 13% of truck accidents happen when trucks turn into another road. 80% of these cases involve the truck colliding with a cyclist or pedestrian. Collisions with cyclists and pedestrians make up a total of around 10% of all serious

truck accidents in the UDB. With a view to carrying out an analysis of a suitable advanced driver assistance system for turning maneuvers, all truck turning accidents were combined (relevance pool 1). The collisions with cyclists (641 cases) and pedestrians (170 cases) were selected from this pool to form relevance pool 2.
The generic system properties correspond to the properties of the turning assistance systems already developed for modern trucks [5]. However, additional functionalities were assumed (Table 6). The system has sensors that allow it to monitor the areas in front of and to the side of the truck and warn the truck driver when starting off or turning that a cyclist or pedestrian is approaching the truck. The turning assistance system can prevent the turning maneuver if there is a pedestrian in front of the vehicle at the time (at traffic lights, for example).
For the case-by-case analysis, an ideal driver was again assumed who reacts to the warning in good time and applies the brakes appropriately. The course of events in each case was examined anew, and it was assessed whether the accident was preventable given the assumptions made (e.g. the driver performs an emergency braking maneuver, or the system prevents the vehicle from starting off). The analysis of preventability was carried out with a view to establishing whether the driver had made a mistake. If the accident happened, for example, because the cyclist swerved while being overtaken and fell after contact with the truck/trailer (i.e. the truck driver could not have influenced the situation), the accident was considered to be not preventable.
A theoretical prevention potential of 4.4% of all truck accidents was calculated for the turning assistance system (Table 7). The prevention potential calculated for all accidents between trucks and cyclists/pedestrians was 42.8% (Table 8). As far as fatalities and injuries are concerned, 31.4% of fatalities, 43.5% of serious injuries and 42.1% of minor injuries would be preventable in these accidents (Table 9). This clearly indicates the great benefits of the system, particularly given that over 90% cyclists and pedestrians involved in these accidents were killed or seriously injured. 4% of the fatalities and 5% of the serious injuries occurring in all truck accidents would be prevented.

Table 6.
System properties and derived database attributes for the truck turning assistance system for cyclists and pedestrians

Turning assistance system (cyclists and pedestrians):		
System description		**Application to the UDB**
- Forward detection of the environment (sensor-independent)		- Turning accidents with cyclists and pedestrians
Detection of:	- Cyclists moving slowly close to the truck's near side that are overtaken by the truck	All truck turning accidents with pedestrians and cyclists, accidents with pedestrians who cross in front of the truck when it is stationary or turning and accidents where the truck overtakes a cyclist
	- Cyclists approaching the truck from behind as it turns to the near side	
	- Cyclists who stop on the near side of the stationary truck	
	- Pedestrians who approach the truck from the side when it is stationary or turning	
	- Pedestrians who are in front of the truck when it starts up	
	- No potential when turning to the off side	

Table7.
Truck accidents that could be prevented by the turning assistance system for trucks, as a proportion of all truck accidents

Truck accidents that could be prevented by the	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Turning assistance system	18,467	2,414	811	811 **4.4% ± 1.9%**

Table 8.
Truck accidents that could be prevented by the turning assistance system for trucks, as a proportion of all accidents between trucks and pedestrians/cyclists

Accidents between trucks and pedestrians/cyclists that could be prevented by the	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Turning assistance system	1,892	854	811	811 **42.8% ± 13.2%**

Table 9.
Fatalities and injuries that could be prevented by the truck turning assistance system in accidents between trucks and pedestrians/cyclists

Fatalities and injuries that could be prevented by the **turning assistance system**	Number of fatalities and injuries in the data pool (all accidents between trucks and pedestrians/cyclists)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	369	116	**31.4 ± 25.2%**
Serious injuries	1,512	658	**43.5 ± 15.2%**
Minor injuries	171	72	**42.1 ± 43.3%**

Lane change and lane departure

In order to carry out an analysis for a Lane Keeping Assist system or lane departure warning system, accidents caused by drivers leaving their lane were identified. Although these are reflected in scenarios (3) and (5) in Figure 3, relevance pool 1 was formed because it describes these accident scenarios in a more concrete form for the purpose of carrying out further analyses. It only contains cases in which a collision occurred because the truck driver changed lane deliberately or left it inadvertently. Relevance pool 1 (2,297 cases) accounts for 12% of the underlying data pool (18,467 cases). In this section, the potential is calculated for the first group of cases, which occurred because of an intentional lane change. These cases (1,452) form relevance pool 2 and could be addressed by means of a suitable blind spot monitor.

Blind spot monitor – description and safety potential The blind spot monitor used here is a purely generic system that does not yet exist in this form for trucks. It monitors the adjacent lanes and detects road users of all kinds. If the driver indicates his intention to change lane by using an indicator and the system recognizes that a collision with a vehicle in the adjacent lane is imminent, it gives the driver a warning. The functionality of this generic blind spot monitor thus corresponds to that of the blind spot monitor that is already available for cars [8].
The analysis of relevance pool 2 shows that accidents that occur because of a deliberate lane change are generally not serious. This is frequently the case when the sides of the vehicles come into contact but neither of the vehicles goes into a skid or is forced off the road. Even the few rear-end collisions that result from a lane change are rarely serious. However, the case-by-case analysis clearly revealed that truck accidents that occur as a result of a lane change can only be inadequately analyzed, since the course of the accident and accident location rarely provide enough evidence to allow a reliable statement to be made about preventability. In some collisions with cars, for example, the truck driver did not immediately notice that the accident happened and simply continued driving. Contradictory accounts from witnesses and a lack of information about the accident location meant that it was no longer possible to work out retrospectively when and under what circumstances the lane change or collision occurred. As a result of this uncertainty, it was not possible to calculate the accident prevention potential of the blind spot monitor for trucks. The positive effect of the system was merely estimated.
The number of cases in which the system could have a positive effect corresponds to relevance pool 2 and is calculated as being 7.9% of all truck accidents (Table 10). Table 11 confirms that fatalities are very rare in these accidents and the number of serious personal injuries is also low. Only 1.4% of serious injuries could be prevented by a blind spot monitor, and the number of fatalities would not change at all.

Table 10.
Accidents that could be addressed by the truck blind spot monitor

Truck accidents that could be addressed by the	**Data pool [100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Blind spot monitor	18,467	2,297	1,452	1,452 **7.9% ± 2.6%**

Table 11.
Fatalities and injuries that could be addressed by the truck blind spot monitor

Fatalities and injuries that could be addressed by the **blind spot monitor**	Number of fatalities and injuries in the data pool (all truck accidents)	Fatalities and injuries that could be addressed	
		Number	SP_{theor} [%]
Fatalities	2,766	0	**0**
Serious injuries	11,959	172	**1.4 ± 1.4%**
Minor injuries	22,194	2,100	**9.5 ± 2.6%**

Lane departure warning system – description and safety potential The second group of accidents caused by drivers leaving their lane (relevance pool 1, containing 2,297 cases) consists of accidents caused by drivers inadvertently leaving their lane (relevance pool 2, containing 845 cases). The analyses showed that these cases were generally attributable to the truck driver being fatigued, distracted or inattentive. These accidents could be addressed by a lane departure warning system.

The functionality of the advanced driver assistance system considered here is based on the lane departure warning systems that are already available on the market [6]. The way in which it works is only slightly different from how the systems used in cars work. A video camera behind the windshield evaluates detected lane markings and warns drivers when they are about to leave the lane inadvertently. It thus helps drivers to keep in lane on freeways and other major roads outside built-up areas when they are being inattentive.

In the case-by-case analysis, the course of each accident was analyzed, assuming an ideal driver and a system working to optimum effect. The material on file is generally well documented and allowed an assessment to be made of preventability. If there was sufficient evidence to indicate that the truck would not have left its lane if the system had been in use, the accident was considered to be preventable.

The safety potential of the lane departure warning system as a percentage of all truck accidents is 1.8% (Table 12). The picture is similar for fatalities and injuries: 1% of serious injuries and 2% of minor injuries would be preventable (Table 13).

The accidents that could be prevented by a lane departure warning system (329) have a safety potential (SP_{theor}) of 38.9% of all accidents in which the driver leaves the road or lane inadvertently (845 cases).

Table 12.
Accidents that could be prevented by the lane departure warning system for trucks

Truck accidents that could be prevented by the	**Data pool** **[100%]**	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Lane departure warning system	18,467	2,297	845	329 **1.8% ± 1.2%**

Table 13.
Fatalities and injuries that could be prevented by the lane departure warning system for trucks

Fatalities and injuries that could be prevented by the lane departure warning system	Number of fatalities and injuries in the data pool (all truck accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	2,766	0	**0**
Serious injuries	11,959	210	**1.0 ±1.2%**
Minor injuries	22,194	404	**1.8 ±1.2%**

ESC – safety potential

Although truck accidents caused by skidding and/or a rollover are rare (5% of all truck accidents), they often have serious consequences. The analysis of the UDB revealed that there is at least one person seriously injured or one fatality in around 60% of these cases.

To begin with, reference pool 1 (consisting of 1,035 cases) was formed from the data pool (of 18,467 cases). This reference pool contains all accidents in which a truck became involved in an accident as a result of unstable driving dynamics. There were a number of possible causes for this instability, such as:

- An evasive maneuver (the truck started to skid as a result of an evasive maneuver, for example, while overtaking when there was traffic coming in the opposite direction)
- Skidding after a minor collision
- Skidding/tipping on a bend in the road (as a result of leaving the road due to excessive speed)
- Skidding on a straight stretch of road (as a result of leaving the lane due to fatigue/inattentiveness and a subsequent corrective steering maneuver).

Relevance pool 2, which was used to examine the potential positive effects of an advanced driver assistance system, was the same as relevance pool 1. The effect of ESC (electronic stability control) was examined. Electronic stability control systems are already optionally available in some new trucks and will be mandatory for all newly registered trucks in the EU from 2013 [1]. The system has sensors that allow it to monitor the vehicle's driving dynamics. If there is a risk of the truck or trailer skidding or tipping, the sys-

tem intervenes by selectively applying brakes to individual wheels and stabilizing the vehicle combination.
Due to the complex processes involved in ESC intervention and insufficient knowledge about the actual course of the skid, it was not possible to carry out a calculation or analyze preventability in the same way as was done for the autonomous emergency braking system. Instead, an assessment was made as to whether ESC would have had a positive effect.
The result was that ESC had the theoretical potential to have a positive effect on 5.6% of all truck accidents (Table 14). There would also have been a positive effect on around 5% of all fatalities and serious injuries (Table 15). In other words, either the seriousness of the injury could have been reduced or accidents would have avoided so that no injuries occurred.

Table 14.
Accidents that could be addressed by ESC for trucks

Truck accidents that could be addressed by	**Data pool** [100%]	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
ESC	18,467	1,035	1,035	1,035 **5.6% ± 2.1%**

Table 15.
Fatalities and injuries that could be addressed by ESC for trucks

Fatalities and injuries that could be addressed by ESC	Number of fatalities and injuries in the data pool (all truck accidents)	Fatalities and injuries that could be addressed	
		Number	SP_{theor} [%]
Fatalities	2,766	57	**2.1 ± 3.5**
Serious injuries	11,959	605	**5.1 ± 2.5%**
Minor injuries	22,194	1,169	**5.3 ± 1.9%**

Reverse assist camera – description and safety potential

Taking the truck data pool of 18,467 cases as a basis, the group of truck/pedestrian collisions (see scenario 6 in Figure 3) was also examined with a view to estimating the potential for preventing them. In these truck/pedestrian accidents (833 cases), it was conspicuous that there was a very high number of pedestrians injured when the truck was reversing. In the next step the extent to which an ADAS could have a positive effect on these accidents was examined.
It was assumed that the generic system monitors the area behind the truck and shows this area on a screen. If the engine is running and there is a pedestrian in the critical area behind the vehicle, an audible warning is given. The system prevents the vehicle from moving off or applies the brakes automatically if the driver does not react.
In the case-by-case analysis, the course of each accident was examined again and it was assessed whether the collision would still have happened under the assumed conditions. As expected, the potential benefits are relatively low: 1.2% of all truck accidents would be preventable by this system (Table 16). On the other hand, 27.1% of truck/pedestrian accidents could be prevented (Table 17). A glance at the number of preventable fatalities and injuries (Table 18) makes the benefits of a truck reverse assist camera even clearer: 18.1% of fatalities and 25.9% of serious injuries caused by all truck/pedestrian accidents could be prevented by a reverse assist camera.

Table 16.
Truck/pedestrian accidents that could be prevented by a truck reverse assist camera, as a proportion of all truck accidents

Truck/pedestrian accidents that could be prevented by the	**Data pool** [100%]	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Reverse assist camera	18,467	833	226	226 **1.2% ± 1.0%**

Table 17.
Truck/pedestrian accidents that could be prevented by a truck reverse assist camera, as a proportion of all truck/pedestrian accidents

Truck/pedestrian accidents that could be prevented by the	**Data pool** [100%]	**Relevance pool 1**	**Relevance pool 2**	**SP_{theor}**
Reverse assist camera	833	226	226	226 **27.1% ± 11.8%**

Table 18.
Fatalities and injuries that could be prevented in truck/pedestrian accidents by a truck reverse assist camera, as a proportion of all truck/pedestrian accidents

Fatalities and injuries that could be prevented by the **reverse assist camera**	Number of fatalities and injuries in the data pool (all truck/pedestrian accidents)	Preventable fatalities and injuries	
		Number	SP_{theor} [%]
Fatalities	226	41	**18.1 ± 26.7**
Serious injuries	632	164	**25.9 ± 22.9**
Minor injuries	57	21	**36.6 ± 66.8**

Relevance of ADASs for different truck categories

In this section it was investigated whether the advanced driver assistance systems (ADASs) investigated as described above had the same significance for different truck categories (i.e. whether they have the same potential benefits). Distinctions were drawn between the following truck categories:

- Solo truck
- Truck and drawbar trailer
- Semi-trailer truck

Table 19 examines the number of accidents that could be prevented by a specific ADAS in relation to the number of trucks involved in each of the three categories. To take an example, 2,890 trucks on their own were involved in the truck accidents under examination, and 64 accidents could have been prevented if the truck had AEBS 1, resulting in safety potential of 2.2%. Since the number of accidents is examined in relation to the number of vehicles involved here, the potential calculated is not directly comparable with the values calculated in the previous sections. However, they can be compared against each other in Table 19.
The two most important ADASs with the greatest potential for all three truck categories are the second autonomous emergency braking system (AEBS 2) and the blind spot monitor. ESC comes in third place for the categories “truck and drawbar trailer” and “semi-trailer truck”, whereas a turning assistance system can be expected to bring considerably greater benefits than an ESC system in the “solo truck” category. Table 19 also shows that a reverse assist camera has far greater safety potential for solo trucks than for trucks with drawbar trailers or semi-trailer trucks.

Table19.
Safety potential of ADASs depending on vehicle category

Advanced driver assistance system (ADAS)	Safety potential, SP [%]		
	Solo truck	Truck and drawbar trailer	Semi-trailer truck
AEBS 1 (p *)	2.2	6.1	5.1
AEBS 2 (p)	7.9	10.7	9.5
Turning assistance system, cyclists (p)	4.2	0.6	2.9
Turning assistance system, pedestrians (p)	0.5	0.9	0.8
ESC (pep **)	1.5	4.6	6.1
Blind spot monitor (pep)	6.8	5.2	6.4
Lane departure warning system (p)	1.6	1.8	1.3
Reverse assist camera (p)	3.0	0.5	-

* p = preventable
** pep = positive effect possible

CONCLUSIONS

EU legislation [1] requires that new truck models (with a gross vehicle weight of 3.5 tonnes or more) must be equipped with an autonomous emergency braking system and a lane departure warning system from November 1, 2013. Moreover, ESC is mandatory for some truck categories from November 1, 2011. This is intended to bring about the universal introduction of ADASs for trucks as quickly as possible.
The investigation showed that modern ADASs for trucks can have a positive effect on real-life accidents (involving personal injury and damage costs of €15,000 or more). The generic truck ADASs investigated were found to have safety potential (in terms of the preventability of accidents) of 1.2% of all truck accidents for a reverse assist camera, 1.8% for a lane departure warning system, 4.4% for a turning assistance system, which detects pedestrians and, in particular, cyclists, and 11.9% for an autonomous emer-

gency braking system, which detects double-track vehicles whether they are moving or stationary and automatically applies the brakes. In addition, a blind spot monitor could have a positive effect on 7.9% of all truck accidents, and ESC a positive effect on 5.6%. If all trucks with a gross vehicle weight of 5 tonnes or more were equipped with an autonomous emergency braking system, a turning assistance system, a lane departure warning system and a reverse assist camera, around 20% of the truck accidents examined in this investigation could be prevented. Moreover, a blind spot monitor and ESC could have a positive effect on around 15% of them.
However, the analyses carried out also showed that not every ADAS is equally valuable for every truck category. For example, the second autonomous emergency braking system (AEBS 2), a blind spot monitor and a turning assistance system are particularly important for solo trucks, whereas AEBS 2, a blind spot monitor and ESC are particularly important for trucks with drawbar trailers and semi-trailer trucks.

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APPENDIX 1

Examples of trucks with a gross vehicle weight (GVW) of 5 tonnes or more

Solo truck ≈ 5 tonnes GVW

Solo truck ≈ 12 tonnes GVW

Solo truck ≈ 18 tonnes GVW

Truck + drawbar trailer ≈ 40 tonnes GVW

Semi-trailer truck ≈ 25 tonnes GVW

Semi-trailer truck ≈ 40 tonnes GVW

VEHICLE SAFETY COMMUNICATIONS FOR COMMERCIAL VEHICLES: ISSUES AFFECTING DEPLOYMENT OF VEHICLE-TO-VEHICLE COMMUNICATIONS FOR HEAVY VEHICLES

Alrik L. Svenson
National Highway Traffic Safety Administration

Jonathan Mueller
Federal Motor Carrier Safety Administration
United States of America

Paper number 11-0169

ABSTRACT

Wireless vehicle-to-vehicle communications (V2V) and the safety applications enabled by such technology are a major component of the U.S. DOT vehicle safety communications (VSC) program. The VSC program also supports wireless connectivity between vehicles and infrastructure (V2I) to deliver safety, mobility, and environmental benefits. To date, the focus of US DOT sponsored research in this area has been on light duty vehicles. However, to obtain maximum benefits, the V2V safety applications need to be deployed among all vehicles including heavy commercial vehicles. The U.S. DOT therefore initiated (in early 2010) several research efforts to examine the issues for adapting V2V safety applications for heavy commercial vehicles. These issues include interoperability with other vehicles, considerations due to vehicle size and geometry, data privacy and policy concerns, compatibility between heavy and light vehicles, and other issues related to special operating environments encountered by commercial vehicles. This paper describes the current technical research on V2V for commercial vehicles being conducted by U.S. DOT (i.e., interoperability, performance requirements and human factors considerations). For each of these studies, interviews were conducted with subject matter experts from the following entities: vehicle manufacturers; truck suppliers, commercial vehicle fleet operators, industry trade representatives, and academic researchers. The early V2V safety applications to be developed for heavy vehicles have been selected based on the most frequent crash types addressable by such technology as identified in previous studies conducted by Volpe. The studies summarized in this paper were limited to commercial vehicles including heavy truck tractors, single-unit trucks, and buses. Results from the studies identify priority issues that need to be addressed for successful deployment of V2V systems on commercial vehicles.

INTRODUCTION

The U.S. DOT is conducting research that has the potential to transform the transportation of goods and people by introducing a new generation of safety systems. Vehicle safety communications (VSC) combines leading edge technologies including: advanced wireless communications; on-board computer processing; advanced vehicle-sensors; navigation; and smart infrastructure to provide the capability for vehicles to identify threats and hazards on the roadway and communicate this information to drivers via alerts, warnings and real time road network information.

VSC consists of the wireless exchange of critical safety and operational data among vehicles within a given proximity of each other (V2V), and between vehicles and the highway infrastructure (V2I). The VSC technology and applications are intended primarily to avoid or mitigate motor vehicle crashes, but can also enable a wide range of, mobility and environmental benefits as well. The U.S. DOT research program is investigating VSC for all vehicle types (light vehicles, heavy vehicles, transit and freight). [1] Further, because the wireless communication protocols to support safety applications are specialized (i.e., not commercial services such as cellular or satellite), it has been recognized that some degree of dedicated telecommunications infrastructure would be needed to support security and other operational aspects of this concept. It should be noted however, that the U.S. DOT's vision for vehicle safety communications is that a minimum level of such infrastructure will be deployed to provide the maximum level of safety and mobility benefits for highway and roadway safety and operational efficiency nationwide.

Precursor Technologies

Crash avoidance technologies such as forward collision warning (FCW), side object detection and others, have emerged over the last few years and have demonstrated the ability to help drivers avoid crashes in particular driving scenarios (or conflicts). Currently, these systems use onboard sensors, such as radar, lidar, or video cameras, to identify crash threats then warn drivers and/or take corrective action. These vehicle-based safety systems (also referred to as autonomous systems) will play a critical role helping to improve motor vehicle safety. However, the opportunity exists to improve the performance of these systems and to accelerate their widespread deployment by shifting the sensing capability from onboard sensors to inter-vehicle communications (often referred to as "cooperative" systems). U.S. DOT has conducted research with the automotive industry to demonstrate that V2V communications will improve the overall effectiveness of autonomous systems and that costs to consumers of such system can be reduced. Further, an analysis of alternative communication media (or protocols) has shown that Dedicated Short Range Communications (DSRC) at 5.9 GHz. is well suited to support V2V applications. DSRC is capable of effectively and reliably providing the capabilities necessary to implement vehicle safety communications applications, such as FCW, Lane Change Warning (LCM), Intersection Movement Assist (IMA), and others. [1]

The research discussed in this paper builds upon the previous work in this area conducted through collaboration between the National Highway Traffic Safety Administration (NHTSA) and vehicle manufacturers participating in the Crash Avoidance Metrics Partnership (CAMP)[1]. CAMP studies conducted between 2002 and 2009, including the Vehicle Safety Communications (VSC) [2] and Vehicle Safety Communications-Applications (VSC-A) [3] investigated the potential of V2V and V2I communications as a means of improving crash prevention, and the development of prototype systems and applications.

Successful deployment of V2V necessitates utilizing the entire vehicle fleet including heavy commercial vehicles. Commercial vehicles (CVs) include all vehicles with a GVWR greater than 10,000 lb. (4536 kg) and includes: tractor-semitrailers, single-unit trucks, buses, and motorcoaches. Therefore, it is important to understand all of the issues affecting these vehicles in order to achieve all of the expected benefits of V2V. These include interoperability with other vehicles, considerations due to vehicle size and geometry, data privacy concerns, compatibility between heavy and light vehicles, special operating environments, and the necessary requirements for the commercial vehicle driver-vehicle interface (DVI) which is significantly different than in passenger vehicles. This paper describes the current U.S. DOT research program on V2V for commercial vehicles and outlines the specific issues of concern that need to be addressed for successful deployment of V2V on these vehicle classes.

COMMERCIAL VEHICLE RESEARCH OBJECTIVES

In 2009, U.S. DOT began V2V research for CVs. The initial phase of the research is focused on identifying the fundamental issues that need to be resolved for successful deployment of V2V systems on commercial vehicles. These areas studied concurrently in 2010 are:

- Interoperability Issues
- Development of Performance Requirements for Safety Applications
- Driver -Vehicle Interface Needs Specification

The following sections describe the research projects in each of these areas.

INTEROPERABILITY ISSUES

The first area of study, *Interoperability Issues for Commercial Vehicles*, was a project conducted by the University of Michigan Transportation Research Institute (UMTRI), and included identification of issues relating to the operation of V2V systems among other equipped vehicles of different makes, models, and vehicle type. The emphasis of this project was to identify the additional challenges and needs that are uniquely associated with the use of DSRC-based safety applications on CVs. The focus was on whether and how the CV-unique aspects may impact standards, applications requirements, certification, and policy requirements in a way that may affect the timing or success of deployment. The project tasks included building and applying an understanding of DSRC operation and root causes of existing challenges, as identified by Subject Matter Experts (SMEs) and other sources. The understanding of operational factors gained was then put into the context of commercial vehicles, with UMTRI's experts' input, to find unique issues.

[1] CAMP VSC-A 2 Project Team consists of Ford, General Motors, Mercedes-Benz, Toyota, Honda, BMW, Nissan, Volkswagen, and Hyundai-Kia.

Research Assumptions

The following assumptions were maintained in this project:

- Limited to DSRC-based applications and devices and their associated standards.
- The potential and risks of integrating aftermarket devices into CVs.
- A focus on V2V.
- Consideration of aspects of V2I that use DSRC for safety only, as these potential applications may affect the communications requirements.
- The diverse range of CVs was considered, however emphasizing the most common types.

Summary of Literature Review

The first task was to gather and assimilate existing information regarding DSRC-based safety applications. This included information about five topic areas: light vehicle applications, communications standards, field performance studies, aftermarket devices, and approaches to certifying compliance. During this process, UMTRI identified potential issues and possible approaches to resolving or mitigating the concerns. The research questions that guided this effort were:

- How does CV V2V system performance change as the number of vehicles within DSRC range increases?
- What methods may be used to increase the reliability of systems under problematic conditions specific to CVs?
- Are there specific issues in testing and evaluating CV V2V applications?
- How can CV V2V components be certified as compliant and interoperable with each other and other devices?
- What are the vehicle size/compatibility issues for communication between light vehicles and CVs?
- What are the security concerns specific to CVs?
- What are the issues for aftermarket and retrofit equipment for CVs?
- What are the issues associated with data privacy in CVs?
- Are there CV specific data reliability requirements for vehicle safety applications?

In reviewing the literature, UMTRI identified the key technical issues that were cited in the literature. However, these issues were primarily within the context of light vehicle applications and needs. Therefore it was necessary to identify whether these issues also apply to commercial vehicles, and if so, whether solutions may have different characteristics for commercial vehicles. Also it was considered whether some issues that have been resolved over the past years for light vehicle applications still remain open issues for CVs. And finally, UMTRI searched for issues that are unique to CVs.

Interviewing CV Stakeholders

The next task was to gather information from commercial vehicle stakeholders regarding the potential safety applications and identify technical and non-technical concerns. This was accomplished using surveys and telephone interviews. UMTRI created two survey and interview protocols used in conversations with the SMEs which included heavy vehicle industry representatives and fleet operators. The first series of conversations addressed the functionalities and basic high-level functional requirements for V2V applications; vehicle classes associated with these requirements; and concerns about technical aspects of V2V communications, interactions with OEM data buses (e.g., for retrofits); and other concerns with integrating these systems into vehicles. This set of interviews included vehicle manufacturers and suppliers. Representatives of key industry groups (e.g., American Trucking Association, Commercial Vehicle Safety Alliance, etc.) were also interviewed. The second set of conversations were conducted with a set of fleet operators, and addressed several issues, among them discussion of driver issues, fleet operations opportunities and concerns; and data ownership and privacy. Representatives from a variety of fleets were interviewed, including small and large fleets, class 8 fleets, and users of smaller (Class 3-6) heavy vehicles.

Identify Priority Issues

In the final task, the inputs of the previous tasks were used to compile a list of issues that were unique to commercial vehicles, and to prioritize them. The priority was determined by considering the issue's potential impact on standards, compliance testing, or deployment timing and deployment success. The type of impact of each item was categorized as follows:

- Requirements for new or revised policy
- Viability for industry (cost vs. apparent added value in the marketplace)
- Technical performance risks
- Issues of acceptance by fleet operators
- Certification and compliance
- Standards and protocols
    - Scalability
    - Reliability
    - Prioritization of messages
    - Compatibility with J1708
    - Security
    - Authentication
    - Data validation, data integrity

Qualitative ratings of impact of the issues were given as minor, significant, and major. The second set of ratings was a qualitative indication of the relative difficulty of overcoming the concern. Dimensions for this rating included the chances of eliminating the concern, as well as the relative amount of time or resources likely needed. At the time of this writing, this project was still ongoing and results are being prepared by UMTRI to be submitted to U.S. DOT in a final report.

DEVELOPMENT OF PERFORMANCE REQUIREMENTS FOR SAFETY APPLICATIONS

The widespread deployment of V2V safety is dependent upon the understanding of the effectiveness of safety applications. The Virginia Tech Transportation Institute (VTTI) was tasked with determining the performance requirements for potential V2V safety applications that are appropriate for heavy commercial vehicles. To accomplish this objective, VTTI conducted the following tasks:

- A review of literature covering collision avoidance systems currently available for heavy CVs
- Interview representatives from the heavy-vehicle manufacturers, suppliers, and fleet operators to determine suitable crash avoidance technologies for the V2V communications
- Identify and develop performance requirements for the selected applications

Literature Review Preliminary Findings

Communications

The enabling technology for V2V safety applications is advanced wireless communications that allow the transmission of data between vehicles, and between vehicles and infrastructure. Examples of these wireless technologies include DSRC at 5.9 GHz, WiFi, and LTE. Some key performance parameters for communication technologies include transmission latency, transmission update rate, and transmission range. [4]

Transmission latency

Because of the time-sensitivity of vehicle crash scenarios, the safety applications require low-latency messages between vehicles. Some critical V2V safety applications require periodic transmissions as low as every 100 millisecond (ms) to address the identified crash scenarios. In fact, the IEEE 802.11p specification provides a minimum allowable transmission latency of 100 ms for periodic messages. DSRC offers the best potential (three orders of magnitude lower than other existing wireless technologies) for effectively supporting these low-latency requirements. [2]

Transmission update rate

Transmission update rate is defined as minimum rate (measured in Hz) at which the transmission needs to be repeated in order to ensure that the safety message is reliably conveyed between vehicles. [4] V2V communication challenges such as multipath fading, shadowing, Doppler shifts created by movement of the vehicles, and data packet collisions must be considered when selecting a minimum update rate. [5]

Transmission range

Shulman and Deering defined the maximum transmission range as the communication distance between two vehicles that is needed to effectively support a particular safety application. [4] The maximum communication range is dependent upon the utility of the broadcast data to adjacent vehicles for upstream and downstream traffic in the same and opposing directions. [6] Many of the proposed safety applications require a communication range between 100-1000 m; the typical range is around 300 m. [2, 7] For situations where the maximum range is not achievable, multi-hop (using vehicles to relay data broadcasts) may be a useful mechanism. [6]

Vehicle positioning

The key to all safety applications is an accurate spatial awareness of the crash scene (i.e., subject vehicle, adjacent vehicles, roadway, and infrastructure). With accurate autonomous spatial data, safety system algorithms can derive positional information including derivatives such as velocity and accelerations as well as distance measures such as gap and closing rate. While there are technologies for localized measurements such as radar, lidars, ultrasonic, or cameras, V2V safety applications require relative positional data from objects well beyond the operational ranges of these conventional sensors. At the root of more far-reaching measurement technologies is the global positioning system (GPS) which provides relatively accurate positioning and a common global clock. [8] While the basic GPS accuracy is sufficient for normal route guidance, safety systems require greater positioning accuracy (on the order of centimeters, especially for identified pre-crash safety scenarios. [2] Derivatives of GPS have improved the accuracy by refining the measurement with corrections. These technologies include DGPS with a reported accuracy of approximately 1 m, and real-time kinematic (RTK) positioning with centimeter accuracy. [8] Because the strength of GPS requires line-of-sight to numerous satellites, occlusions by overpasses, urban buildings, and deep valleys pose a problem in maintaining real-time positional data. A proposed solution is the fusion of GPS with inertial measurement units (IMUs) to maintain spatial awareness during these GPS blackout periods. [8] One GPS/IMU has been reported to provide a 2 cm horizontal and 5 cm vertical accuracy when the GPS signal is present, and maintain a 10 cm horizontal and 7 cm vertical accuracy during a 1-minute GPS signal blackout. [8]

Vehicle boundary envelopes

In addition to knowing the relative and absolute positioning of the objects within the crash scene, it is also vital to understand the boundary envelopes of the subject vehicle as well as other objects in the crash scene. This is particularly true for CVs where the vehicle lengths can typically range from 10 to 75 ft. (3 to 22.9 m). This length can be even longer in less populous areas in the western states such as Idaho, Nevada, and Montana, where CVs are allowed to pull triple trailers. Heights and widths of CVs (without special permits) typically range between 13.5 to 14.5 ft. (4.1 to 4.4 m) and 8.5 to 14 ft. (2.6 to 4.3 m), respectively. These dimensions vary with loads and must be accurately accounted for in crash avoidance algorithms.

Industry Outreach Preliminary Findings

Industry SMEs from the heavy vehicle manufacturers, suppliers, and fleet operators were interviewed to determine suitable crash avoidance technologies for V2V communications. Responses were received in the following areas:

Return on investment

An issue raised by several of the fleets was return on investment (ROI). Crash avoidance technologies can be expensive and fleets must justify their purchase. Fleets need to ensure that the technologies they invest in actually reduce crashes (thereby reducing operational costs) and are durable enough to recover the initial cost. Some of the issues related to ROI described by fleets include: the need for ongoing support of the technology by the vendor, the ability to transfer the technology to newer vehicle models, the expected life of the technology compared to the expected life of the tractor, and driver acceptance of the technology. As an example, one participant mentioned having purchased a crash avoidance system that his company assumed would last for 10 years. However, after four years of use, the company changed its model of tractor and could not transfer the technology to the new model tractors. The benefit from the technology therefore was greatly reduced: what was expected to be a 10-year investment only worked for 4 years. Another suggestion offered by an interviewed participant for increasing the technology ROI was a “plug-and-play box” that could be placed in a truck, so that if a carrier decided to switch technologies, the new technology could merely be “plugged in” and the truck would be able to accommodate it.

Installation

Several fleet participants described installation as an implementation issue with new technology. Having technology installed by the original equipment manufacturer (OEM) was generally viewed as more efficient than trying to retrofit a tractor with new technology. For example, one fleet participant described how bringing the vehicle in from the road and having to reinstall equipment in order to update to a new technology is an expense as it creates down time for the vehicle. “It is more efficient to put the technology in once and be done”.

Maintenance

Crash avoidance systems are only useful if they are maintained; therefore, it is important for drivers to understand that if the system gets damaged, they will need to have the truck repaired. Participants mentioned issues with external components and sensors. For example, one participant said, "that if a driver hits something, whether it is an animal or an object on the road, the antenna on their system is sticking right out in front of the truck and can be damaged". This presents a problem if the driver is unaware of the damaged, faulty sensor and continues to rely on the system. Crash avoidance systems need to be designed to minimize maintenance down times and susceptibility to damage from road debris and normal truck operations (such as dropping and hooking trailers). These systems should also provide feedback of degraded performance to both the driver and the fleet when appropriate.

System adjustability

Fleet participants described how they are sometimes frustrated by the inability to program or adjust their crash avoidance systems to perform in accordance with their company policies and procedures. For example, one fleet participant described how his company's drivers are trained to maintain at least a 7 second following distance from the vehicle in front of them, yet their crash avoidance system only alerts the driver when they are within 3 seconds of the vehicle in front of them. This company would prefer the ability to align the system parameters with their company policies.

While system adjustability does appear to be an issue for some fleets, another fleet participant described how his company is able to program their crash avoidance system. While the system is not adjustable by the driver, the company management can set the system parameters which are based on speed. For example, the participant described how at lower speeds it is acceptable to have the following distance be shorter than would be accepted at medium or high freeway speeds.

A few participants interviewed had comments regarding adjustability of volume of the alerts. For example, a fleet participant mentioned that his company allows drivers to reduce the volume of alerts to a certain minimum level that allows the co-driver to sleep. Yet another participant said that when testing a lane departure warning system with his company's team units, the team partner sleeping in the bunk liked hearing the alerts because it provided feedback to the resting team member that the driver was getting tired.

System reliability

Fleet participants described how the reliability of a crash avoidance system is important so that drivers maintain their trust in the system and do not become desensitized and ignore alerts. For example, a participant mentioned that lane departure warning systems are "too sensitive in some circumstances; they tend to go off more in construction zones where lane lines may be uneven and in snowy conditions where the system can detect tire tracks in the snow". Another participant described how he gets a "high rate of false alarms from the crash avoidance system every time the truck passes under an overpass".

While avoiding the problem of driver mistrust in a system resulting from false alerts is important, system reliability is especially critical in systems that intervene to reduce or mitigate a crash. During the interviews, one participant shared his concern that if a system brakes the vehicle to a complete stop then it needs to be identifying a vehicle and not some other non threat (e.g., a beverage can) on the road. This issue is important for vehicle control because of the implications of stopping on the highway with surrounding traffic.

Behavior monitoring

Crash avoidance technologies are being used by some fleets to monitor driver behavior. A fleet participant mentioned that they can examine data from the crash avoidance system on an exception report basis, review the lowest performing 20 percent of drivers on a weekly basis and conduct additional observation, evaluation, coaching, and training with the poorly performing drivers. Another fleet described how with their crash avoidance system they are able to view the environment surrounding an event, including where it occurred and the vehicle's speed 5 minutes prior to and 2 minutes following the event.

Data accessibility

The ability to use crash avoidance technologies to capture data about a crash as well as data regarding driver behavior (e.g., lane departures, following distances, etc.) is viewed as desirable by some fleets. Fleet participants that access data from crash avoidance systems said it is useful in identifying poor driver behavior and helpful in litigation. For example, a participant said that data from a crash avoidance system was used by his company in a liability case to show that the company was not at fault in a crash.

Not all fleets want access to data from their crash avoidance systems. Some of the reasons cited in the interviews for not wanting access to the data were a lack of resources to manage the data properly and a fear that if the data is accessible, yet not being used, that a company could be considered negligent. For example, one participant described how getting more data when manpower is staying the same can become problematic because "there was no one to monitor and analyze the data". In this case, the participant's preference was for the system to only alert the driver when necessary and not capture data.

Driver acceptance

Securing driver buy-in and acceptance of crash avoidance systems is important so that drivers are willing to use the systems. For instance, one fleet participant described how some drivers will tamper with the system in an attempt to disable it while others attempt to block alerts (e.g., using pillows to muffle the sound). Several fleet owners described ways that they work to gain driver acceptance, including cultivating a strong safety culture, seeking driver feedback on new technologies, and having managers test the systems to show drivers that management understands how the technology works. For example, the owner of one fleet described how he allows some of his drivers to test a new technology before being fully implemented and obtains the drivers' feedback. It is his opinion that considering drivers' reactions to a new system helps with driver acceptance of the systems that are ultimately used.

Driver distraction

Fleet participants indicated that crash avoidance technologies lose their benefit if they become a distraction to the driver. Participants said a system that encourages drivers to watch a display or screen more than the road is not beneficial. For instance, one participant described how his company was testing a lane departure warning system that had a small graph on the dash indicating where the truck was positioned in the lane. Drivers testing the system told their management that they were spending more time watching the graph than the road. Another participant said that his company was addressing distraction by integrating systems to reduce the number of technologies the driver needs to interact with while driving.

Driver overreliance

Fleet participants described the importance of having technologies that can improve safety while reminding drivers not to over rely on the technologies. Overreliance can be problematic if there is a technical problem with the system and the driver has invested too much trust in the technology. One participant described how his company actively reinforces the idea that technology is merely a tool to assist a driver and that drivers need to rely on their own ability and defensive driving skills.

Advanced capabilities

Fleet participants were interested in the advanced capabilities of a DSRC system over (or coupled with) their current sensor suites. For example, in regard to left turn across path, opposite direction (LTAP/OD) crash scenarios, a participant mentioned the advantage of wireless messages that have a wider distance or range. Figure 1 illustrates the LTAP/OD crash scenario. In rear-end scenarios, a participant described how he would be interested in V2V in trail communication (i.e., where one vehicle is creeping up on the other vehicle), so that the lead vehicle would be informed of the condition. Figure 2 shows the rear end crash scenario. Another participant liked the idea of knowing the "intentions of another vehicle". He gave the example of two vehicles side-by-side; if one vehicle starts moving towards the other vehicle, the system would warn the driver that there is an object in the vehicle's path.

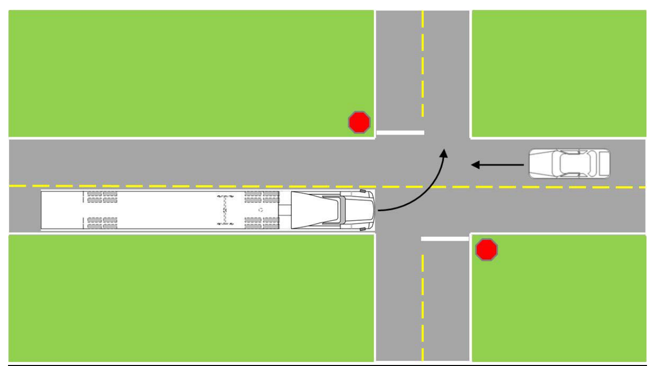

Figure 1. Left turn across path opposite direction (LTAP/OD) crash scenario. [12]

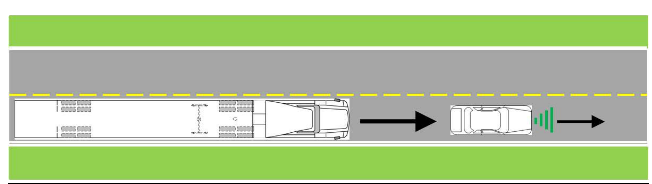

Figure 2. Rear end crash scenario. [12]

Behavior management

The ability to access more up-to-date information on driver behavior was mentioned as a potential benefit of DSRC. As one participant said "I want to know about behavior, do I have a driver who is constantly merging onto other vehicles? Do I have a driving behavior issue that I need to address?" Another participant liked the idea of having wireless communications transferring existing data back to the company's computer systems so that information on a critical event is available for management to use when talking to a driver the very same day.

Data management

A potential benefit of DSRC mentioned by fleet participants is the ability to capture data that can be used for legal and management purposes. For example, a participant said that in a rear-end crash scenario, his fleet would like to know what the truck was doing when it rear-ended a car. As was discussed previously, not all managers of fleets agree that access to crash and behavioral data is beneficial to their operations.

Integration

The ability to have one system provide multiple forms of crash avoidance information to a driver was mentioned by participants. As one participant noted, "Having one system would have huge advantages instead of having multitudes of different systems out there that are doing different things in different ways. Having one would certainly have its benefit, especially one that would bridge between normal driving public and commercial motor vehicle." Another participant said that he would like, "…something where all of the technology would be available in one package or in different modules attached to the truck, and that all use the same driver display or alert system so the driver needs only to look in one place for alerts".

V2V Safety Applications That Map To Real-World Crash Scenarios

With the advances in wireless communications and vehicle positioning, innovative safety applications can be applied to real-world crash scenarios that have been identified by Volpe. [11] While CVs have unique characteristics (e.g., size and weight) that must be considered in the development of safety applications, the real-world crash scenarios are similar whether a CV or light vehicle is involved. In previous work, CAMP evaluated a similar set of pre-crash scenarios and developed six safety applications: Emergency Electronic Brake Light (EEBL), FCW, Intersection Movement Assist (IMA), Blind Spot Warning + Lane Change Warning, Do Not Pass Warning (DNPW), and Control Loss Warning (CLW). [3] These applications served as a starting point for the CV safety applications considered by VTTI. The following list includes those applications that VTTI determined to be suitable for CVs.

Cooperative Forward Collision Warming (FCW)/Adaptive Cruise Control (ACC)

The FCW/ACC safety application determines when a rear-end collision is imminent and either issues an alert to the subject vehicle's driver or potentially produces an evasive maneuver (i.e., braking) to mitigate an impending collision with the vehicle ahead.

Emergency Electronic Brake Light (EEBL)/Enhanced Rear Signaling (ERS)

Because of their physical characteristics (e.g., size and weight), CVs may present obstacles for adjacent traffic. For instance, the width and height of the CV may limit the following traffic's view of the roadway ahead of the commercial vehicle. Unable to see beyond the commercial vehicle directly in front of them, the following vehicles' drivers will be hindered in their ability to anticipate and react to emergency events well ahead of them. When the CV brakes hard, the EEBL safety application enables the commercial vehicle to broadcast a self-generated message regarding its rapid deceleration to surrounding remote vehicles. [3, 4] In turn, the receiving vehicles determine the relevance of the message and either provide a warning to the driver or potentially produce an evasive maneuver (i.e., braking) to mitigate an impending collision with the commercial vehicle.

Another way commercial vehicles can create obstacles is due to their slower acceleration profile. Because of the large mass of these vehicles, commercial vehicles accelerate much slower than passenger vehicles, creating a larger than normal speed differential between vehicles traveling in the same direction. Working in the opposing direction as FCW, the ERS safety application would determine the rapid approach of following vehicles and broadcast a self-generated message of the imminent crash situation to the vehicles directly behind the commercial vehicle.

Blind Spot Warning (BSW)/Lane Change Warning (LCW)

During a lane change attempt (intended or unintended), the BSW/LCW will alert the subject vehicle's driver if the space adjacent to the subject vehicle is occupied by another vehicle. [3, 9] Compared to light vehicles, CVs are known for their large blind spots around the vehicle that pose a hazard to adjacent traffic. [10] As mentioned, CVs have variable lengths, widths, and heights that create shifting blind spots that must be accounted for in safety countermeasures.

<u>Control Loss Warning (CLW)</u>

The CLW safety application enables a CV to broadcast a self-generated control loss event to adjacent traffic. In turn, the receiving vehicles determine the relevance of the message and either provide a warning to the driver or potentially produce an evasive maneuver (i.e., braking) to mitigate an impending collision with the commercial vehicle. [3, 9]

<u>Intersection Movement Assist (IMA)</u>

The IMA safety application warns the CV driver when it is not safe to enter an intersection due to high collision probability with one or more remote vehicles in cross traffic. [3, 9]

<u>Wrong Way Driver Warning (WWDW)</u>

Using precise positioning information, the WWDW safety application provides a warning to the driver who is proceeding against the flow of traffic and a warning is broadcast to other vehicles in the at-risk area. [3]

<u>Do Not Pass Warning (DNPW)</u>

The DNPW safety application provides a warning to the CV driver when a slower moving vehicle cannot be safely passed using a passing zone which is occupied by oncoming vehicles. [3, 9]

<u>Cooperative Stop Sign Violation Warning (CSSVW)</u>

The CSSVW application uses both infrastructure-to-vehicle (I2V) and V2V communication to warn the subject-vehicle driver of an impending stop sign violation, and instructs the driver to stop at the legally prescribed location. The application also provides a warning to other drivers approaching the non-signalized intersection of the impending infraction.

<u>Left Turn Assist</u>

The Left Turn Assist safety application provides an impending crash warning to the subject vehicle's driver who is attempting a left turn at a signalized intersection without a phasing left turn arrow. [2]

<u>Cooperative Traffic Signal Violation Warning (CTSVW)</u>

The CTSVW application uses both (I2V) and V2V communication to warn the subject-vehicle driver of an impending traffic signal violation and instructs the driver to stop at the legally prescribed location. The application also provides a warning to other drivers approaching the signalized intersection of the impending infraction.

The success of future CV safety systems is dependent on the clear requirements to meet the needs identified by both crash analyses and the prescribed concept of operations. At the time of this writing VTTI was completing this task and a final report was being prepared detailing the performance requirements of the safety applications.

DRIVER-VEHICLE INTERFACE NEEDS SPECIFICATION

Overview

A key factor in determining the technical feasibility of migrating new and existing safety and mobility applications for future systems utilizing vehicle safety communications is the availability of an effective DVI for the system. At a minimum, there should be a clear understanding of relevant DVI requirements and potential solutions. In this context, "DVI" refers to the displays (i.e., visual, haptic, and or auditory) that the vehicle safety communications environment uses to communicate information to the driver, and the controls through which the driver interacts with the system. A project was initiated with the Battelle Center for Human Performance and Safety to investigate the specifications needed for an effective CV DVI.

The CV environment presents a number of challenges to the development of the DVI, including the: relatively long braking distances associated with commercial vehicles, extensive blind spot areas on all sides of the vehicle, and high levels of ambient vehicle noise and vibration around the driver. There are also advantages to developing the vehicle safety communications DVI within the heavy truck environment, including highly trained drivers and (typically) an organizational culture that encourages and rewards safe driving habits and overall performance.

It is expected that vehicles equipped with vehicle safety communications present a "message rich" environment to the CV driver, with a mix of: cautionary or advisory messages; time-critical messages such as collision warnings; messages related to navigation, routing, and travel decisions; and perhaps a special class of system status messages that communicate (e.g., transitions from full-manual control by the driver to at least partially automated control of certain vehicle subsystems). Poorly developed DVIs have the potential for confusing or distracting the drivers, leading to driver errors and, ultimately, crashes.

Importantly, from a driver's perspective, the source of information presented through a DVI (e.g., from the vehicle's sensors, from another vehicle's sensors, or from the infrastructure) is much less important than the timing, modality, format and reliability of the information presented. That is, the source matters less than the characteristics of the message itself.

Overall, the basic requirement for a vehicle safety communications DVI is that it is safe and effective. The DVI needs to avoid overloading the driver, interfering with the primary driving task, or contributing to driver errors or confusion. Also, the DVI should support quick and appropriate responses by the driver. In practice, assessing the feasibility of candidate applications or safety countermeasures to the connected vehicle environment (either V2V or V2I) requires consideration of a number of DVI features and related design questions, including the availability of specific design solutions or general design guidance for:

- The format, modality, location, and timing of messages, alerts, and warnings
- Strategies for minimizing false and nuisance alerts
- Integrating multiple subsystems within the vehicle environment, and prioritizing/managing messages presented to the driver
- Status, particularly as it relates to automated vehicle control functions
- Strategies for mitigating driver distraction
- Maintaining compatibility between message design and the desired driver response
- Special requirements of CV drivers

Industry Outreach Preliminary Findings

The objective of this task was to talk with SMEs to fill-in key information gaps identified in the literature review, and to provide some validation of existing findings that may be used in the development of the DVI functional requirements. In particular, multiple themes were identified for each of the information gaps covered in the interviews. While interviews involved mostly qualitative information and opinions on these topics, these findings still provide useful "starting points" for addressing these issues and developing the DVI functional requirements.

Although the SME responses to the interview questions covered a wide range of themes and subjects, a few overarching themes were apparent across several questions. These key points are summarized in the next sections for the following areas:

<u>Driver distraction and workload</u>

Driver distraction and workload are viewed by SMEs as some of the primary challenges facing drivers in the future. Moreover, technology was seen both as a potential solution for minimizing demands on drivers, and as a potential source of distraction. For example, several SMEs discussed beneficial applications of vehicle safety communications in terms of reducing demands on drivers by automating certain productivity and safety-related tasks, and also by providing reliable and actionable information to facilitate driver decision making. In contrast, potential drawbacks discussed included problems with poor DVI implementation and insufficient integration of technology (i.e., not integrating all systems that drivers use), which would likely make the driver's job more difficult. Another recurring concern was excessive false or nuisance alarms.

<u>Information management should be a key function</u>

This aspect has important implications for the driver workload and driver distraction issues described previously. A dominant theme in conversations with SMEs was the increase in information available to drivers, and importantly, the opportunities that vehicle safety communications could provide for managing information in a way that benefited driver safety and productivity. Information management involves several aspects; some of the most relevant ones for the DVI functional requirements are:

- <u>Management of immediate information</u>. This involves prioritization and integration of display messages (e.g., warning messages) so that drivers receive important, safety-critical information in a timely manner, while other “less critical” messages are presented when they will not interfere with the primary driving task.

- Integration of information from multiple systems. This includes some form of message arbitration to minimize the information that requires a driver response (i.e., offloading some information to autonomous systems in the CV so drivers are not overloaded).

- Supervisory role of drivers. There was a recognition that the driver's relationship with some information could evolve to more of a supervisory role. This potentially opens up a new set of problems (i.e., driver vigilance, system trust); however, several of these issues are well understood in other domains, such as process control.

Driver acceptance

Driver acceptance of vehicle safety communications technology is also an issue that warrants special consideration. Ultimately, the effectiveness of any technology depends on drivers' willingness to make full use of available capabilities. This in turn requires that the technology is designed in a way that it accommodates the characteristics of the driver population, including the increasing mix of younger and older drivers, with the addition of greater cultural diversity than was previously the case. Similarly, including drivers in the testing and development process was another aspect of promoting driver acceptance mentioned by several SMEs. The use of driver feedback was also cited as a potential factor in driver acceptance. In particular, the concern is that drivers would be reluctant to use the system if information is used in a punitive manner. However, using feedback for training opportunities was seen as a way to potentially improve driver acceptance.

Return on investment

A practical reality of vehicle safety communications in commercial vehicle operations is that productivity applications and overall ROI will be important drivers with respect to technology adoption. It is likely that applications for productivity information may in the future be incorporated in these systems, which requires special considerations with regard to integration with other components and information management.

Overall, the SME interviews conducted in this task provided a broad range of important insights about key information gaps. This information is being taken into consideration for developing the DVI functional requirements; however, care is being taken when applying this information, since it is qualitative in nature, and comes from a relatively limited number of SMEs. Overall, the SMEs provided numerous insights and ideas relative to both our short-term focus on the CV DVI functional requirements, as well as future CV DVI development, design, and evaluation activities.

Using the information gathered from the SME interviews and other sources, Battelle is currently developing guidelines for effective commercial vehicle DVIs for vehicles equipped with vehicle safety communications. This information is being prepared in a final report to U.S. DOT to be submitted at the conclusion of the project.

FUTURE ACTIVITIES

During the next phase of the CV vehicle safety communications program, prototype vehicles will be built with integrated V2V systems. These vehicles will undergo objective testing and participate in large scale field demonstrations of this technology being conducted by U.S. DOT beginning in 2012-13.

SUMMARY

This paper provided an overview of vehicle safety communications research for commercial vehicles being conducted by U.S. DOT. This program has made progress by identifying the fundamental issues that need to be resolved to implement V2V on this class of vehicles. Three research projects have been initiated in 2010 to study CV-specific interoperability issues, development of performance requirements for CV safety applications, and determine the CV-specific driver-vehicle interface (DVI) needs. This research directly supports the larger effort by U.S. DOT investigating V2V for all vehicle types. Resolution of the CV issues will help facilitate deployment of V2V for all vehicle types so that the potential safety benefits of V2V can be fully realized.

AKNOWLEDGEMENTS

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Development and Evaluations of Advanced Emergency Braking System Algorithm for the Commercial Vehicle

Taeyoung, Lee
Kyongsu, Yi
School of Mechanical and Aerospace Engineering, Seoul National University
Korea
Jangseop, Kim
Research & Development Division, Hyundai-Kia Motors
Korea
Jaewan, LEE
Korea Automobile Testing & Research Institute, Korea Transportation Safety Authority
Korea
Paper Number 11-0290

ABSTRACT

This paper presents a development and evaluations of the Advanced Emergency Braking System (AEBS) Algorithm for the commercial vehicle. The AEBS is the system to slow the vehicle and mitigate the severity of an impact when a rear end collision probability is increased. To mitigate a rear end collision of the commercial heavy truck, the AEBS comprises of a millimeter wave radar sensor, CCD camera and vehicle parameters of which are processed to judge the likelihood of a collision occurring. If the likelihood of a rear end collision with an obstacle is judged as probable, warning signals are provided to alert the driver by the AEBS algorithm. If driver fail to react to the warnings when the collision likelihood is judged as being high, the AEBS algorithm applies autonomous braking in order to reduce the impact speed.

To demonstrate the control performance of the proposed AEBS algorithm's, longitudinal vehicle model of the commercial target vehicle was developed by using the real vehicle's test data and vehicle dynamics. Also, closed-loop simulation of the AEBS was conducted.

In order to indicate the safety level of the driving situation, new safety indexes are suggested. From the simulation result and analysis using this safety indexes, it is shown that proposed AEBS algorithm can enhance the commercial heavy truck's longitudinal safety in the dangerous driving situation which can be occurred rear-end collision.

INTRODUCTION

Road safety is a major concern in most countries and the attention is turning towards active safety system that is not only developed to reduce the consequences of accidents but also to reduce the number of driver errors and thereby the number of accidents. In case of Korea, there is the unenviable record being one of the highest traffic accidents and fatality rates. In 2009, there were 5,838 fatalities on the road.[1] Therefore, a new and systematic approach to safety system is necessary to reduce traffic casualties. In this point of view, an Adaptive Cruise Control (ACC) system for the passenger vehicle had entered the market to mitigate the consequences of an accident and to reduce the number of fatalities among car occupants.

Especially, with truck-related accidents are made up a relatively large part of all road fatalities. In 1998 heavy goods vehicles were involved in 17% of all road accident fatalities despite making up just 7% of the traffic on the roads of Great Britain[2]. Also, according to Swedish and European authorities, approximately 13000 lives are lost in Europe yearly in traffic accidents involving Heavy Goods Vehicles. 40% of these fatalities are unprotected road users, 6% are truck drivers, and 54% are drivers and passengers of cars.[3] Hence, an Autonomous Emergency Braking System (AEBS) for trucks is able to not only decrease the truck-related accidents, but also lead the reduction of road fatalities. [4]

To assure real road safety improvements by the AEBS, the relationship between changes with and without of the AEBS in the same driving situation must be established. In order to obtain the estimation of the overall safety impact of the AEBS, a safety index which is able to measure an objective safety of the system is needed.

The goal of this research is the development of the AEBS Algorithm for the Commercial Vehicle and relevant assessment methods of the AEBS by the objective safety index in the dangerous driving situation which can be occurred rear-end collision.

The AEBS control algorithm consists of two parts: obstacle detection part and main controller part. In the obstacle detection part, front obstacle information was measured and collected for the main controller's decision. The main controller for the AEBS is composed of the two control stage: upper and lower level controller. By using the collected obstacle information, the upper level controller of the main controller decides the control mode. Next, the lower level controller determines warning level and braking level to maintain the longitudinal safety. When the control algorithm calculates the desired deceleration, braking part generate the brake pressure to maintain the controller's decision.

To formulate the safety level of the driving situation, it is suggested that Longitudinal Safety Index (I_{Longi}) which is derived by using a warning index and an inverse Time To Collision (*TTC^{-1}*). Also, by using this safety index, Total Warning Time (*TWT*) and Total Longitudinal-safety Value (*TLV*) are defined.

Finally, closed-loop simulation was conducted to demonstrate the proposed algorithm by using longitudinal vehicle model which is developed by using the real vehicle's test data and vehicle dynamics. From the simulation result, the control performances of the proposed AEBS algorithm was concluded in the rear-end collision probable situation.

SAFETY INDEXES FOR DEVELOPMENT OF THE AEBS ALGORITHM

Several authors have derived safety indexes for evaluation of vehicle's safety systems. Especially, the *TTC* and the warning index are well-known parameters in Adaptive Cruise Control (ACC) system and Collision Warning/Collision Avoidance (CW/CA) systems.

The *TTC* is defined as the time left to a collision. Form the definition of the *TTC*, TTC^{-1} can be defined as:

$$TTC^{-1} = \frac{v_{long}}{P_{long}} \qquad (1)$$

where, v_{long} is the relative velocity between the subject vehicle and the preceding vehicle and p_{long} is the longitudinal vehicle spacing for the subject's driving direction.

The warning index represents the danger of physical collision in the current driving situation and this is defined as follows:

$$x = \frac{p_{long} - d_{br}}{d_w - d_{br}} \qquad (2)$$

where, d_{br} and d_w are the braking-critical and warning-critical distances. If p_{long} exceeds d_{br} and d_w, then the warning index is a positive value that is greater than unity, and indicates that the current driving situation is in a safe region. If p_{long} is below d_{br}, then the warning index is a negative value and indicates that the current driving situation can be dangerous. The warning-critical and braking-critical distances are defined as follows:

$$\begin{aligned} d_{br} &= v_{long} T_{s,delay} + f(\mu)\left(\frac{v_s^2 - (v_s - v_{long})^2}{2a_{\max}}\right) \\ d_w &= v_{long} T_{s,delay} + f(\mu)\left(\frac{v_s^2 - (v_s - v_{long})^2}{2a_{\max}}\right) + v_s T_{h,delay} \end{aligned} \qquad (3)$$

where, $T_{sys,delay}$ is the system delay, which is given by the brake-system hardware, a_{max} is the maximum deceleration of the vehicle under normal road conditions, v_s is the velocity of the subject vehicle, $T_{h,delay}$ is the delay in human response between recognition and manipulation, *f(-)* is the friction scaling function, and μ is the estimated value of the tire-road friction coefficient. [5]

Longitudinal Index

In case of the TTC^{-1}, it is suitable for assessments of safety measure with the vehicle in front of the speed difference between the vehicle and its leader is maintained. On the other hand, the warning index is physically driven index based on the driving situation and considered as maximum deceleration of the vehicle.

To make up for the each parameter's insufficiency, the longitudinal index to monitor the vehicle-to - vehicle collision can be determined by using the warning index and the TTC^{-1}.

In the case of the warning index beyond a threshold value and the TTC^{-1} below a threshold value, it indicates that the current driving situation is in a safety region. Otherwise, the current driving situation can be dangerous. Therefore the longitudinal index using the warning index and the TTC^{-1} can be determined as follows:

$$I_{longitudinal} = \max\left(\frac{|x_{\max} - x|}{|x_{\max} - x|}, \frac{|TTC^{-1}|}{|TTC_{th}^{-1}|}\right) \qquad (4)$$

where, x_{max} is the maximum warning index, TTC_{th}^{-1} is the threshold of the TTC^{-1}.

Figure 1 shows the warning index- TTC^{-1} plane and describes the determination of the longitudinal index more detail. [5]

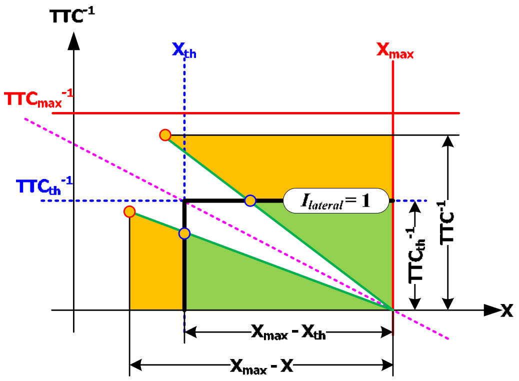


Figure 1. The Longitudinal Safety Index in the warning index- TTC^{-1} plane

From the definition, the longitudinal safety index is able to indicate the dangerous ratio about the longitudinal safety threshold of the warning index and TTC^{-1}. In other words, in the case of the longitudinal safety index is exceed '1', it indicates that the current driving situation's dangerous level is directly proportional to the longitudinal safety index value.

Safety Indexes: Total Warning Time & Total Longitudinal-safety Value

The safety values derived in the longitudinal safety index indicate vehicle's instantaneous safety level. Therefore, if the longitudinal safety index with respect to the preceding vehicle in every simulation time step can be recorded, it is possible to check the system's overall control performance during the driving the driving from analysis of the longitudinal safety index trajectories.

To evaluate the overall safety of the system, *Jan Lundgren at al.* suggests the Time Exposed TTC and Time Integrated TTC values. [6]

Similarly this study, safety indexes can be derived from the trajectories by defining the longitudinal safety threshold, I_{Longi_th}. One measure of the total time spent in dangerous situations is Total Warning Time, which is defined as

$$TWT = \sum_{t=0}^{T} \delta(t) \cdot \tau$$

$$where \quad \delta_i(t) = \begin{cases} 1 & 0 \le I_{Longi_i}(t) \le I_{Longi}^{*} \\ 0 & otherwise \end{cases} \quad (5)$$

$I_{Longi}(t)$ is the longitudinal safety index of vehicle in time step t . The simulation time step is denoted τ ,

The severity of the danger can be measured by Total Longitudinal-safety value of the total exceed values of the threshold which is defined as

$$TLV = \int_0^T \left(I_{Longi,i}(t)\right) \cdot \delta(t)\, dt \quad (6)$$

The TWT and TLV are illustrated in Figure 2. The TTC trajectory

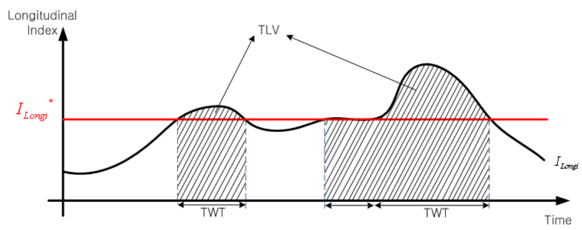


Figure 2. Longitudinal Safety Index trajectory and definition of TWT and TLV

AEBS CONTROL ALGORITHM FOT COMECIAL VEHICLES

To avoid or mitigate a rear end collision of the commercial heavy truck, the AEBS algorithm was developed. The AEBS control algorithm consists of two parts: obstacle detection part and main controller part.

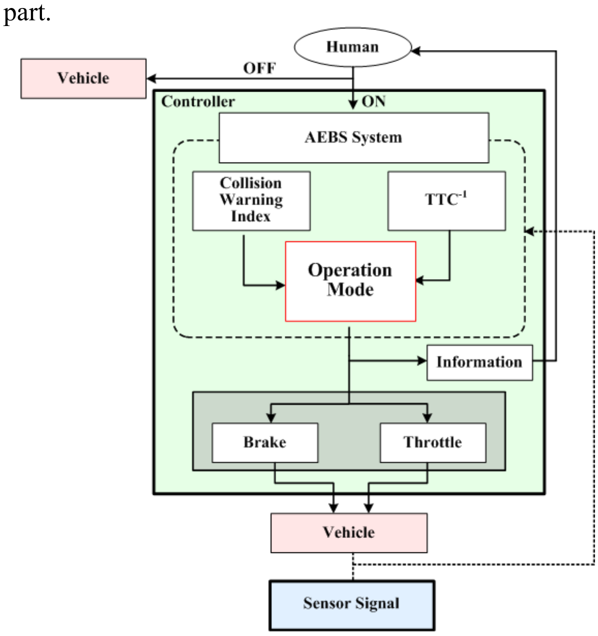


Figure 3. Flow chart of the AEBS algorithm

Obstacle Detection

In the obstacle detection part, front obstacle information was measured and collected for the main controller's decision. Vision sensor is known for its capability of measuring of a target's outline accurately. Also, vision system can provide a classification of objects. However, range and speed measurements are less accurate. On the other hand, radar sensor has a high accuracy in measuring of the range and speed. Therefore, these two types of the sensor are used to detect the front obstacle information.

Considered each sensor's detecting range and accuracy, the main target information is decided in the data fusion part. The data fusion part receives primary target information which is processed to judge in-lane target from the individual sensors and merges them to decide main target information.

Main Controller

The main controller of the AEBS algorithm is composed of the two control stage: upper and lower level controller.

Upper-level Controller: Control Mode Decision

By using the collected obstacle information, the upper level controller of the main controller decides the control mode.

To decide the control mode of the AEBS algorithm, warning index and TTC^{-1} parameters are considered. From the definition of theses parameters, if the vehicle's longitudinal safety comes to dangerous situation, TTC^{-1} will be increasing but warning index will be decreasing. Therefore, vehicle's longitudinal safety level can be defined in the warning index – TTC^{-1} phase.

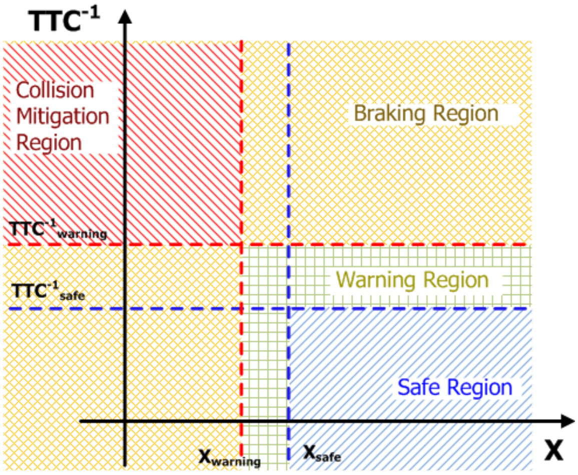


Figure 4. Safety Mode in the warning index – TTC-1 phase plane

To divide the control model, threshold value for each parameter is set two levels: 'Safety threshold' and 'Warning threshold'. The 'Safety threshold' means the value of which driver start feeling fear for driving situation. When the parameter near the 'Warning threshold' value, it means that driver should be start braking to avoid the rear-end collision.

By using these two level threshold values of each parameter, control mode can be defined as 4 Phase: 'Safe Region', 'Warning Region', 'Braking Region' and 'Collision Mitigation Region'.

In case of the 'Braking Region' and 'Collision Mitigation Region', it is important that the assurance assessing approach whether a collision with an observed object is avoidable or not.

To check the physical collision capability, the last moment of the physical collision is defined as the situation when relative velocity and clearance between subject vehicle and target vehicle are zero. Also, assume the 'required relative acceleration' for the last moment of the physical collision during 'physically required time'. From these definitions and assumption, physically required time can be calculated as equation (7).

$$\begin{cases} p_{long} + v_{long} \cdot \left(T_{req}\right) + \frac{1}{2} \cdot a_{r,req} \cdot \left(T_{req}\right)^2 = 0 \\ T_{req} = -\frac{v_{long}}{a_{r,req}} \end{cases} \tag{7}$$

where, T_{req} is physically required time and $a_{r,req}$ is required relative acceleration.

From this method, 'Collision Mitigation Region' is decided based not only on parametric division, but also on physical collision capability.

Lower-level Controller: Control Input Decision

When the upper-level controller decides the control mode, the lower level controller determines warning level and braking level to maintain the longitudinal safety.

i) Warning phase

If the upper-level controller decides that vehicle isn't in the 'Safe Region', lower-level controller gives the warning signal to the driver. The warning level is classified two levels. When the driving state is in a 'Warning Region', the first level warning starts running. If the driving state is in the 'Braking Region' or 'Collision Mitigation Region', the second level warning is operated. According to the warning level, the warning is composed of two kinds of alarm: 'alarm sound only' and 'alarm sound with tightening a seat-belt'.

ii) Braking phase

If the vehicle is in the 'Braking Region' or 'Collision Mitigation Region', in spite of the driver doesn't give a braking maneuver, autonomous braking is necessary until the vehicle's control mode return to 'Safe Region'. Also, when the driver gives a brake actuation, the driver's braking intention should influence to the AEBS braking level. Therefore, the braking level of the AEBS algorithms are based on control mode and braking maneuver.

In case of the 'Braking Region', lower-level controller gives first level brake operation. When the lower-level controller decides the 'Collision Mitigation Region', the second level brake starts operating. Only if both 'Collision Mitigation Mode' is decided and driver's braking maneuver is operation, the full braking action is triggered.

EVALUATIONS OF THE AEBS ALGORITHM

To demonstrate the AEBS algorithm, closed-loop simulation with human driver model was comprised ‘with AEBS driving case’ and ‘without AEBS driving case’ by using the proposed safety indexes. Also, for evaluation of the AEBS algorithm, simulation model is composed of longitudinal vehicle model and sensor model. The longitudinal vehicle model of the commercial target vehicle was developed by using the real vehicle’s test data and vehicle dynamics. The sensor model gives the front obstacle information which is consists of clearance, relative velocity and target on/off signal.

Two simulation scenarios were selected: emergency deceleration case and vehicle cut-in case.

Case □: Emergency Deceleration

To evaluate the proposed AEBS algorithm, simulation scenario is composed of emergency deceleration case as follow:

- Preceding Vehicle Speed: 80km/h
- Subject Vehicle Speed: 80km/h
- Initial Clearance: 20m
- Preceding Vehicle’s Final Speed : 30km/h
- Preceding Vehicle’s Deceleration: -4.5m/s^2
- Driver’s Reaction Delay Time: 0.8sec

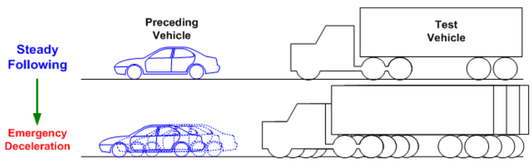
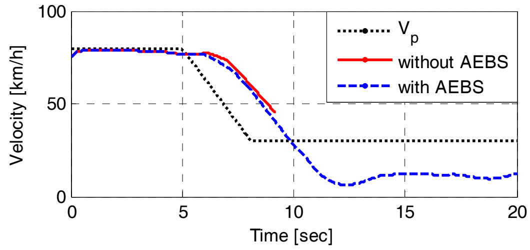


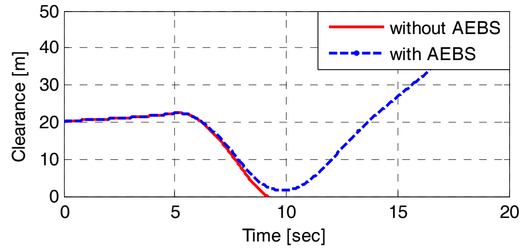
Figure 5. Simulation scenario for evaluation of the AEBS algorithm: Emergency Deceleration Case

As shown in Figure 6-d, when the preceding vehicle starts to decelerate, the AEBS algorithm gives a warning signal immediately. Also, as shown in Figure 6-a and 6-b, the AEBS algorithm operates autonomous braking to avoid the rear-end collision. However, without AEBS algorithm case, driver's braking input which is working after reaction delay cannot prevent the vehicle’s collision.

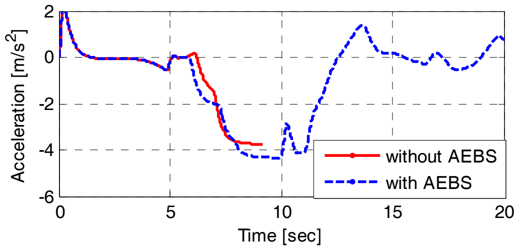
In order to validate the AEBS algorithm, safety indexes are comprised between ‘with AEBS’ and ‘without AEBS’. Safety indexes (‘Warning index’, ‘TTC^{-1}’ and ‘I_{Longi}’) are shown in Figure 7. After preceding vehicle starts deceleration, all safety indexes over the safety threshold. In case of the ‘without AEBS’, safety indexes are getting dangerous until collision occurred. However, ‘with AEBS case’ returns to the safety region by using the AEBS operation.



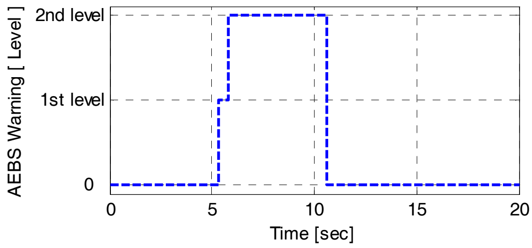
a. Velocity [kph]



b. Clearance [m]

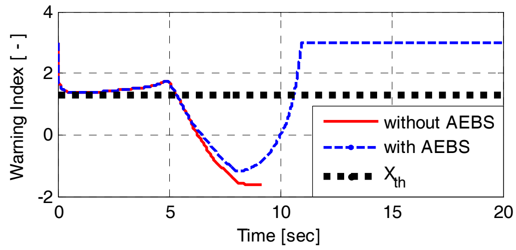


c. Acceleration [m/s2]

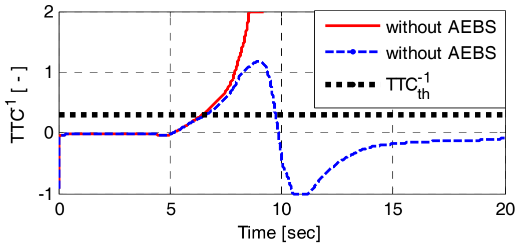


d. Warning Signal

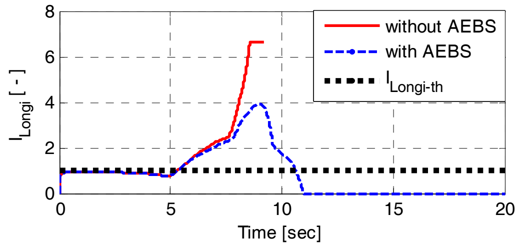
Figure 6. Simulation Results: Emergency Deceleration Case



a. Warning Index



b. Inverse TTC



c. Longitudinal Index

Figure 7. Safety Indexes: Emergency Deceleration Case

Also, ‘TWT’ and ‘TLV’ can be calculated by using I_{Longi} trajectories as shown in Figure 7-c. From these result, Table 1 contains the resulting of comparison of safety indexes between ‘with’ and ‘without’ AEBS. As shown in Table 1, all safety indexes indicate with AEBS case is safer than without case.

Table 1 Values of safety indexes: Emergency Deceleration Case

	without AEBS	**With AEBS**
Min. X	*-1.62*	*-1.20*
Max. TTC^{-1}	*2.0*	*1.76*
Max. I_{Longi}	*6.67*	*3.92*
TWT	*3.83*	*5.28*
TLV	*12.14*	*12.09*

Case Ⅱ: Low-speed Vehicle Cut-in Case

The second simulation scenario is low-speed vehicle’s cut in situation. The detail options of the scenario are as follow:

- Preceding Vehicle Speed: 80km/h
- Subject Vehicle Speed: 80km/h
- Initial Clearance: 20m
- Cut-In Vehicle Speed : 65km/h
- Cut-In Distance: 15m
- Driver’s Reaction Delay Time: 0.8sec

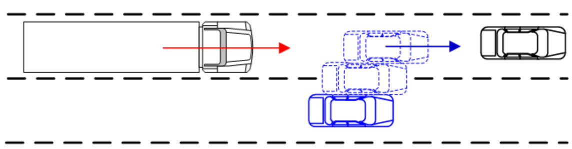
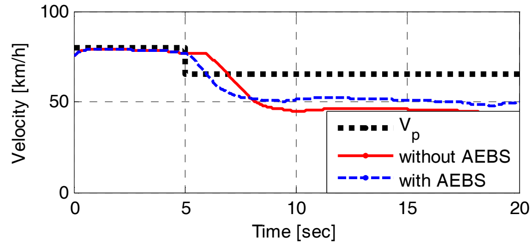
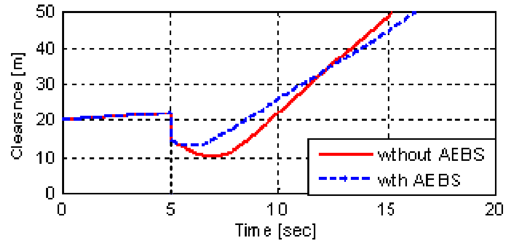


Figure 8. Simulation scenario for evaluation of the AEBS algorithm: Low-speed Vehicle Cut-in Case

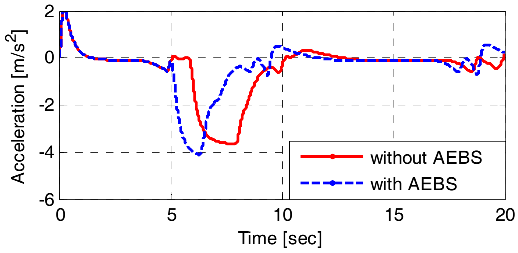
As shown in Figure 9, the braking operation of the ‘with AEBS’ case was faster than ‘without AEBS’ case. Also, when the lower speed vehicle starts to cut-in, the AEBS algorithm gives a warning signal immediately as shown in Figure 9-d.



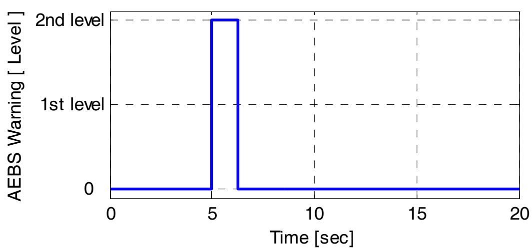
a. Velocity [kph]



b. Clearance [m]



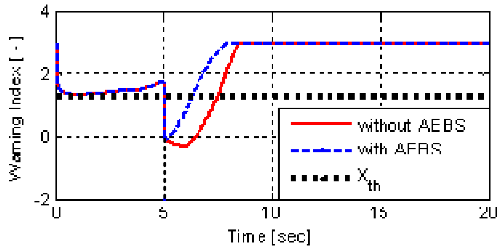
c. Acceleration [m/s2]



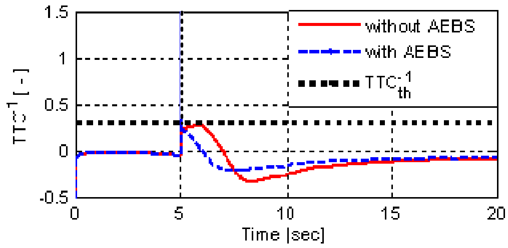
d. Warning Signal

Figure 9. Simulation Results: Low-speed Vehicle Cut-in Case

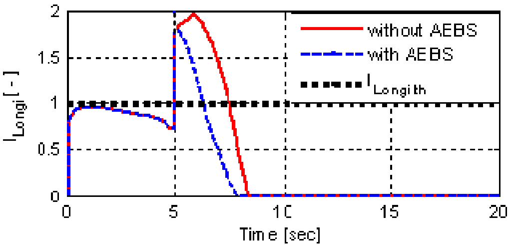
Safety indexes in the low-speed vehicle cut-in scenario are shown in Figure 7. In case of the warning index and longitudinal safety index exceed the safety threshold during the low speed cut-in is operation and return to the safe region. However, in case of the TTC^{-1} value, the whole of driving trajectories are maintained the safe region.



a. Warning Index



b. Inverse TTC



c. Longitudinal Index

Figure 10. Safety Indexes: Low-speed Vehicle Cut-in Case

Safety indexes can be compared between 'with' and 'without' AEBS in detail, as shown in Table 2. As shown in Figure 10-b and Table 2, TTC^{-1} values are not suitable for comparison in this simulation scenario. Also, maximum values of the warning index and I_{Longi} are little different. On the contrary to this, TWT and TLV can be distinguished from with AEBS and without AEBS.

Comparison results of the TWT and TLV indicate that the proposed AEBS algorithm can be improved the commercial vehicle's longitudinal safety compared to the without control case.

Table 2 Values of safety indexes: Low-speed Vehicle Cut-in Case

	without AEBS	With AEBS
Max. X	*-0.34*	*0.07*
Min. TTC^{-1}	*0.3*	*0.22*
Max. I_{Longi}	*1.96*	*1.81*
TWT	*2.50*	*1.29*
TLV	*4.24*	*1.95*

CONCLUSIONS

In this paper, the AEBS algorithm for the commercial vehicle was proposed. The proposed AEBS Algorithm consists of obstacle detection part and main controller part. In the obstacle detection part, front obstacle information was measured and collected by using the vision sensor and radar sensor. Considered each sensor's detecting range and accuracy, the main target information is decided. The main controller of the AEBS algorithm is composed of the two control stage: upper and lower level controller. By using the collected obstacle information, the upper level controller of the main controller decides the control mode based not only on parametric division, but also on physical collision capability. The lower level controller determines warning level and braking level to maintain the longitudinal safety.

To formulate the safety level of the driving situation, safety indexes (Total Warning Time: *TWT* and Total Longitudinal-safety Value: *TLV*) are suggested which are defined by using the longitudinal safety index and its threshold value.

Finally, closed-loop simulation was conducted to demonstrate the proposed algorithm by using longitudinal vehicle model and sensor model.

From the simulation result and analysis using this safety indexes, it is shown that proposed AEBS algorithm can enhance the commercial heavy truck's longitudinal safety in the dangerous driving situation which can be occurred rear-end collision.

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DRIVER PERFORMANCE WITH A CAMERA/VIDEO IMAGING SYSTEM

Paul Rau
National Highway Traffic Safety Administration
USA
Gregory M. Fitch
Myra Blanco
Richard J. Hanowski
Matthew C. Camden
Virginia Tech Transportation Institute
USA
Paper Number 11-0443

ABSTRACT

Camera/Video Imaging Systems (C/VISs) help drivers monitor the areas around their truck by relaying live video images collected from cameras mounted on the truck's exterior to monitors mounted inside the truck's cabin. The purpose of this study was to expand on the favorable results from previous C/VIS test-track research performed by NHTSA and FMCSA by evaluating the implementation of C/VISs in a real-world operation. Drivers' performance with and without a C/VIS was unobtrusively recorded using a naturalistic driving study approach. Twelve drivers from a fleet company participated in this research and drove a company truck on revenue producing routes. Each driver drove one truck that had either a commercially-available C/VIS, or an Advanced-C/VIS (A-C/VIS) developed by VTTI. The commercially-available C/VIS selected was called SIDETRACKER™ and had a side-view camera on each fender. The A-C/VIS had side-view cameras, a rear-view camera, and night-vision capabilities. The trucks that were driven in this study remained permanently coupled to 48-ft long trailers over the course of the twelve-month data-collection interval. Each driver drove a truck for one month with the C/VIS disabled (Baseline condition), and three months with the C/VIS enabled (Test condition). Drivers completed surveys regarding their driving performance and overall experience with C/VISs every two weeks. It was found that C/VISs are able to assist commercial motor vehicle (CMV) drivers in their daily driving task without deteriorating their driving performance. Specifically, the probability that drivers looked forward, their clearance to an adjacent vehicle when changing lanes, and their involvement in safety critical events (SCEs), did not change when driving with a C/VIS. Drivers also reported that the CVIS improved their awareness of surrounding objects and assisted them in performing lane changes and merge maneuvers, particularly when making right lane changes. The A-C/VIS's rear-view vantage point was the most frequently used feature and was highly rated by drivers. Even though drivers' positive subjective ratings can contribute to safety, it is important to note that drivers did not encounter fewer SCEs when driving with a C/VIS. A potential limitation with the study is that the driving data were collected when traffic density was low. Further research could observe drivers' performance with and without C/VISs in congested traffic. Performance in dense traffic could provide a continued analysis of the distribution of SCE's as an index of safety benefit. OEMs and tier-1 suppliers have developed multiple methods to implement C/VISs. The A-CVIS is an innovative approach to C/VIS that assists drivers to overcome blind spots; this paper presents a real-world evaluation of such a system including the identification of potential safety benefits.

INTRODUCTION

Data from the 2009 National Automotive Sampling System General Estimates System indicate that 20 percent of the 6,703 truck crashes were classified as a sideswipe in which both vehicles were travelling in the same direction (U.S. Department of Transportation, 2009). This statistic comprises crashes where the truck sideswiped another vehicle (i.e., cases where the truck was the striking vehicle), crashes where the truck was sideswiped by another vehicle (i.e., cases where the truck was struck), and cases where vehicle role was indeterminable. In only considering the crashes were the truck was the striking vehicle, 20 percent (653 crashes) of the 3,397 striking truck crashes were classified as sideswipes in the same direction. Table 1 organizes these 653 sideswipe crashes by their pre-crash maneuver. These data indicate that a total of 457 crashes involved the truck changing lanes, merging, passing a lead vehicle, turning left or right, making a u-turn, leaving a parked position or starting in the traffic lane. These crashes comprise 6.8 percent of the 6,703 truck crashes, and are of interest because they may be related to the truck driver not having a complete view of the adjacent vehicles when executing a maneuver. It should be noted that sideswipes occurring when the truck was going straight, decelerating, or negotiating a turn may involve the driver drifting out of their lane, and may not represent cases where a crash occurred because the driver failed to observe an adjacent vehicle when executing a lateral maneuver.

Crashes involving truck drivers failing to observe an adjacent vehicle are of interest to the U.S. DOT. This is because trucks have large blind spots around the left, right, front and back of the vehicle. These blind spots, or 'No-Zones', allow vehicles to travel beside the truck unbeknownst to the truck driver and thus make them susceptible to a collision if the driver executes a lateral maneuver.

Table 1.
Classification of sideswipe crashes by pre-crash maneuver

Pre-Crash Maneuver	Frequency	Percent (%)
Going Straight	175	26.8
Decelerating in Traffic Lane	5	0.77
Starting in Traffic Lane	4	0.61
Passing or Overtaking Another Vehicle	11	1.68
Leaving a Parked Position	3	0.46
Turning Right	54	8.27
Turning Left	26	3.98
Making U-turn	5	0.77
Negotiating a Curve	7	1.07
Changing Lanes	344	52.68
Merging	10	1.53
Other	1	0.15
Unknown	8	1.23
Total	653	100

A simple, low-cost countermeasure to No-Zone-related crashes is to provide drivers with a view of the areas surrounding their truck with a Camera/Video Imaging System (C/VIS) (Rau, Schaudt, Wierwille, Hanowski, & Bocanegra, 2009). C/VISs help drivers monitor the areas around their truck by relaying live video images collected from cameras mounted on the truck's exterior to monitors mounted inside the truck's cabin. These C/VISs supplement the existing mirror system, and are not used to replace the mirror system. Various C/VISs have been developed and are commercially available. For instance, VTECH USA manufactures a C/VIS called SIDETRACKER™ and reports that this system has been installed on 8000 US XPRESS trucks (V-TECH USA LLC, 2009).

Both the National Highway Traffic Safety Administration and the Federal Motor Carrier Safety Administration have been interested in the potential benefits C/VISs offer the commercial driving industry. The indirect visibility research program has involved: 1) developing a static testing method for assessing the quality of indirect visibility on heavy trucks (Jenness, Llaneras, & Huey, 2008), 2) developing a performance specification for daytime C/VISs on heavy vehicles (Wierwille, Schaudt, Gupta, Spaulding, & Hanowski, 2008), and 3) developing an enhanced C/VIS (E-C/VIS) to provide all-around visibility to drivers during nighttime and inclement weather conditions (Schaudt, Wierwille, & Hanowski, 2008; Wierwille, Schaudt, Blanco, Alden, & Hanowski, in press). In addition, NHTSA and FMCSA contracted with the Virginia Tech Transportation Institute (VTTI) to perform a C/VIS Technology Field Demonstration (TFD) and evaluate driver performance with C/VISs in a revenue-producing environment. Findings from the TFD are presented in this paper.

METHOD

Participants

Twelve Commercial Driver's License (CDL)-qualified drivers participated in this study. All drivers were employees of Schneider National, Inc and worked at the Winchester, Virginia operation. This operation ran a daily-delivery service where each participant drove the same route each day. The majority of the participants' driving was performed at night. Their shifts began as early as 5:00 PM and as late as 1:00 AM. Participant shifts ended as early as 3:30 AM and as late as 11:00 AM. All participants traveled alone for the duration of their shifts. The drivers' average age was 39 years old (Min = 26 years old, Max = 53 years old). All participants had a minimum visual acuity of 20/40. Eleven drivers completed all four months of the study, while one driver completed three months of the study before he quit his employment.

Test Vehicles

Schneider National, Inc provided six Freightliner C120 Century tractors from their Winchester, Virginia operation for use in the TFD (Figure 1). The tractors were attached to 48-foot long trailers, which were the longest trailers available at this operation. In order to minimize interference with the data collection system, the study required that the tractors remained permanently coupled with the trailers. This is atypical in the trucking industry. During the fleet company recruitment process Schneider National, Inc was the only company who agreed to operate under this constraint. The Winchester, Virginia operation was selected because it was the most cost-effective to travel to with respect to collecting data throughout the TFD.

Figure 1. Freightliner C120 tractor with 48-ft trailer

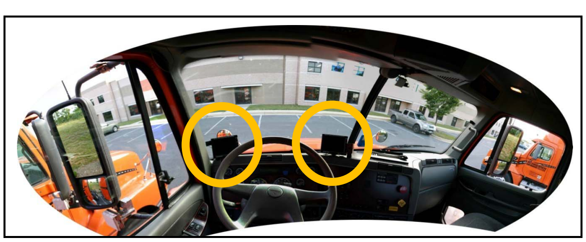
C/VISs

Two C/VISs were used in the TFD. The first was a commercially available C/VIS, while the second system was an Advanced C/VIS (A-C/VIS) developed by VTTI. Both are briefly described below, while additional information is presented in Fitch, Blanco, & Hanowski (2009).

Commercially Available C/VIS

The selected commercially available C/VIS was a cab-only solution, where one camera was mounted on the left fender pointing back along the left side of the trailer, and another camera was mounted on the right fender pointing back along the right side of the trailer (Figure 2). Each camera's Field-of-View (FOV) was 88 degrees, which provided wide coverage but also increased image distortion. Two monitors were mounted on the dash inside the truck cabin, one on the left side of the steering wheel, and one on the right side of the steering wheel (Figure 2). The Sidetracker settings were selected through an on-screen menu and included the ability to adjust the brightness, contrast, tint, and color of the video image.

a) b)



c)

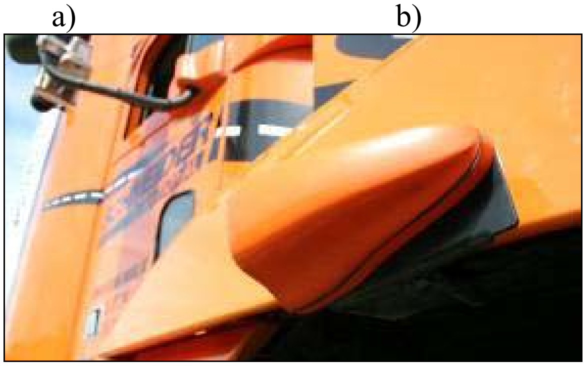
Figure 2. Left (a) and right (b) fender cameras from a commercially available C/VIS mounted on a freightliner C-120 tractor. c) commercial C/VIS monitors mounted on dash.

A-C/VIS

The A-C/VIS was a roadworthy version of a prototype C/VIS developed and tested by VTTI (Wierwille et al., in press). The A-C/VIS met established C/VIS daytime performance specifications (Wierwille et al., 2008), and encompassed the day, night, clear, and inclement weather operational window set forth in Wierwille et al. (in press). The A-C/VIS consisted of three cameras mounted on the truck: a camera on each fender pointing back along the trailer (Figure 3a and 3c), and a rear wide-angle look-down camera mounted on the top-center of the back-side of the trailer (Figure 3b). The side cameras' FOV was 45 degrees, providing coverage and image distortion similar to the fender-mounted mirrors. The rear camera's FOV was 102 degrees and provided coverage of the rear roadway (as far back as 9.7 m as measured from the center of the trailer) as well as the adjacent lanes.

a)

b)



c)

Figure 3. Placement of A-C/VIS left fender camera (a), rear trailer camera (b), and right fender camera (c).

Three monitors were mounted inside the cabin: one at the top of the left A-pillar, one at the top-center of the windshield, and one at the top of the right A-pillar (Figure 4). The Driver-Vehicle Interface (DVI) was built into the left monitor and allowed all functionality to be accessed using one button press. The functionality included switching between color (day mode) and monochrome (night mode), adjusting the monitor brightness, activating the object detection feature (which traced white lines around objects to enhance the video image), and adjusting the amount of object detection (the driver could select the preferred thickness of the lines). Infrared illuminators mounted on the truck and trailer was also used by the A-C/VIS to provide night-vision capabilities during night mode.

Figure 4. Placement of A-C/VIS monitors in truck cab.

Procedure

Six trucks were instrumented with a data acquisition system that allowed for the continuous recording of parametric data that included vehicle speed, distance travelled, and brake pedal application obtained from the truck's on-board network, vehicle position obtained from a Global Positioning System antenna, vehicle deceleration obtained from accelerometers, range to forward and trailing vehicles obtained from radar sensors, and vehicle lane position obtained from a camera-based lane tracking system. Video data of the driver and roadway were also continuously recorded. Four cameras recorded the driver's face and control of the steering wheel, while another four cameras recorded the forward roadway, the left fender camera, the right fender camera, and the rear look-down camera. Although trucks equipped with the commercially available system did not display the rear video image to drivers on a monitor, this view was recorded to assist with analyses of drivers' lane change performance.

Drivers had to be employed by Schneider National, Inc to participate in this study. Because there were only six routes at the Schneider National Winchester, Virginia operation that allowed the use of 48-ft-long trailers, and there were a limited number of drivers that were based out of Winchester, Virginia, drivers were recruited to participate in the study on a first-come, first served basis. After obtaining drivers' informed consent, an experimenter explained what a C/VIS was to the drivers, and then administered a questionnaire that measured drivers' opinions of their driving performance and the hypothetical C/VIS. Drivers were then assigned to one truck that had either an A-C/VIS or the commercial system installed. They drove one month with the C/VIS disabled (Baseline condition), and then three months with the C/VIS enabled (Test condition). Drivers completed surveys pertaining to their driving performance and the C/VIS they were using every two weeks. Drivers were compensated $100 per week plus a $100 bonus for completing surveys and cleaning the C/VIS fender cameras.

Technicians visited the trucks on a weekly basis to perform a health check of the data acquisition systems and C/VISs. The encrypted hard drives were transported back to the research institution where they were uploaded to a secure server. A series of quality control checks were then performed on the data and the results were used to identify additional maintenance issues. Algorithms were then used to trigger potential Safety-Critical Events (SCEs). These algorithms were successfully used in previous naturalistic driving studies (Blanco et al., in press) and in general, identified events when the truck performed a hard deceleration or a swerve maneuver. Data reductionists viewed the triggered events and verified whether an event was indeed an SCE. Valid SCEs were then reduced by one reductionist that recorded the environmental conditions present, vehicle maneuvers that were performed, and whether the driver was distracted. Another reductionist recorded the drivers' eye glance locations during the 10 s prior to the SCE and 5 s following the SCE.

An algorithm was developed and applied to identify potential lane change maneuvers. One reductionist inspected these lane change triggers and identified valid lane changes performed above 35 mph in which an adjacent vehicle was tracked by the side radar system. Eleven valid lane changes per driver, per week were sampled. The same eye glance reductionist reduced drivers' visual behavior during the 10 s prior to a lane change and 5 s following the initiation of a lane change.

Experimental Design

The data was analyzed using a 2 (C/VIS) x 4 (Month) Mixed Factors Analysis of Variance. The two levels of the C/VIS between-subjects independent variable comprised the A-C/VIS and commercially available system. The four levels of the Month within-subjects independent variable comprised Month 1, Month 2, Month 3, and Month 4 of the study.

The following dependent variables were analyzed. Participants' driving performance was assessed by analyzing their SCE rate, which has been defined as the number of SCEs encountered per 100 hours of driving (Blanco et al., 2009). Drivers' clearance to an adjacent vehicle when initiating a lane change was analyzed to assess whether the clearance changed when driving with a C/VIS (Fitch, Wierwille, Schaudt, & Hanowski, 2008). The probability that drivers' looked forward was analyzed to assess whether the C/VIS compelled drivers to look away from the road. The eye glance probability was computed by summing the number of frames a driver looked forward in a specified period of time and dividing this number by the total number of frames in this period of time (Wierwille, 1981). Drivers' forward glance probability prior to encountering an SCE was computed using the 8 seconds prior to the SCE (8 s x 10 frames/s + frame of SCE = 81 frames), while drivers forward glance probability during a lane change was computed using the interval of time spanning 8 s prior to the initiation of the lane change to 5 seconds after initiating the lane change (13 s x 10 frames/s + frame of lane change initiation = 131 frames). Finally, drivers rated how easy it was to be aware of surrounding vehicles by completing a survey every two weeks during their participation.

RESULTS

Drivers' Involvement in SCEs

A total of 5,161 hours of driving that spanned 412,417 km was recorded by the 12 participants (comprising 3.35 Terabytes of data). These drivers encountered a total of 277 SCEs. One driver did not encounter any SCEs during his first two months of participation, while another driver did not have any data in his final month because he left the study shortly after completing Month 3. The SCE rate was computed for each driver for each month that they were in the study and analyzed. Drivers' mean SCE rate was not found to differ across the months that they were in the study ($F(3, 29) = 0.02$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 0.58$, $p > 0.05$), nor was a Month x C/VIS interaction found ($F(3, 29) = 0.13$, $p > 0.05$). Figure 1 shows the mean SCE rates for drivers in the A-C/VIS-equipped and commercially available C/VIS-equipped trucks for each month that they were in the study. Table 2 presents descriptive statistics pertaining to the computed SCE rates.

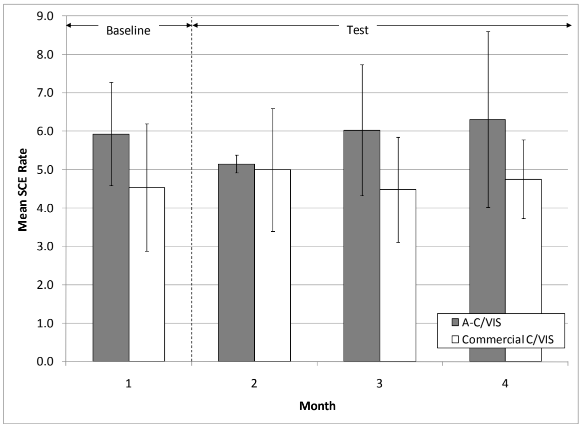


Figure 5. Drivers' mean SCE rates by month in study and type of C/VIS.

Table 2.
Drivers' Mean SCE Rates by Month in Study and Type of C/VIS

C/VIS	Month	Mean	SEM	n	Min	Max
A-C/VIS	1	5.9	1.3	6	1.9	9.2
	2	5.1	0.2	6	4.4	6.2
	3	6.0	1.7	6	1.6	11.4
	4	6.3	2.3	5	0.8	13.6
Commercial C/VIS	1	4.5	1.7	6	0.0	10.7
	2	5.0	1.6	6	0.0	9.7
	3	4.5	1.4	6	0.9	8.3
	4	4.8	1.0	6	2.0	8.3

Drivers' Visual Behavior Prior to SCEs

An eye glance analysis was performed on 264 SCEs. This was because there was one SCE in which the driver did not look forward (he was stopped at an intersection) and because eye glance data was not available on 12 SCEs (e.g., drivers were wearing sunglasses during the SCE). The probability that drivers' looked forward was computed for each SCE and analyzed. Drivers' mean probability of looking forward was not found to differ across the month that they were in the study ($F(3, 27) = 0.25$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 0.42$, $p > 0.05$), nor was a Month x C/VIS interaction found ($F(3, 27) = 0.49$, $p > 0.05$). Figure 2 shows the mean probability that drivers looked forward during the 8 seconds prior to an SCE across the four months of participation. Table 3 presents descriptive statistics pertaining to the computed eye glance probabilities.

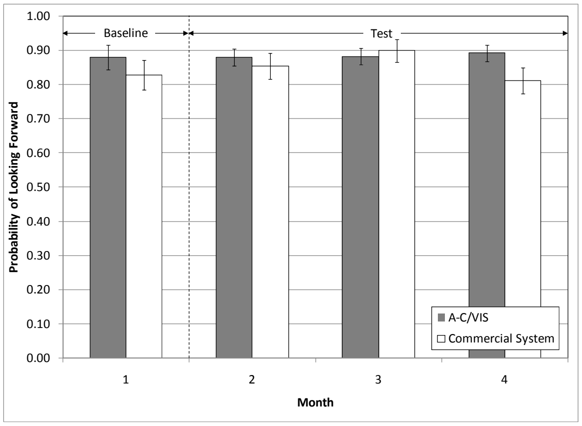


Figure 6. Mean probability that drivers looked forward in the 8 s prior to encountering an SCE by month in study

Table 3.
Mean probability that drivers looked forward in the 8 s prior to encountering an SCE by month in study

C/VIS	Month	Mean	SEM	n	Min	Max
A-C/VIS	1	0.88	0.04	38	0.15	1.00
	2	0.88	0.03	32	0.38	1.00
	3	0.88	0.02	45	0.36	1.00
	4	0.89	0.02	42	0.19	1.00
Commercial C/VIS	1	0.83	0.04	27	0.10	1.00
	2	0.85	0.04	26	0.21	1.00
	3	0.90	0.03	25	0.27	1.00
	4	0.81	0.04	29	0.14	1.00

Drivers' Lane Change Performance

A total of 2,012 lane changes were sampled (528 lane changes in the Baseline condition and 1,484 lane changes in the Test condition). The truck had to be travelling above 56 km/h, and there had to be a vehicle travelling in the adjacent lane behind the truck, for a lane change to be included in this sample. The clearance between the back edge of the trailer and the front of an adjacent vehicle was analyzed. It was not found to differ across the months that drivers participated in the study ($F(3, 29) = 0.2$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 0.14$, $p > 0.05$), nor was a C/VIS x Month interaction found ($F(3, 29) = 1.28$, $p > 0.05$). Figure 7 shows the mean clearance for drivers of A-C/VIS-equipped and commercially available C/VIS-equipped trucks by month of participation. Table 4 presents descriptive statistics pertaining to the measured clearances.

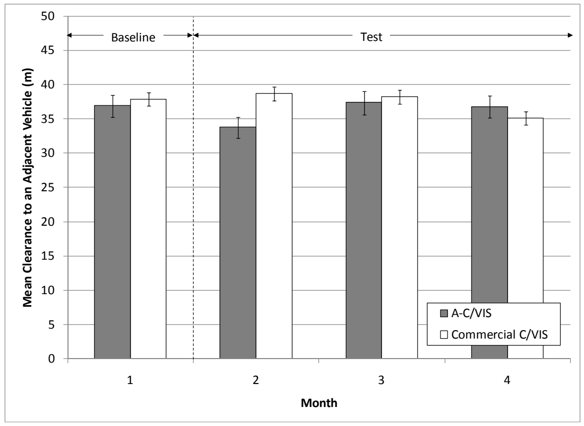


Figure 7. Drivers' mean clearance to an adjacent vehicle by C/VIS and month in study

Table 4.
Drivers' mean clearance to an adjacent vehicle by C/VIS and month in study

C/VIS	Month	Mean (m)	SEM (m)	n	Min (m)	Max (m)
A-C/VIS	1	36.91	1.55	264	-12.83	120.51
	2	33.77	1.47	264	4.42	119.10
	3	37.39	1.61	226	-3.68	118.62
	4	36.72	1.66	202	-9.86	114.02
Commercial C/VIS	1	37.86	1.67	264	-3.87	125.54
	2	38.66	1.61	264	3.58	121.47
	3	38.22	1.77	264	-0.77	121.63
	4	35.09	1.54	264	-0.38	123.26

Drivers Visual Behavior during Lane Changes

An eye glance analysis was performed on 1,930 lane changes that had eye glance data available. The probability that drivers looked forward was computed for each lane change. Drivers' mean probability of looking forward was not found to differ across the months that they participated in the study ($F(3, 29) = 0.9$, $p > 0.05$). A C/VIS main effect was not found ($F(1, 10) = 1.15$, $p > 0.05$), nor was a Month x C/VIS interaction found ($F(3, 29) = 2.04$, $p > 0.05$). Figure 8 shows the mean probability that drivers looked forward when changing lanes by month in study. Table 5 presents descriptive statistics for these probabilities.

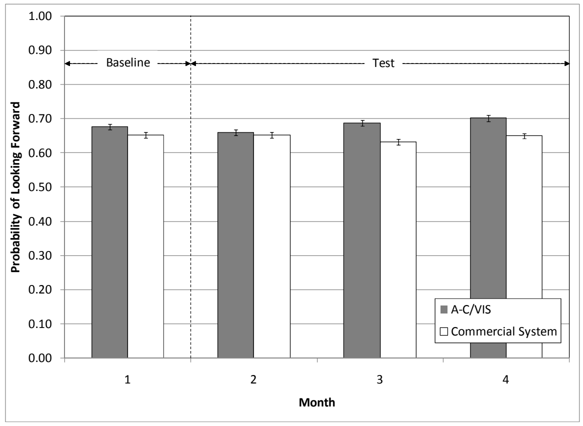


Figure 8. Mean probability that drivers looked forward when changing lanes by month in study

Table 5.
Mean probability that drivers looked forward when changing lanes by month in study

C/VIS	Month	Mean	SEM	n	Min	Max
A-C/VIS	1	0.68	0.01	256	0.30	0.95
	2	0.66	0.01	252	0.35	0.95
	3	0.69	0.01	226	0.30	0.97
	4	0.70	0.01	202	0.20	0.93
Commercial C/VIS	1	0.68	0.01	256	0.30	0.95
	2	0.65	0.01	250	0.27	0.92
	3	0.63	0.01	255	0.26	0.91
	4	0.65	0.01	233	0.29	0.89

Drivers' Awareness of Surrounding Objects

Drivers rated the difficulty of being aware of objects located in the area around their truck while driving in various environmental conditions. Because drivers responded to this question twice per month, their mean rating from each month was used when performing a Friedman Two-Way ANOVA to investigate whether their opinion changed over time. Drivers of A-C/VIS equipped trucks indicated that maintaining spatial awareness at night and in inclement weather became easier when driving with a C/VIS ($\chi_F^2(3) = 8.02$, $p < 0.05$). Drivers' mean ratings are shown in Figure 9. Statistically significant pairwise comparisons between drivers' monthly mean ratings were not found (p > 0.05). For drivers of trucks equipped with the commercially available C/VIS, a significant Month in Study effect was not found ($\chi_F(3)^2 = 0.23$, $p > 0.05$).

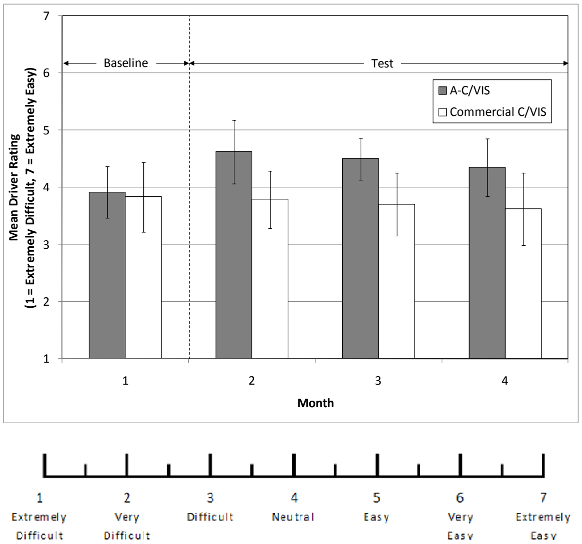


Figure 9. Drivers' mean monthly ratings in response to the question, "During the night and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck while driving?"

Drivers' Rating of Merging into Traffic

Drivers rated the difficulty of merging into traffic while driving in various environmental conditions. A Friedman Two-Way ANOVA was performed to investigate whether their opinion of this task changed over time. Drivers of A-C/VIS equipped trucks indicated that merging into traffic during the day and in inclement weather became easier when driving with a C/VIS ($\chi_F^2(3) = 8.4116$, $p < 0.05$). Their mean rating using the scale in Figure 9 was 4.0 in Month 1 (*SEM* = 0.2), 4.7 in Month 2 (*SEM* = 0.4), 4.6 in Month 3 (*SEM* = 0.4), and 4.7 in Month 4 (*SEM* = 0.3). Statistically significant pairwise comparisons between drivers' monthly mean ratings were not found ($p > 0.05$). Drivers of trucks equipped with the commercially available C/VIS indicated that merging into traffic during clear daytime conditions became easier when driving with a C/VIS ($\chi_F(3)^2 = 9.2449$, $p < 0.05$). Their mean rating using the scale in Figure 9 was 4.4 in Month 1 (*SEM* = 0.4), 5.3 in Month 2 (*SEM* = 0.2), 5.4 in Month 3 (*SEM* = 0.2), and 5.1 in Month 4 (*SEM* = 0.7). Statistically significant pairwise comparisons between drivers' monthly mean ratings were not found ($p > 0.05$).

Driver Ratings of C/VIS Monitors

Partway through data collection, it was determined that additional information regarding drivers' opinions on the usefulness of specific monitors was desirable. Modifications to the experimental protocol were made and were approved by the IRB. Since these modifications were approved after four drivers had completed the study, the additional questions were posed to only eight drivers. Five drop A-C/VIS equipped trucks, while three drove commercially available C/VIS-equipped trucks.

The eight drivers were asked to rate the usefulness of each monitor. Drivers of A-C/VIS-equipped trucks rated the left monitor to be "Useful" (*M* = 5.1, *SEM* = 0.18, *Min* = 4, Max = *7*), while drivers of the commercially available C/VIS-equipped trucks rated the left monitor to be

"Useless" (*M* = 3.18, *SEM* = 0.42, *Min* = 1, *Max* = 5.5). However, the ratings of the commercially available C/VIS' left monitor ranged from "Extremely Useless" to "Very Useful." Drivers of A-C/VIS-equipped trucks rated the right monitor to be "Very Useful" (*M* = 6.0, *SEM* = 0.12, *Min* = 5, *Max* = 7), while drivers of the commercially available C/VIS-equipped trucks were neutral when rating the right monitor (*M* = 4.2, *SEM* = 0.3, *Min* = 1, *Max* = 6). Again, the ratings of the commercially available C/VIS's right monitor ranged from "Extremely Useless" to "Very Useful." Drivers of A-C/VIS-equipped trucks rated the center monitor as "Very Useful" (*M* = 5.8, *SEM* = 0.1, *Min* = 4, *Max* = 7).

The eight drivers were also asked to rank-order the C/VIS cameras according to their usefulness. For drivers of A-C/VIS-equipped trucks, the center monitor was ranked highest by three of the five drivers, the right monitor was ranked highest by one of the five drivers, and the left monitor was ranked highest by one of the five drivers. The left monitor was ranked lowest by four drivers. The three drivers of the commercially available C/VIS-equipped trucks ranked the right monitor as more useful than the left monitor.

DISCUSSION

This study evaluated whether providing CMV drivers with enhanced visual information improves their spatial awareness and leads to an improvement in driving performance. It was found that when driving with a C/VIS: 1) drivers' involvement in safety-critical events did not change, 2) the clearance to an adjacent vehicle when changing lanes did not change, and 3) the likelihood that drivers looked forward did not change. Although a reduction in safety-critical events was not observed when driving with a C/VIS, drivers indicated that the C/VISs helped them see other vehicles around their tractor-trailer and made it easier to merge into traffic. These ratings indicate that C/VISs can help drivers with the driving task, which may lead to an improvement in safety when deployed on a larger scale. It should be noted that a limitation of the study is that the majority (95 percent) of the sampled lane changes occurred in low traffic density (Level of Service A), where there are fewer vehicles on the road and therefore fewer opportunities to encounter vehicle-to-vehicle SCEs. Drivers' involvement in SCEs may have differed had they operated their tractor-trailers in rush-hour traffic when traffic density is higher.

A concern with introducing any visual display inside a vehicle is that it may be a source of visual distraction. An important finding from this study is that drivers were not less likely to look at the forward roadway when driving with a C/VIS. This finding suggests that the C/VIS display did not compel drivers to look away from the road. The interested reader is referred to Fitch et al. (in press) for an in-depth analysis of drivers' visual behavior.

Previous research that evaluated driver performance with a C/VIS prototype on a closed-course test track found that drivers cut in closer to an adjacent vehicle when changing lanes with a camera view obtained from a wide-angle rear-lookdown camera mounted on the rear of the tractor-trailer (Fitch et al., 2008). There was therefore a concern that drivers in the TFD would exhibit similar behavior. However, drivers' mean clearance to an adjacent vehicle was not found to vary when changing lanes with either the A-C/VIS or commercially available C/VIS. This suggests that the CMV drivers recognize the importance of keeping a safe clearance to an adjacent vehicle when executing lane changes on a public road. This finding also demonstrates the importance of field testing driver assistance systems in real-world driving conditions where driver performance is affected by the environmental constraints.

Drivers using the advanced C/VIS rated its features highly and ranked the rear-view camera more than the left or right fender cameras. This was likely because the rear camera provides a bird's-eye-view of the area behind the trailer as well as the adjacent lanes. Drivers can use this vantage point to perceive whether the back edge of the trailer overlaps a vehicle travelling in the adjacent lane. During the day, drivers are known to use the shadow cast by the trailer to assess the clearance to adjacent vehicles, but must perform a relative-judgment task using less distinctive roadway and trailer cues when changing lanes at night. For this reason, there is merit in adopting this advanced feature when implementing a C/VIS in a commercial trucking operation.

CONCLUSION

OEMs and tier-1 suppliers have developed multiple methods to implement C/VISs. The A-CVIS is an innovative approach to C/VISs that assists drivers in overcoming blind spots. This paper presents a real-world evaluation of both commercially available, and advanced, C/VISs. Overall, although a reduction in safety-critical events was not observed, this study shows that providing CMV drivers with enhanced visual information does improve their situational awareness and simplifies the execution of lane change maneuvers. It is possible that the simplification of these tasks could lead to a safety benefit in situations where the driving task demands are great.

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MOLIFE – HAZARD DETECTION IN A COOPERATIVE ASSISTANCE SYSTEM FOR MOTORCYCLES

Lattke, Benedikt
Sperber, Frank
Müller, Tobias
Winner, Hermann
Technische Universität Darmstadt, Institute of Automotive Engineering
Germany
Eberlein, Richard
Hoffmann, Rainer
carhs.communication GmbH
Germany
Paper Number 11-0070

ABSTRACT

Vehicle-to-vehicle communication promises a large safety benefit for motorcycles. Furthermore, new motorcycles are equipped with an increasing number of vehicle dynamics sensors (e.g. wheel speed sensors, gyro sensors). These deliver information about the current driving state variables.
Hence, the *Institute of Automotive Engineering at Technische Universität Darmstadt* and *carhs.communication* are in the process of researching the fundamentals of a communication-based warning system for motorcycles. This system generates sensor-based or manually entered warning messages and sends these to other motorcyclists using wireless communication devices. In this way, riders can receive early warnings of road hazards. In order to detect hazards based on standard sensors, new methods were developed, which are presented in this paper.

An analysis of an accident database and a motorcycle rider survey revealed the following main causes for accidents that would be avoidable using a system such as that investigated here:

- Roadway damages, e.g. unevenness, ground waves, transversal ruts, pot holes
- Obstacles on the road, such as broken down vehicles behind a curve
- Excessive speed in curves, especially in irregular road conditions
- Friction steps caused by oil, gravel sand, bitumen

Driving dynamics for the above mentioned situations were analyzed. New criteria were derived and used to generate warning messages based on vehicle dynamics sensor information. In order to validate the criteria, over 500 test drives were conducted.
To detect hazards caused by individual roadway damages, a new criterion was derived based on the measurement of the vertical wheel acceleration. With this criterion, hazard detection becomes independent of hazard type and shape.
Obstacles are detected by identifying evasive maneuvers. These are distinguished from other maneuvers by means of a correlation factor, determined on the basis of a previously defined standard maneuver and the current driving state.
In a previous study, the vehicle side-slip angle velocity was found to be a criterion to detect critical driving situations during cornering. These situations are caused by friction steps or by exceeding the maximum lateral acceleration. The current study adapts this criterion for use in a communication-based warning system.
Friction steps and low friction (during straight driving) are detected by evaluating braking activity and longitudinal acceleration.

In addition to methods for hazard detection, a methodology to design an appropriate HMI was also developed and validated. To increase market acceptance, an additional comfort-oriented functionality was implemented und tested. This function is based on the same technology as the safety function.

INTRODUCTION

The accident rate of motorcycles has decreased very slowly compared to the accident rate of passenger vehicles and is still high [1]. The possibilities of passive safety systems for motorcycles are limited. Consequently, focus is placed on active safety systems. This results in an increase of vehicle dynamics sensors in motorcycles.

One type of active safety systems are communication-based systems (also known as cooperative systems). These are assumed to have a high accident avoidance potential, especially when employed as forward looking systems.

This was motivation behind developing a communication-based safety system for motorcycles that uses data from already existing vehicle dynamics sensors for further applications.

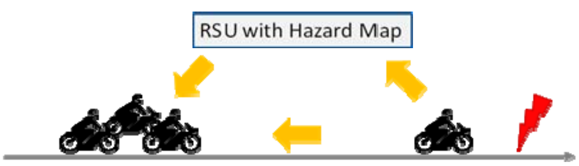

Figure 1: Schematic of the basic function of a communication-based warning system (RSU: Road Side Unit)

The basic function of a communication-based warning system is shown in Figure 1. Hazards are detected by the motorcycle sensors or the rider. Based on this, a warning message is generated and transmitted directly or via a road side unit (RSU) to other motorcycles whose riders are then warned. In order to develop such a system, research is needed in the following areas:

- Identification of hazards which lead to accidents that could be avoidable using a system such as that studied here.
- Analysis of driving behavior in hazardous situations (as the basis for generating warning messages, based on an evaluation of the information from vehicle dynamics sensors).
- Development of a methodology to find and compare appropriate warning elements (human-machine interface) for a communi-cation-based warning system in motorcycles.
- A concept for market introduction, as a minimum degree of market penetration is required for most functions.
- Development of an additional comfort oriented functionality to increase market acceptance using the same technology.

These are the issues investigated in the “MoLife” project, a cooperation project of the *Institute of Automotive Engineering at Technische Universität Darmstadt* and *carhs.communication GmbH*. The present paper concentrates on the results of the second area mentioned above: analysis of driving behavior in hazardous situations. The findings from investigations into the other areas are briefly summarized. Details can be found in other publications of the authors.

In addition to the issues mentioned, a management system is needed for warning messages sent to and from numerous and varied vehicles. The dilemma of data security and privacy is another important point that needs to be regarded. However, these are general issues of vehicle communication and are not investigated within MoLife.

STATE OF THE ART

A large number of communication-based warning system prototypes already exist. Most of these were developed in research projects (e.g., IVHW [2], CarTalk 2000 [3], WILLWARN [4]). Such applications concentrate mainly on cars. Warning messages are generated based on an evaluation of information obtained from environmental sensors and vehicle dynamics sensors. Some systems also use the driver as a “sensor”.

Existing communication-based driver assistance systems for motorcycles [5] have demonstrated the feasibility of such systems for motorcycles and have indicated a high potential to avoid accidents. These systems concentrate on the avoidance of intersection accidents. An exception is one application, which gives a warning when approaching roadworks [6]. The systems are based on the evaluation of the relative position and the interaction between motorcycles and cars or motorcycles and road side units.

HAZARD IDENTIFICATION

An analysis of the GIDAS accident database and a motorcycle rider survey were conducted. These revealed the following main causes for accidents that would be avoidable with a system such as that investigated here:

1) Roadway damage, e.g. unevenness, ground waves, transversal ruts, pot holes
2) Obstacles on the road, such as broken down vehicles behind a curve
3) Excessive speed in curves, especially in irregular road conditions
4) Friction steps caused by oil, gravel sand, bitumen

Table 1 shows the number of potentially avoidable accidents in the GIDAS database (till 2007) for all powered two-wheelers (PTWs) and for PTWs with a displacement larger than 125 cc. For the first category 6.7% and for the second category 6.0% of accidents contained in the GIDAS database would have been avoidable.

Table 1: Number of potential avoidable accidents in the GIDAS database

accident class	**all (n=1411)**	**> 125 cc (n=729)**
1)	20	9
2)	14	7
3)	23	11
4)	38	17
total	**95 (6.7%)**	**44 (6.0%)**

Because, in comparison to official statistics, accidents with certain characteristics (e.g. urban accidents with fatalities) are overrepresented in GIDAS database, a weighting of the accident data was conducted. However, the resulting accident avoidance potential is only slightly higher. A description is, therefore, omitted. A more detailed description about the hazard identification (including literature survey, analysis of the accident database and rider interviews) can be found at [7].

ANALYSIS OF DRIVING DYNAMICS FOR HAZARD DETECTION

The results of the accident database analysis and the rider interviews show that the identified hazardous situations are not negligible. Therefore, driving dynamics for the following situations are analyzed to determine criteria as a basis for generating warning messages:

- roadway damage
  - individual roadway damage
  - unevenness
- obstacles on the road
- friction steps on straight road sections
- friction steps and excessive velocity during cornering

Individual Roadway Damage

Analysis

Typical individual roadway damages are, for example, ground waves or pot holes. It is assumed that a high effort is needed to recognize the type and shape of such damage using vehicle dynamics sensors. The task, therefore, was to find a criterion, which characterizes individual roadway damage without determining its type or shape.
Cucuz [8] demonstrates that, for single roadway damages, drivers' perception depends mainly on the vertical velocity, which impacts on the driver. This indicates that the unevenness velocity (derivative of unevenness height) mainly influences the riders' perception. As the transfer characteristics of the wheel are approximately neutral in a broad frequency range $(f = 1...10 \text{ Hz})$, for this range, the unevenness velocity is approximately equal to the vertical wheel velocity $\dot{z}_W$. Therefore, a criterion KW is developed, which is based on the vertical wheel velocity $\dot{z}_W$. In the following, the determination of this criterion is described, as shown in Figure 2. For reasons of clarity, details of signal processing are omitted.

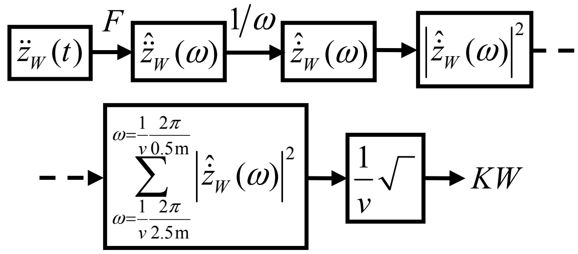

Figure 2: Determination of a criterion characterizing individual roadway damages

The vertical wheel velocity $\hat{\dot{z}}_W$ can be calculated based on the measured vertical wheel acceleration $\hat{\ddot{z}}_W$ (sampling rate: $F_S = 100\ \text{Hz}$) by multiplication by $1/\omega$, the same as an integration. Pre tests showed that typical roadway damages lead to spring-and-damper reactions with a wave length between 0.5 m and 2.5 m. With this assumption, the sum of the energy spectral density (ESD) amplitudes of the vertical wheel velocity (in this frequency range) is a measure for the excitation energy of the damage. Extracting the square root and division by longitudinal velocity v lead to the criterion KW, which is independent of the damage type and shape and also of longitudinal velocity.

Validation

Figure 3: Obstacles: low speed bump, high cleat, duct cover, high cosine wave

Seven different obstacles were constructed. To simulate a broad group of typical individual roadway damages, height h, length L and shape (steep, round) are varied in a range assumed to be typical for individual roadway damages. Figure 3 shows some obstacles, all obstacles are listed in the following:

- D1: duct cover $(h = 38\ \text{mm}, L = 0.5\ \text{m})$
- D2: high cleat $(h = 48\ \text{mm}, L = 0.048\ \text{m})$
- D3: low cleat $(h = 32\ \text{mm}, L = 0.048\ \text{m})$
- D4: high cosine wave $(h = 80\ \text{mm}, L = 1.8\ \text{m})$
- D5: low cosine wave $(h = 40\ \text{mm}, L = 1.8\ \text{m})$
- D6: high speed bump $(h = 70\ \text{mm}, L = 0.28\ \text{m})$
- D7: low speed bump $(h = 35\ \text{mm}, L = 0.21\ \text{m})$

For validation, the obstacles are driven over at different speeds. The speed range is chosen according to the test rider's experience and sensor characteristics. For example, evaluations as critical maneuver or clipping of the sensor $\left(\ddot{z}_W > 160\ \text{m/s}^2\right)$ define the maximum speed.
Based on the measured vertical wheel acceleration, the criterion KW is determined as described above. Table 2 shows the determined average values of KW and its standard deviation $\sigma(KW)$.

Table 2: Determined average values and standard deviation of the criterion KW for various kinds of obstacles

Obstacle	v in km/h	$\overline{KW}$	$\sigma(KW)$
D1 (n=15)	30 … 70	0.027	0.004
D2 (n=8)	15 … 50	0.017	0.002
D3 (n=9)	15 … 50	0.012	0.002
D4 (n=15)	10 … 50	0.048	0.008
D5 (n=12)	20 … 80	0.022	0.004
D6 (n=8)	10 … 30	0.036	0.006
D7 (n=15)	20 … 60	0.016	0.002

Standard deviations account for 11% to 18% of the criterion KW. For hazard detection in a warning system, this is an acceptable range. The criterion's independence of longitudinal velocity v is, therefore, proven for the mentioned application.

In order to demonstrate that the criterion KW is a measure for the felt hazardousness of individual roadway damages, a test-subject study with 13 experienced motorcycle riders was conducted. The riders were asked to drive over the mentioned obstacles. Starting with a speed of $v = 10$ km/h, they increased their speed in steps of 10 km/h till they felt uncomfortable. After finishing this task, they were asked at which speed they wanted to be warned (when reaching such an obstacle). The results are shown in Table 3 and Figure 4.

Table 3: Warning speed for investigated obstacles, determined through a test-subject study (n=13)

Obstacle	$\tilde{v}$ in km/h	$\sigma(v)$ in km/h
D1	30	8.2
D2	41	13.8
D3	48	8.4
D4	22	11.8
D5	42	13.9
D6	22	5.9
D7	44	8.8

Based on these results, it is concluded that a higher KW value generally leads to a lower average warning speed. This indicates that the criterion is a measure for the felt hazardousness of roadway damage, independent of its type and shape. A more detailed conclusion about the dependency between v and KW cannot be made at the current state of research.

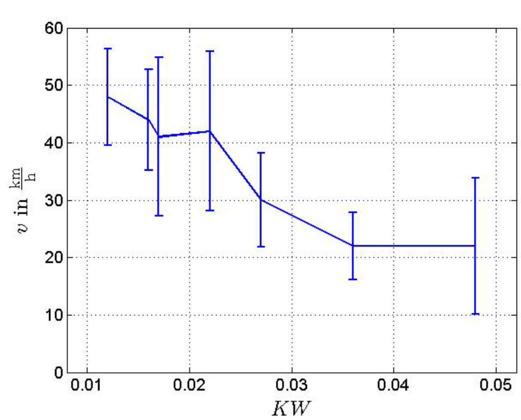

Figure 4: Dependency between v and KW (error bars for the determination of KW are not shown)

Unevenness

Analysis

In Germany, the longitudinal unevenness of pavement is generally characterized by the general unevenness index *Allgemeiner Unebenheitsindex* (*AUN*). It is calculated by determining the power spectral density (PSD) of unevenness height $\Phi_h(\Omega)$. The PSD can be approximated depending on waviness w and distance-related angular frequency Ω as following [9]:

$$\Phi_h(\Omega) = \Phi_h(\Omega_0)\left(\frac{\Omega}{\Omega_0}\right)^{-w}$$

The AUN is defined as PSD at the characteristic angular frequency $\Omega_0 = 1$ rad/m :

$$AUN = \Phi_h(\Omega_0)$$

The AUN increases with longitudinal unevenness. This can be a criterion for hazard detection. The determination of the AUN is generally based on a measurement of unevenness height h. Optical sensors are used. In this study, an approach is implemented, which uses sensors for a measurement of the vertical wheel acceleration $\ddot{z}_W$.

Figure 5 demonstrates this approach. For clarity reasons, details of signal processing are omitted. It is assumed that transfer characteristics of the wheel are neutral (in the frequency range $f = 1...10$ Hz). Because of this, the determined PSD is only valid for a certain bandwidth.

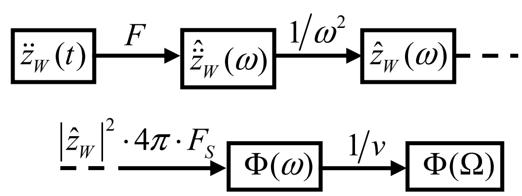

Figure 5: PSD determination based on measurement of vertical wheel acceleration

First, measured acceleration signal $\ddot{z}_W(t)$ (sampling rate: $F_S = 100$ Hz) is Fourier transformed into frequency domain and multiplied by ω^{-2}, the same as a twice integration, to obtain wheel travel $\hat{z}_W(\omega)$. Squaring and multiplication by 4π and sampling frequency F_S lead to PSD, depending on time-related angular frequency ω. Division by velocity v yields the PSD depending on distance-related angular frequency Ω (under the assumption of constant velocity). The AUN value is the PSD value at the characteristic angular frequency $\Omega_0 = 1\ 1/\text{m}$ of a best-fit line.

Validation

For validation of the described method, test drives on 19 roads with known AUN values ($AUN = 1$ to $AUN = 28$) were conducted. Figure 6 shows the measured PSD for three different types of roads. The determined AUN value is the PSD value at the characteristic angular frequency $\Omega_0 = 1\ 1/\text{m}$ of a best-fit line.

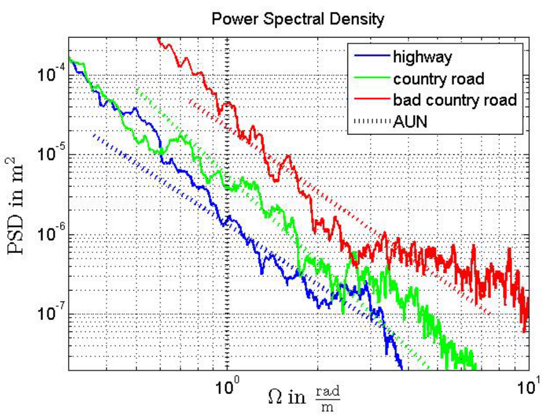

Figure 6: PSD/AUN for three different types of roads

For all test drives, the maximum error of the AUN value does not exceed 20%. It is assumed that such a rough determination of the AUN is sufficient as a basis for the generation of warning messages. Riders do not want to know the exact AUN value. They just want to be warned of bad road conditions. This leads to the conclusion that the presented method is suitable for the mentioned application.

Obstacles on the Road

Analysis

It is assumed that suddenly appearing obstacles on the road, e.g. broken car behind a curve, lead to typical driving maneuvers. One of these is an evasive maneuver. It is concluded that obstacles on the road can be recognized by detection of evasive maneuvers. These maneuvers were investigated more in detail. A literature research leaded to the following findings:

- According to Burg [10], the evasion time t_{evas} of a motorcycle is (in dependence of the lateral acceleration a_y) about 2-2.5 s (excluding stabilization phase).
- In Rauscher [11] the evasive maneuver is divided into three phases: initiation phase, evasive phase, stabilization phase. The following approximation was investigated to determine the evasion time t_{evas} (depending on lateral displacement B and lateral acceleration a_y):

  $$t_{evas} = t_1 + \sqrt{\frac{B}{a_y}} + t_3$$

  $t_1 = 0.7...0.9\ \text{s} \quad t_3 = 0.9...1.2\ \text{s}$
- According to Spiegel [12], a roll angle of $\lambda = 20°$ is not exceeded by "normal" riders in "normal" driving situations. This is equivalent to a lateral acceleration of $a_y = g \cdot \arctan \lambda = 3{,}6\,\text{m/s}^2$.
- In Hohm [13], it is assumed that a lateral acceleration of $a_y = 2.2\,\text{m/s}^2$ is not exceeded during over-taking maneuvers of cars.

Based on these findings, a "standard evasive maneuver" with the following characteristics is defined:

- The maneuver can be described by 1.5 periods of a sine wave.
- The first and the third amplitude are smaller than the second amplitude (e.g., damped by a Hanning window).
- The evasive time is $t_{evas} = 2.75$ s. This leads to a period of $T = \frac{2.75}{1,5}\text{s} \approx 1{,}8$ s.
- The maximum roll angle is $\lambda = 20°$. This yields a maximum roll rate of $\hat{\dot{\lambda}} \approx 80°/s$.

This results in the following equation describing the "standard evasive maneuver":

$$\dot{\lambda}^* = \left(0.5 + 0.5\cos\frac{t}{2.75\text{ s}}\right)\cdot 80\frac{^\circ}{\text{s}}\cdot\sin\left(\frac{2\pi}{1.8\text{ s}}t\right)$$

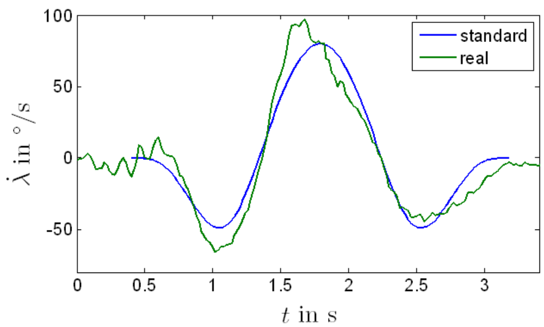

Figure 7: Roll rate of the "standard evasive maneuver" and a real evasive maneuver

Figure 7 shows the roll rate of the standard maneuver and of a real maneuver. **To detect evasive maneuvers, the course of the measured roll rate $\dot{\lambda}$ is correlated with the roll rate of the standard maneuver $\dot{\lambda}^*$. The cross correlation function $\Psi_{\dot{\lambda}\dot{\lambda}^*}(\tau)$ is determined as follows:**

$$\Psi_{\dot{\lambda}\dot{\lambda}^*}(\tau) = \lim_{T\to\infty}\frac{1}{T}\int_0^T \dot{\lambda}(t)\dot{\lambda}^*(t+\tau)dt$$

Based on this correlation, a factor with values between 0 (no match) and 1 (exact match) is determined. This correlation factor is calculated as follows:

$$c_{evas} = \frac{\left(\max\left(\Psi_{\dot{\lambda}\dot{\lambda}^*}\right)\right)^2}{\max\left(\max\left(\Psi_{\dot{\lambda}\dot{\lambda}}\right),\max\left(\Psi_{\dot{\lambda}^*\dot{\lambda}^*}\right)\right)\cdot\max\left(\Psi_{\dot{\lambda}^*\dot{\lambda}^*}\right)}$$

To ensure reliability, the maneuver has to be completed, but only the maximum value of the cross correlation function $\max\left(\Psi_{\dot{\lambda}\dot{\lambda}^*}\right)$ is relevant. To normalize the factor, it is divided by the maximum of the auto correlation functions of the measured and the "standard" roll rate. To avoid high values of c_{evas} at low measured roll rates, in this cases it is divided by $\max\left(\Psi_{\dot{\lambda}^*\dot{\lambda}^*}\right)$ instead of $\max\left(\Psi_{\dot{\lambda}\dot{\lambda}}\right)$.

<u>Validation</u>

To validate the explained method, various kinds of maneuvers are conducted. These include simple driving maneuvers, evasive maneuvers and dynamically similar maneuvers (e.g. overtaking, slalom) at speeds from 30 km/h to 100 km/h. A consecutive list of the conducted maneuvers reads as follows:

- A: Straight driving (n = 25)
- B: Cornering (n = 31)
- C: Overtaking after following another vehicle (n = 13)
- D: Overtaking after following another vehicle and wobbling (n = 15)
- E: Free overtaking (without following another vehicle before) (n = 13)
- F: Slalom (n = 26)
- G: Evasive maneuver without a preceding braking (n = 36)
    - speed: $v = 30\,\text{km/h}\ldots 100\,\text{km/h}$
    - lateral offset: $B = 1\text{ m}\ldots 2\text{ m}$
    - lateral acceleration: $a_y = 3\,\text{m/s}^2\ldots 8\,\text{m/s}^2$
- H: Evasive maneuver with a preceding braking (n = 18)

Table 4 gives the minimum and maximum determined values of the correlation factor c_{evas} for the conducted maneuvers. For all evasive maneuvers (*n*=54), the determined correlation factor is at least 0.56. For all other maneuvers (*n*=123), a value of 0.36 is not exceeded.

Table 4: Determined values of c_{evas}

maneuver	min(c_{evas})	max(c_{evas})
A: straight driving	0.00	0.01
B: cornering	0.01	0.09
C: overtaking	0.04	0.35
D: overtaking	0.14	**0.36**
E: free overtaking	0.05	0.33
F: slalom	0.21	0.35
G: evasive maneuver	**0.56**	0.92
H: evasive maneuver	0.75	0.92

Friction Steps on Straight Road Sections

Analysis

Maximum utilization of grip without using control systems leads to locking of the wheels (during braking) or to a high wheel slip (during accelerating). Modern motorcycles are equipped with ABS or traction control. These systems control the slip. Nevertheless, according to Weidele [14] the activity of these systems indicates the maximum utilization of grip.

In this case, the maximum friction coefficient $\mu_{\max}$ can be approximated by the quotient of wheel load G_i and longitudinal force F_x (lateral forces are neglected):

$$\mu_{\max} = \frac{\sqrt{F_x^2 + F_y^2}}{G_i} = \frac{F_x}{G_i}$$

The wheel loads of the front wheel G_f and the rear wheel G_r are calculated as following, depending on wheel base l, distance center of gravity to rear/front wheel patch l_r / l_f, height of center of gravity h_c, gravity constant g, vehicle mass and vehicle longitudinal acceleration $\ddot{x}$:

$$G_{f,dyn} = \left(m \cdot g \cdot \frac{l_r}{l} \right)_{stat} - m \cdot \ddot{x} \cdot \frac{h_c}{l}$$

$$G_{r,dyn} = \left(m \cdot g \cdot \frac{l_f}{l} \right)_{stat} + m \cdot \ddot{x} \cdot \frac{h_c}{l}$$

The determination of the friction coefficient is described consecutively, for the various situations.

In cases where **ABS controls both wheels**, the braking force is transmitted to the road over both wheels. This yields:

$$\mu_{\max} = \frac{F_x}{G_f + G_r} = \frac{m \cdot \ddot{x}}{m \cdot g} = \frac{\ddot{x}}{g}$$

In situations where **ABS controls only the front wheel** and the rear wheel is not braked, the braking force is transmitted to the road over the front wheel. This implies:

$$\mu_{\max} = \frac{F_x}{G_f} = \frac{\ddot{x}}{g \cdot \frac{l_r}{l} - \ddot{x} \cdot \frac{h_c}{l}}$$

If ABS controls only the rear wheel and the front wheel is not braked, the braking force will be transmitted to the road over the rear wheel. This results in:

$$\mu_{\max} = \frac{F_x}{G_r} = \frac{\ddot{x}}{g \cdot \frac{l_f}{l} + \ddot{x} \cdot \frac{h_c}{l}}$$

With these assumptions, the friction coefficient $\mu_{\max}$ can be determined just by using the following signals:

- activity of ABS or traction control
- longitudinal acceleration $\ddot{x}$

For the further investigations, the friction coefficient was divided in the following three classes:

critical friction: $\mu \le 0.3 = \mu_{crit}$

low friction: $0.3 < \mu \le 0.6 = \mu_{low}$

normal friction: $\mu \ge 0.6 = \mu_{norm}$

The detection of low and critical friction is based on the continuous determination of the friction coefficient (during ABS or traction control) as described above. Where the determined friction coefficient falls for at least 200 ms under the upper limit of one friction class, it is assigned to this class.

This method is demonstrated taking an example braking maneuver on a friction step from $\mu = 1.1$ to $\mu = 0.5$, shown in Figure 8. At $t = 11.45$ s, ABS starts controlling the wheel slip. The friction coefficient is determined from here on (till the end of ABS-control at $t = 12.37$ s). During that period, the determined friction coefficient falls under the upper limit of critical friction μ_{crit}, but for less than 200 ms. Hence the friction coefficient is lower than the upper limit of low friction μ_{low} for more than 200 ms, this results in an assignment of the friction step to the class of low friction.

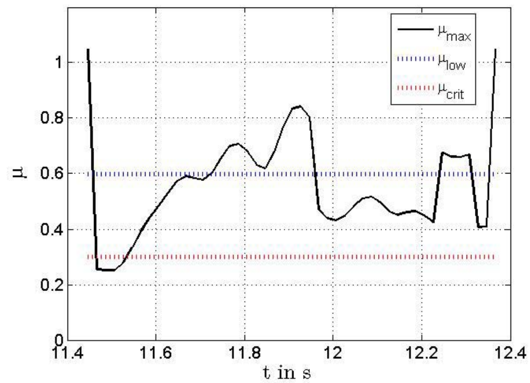

Figure 8: Determination of the friction coefficient during ABS-control at a braking maneuver $(v_0 \approx 50 \text{ km/h})$ **on a friction step from** $\mu = 1.1$ **to** $\mu = 0.5$ **.**

Validation

For validation of the described method, braking maneuvers on roads with various known friction coefficients were conducted. The friction coefficient was determined with the described method. Consecutively, the conducted maneuvers are:

- braking on "critical" and "low" friction (μ = 0.2; 0.5)
- braking on friction steps (from μ = 1.1 to μ = 0.2; 0.5; 0.7)
- braking on "normal" friction (μ = 0.7; 1.1)

Table 5 and Table 6 show the results of the validations tests for braking maneuvers using both brakes and using only the front brake. For nearly all test runs (103 of 109), the correct friction class could be determined with the described method.

Table 5: Friction detection (both brakes)

friction coefficient (number of tests)	detection		
	normal	low	critical
μ = 1,1 (n=12)	12	0	0
μ = 0,7 (n=17)	15	2	0
μ = 0,5 (n=12)	1	11	0
μ = 0,2 (n=12)	0	2	10

Table 6: Friction detection (front brake)

friction coefficient (number of tests)	detection		
	normal	low	critical
μ = 1,1 (n=12)	12	0	0
μ = 0,7 (n=20)	19	1	0
μ = 0,5 (n=12)	0	12	0
μ = 0,2 (n=12)	0	0	12

Friction Steps and Velocity during Cornering

Analysis

Seiniger [15] investigated the potential of future vehicle stability control systems for motorcycles. Two types of accidents were mentioned. One is caused by a drop of the road friction coefficient (friction step, type 1); the other one is caused by exceeding the maximum lateral acceleration (type 2). The vehicle side-slip angle velocity $\dot{\beta}$ was found to be a criterion for detecting these critical driving situations.

On the assumption that in uncritical situations all components other than geometric side-slip velocity are negligible, the (nominal) vehicle side-slip angle velocity $\dot{\beta}_{nom}$ is described depending on caster n, wheel base l, distance center of gravity to rear wheel patch l_r and horizonted steering angle velocity $\dot{\delta}$ as follows:

$$\dot{\beta}_{nom} = \frac{l_r + n}{l}\dot{\delta}$$

In general, (actual) vehicle side-slip angle velocity $\dot{\beta}_{act}$ is determined depending on the horizonted, measured yaw rate $\dot{\psi}$, lateral acceleration a_y and longitudinal velocity v as follows:

$$\dot{\beta}_{act} = \frac{a_y}{v} - \dot{\psi}$$

Taking into account a measurement uncertainty $\dot{\beta}_{uncertain}$, this yields the following criterion for detecting unbraked cornering accidents:

$$\left| \left(\frac{a_y}{v} - \dot{\psi} \right) - \left(\frac{l_r + n}{l}\dot{\delta} \right) \right| \geq \dot{\beta}_{uncertain}$$

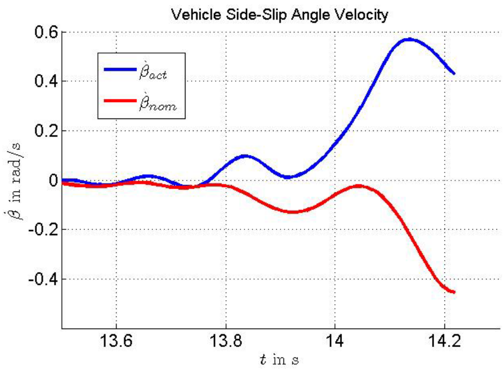

Figure 9: Vehicle side-slip angle velocity for an unbraked cornering accident caused by a friction step at 13.75 s (v = 30 km/h)

Figure 9 shows the nominal and the actual vehicle side-slip angle velocity over time t for an accident caused by a friction step. A difference between the two values can clearly be identified.

<u>Validation</u>

Figure 10: Safety device to avoid injuries during critical driving situations

To validate the explained detection method, both causes of critical driving situations (type 1 and type 2) are investigated on a test track with areas of low and high friction. To avoid any injury in the event that the motorcycle should fall, a safety device, shown in Figure 10, was constructed and used. Its influence on the driving behavior of the motorcycle is assumed to be negligible (additional roll moment of inertia: approx. 10%, additional yaw moment of inertia: approx. 30 %). The photo in Figure 11 shows a type 1 test.

Figure 11: Conducting a test drive (type 1) on a test track

In addition to the named critical driving situations, uncritical rides were conducted. These included maneuvers like cornering, double lane change, slalom and rides in public traffic. Table 7 shows the results of critical driving situation detection. The number of false detections is zero. All type 1 and about 65% type 2 situations were detected as critical. 35% of type 2 situation were not detected as critical. In these cases improvements of the method has to be investigated.

Table 7: Detections of critical driving situations

maneuver (number of tests)	**type 1 detected**	**type 2 detected**	**no de-tection**
cornering (n=15)	0	0	15
slalom (n=12)	0	0	12
lane change (n=4)	0	0	4
public road (120 min)	0	0	120 min
critical situation type 1 (n=22)	22	0	0
critical situation type 2 (n=17)	0	11	6

DESIGN OF HUMAN-MACHINE INTERFACE (HMI)

In order to warn the rider about hazards on his/her route, it is necessary to design a human-machine interface. It is important that this interface warns riders effectively, but also does not disturb them too much. Five various warning elements (Haptic Saddle, Auditory Warning, Warning Flashes, LED-Band, Display) and a warning strategy were implemented and analyzed through a test subject study. The analyzed elements are shown in Figure 12. In [7], this methodology is described and results of the evaluation are presented.

Figure 12: Warning Elements: Haptic Saddle, Auditory Warning, Warning Flashes, LED-Band, Display

COMFORT ORIENTED FUNCTIONALITY FOR GREATER MARKET ACCEPTANCE

The MoLife comfort-oriented feature is a simple to use voice communication application between motorcycles, called viitalk®. For this purpose, the system establishes a mobile wireless network with all equipped vehicles in range. Every rider can be identified by his/her nickname and unique ID. These functions are known from common internet instant messaging services, like Skype® or ICQ®. The users in the viitalk networks can initiate friendships with other users to become members on their buddy lists. They can talk with each other in private sessions, or they can communicate in conference calls.

The viitalk system works in the same way with an additional feature. Motorcycle riders add each other to their buddy lists and if one of them is in range the system shows his/her presence and indicates the location by showing the direction and the distance to the buddy. This could also be done in combination with a navigation function and a symbol in a map. The user can easily request a call to the buddy by pushing the call button. When the channel is established, other riders can join the session. Talking is very simple and unrestricted; there is no need to hold down a special key while speaking or to wait for others to stop speaking as in push-to-talk based systems. In contrast to mobile-phone-based systems, viitalk does not require sufficient network coverage by a provider and it does not incur additional costs, because viitalk builds up and moves the network with the group.

The communication in viitalk is based on voice over IP (VoIP) technology and is enhanced with methods to establish connections very simply.

Riders can talk to others and make arrangements, e.g. for breaks or refueling. With this communication, a group can reduce risks during overtaking or turning maneuvers. With viitalk the group sustains less misunderstanding caused by using hand signs. The biggest advantage of viitalk is the possibility for riders to simply and reliably advise their buddies (in the group) of any recognized hazardous situation. Viitalk enhances vehicle-to-vehicle communication with a direct rider-to-rider communication. For future vehicle communication systems, this enables a direct customer value, which is based on the same technology as the safety function.

CONCLUSION

Before implementing the “MoLife” project, a communication-based warning system for motorcycles that generates warning messages based on the evaluation of vehicle dynamics sensor information was not known. During the project, research gaps for the development of such a system were identified and addressed.

First, hazards which lead to accidents that can be avoided by such a system were identified. Second, an analysis of driving behavior in hazardous situations was conducted. This can be used as the basis for the generation of warning messages based on vehicle dynamics sensor information. Third, a methodology to design an appropriate HMI was developed and validated. Finally, an additional comfort-oriented functionality to increase market acceptance was implemented und tested.

OUTLOOK

Beside the technical sensors, it is possible to use the rider as a "sensor". This will offer the possibility to detect more hazards than the current system. Nevertheless, this makes the system more prone to malicious attacks. Furthermore, a much more sophisticated warning message management system is required.

Market introduction of communication-based systems is a big challenge, as a certain degree of market penetration is required in order for a system to be effective. This problem can be circumvented by employing the described system to a group of motorcycles. Riders often drive in groups. If a group is equipped with this system, it will benefit by it. Nevertheless, for the use of all functions a certain degree of market penetration is required.

ACKNOWLEDGEMENT

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MODELLING OF INDIRECT VISIBILITY

Krzysztof Olejnik
Jerzy W. Kownacki
Motor Transport Institute
Poland
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ABSTRACT

It is necessary to retrofit the vehicles and road infrastructure with the devices of indirect visibility. For the purpose of the tests, a mathematical model of the tests' subject was created, which was used to write the analytical computer program for the PC class computer. The mathematical model of the visual image transfer from the vehicle's surroundings transmitted by the mirrors encompasses: driver's eyes represented by the ocular points placed in the three-dimensional, rectangular left-handed, Cartesian system, the vehicle's block, described in this system by the clear and opaque surfaces; mirrors of the known features, mounted on the vehicle's block; the space surrounding the vehicle placed on the horizontal surface. This mathematical model was used to create the calculation program in the C++ programming language and using the Open GL library, working under the Microsoft Windows operating system. In the specific range of values it is possible to increase or decrease the size of the presented object – it helps to see the details, to change the direction of the observations. The operating program relies on an input of such quantities as width of the vehicle, location and extent of the transparent elements. The location of ocular points, and regions which driver should observe, in respect to the vehicle are also set. The results of the program calculations are presented graphically as the virtual picture of reality on the computer monitor. Apart from that, the program presents in the tabular form, values of coordinates of the points on the planes **Oxy** and **O'yz**, calculated for the given step, and for accepted parameters. Additionally there is a possibility to draw the regions covered by the eyesight. The created model of the visual transfer from the vehicle's surroundings, transmitted by the mirror enables to conduct the virtual tests of the real objects. The necessary data such as: position of ocular points in the real vehicle, the location of the mirrors and their features, width of the vehicle must be measured in the vehicle and introduced into the program.

Key words: mathematical model, indirect visibility, safety.

INTRODUCTION

There is the need to retrofit the vehicles and road infrastructure with the devices of indirect visibility. For the purpose of tests there was a mathematical model of the tests' subject created, which was used to write the analytical computer program for the PC class computer [1, 2]. The mathematical model of the visual image transfer from the vehicle's surroundings transmitted by the mirrors projects:

- driver's eyes by the ocular points placed in the three – dimensional space – Cartesian system, rectangular left-handed,
- the vehicle's block, described in this space by the clear and opaque surfaces,
- mirrors of the known features, mounted on the vehicle's block,
- the space surrounding the vehicle placed on the horizontal surface (Fig. 1.).

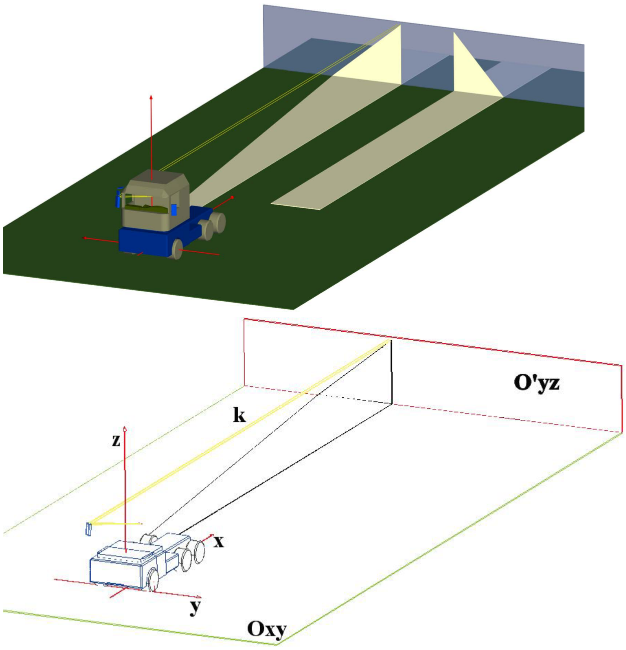

Fig. 1. Model of the real object of the tests and the diagram of the arrangement in the coordinates system

The front of the vehicle is turned in the opposite direction to that of the **Ox** axle. The coordinates system (with respect to the vehicle) is placed in the following way:

- the vertical surface **Oxz** runs through the longitudinal axle of the vehicle,
- the vertical surface **Oyz** is perpendicular to the surface **Oxz** which runs through the eyes' points,
- the horizontal surface **Oxy** lies on the road surface, which the vehicle stands on.

On the horizontal surface **Oxy** there are areas of the vehicle's surroundings projected, which, for example, in accordance with the current regulations, the driver should have the possibility to observe. The line of the horizon is projected on the surface **O'yz** which is parallel to the surface **Oyz**. The surface **O'yz** is at the rear behind the vehicle in the distance of the given value from the surface **Oyz**, Fig. 1.

MATHEMATICAL MODEL

Having given points **A**, **B**, **C** in the space, which project the following:

- **A** – the center of the sphere (sphere on which there is the surface of the mirror),
- **B** – one of the ocular points,
- **C** – point on the mirror, at which the observer's eyesight is directed; we look for the equations of the straight line **CE**. On the drawing no 2 there is a position of the mentioned points illustrated.

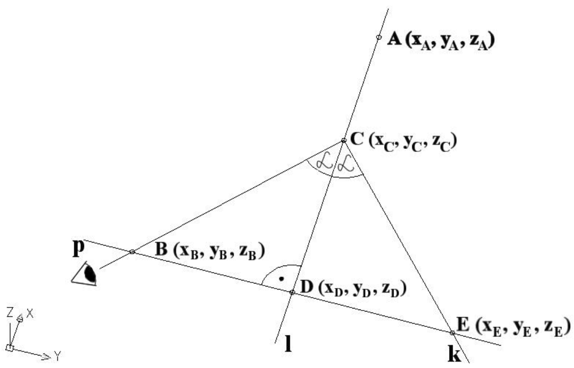

Fig. 2. The model of the elementary reflection problem in the mirror for the specular reflector placed on the vehicle

Coordinates of point **D** on line **l** were determined by drawing line p through point **B**, which is perpendicular to line **l**. Because the vectors of line **l** and line **p** are not zero, in accordance with the properties of the scalar product, the vectors of these lines, it transpires that when the scalar product of vectors produces the zero result, then the lines **l** and **p** are perpendicular to each other.

The common point (the point of crossing) of lines **l** and **p** was marked as **D**. The common point of lines **l** and **k** was marked as **E**. The point $\mathbf{D(x_D,y_D,z_D)}$ found, enables us to determine the coordinates of the point $\mathbf{E(x_E,y_E,z_E)}$ as the symmetrical one to the point **B** against the line **l**. Coordinates of the point **E** because of symmetry against line **l** are described by the following equations (1):

$$\begin{aligned} x_E &= 2\cdot x_D - x_B \\ y_E &= 2\cdot y_D - y_B \\ z_E &= 2\cdot z_D - z_B \end{aligned} \qquad (1).$$

Thus points **C** and **E** determine the line **k** in the space. Knowing the equation of line **k** we can calculate coordinates of the point of the penetration of planes **Oxy** and **O'yz** by this line.

Points of the penetration of these planes by line **k**, were reflected on the whole surface of the mirror, and provide the ability to determine the place and the extent of the region observed by one eye for the given location and setting of the mirror. Similarly we should act to determine the region observed by the second eye. Changing the values of point **A** coordinates in such a way that it moves on the surface of the sphere whose radius is determined by the interval **AC** and its centre, by point **C**, we set the mirror in such a way to direct the observer's eyesight at the area around the vehicle, which the observer wants to see. By analyzing the area around the vehicle, the area on the planes **Oxy** and **O'yz** for example, which is compatible with the current rules or with the expectations, we can determine:

- if for the given mirror and its placement on the vehicle the driver can take in a view of the required area,
- what conditions must be fulfilled (height, width, radius of curvature of the mirrors, parameters of its placement on the vehicle, settings) to enable the driver to take in a view the required area for the specific vehicle,
- the limitations of the use of mirrors for the indirect visibility of the regions of the vehicle's surroundings for the specific category of the vehicle and the constructional solutions,
- sensitiveness of the tests object (which is the function of many variables) to the particular variables.

This mathematical model was used to create the calculation program in the C++ programming language and using the Open GL library, working under the Microsoft Windows operating system. In the specific range of values it is possible:

- to increase or decrease presented object – it helps to watch details,
- to change the direction of the observations.

The operating program relies on an input of such quantities as width of the vehicle, location and extent of the transparent elements. In addition, to setting the location with respect to the vehicle, it is also possible to include the following factors:

- ocular points,
- regions which driver should observe,

- mirrors which are considered (its width, height and radius of curvature).

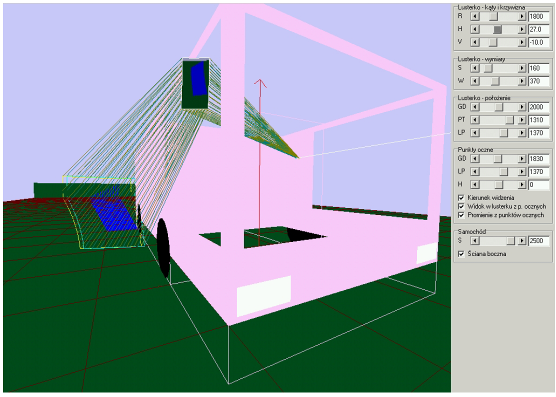

Fig. 3. The example of the picture, generated by the program, received in the monitor

Next, while changing the angles of the mirror adjustment vertically and horizontally we check if the region covered by the driver's eyesight through the mirrors will cover completely the region determined by the regulations or given as the result of the other limitations.

considerably less strenuous than in the real tests, Fig. 4 and 5.

Moreover, the model enables to test sensitiveness to particular variables and determine the limits of the mirrors' use in the indirect visibility of the areas of the vehicle's surroundings. An increase of the extent of the regions which can be observed by the driver with the help of the indirect visibility devices lowers the danger of a collision or accident occurring. It concerns the newly produced vehicles. The vehicles operated so far are the potential source of accidents. The high level of the danger of collision or accident occurrence can be lowered by retrofitting the older vehicles with devices of the visual transfer – Fig. 5.

To estimate the possibilities of taking these actions, the comparative analysis was made.

It relied on determining relationships of minimum dimensions of the mirror (height **W**x**S** width) on the values of the curvature radius of the mirror sphere taking into consideration the fact that such mirror enables the driver to observe the region which must correspond with the previous regulations and the new ones.

Fig. 4. View the real measuring stand with the manikin and the halogen head

The results of the program calculations are presented graphically as the virtual picture of reality on the computer monitor. Apart from that, the program presents values of coordinates of the points on the planes **Oxy** and **O'yz**, calculated for the given step, and accepted parameters in the tabular form. Additionally there is a possibility to draw the regions covered by eyesight.

The created model of the visual transfer from the vehicle's surroundings, transmitted by the mirror enables us to conduct the virtual tests of the real objects. The necessary data such as: position of eyes points in the real vehicle, the location of the mirrors and their features, and width of the vehicle must be measured in the vehicle and introduced into the program (Fig. 3). The evaluation of fulfilment of the demands by the vehicle is

In the case considered, the test object is the system K – P – O (Driver – Vehicle – Surroundings) and to be precise, the driver observing surroundings of the vehicle through the mirrors, placed on the vehicle, which he is not able to watch directly. The object of the tests is an indirect visual transfer made with the help of the mirrors, being the vehicle's equipment.

The comparative analysis was made by using the above described mathematical model of the tests' object, created by the author and the program in the language C++ developed based on the model with the use of the Open GL library. The relationship between the extent the mirrors cover the regions of classes IV and V, vehicles (which are the trucks' equipment) and the value of the radius of the mirror's curvature, was tested.

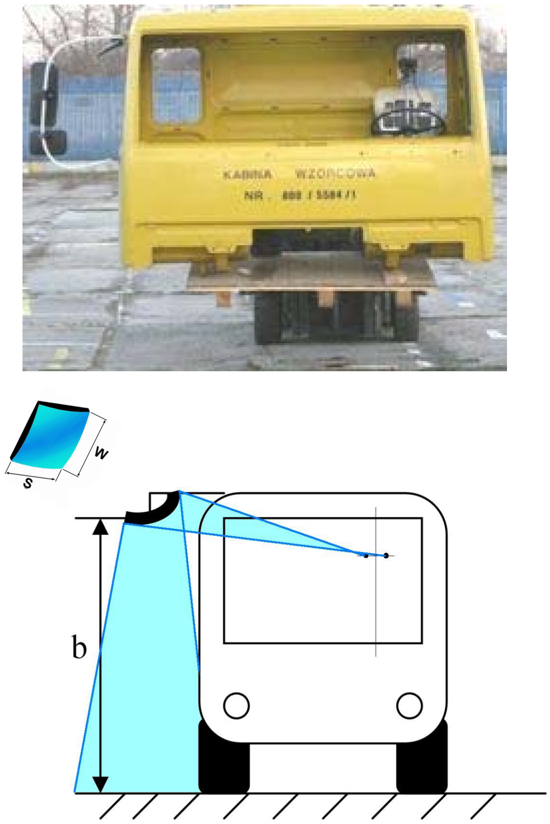

Fig. 5. The diagram of the measurement of the height over the road – b, of the close vision mirror location over the road and the mirror's dimensions and the real measuring stand with the manikin and the halogen lamp head

Everybody should have the possibility to observe a sufficiently long section to be able to perform a braking manoeuvre that stops the vehicle and in this way avoids a collision. When the natural hindrances that obscure the view occur, the drivers should be assisted for example by mirrors. These situations occur in the places where there is a building (colliding with the widening of the road) which creates a potential area for the accident threat – Fig. 6. The similar impediments appear when in the road's surroundings are the steep hills – for example in the mountainous region – drawing no 7.

If we compare the Polish requirements for the mirrors on the road with the requirements concerning the vehicle mirrors included in UN ECE Regulation No. 46 [3], we can draw the following conclusions:

1. for the mirrors on the road there is no convexity defined for example of the curvature radius of the section of the sphere, cylinder or other surface which the mirror should be. The lack of set standards concerning the kind of convexity of the value of the curvature radius (spherical or cylindrical) creates a situation where each manufacturer shapes the mirror arbitrarily and not in a unified way. As a result, the traffic participants need a long time to adapt and understand the visual transfer transmitted by this mirror.

Fig. 6. The example above reflects the limitation of visibility on the crossing by the building which covers the part of the road for people arriving from the left and the diagram shows an example of this real situation.

Fig. 7. The example of the mirrors' installation – from the right and from the left of the steep hills causing the visibility impediment

2. as a result of the above there were no values determined of the admissible deviations of the radius of this curvature which determines the disfigurement of the picture transmitted by the mirror – the inability to determine the admissible values of the deviations of the curvature radius on its whole surface admits its great irregularity. Thus

it admits considerable disfigurements of the picture transmitted by this mirror. This extends the time of understanding the information.

3. there was no value determined for the minimum reflection coefficient of the shiny surface, which is particularly important at night – a lack of the minimum value for the coefficient of a shiny surface reflection introduces a complete freedom of choice, which at the small values of this coefficient reduces considerably the visual transfer and impairs the observation as an example in the weak light.

4. a complete freedom of choice introduced as far as the mirror dimensions and shape are concerned causes the existence of the great variaty of the picture distortion. This way, the driver needs considerably longer time to receive the visual transfer which is transmitted by the mirror, to understand it and to make a proper decision. The impediments caused by the above can result in making mistakes, thus creating an accident threat. Insufficient training and misunderstanding of information increase the accident threats.

5. new terms were introduced such as: mirrors with increased observation angle, minimum distance of angle observation; the introduced terminology is not defined, unclear and inaccurate. Appropriate application of the regulation - UN ECE to the vehicles accurately determines parameters of the mirror which must be installed on the vehicle to assure possibility of observation of defined regions around the vehicle's surroundings. During testing of the limitation of visual transfer in the particular configuration of the road surroundings - drawing no 6 - the author worked out a mathematical model of this occurrence, in the form of calculation algorithm. Fig. 8 represents a diagram of a model that shows the problem of reflection in the specular reflector for the mirror placed on the road.

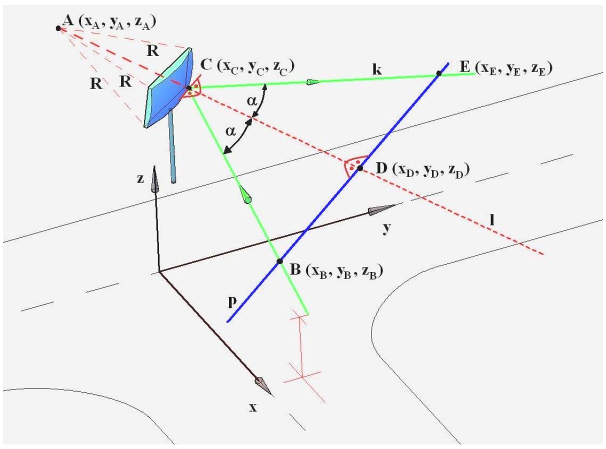

Fig. 8. Model of the problem of reflection in the specular reflector for the mirror placed on the road

Setting up, around the vehicle, the area on the surface **xy**, for example compatible with the current regulations or expectations, we can determine:

- whether, for a given mirror and its position on the road, the driver can see the area required with his eyesight,
- what conditions must be fulfilled (height, width, curvature radius of the mirror, parameters of mirror placement on the road, adjustment) to enable the driver to see with his eyesight the area required for a given place,
- the limitations for the use of the mirror for the indirect visibility of the road surroundings for a given category of the vehicle and constructional solutions,
- susceptibility of the test object (which is the function of many variables) to the particular variables.

The mathematical model of the visual transfer from the vehicle's surroundings transmitted by the mirrors described above, was helpful to create the calculation program in the C++ programming language with the use of the Open GL library, operating under the Microsoft Windows operating system. On Fig. 9 there is an example of the picture generated by the program which is seen by the program operator on the computer screen.

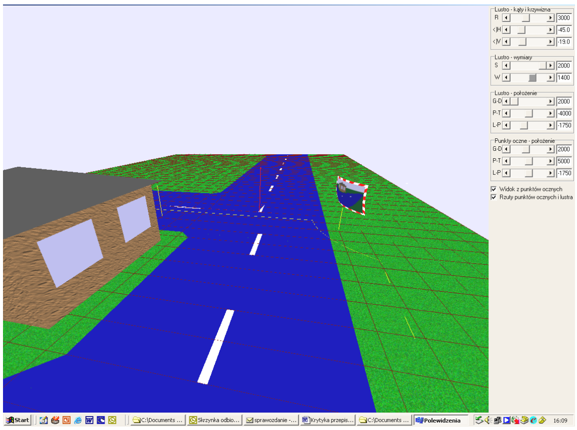

Fig. 9. Computer simulation of indirect observation through the mirror on the road

The algorithm of the picture generating in the program is as follows. The reflected radius was marked (sent from point **B**). The penetration point of the reflected beam with the walls structure (the group of triangles defining the opaque elements in the space) was determined. The result of the above was the point (spatial coordinates) of cutting of the beam (line of reflection) and the colour of the wall with which the cut through took place. For the points lying on the circumference of the mirror, the proper radiuses were drawn. The rest of the points lying on the surface of the mirror were marked with

the colour of the wall with which the cutting of the beam took place.
This way, on the surface of the mirror was created a picture projecting the surroundings seen by the mirror – Fig. 9. In the defined range of the values we can:
- decrease and increase the size of the presented object – it facilitates seeing the details.
- change the direction of the observation.
The operation of the program relies on inputting such values as the vehicle's position, mirror adjustment. Apart from that, being set is the location against the road and vehicle of:
- driver's ocular points,
- regions which should have been seen by the driver,
-mirrors which are considered (their width, height and the curvature radius, locations)
This modelling method allows to run the tests to select the optimum parameters of the mirror and its location on the road to help the traffic participants use the indirect visibility.

RECAPITULATION AND CONCLUSIONS

The choice for the solutions of the mirrors placed on the roads adopted in the regulations brings about a wide variety of the mirrors used. As a result, for the traffic participants to understand such inconsistent distorted visual transfers becomes a considerable problem.
Unclear and not readily understood picture transferred by the mirror can cause taking wrong actions and in the effect lead to a collision or an accident.
There are no sufficient arguments for admitting such a variety of mirrors' construction when the counter indications exist. There are no precise requirements concerning the mirrors' construction. It is necessary to propose unified solutions and more accurately specificity of the requirements for the mirrors' construction. There also should be uniform principles worked out for the locations of these mirrors in the places with limited direct visibility.
The skill to use the mirrors on the roads should be an element of training within the courses organized for obtaining a driving license. Also, popularising the skills to use the mirrors, should take place, amongst the drivers who got the driving licenses earlier. The care for undisturbed visual transfer as indispensable source of information is the basic element of the active safety system of the traffic participants in the road transport.

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CONSPICUITY OF POWERED-TWO-WHEELERS

Rainer Krautscheid
Nadine Müller
Jost Gail
Bundesanstalt für Straßenwesen (BASt; Federal Highway Research Institute)
Germany
Paper Number 11-0109

ABSTRACT

The 2BeSafe project (2-Wheeler Behaviour and Safety) is a collaborative project (co financed by the European Commission) that aims to study the naturalistic behaviour of Powered-Two-Wheeler (PTW) riders in normal and critical riding situations. That includes the interaction between PTW riders and other road users and possible conflicts between them.

One of the predominant causes of accidents involving PTWs is that PTWs are often overlooked by other road users. One task of the project lead by BASt therefore deals with possible improvements in conspicuity and the development of recommendations.

Particularly using the findings of the studies on conflict situations, promising lighting arrangements to enhance conspicuity of PTWs during the day and at night are selected. An abstract recognizing pattern for PTWs is defined, enabling other road users (e.g. car drivers) to clearly identify riders. Lamps and outfit like lighting configurations of different colours, different helmet lights, reflect / luminescent clothing parts and retro-reflective markings are designed and manufactured. Then, the different solutions are tested in a laboratory setting using experimental motorcycles together with riders to which the equipment is fitted. As result a proposal for a uniform signal pattern or lamp configuration in the front of all motorcycles and riders will be outlined.

The contribution first gives a short overview of the topics of the research project that deal with conflicts and their connection with poor conspicutiy and then presents in detail the methods used in the activities concerning solutions for the improvement of conspicuity together with first results.

INTRODUCTION

The background for considering an improvement of the conspicuity of powered-two-wheelers is that the development of the number of fatal accidents involving motorcycles are completely different to the declining number of accidents in general in recent years [1]. The number of fatal PTW accidents remains constant and thus the percentage of deaths of PTW riders increase. They have a much greater risk to die in a traffic accident then passenger car occupants. One of the most important reasons why accidents happen to motorcyclists is that they were not seen or were seen too late. Until now, the use of low (or passing) beam by day, is especially a feature of motorcycles and mopeds, but from now on there is an increasing number of multi-track vehicles with daytime running lights (low beam or equipped with dedicated daytime running lights) on the road since dedicated DRL are mandatory for new passenger car types in the European Union since February 2011 [2]. Thus, it is feared that motorcyclists could be seen worse in the future, because low beam on the day is less visible than special daytime running lights. It is expected that by using daytime running lights in conjunction with an innovative arrangement powered-two-wheelers could become more visible and clear.

To examine this hypothesis different subjects rated various lighting configurations during the day and at night have been examined in the context of the 2BeSafe project.

The overall strategy of 2BeSafe consists in conducting innovative research focussing on riders' behaviour and on riders-drivers' interactions. These topics of research are derived from accidentology findings and are supported by activities in designing the required technological tools to measure naturalistic driving behaviour.

The results acquired are then compiled and transversally analysed, following a systemic approach to develop guidelines and policy recommendations for the observation of riders' behaviour and for the elaboration of measures to improve PTWs' safety through the design of relevant and adapted countermeasures.

The part of the project that deals with conspicuity is divided into the following tasks:

- Conflict studies
- Experimental studies on PTW visual conspicuity
- Development and evaluation of recommendations

A short outline of these tasks is given in the following sections. Thereafter, as consequence of the identification of possible safety measures, we describe in detail the realisation of certain solutions for better lighting and their evaluation by use of experiments involving human subjects.

CONFLICT STUDIES

The goal of the conflict studies in 2BeSafe is to understand the behaviour of PTW riders and especially their interaction with other motor vehicle drivers. There is a substantial portion of accidents in which PTWs are involved that happen in the frame of interactions, or as consequences of interaction. For that reason it is important for safety work to understand interaction processes with other road users.

Appropriate high risk sites (intersections, curves or route sections that can be overlooked by one or two observers) are selected in many European countries on the basis of accident analyses (typical safety problems) in combination with local experience. In the following two examples are described more in detail:

Figure 1: Observation site at an intersection (Dresden / Germany) /BASt/

One observation site is a big road network where two traffic streams cross and is located in an area zoned for economic activities at the boundary of Dresden (see figure 1). Carriage ways are separated and contain multiple lanes for the each direction. Both roads work as motorway feeder but are also used by road users for accessing shopping parks etc. The whole intersection is signalized through traffic lights.
Motorcycles and scooters approaching from all directions have been observed and registered by two observers, if feasible (simultaneous occurrences of PTWs at the big intersections led to non-observance of some cases). The manual observation sheets from the observers were post-hoc double-checked with video tapes recorded during the observation time.

Figure 2: Observation site at a curve (Linz / Germany) /BASt/

As other observation site a certain curve has been selected in result of interviews with traffic and motorcycle experts. The curve is at a rural road track located near to Linz / Germany (see figure 2). The road consists of 1 lane for each direction and within the course of the curve overtaking is prohibited (signalized by traffic signs and a solid line). The 180° shape is a specific feature of this curve which challenges the riding skills and might provoke also critical situations within the interaction with other road users.
Motorcycles and scooters approaching from both directions have been observed.

At those sites analyses were carried out, including traffic conflict analyses making use of comparable traffic-conflict-registration techniques.

More than 1600 PTWs were recorded. "30.6 % of the observed PTWs could be identified as *sports bikes*, 39.6 % have been categorized as *scooters,* whereby *scooters with max. 50 ccm* engine displacement was the most frequently observed category (37.2%). Furthermore, 8.5 % *mopeds*, 4.9 % e*nduros* 3.4 % *cruiser* and 3.3 % t*ourer* have been registered. Additionally, 8.2% were classified as "others" whereby that category covers, among others, naked bikes with 4.7 %

Nearly all registered riders wore a helmet, except one BMW C1 rider (it is not mandatory to wear a helmet while riding that PTW model). 60.0 % of the riders wore a rather dark helmet and in 13.1 % of the observed cases the helmet was rather bright. The remaining 26.9 % of riders wore a helmet that was neither dark nor bright. The same trend could be observed for the PTW's color: the most frequently observed PTW color was a dark color (60.9%). In 6.8 % of the cases, the observed bike was bright and 31.6 % of the color of the bike was neither particular dark nor particular bright. Concerning the riders' preferences of clothing colors, it has been observed that 77.1 % of the PTW rider wore dark clothes, 3.7 % wore bright clothes and 19.1% wore clothes which were neither dark nor bright. Furthermore, 32.2 % of the riders were fully equipped with motorcycle clothing, 34.4 % wore just partly motorcycle clothing and 31.8% rode the bike with normal street clothes.

PTWs were riding without running head light in 8.2 % of the registered cases, 89.1 % of the riders had their head lights on. Particularly, moped riders and 50 ccm-scooters more likely had their head lights off." [3].

These observations show that although conspicuity should be an issue taken into account by PTW riders, dark clothing, dark helmets and dark PTWs are very common.

EXPERIMENTAL STUDIES ON PTW VISUAL CONSPICUITY

It is the objective of this activity of the 2BeSafe project to address phenomena related to PTW visual conspicuity as a critical factor in between-vehicle interaction. Specific issues are considered:

- Failed recognition of oncoming PTWs in spite of appropriate roadway inspection by car drivers
- Effects of modifying certain PTW features on sensory and cognitive conspicuity
- Identification of effective conspicuity treatments (e.g. helmet and headlight features)
- Description and examination of the relative and absolute conspicuity of the motorcycle in different background lighting conditions and traffic situations

These tasks are carried out by the 2BeSafe partners INRETS, University of Nottingham, Technical University Dresden and Ben Gurion University.

The sensory and cognitive conspicuity of PTWs on rear-view mirrors is investigated in a simulated car-driving task and by means of video footage and picture analysis. A tool for semi automatic analysis of data coming from an eye tracker is developed.

PTW conspicuity is also assessed through detection by using real-world video sequences of intersection traffic, including various conditions of visual noise (e.g. presence of car DRL), ambient illumination and special PTW conspicuity treatments.

Gaps accepted by car drivers towards PTWs when crossing or turning at intersections are investigated in a simulator study using various conditions of visual noise and PTW conspicuity treatments. Significant visual situations in traffic and their characteristic conditions are defined; these conditions are systematically varied and tested through simulations and emulations [3].

The following two aspects of the outcome of the above mentioned experimental studies have importance with regard to the tests carried out by BASt which are described in the next chapter: Experiments lead and carried out by Technical University Dresden yielded a T-arrangement and a V-arrangement (which are explained below) for the lighting pattern as two reasonable solutions for improving PTWs conspicuity. In parallel, studies from Ben Gurion University recommended helmet lights [4]. Although helmet lights are a rather inconvenient measure which would be connected with unforeseeable hurdles if a legislative approach on UNECE level with regard to allowing such a solution in real traffic will be started it was included in the study for research reasons.

DEVELOPMENT AND EVALUATION OF RECOMMENDATIONS FOR IMPROVED CONSPICUITY

This activity of 2BeSafe dealing with the development and evaluation of possible solutions for improved conspicuity is lead by BASt and is carried out together with the partners Technical University Dresden and FACTUM. Particularly using the findings of the experimental studies on PTW visual conspicuity mentioned above contrived possible lighting arrangements to enhance conspicuity of PTWs during the day and at night were tested in a laboratory setting. For those tasks, experimental motorcycles with different lighting configurations of different colours as well as different helmet lights, reflect / luminescent clothing parts and retro-reflective markings were used.

Discussions with PTW riders concerning conspicuity aspects were conducted. Test viewers were asked to assess and to compare the different lighting patterns for typical traffic situations and ambient lighting conditions; in this way it could be found out which measures are suited best to enhance conspicuity and thus to protect the riders .

Solutions for improving the identification of PTWs in situations with interaction and simultaneous appearance of other vehicles were studied in an experimental environment; concurrently the acceptance of design solutions by PTW riders was evaluated in laboratory settings as well as in field trials [5]. Scale models were made for all designs by Technical University Dresden.

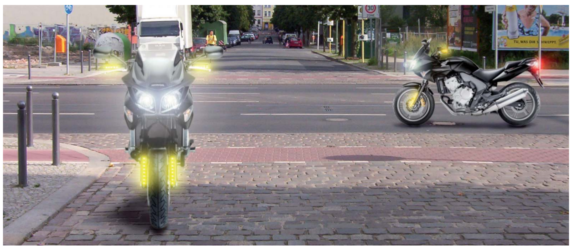

Figure 3: T-Design, Honda CBF 600 /TU-Dresden/

The T-arrangement of light sources in one horizontal line (handlebar) and in a vertical line at the bottom of the front fork is one of the proposed design solutions as result of the studies mentioned above (see figure 3). The advantages of the T-arrangement are a good reproduction of the motorcycle shape and size for the front view), large luminous surfaces and a high recognition in front view. The disadvantages are mounting problems - especially at the front end with a single arm front fork (scooter) - and no sufficient clarification of the front end in lateral view.

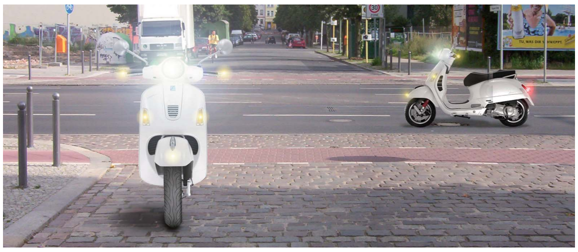

Figure 4: V-Design, Vespa GTS 300 /TU Dresden/

Another promising solution is the V-arrangement shown in figure 4 with light sources in an open top arrangement with top lamps at the handlebar and lower lamps on the front fender. The advantages are a clear form in front view, the clarification of the anterior end in lateral view; a high recognition in both views and a simple arrangement. The disadvantages are a poor visibility of the actual motorcycle size and an arrangement of the medium lamps possibly too close to low beam and high beam headlamps.

After considering the advantages and disadvantages the T-Design was selected to be used for the experiments with and without helmet lights [5].

ASSESSMENT OF NEW LIGHTING ARRANGEMENTS

Experimental Setup

In following the installation of the T-arrangement to a real motorcycle is described. For the installation of the T-arrangement five type approved DRLs were used. The choice of the applied DRLs resulted from comparisons between different light sources. The best solution turned out to be light emitting diodes. One of the most important aspects are the energy consumption as well as the freedom of designing and the small cross-section. Other available solutions would have been the use of bulb light sources H4, new H15 or gas-discharge light sources.

Daytime running lights of “Hella KGaA Hueck & Co.” fulfilled our requirements best. Two different models of DRL types were fixed to the Motorcycle. A total of 5 DRLs plus 2 lights attached to the helmet were used for the realization of the T-configuration. One of the chosen DRL products is called “LEDayFlex”. The advantage of it is that the lamps consist of different numbers of single modules, from 5 to 8 single modules are available. In the end we attached to the motorcycle: 2 x 8 series (for the wheel fork), 1 x 5 series (in center over the headlamp), 2 x 1 series (for the helmet) and 2 x 5 series (in this case called LEDayLine right and left under the handlebar).

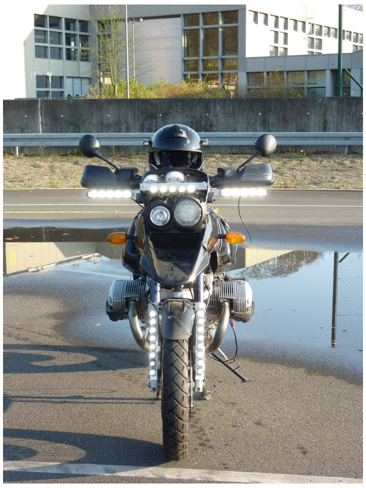

Figure 5: Test motorcycle with LED-DRL forming the T-arrangement

Before attaching the DRLs to the motorcycle they were calibrated in the laboratory. The method of testing is indicated in the corresponding ECE-Regulation. The aim of calibrating the DRLs was to compare the results from BASt with the manufacturer´s information to get an impression of the real luminous intensity of all DRLs. These tests gave also information about the duty factor. So the characteristic curve (luminous intensity vs. applied voltage) of the different DRLs was generated. The obedience between light intensity and duty factor is important since one future consideration is to adapt the luminous intensity to the ambient light intensity. First of all the positions of the attachments were defined. After that the elaboration of the design of the attachments for the DRLs took place.

Different requirements while designing the fittings for the DRLs had to be followed. For example detachable connections, lightweight, short dimension, illustration of the T-Design, helmet light, orientation of the DRLs etc. had to be considered.

The drafting of the different attachments took place with a CAD program. The mechanical drawings resulted from the stereoscopic models which were designed with the drawing program after measuring the dimensions of the motorcycle. The angle of the wheel fork is one of the important dimensions because it has impact on the arrangement of the DRLs (see figure 6). DRLs have to radiate in forward direction parallel to the road surface. One other important aspect was that the constructions should have detachable connections that are why the most of them use screws. Altogether the motorcycle got 8 components to attach the DRLs. All of them consist of Aluminum because of the light weight.

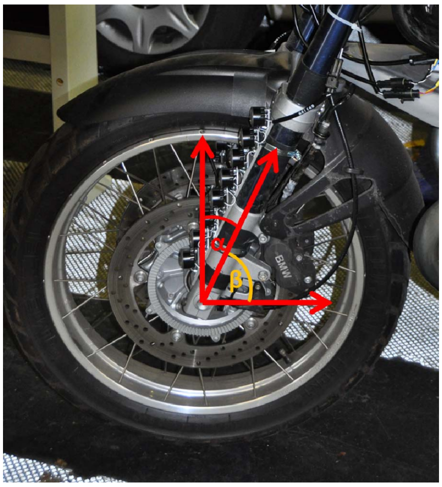

Figure 6: DRL attachment at the front fork of the motorcycle

After the mechanical workshop had produced all parts and attached them to the motorcycle, the tests could start. Tests for darkness took place in a hall, daytime tests took place on an open proving ground.

The different signal patterns that were presented to compare the new T-arrangement with other signal patterns were:

A: Low Beam
B: DRL (white); row of 5 LEDs
C: T-arrangement (day level)
D: T-arrangement (night level = DRLs were dimmed down to position lamp luminous intensity)
E: T-arrangement + helmet lights flashing (day level)
F: T-arrangement + helmet lights flashing (night level)

In the tests the subjects had to judge the different light configurations in a paired comparison of the different signal patterns. At a distance of 50 m and at a distance of 100 m the subjects had to observe the signal patterns (in the following only the results for 50 m are given). Each signal pattern was shown for 3 seconds.

Afterwards the subjects had the time to decide which one, in their opinion had a better conspicuity.

For the test at night, the signal patterns A, D and F were compared. The test for the day level contained signal patterns A, B, C and E.

Tests with night level

A number of 40 subjects participated in the test with nighttime conditions (darkness). The group of the interviewed subjects involved motorcycle riders as well as other road users; all age classes and both sexes were represented. The result was unambiguous. The diagram below (figure 7) shows the evaluation of the different signal pattern referring to a better conspicuity. Signal pattern D and F were definitively judged much better than signal pattern A. Signal pattern F got 245 votes from a total of maximum 320 votes. That means with a frequency of about 77 %, signal pattern F was chosen when it was presented in a paired comparison. Signal pattern D was following behind F with about 63 %. Signal pattern A only got about 10 %. That means the current allowed signal pattern in road traffic (just low beam) is inferior to the new designed ones. So the results clearly indicate that further improvements of the conspicuity of the signal pattern of PTWs are possible to increase safety.
With all different configurations the motorcycle was recognized as single-track vehicle. Some subjects pointed out that the T-arrangement gives a good impression of the dimension of the motorcycle. One negative aspect in reference to signal pattern A (low beam) is that these vehicles could also be a double-track vehicle which one defect head lamp. The problem of signal pattern F (T-arrangement + helmet light flashing) is that some subjects noted that the flashing is irritating or annoying.
However, the question, which signal pattern would make sense as standard equipment, was answered by a majority of 21 subjects with signal pattern D. 9 subjects would choose the current signal pattern A and just 3 subjects thought that signal pattern F would make sense as standard equipment.

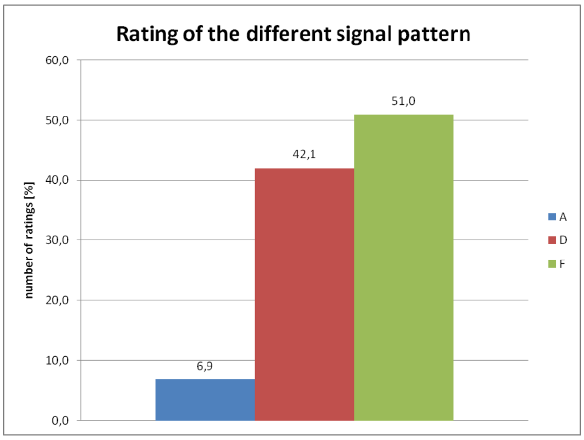

Figure 7: Result of the test with night level (distance: 50 m; 40 subjects)

Tests with day level

For the day level tests 45 subjects regarded and evaluated the different signal patterns. As well as for the test at night level subjects of different ages and sexes were involved. The result of the daytime tests was again unambiguous (see figure 8). That means signal pattern E got the most votes with a frequency of about 44 %. Second-best visible signal pattern was signal pattern C with 37 %. The difference between these two signal patterns is relatively small. But it is noticeable that the flashing helmet light in signal pattern E is chosen more often than signal pattern C. The difference of these two signal patterns in reference to the signal patterns A and B is much bigger. Signal pattern A, the current low beam, is just voted with a frequency of 3 % referring to a better conspicuity. Signal pattern B got about 15 %.

Thus, the results of the night level and the day level tests are similar. All signal patterns are judged as more efficient concerning the conspicuity than the low beam. That means for improvement of the conspicuity of PTWs the DRLs will be a sensible further development especially in the T-arrangement. The comments to the different configurations following the paired comparisons in general correspond to those given for the night level. Some subjects noticed that the low beam is not bright enough compared with the DRLs. So it is an issue that a couple of subjects are of the opinion that signal pattern B (one DRL in the centre over the headlamp) is better than the low beam. The statements to signal pattern C and E are similar to the nighttime statements: The T-arrangement gives information about the size of the motorcycle. On the one hand the helmet light attracts interest but on the other hand it is irritating and it could lead to distraction. Some subjects also said that the helmet luminous intensity was too low, that means that it was not conspicuous enough.

The question of which signal pattern would be reasonable as standard equipment is answered mostly with signal pattern C. A total of 20 subjects chose the T-arrangement. Signal pattern B followed by 17 votes. The fewest votes got signal pattern E with only 2 votes. Even the low beam got a number of 7 votes.

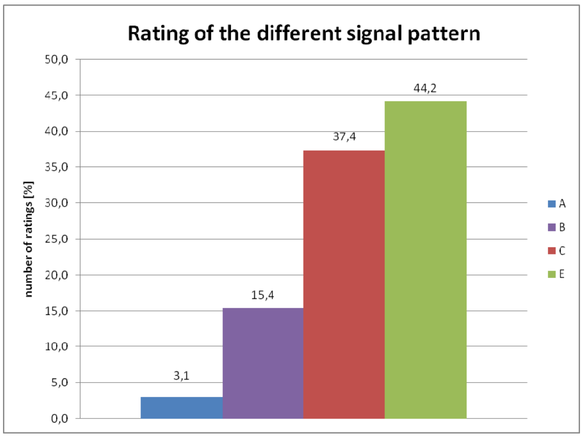

Figure 8: Result of the test with daylevel (distance: 50 m, 45 subjects)

CONCLUSIONS

The motivation for this study considering an improvement of the conspicuity of powered-two-wheelers comes from the fact that the development of the number of fatal accidents involving motorcycles are completely different to the declining number of accidents in general in recent years. The number of fatal PTW accidents nearly remains on a constant level. One reason why accidents happen to motorcyclists is that they were overlooked by other road users. Until now, the use of low (or passing) beam by day, is especially a feature of motorcycles and mopeds, but from now on there is an increasing number of multi-track vehicles with daytime running lights (low beam or equipped with dedicated daytime running lights) on the road since dedicated DRL are mandatory for new passenger car types in the European Union. Thus, it is feared that motorcyclists could be seen worse in the future, because low beam on the day is less visible than special daytime running lights. It is expected that by using daytime running lights in conjunction with an innovative arrangement powered-two-wheelers could become more visible and clear.

To examine this hypothesis different subjects rated various lighting configurations during the day and at night. Paired comparisons and an additional questionnaire show the benefits of daytime running lights used on motorcycles.

The present low beam has been rated significantly worse than new lighting configurations. In particular, the so-called T-design was estimated to yield very good visibility and among other things the shape and the size of the motorcycle was said to be reflected much better. An even better visibility became obvious when the T-design was combined with additional flashing helmet lights. However, due to some disadvantages, the hurdles for an introduction of flashing helmet lights in road traffic are high.

As a consequence, based on the test results, the T-design could be a promising candidate for a future lighting arrangement for motorcycles. However, this design would need changes and amendments to various international regulations. In addition, possible glare needs to be taken into account. The aspect of glare could be addressed by adaptive daytime running lights which have to be examined in further experiments - not only for powered-two-wheelers.

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THE POTENTIAL OF DIFFERENT COUNTERMEASURES IN REDUCING MOTORCYCLE FATAL CRASHES: WHAT IN-DEPTH STUDIES TELL US

Matteo Rizzi (1,5)
Johan Strandroth (2,3)
Roger Johansson (2)
Anders Lie (2,4)

1) Vectura Consulting
2) Swedish Transport Administration
3) Chalmers University of Technology
4) Karolinska Institutet
5) Monash University Accident Research Centre

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ABSTRACT

Every year approximately 50 motorcyclists are killed on the Swedish roads and almost 400 are severely injured according to police records.
The objective of this study was to analyze the relationship between a number of risk factors related to motorcycle fatal crashes in Sweden and to investigate the potential of different countermeasures aimed to motorcycle safety. The study used in-depth studies of fatal motorcycle crashes conducted by the Swedish Transport Administration during the period 2005–2008 (n=182). Proven or reasonable relationships between a specific countermeasure and the reduction in the number of fatalities were used as the basis for every calculation. Every fatal crash was analyzed and critical events throughout the chain of events leading to the crash were identified. An assessment was then made of whether certain countermeasures could have prevented the crash or mitigated the injury outcome. However, for natural reasons, the reliability of these assessments could vary depending on the problem area. In certain cases they were very dependable, whereas in other cases they could merely represent assessments of the maximum benefit.
The potential (number of saved lives per year in Sweden) of different countermeasures or intervention areas included in the study were presented depending on which element of the road system (user, vehicle and infrastructure) they related to, and were successively grouped depending on the reliability of the assessment.
It was also shown how no use of helmet, drunk-driving, no motorcycle driving license or excessive speeding may occur in the same crashes. For instance, it was found that all killed motorcyclists who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license.

This study may constitute a suitable basis for developing local and national strategies aimed at reducing the number of fatalities among motorcyclists, as interventions should be objectively prioritized depending on the expected effects. However, it is also important to note that Swedish conditions may differ from other countries. Furthermore, these calculations did not take into account any behavioral effects that could conceivably follow from certain countermeasures.

INTRODUCTION

In 2009, more than 5000 motorcyclists were killed in road crashes across the European Union [1], as shown in Figure 1.

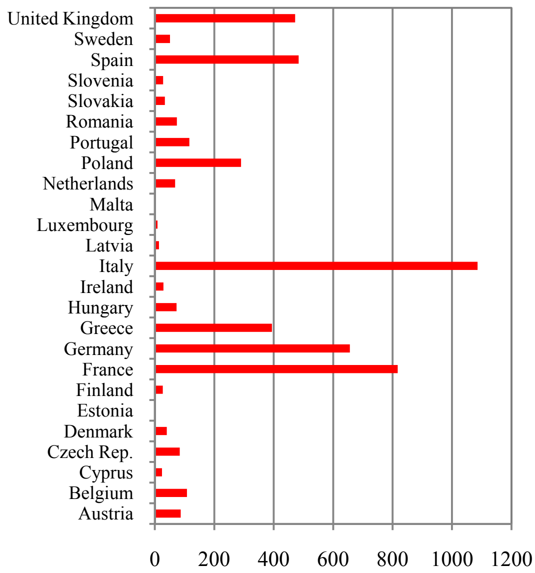

Figure 1. The number of killed motorcyclists in the European Union in 2009.

Every year approximately 50 motorcyclists are killed on the Swedish roads (see Figure 2) and almost 400 are severely injured [2].

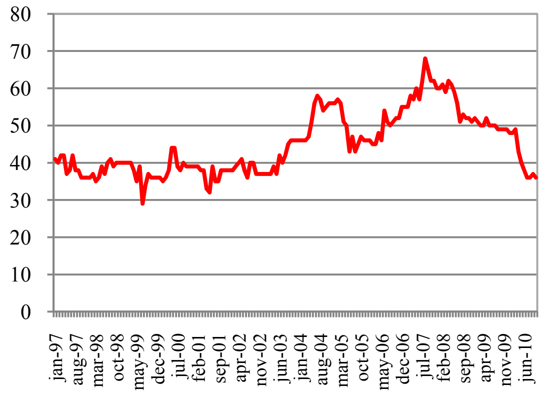

Figure 2. Number of killed motorcyclists in Sweden during the last 12 months (rolling 12 month average).

Motorcycles are becoming increasingly popular in Sweden – the number of motorcycles on the road has doubled during the past decade [2]. While motorcycles may meet important transport needs for their users, due to the growing congestion in urban areas and the demand for more energy-efficient transports, they may also meet important future needs for the whole society. However, a disadvantage associated with motorcycles is their shortfall in safety, compared to passenger cars. While the risk of being killed or severely injured per 1000 casualty crashes in Sweden has been almost the same since the 1980s for motorcyclists, the same risk for passenger car occupants has been decreased by more than 50% (see Figure 3).

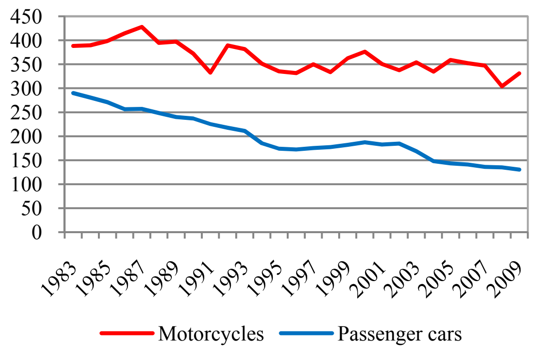

Figure 3. Number of persons killed or seriously injured in Sweden per 1000 casualty crashes with passenger cars and motorcycles.

Motorcycles and power-two-wheelers in general are a natural element of the road transport system and it is therefore of great importance to continually improve our knowledge and understanding of how motorcycle crashes can be prevented and injures can be mitigated.

STUDY OBJECTIVES

The objectives of this study were:

- to analyze the relationship between a number of risk factors related to motorcycle fatal crashes in Sweden during the period 2005-2008;
- to investigate the potential of different countermeasures in reducing those fatal crashes.

MATERIAL

The Swedish Transport Administration (STA) has been carrying out in-depth studies for each fatal road crash since 1997. The vehicles involved and the crash site are inspected by crash investigators at STA and further information is provided by forensic examinations, questioning and witness statements from the police and reports from the emergency services. These in-depth studies therefore represent a uniquely detailed material that is well suited for a qualitative analysis.

This study used 182 in-depth studies of fatal motorcycle crashes that occurred in Sweden during the period 2005-2008. Crashes with any kind of motorcycle with an engine displacement of at least 125 cc were included in this study (see Table 1). All available in-depth studies for the period 2005-2008 were used which should guarantee a representative material for Swedish conditions.

Table 1.
Types of motorcycles included in the study

Motorcycle category	n	%
Sport	65	36%
Custom	35	19%
Standard/naked	22	12%
On/off	16	9%
Cross/enduro	15	8%
Sport touring	12	6%
Scooter	7	4%
Supermotard	5	3%
Touring	5	3%
Sum	182	100%

METHOD

This study used a qualitative approach to investigate motorcycle crashes. The entire chain of events (see Figure 3) leading to motorcycle fatal crashes in Sweden during the period 2005-2008 was analyzed to identify factors that contributed to the crash itself or to the fatal injury outcome.

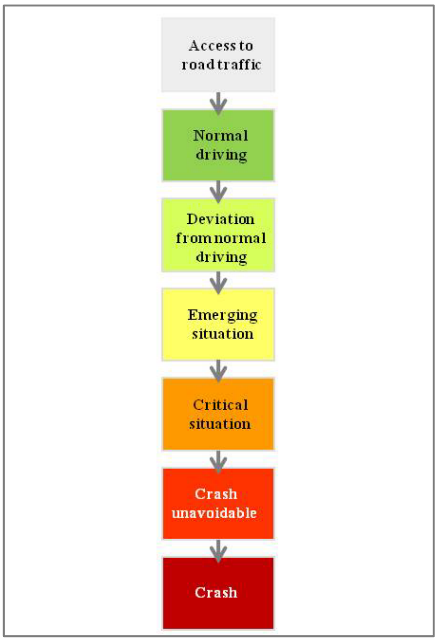

Figure 1. The chain of events, from access to road traffic to the actual crash [3].

A number of risk factors generally known to be associated to motorcycle crashes were studied in order to determine whether they occur simultaneously in these same crashes or not. The analyzed factors were no use of helmet, drunk-driving, no motorcycle driving license and excessive speeding. This analysis was carried out by simply checking in each crash if/how many of these risk factors were present. For instance, if it was found that a killed motorcyclist was under the influence of alcohol, it was checked if he or she did use a helmet, had a valid motorcycle driving license and drove at a speed that was judged to be within the speed limit by the STA crash investigator.

An assessment was then made of whether certain countermeasures could have prevented the crash (back to normal driving, see Figure 3) or mitigated the injury outcome. Two different crash investigators analyzed each crash separately. A number of crashes were further analyzed in a consensus group in order to guarantee objective assessments. For instance, if excessive speeding was involved in the crash, it was discussed at which extent a lower driving speed could have affected the crash. While this method provides an understanding of the effect that may be expected from a certain countermeasure, it is evident that the true effectiveness may only be calculated with real-world evaluations. Besides, for natural reasons, the reliability of these assessments may vary depending on the problem area. In certain cases, they were very dependable, whereas in other cases they could merely represent assessments of the maximum benefit. Therefore, the potential (number of saved lives per year) of different countermeasures or intervention areas were grouped depending on the reliability of the assessment. Countermeasures were also grouped depending on which element of the road system (user, vehicle and infrastructure) they related to.

The countermeasures or intervention areas to be included in this study were discussed with a number of stakeholders within the joint strategy for improved safety for motorcycle riders in Sweden for the period 2010-2020 [2] and are listed below. The basis for each assessment is explained separately.

- Antilock brake systems (ABS) on motorcycles
- Improved motorcycle conspicuity
- Traction Control systems (TC) on motorcycles
- Airbags on motorcycles
- Intelligent Speed Adaptation (ISA) on motorcycles
- Immobilizers on motorcycles
- Alcolocks on motorcycles
- E-call on motorcycles
- Improved visibility in other vehicles (i.e. A-pillar etc.)
- Approved motorcycle technical inspection
- Median barriers
- Improved sight distance in the road environment
- Safe intersections in urban areas
- Safe roadsides
- Motorcycle-friendly side barriers
- Clean and regular road surface
- Proper road repairs
- Safe intersections on rural roads

- Motorcyclists' speed limit compliance
- Improved motorcycle rider conspicuity/other road-users' attention
- No drunk-driving
- Motorcycle riders' proper risk judgment or capability
- Use of helmets
- Use of full-body protective clothing
- No motorcycle lending
- More strict medical requirements for motorcycle driving
- Other road-users' proper risk judgment or capability
- No use of unregistered motorcycles on the road
- Safe motorcycle riding in groups
- Rested motorcycle riders
- Motorcycle riders' appropriate driving license category
- Improved motorcycle riders' attention

The vehicles

Antilock brake systems (ABS) on motorcycles were estimated to decrease all types of fatal crashes by 40%. This assessment was considered to be certain, since a study based on Swedish real-life crash data [3] as well as others [4, 5] have shown that ABS has approximately this effect.

Improved motorcycle conspicuity was based on the number of crashes in which the critical event was another road-user not seeing or spotting the motorcycle. Crashes in which the line of sight was obstructed due to obstacles in the road environment (i.e. trees) were not included in this assessment. However, this potential was considered to be uncertain, since in in-depth material it can be difficult to discern visibility from attention, i.e. to distinguish between scenarios in which the crash was due to the other road-user actually not seeing the motorcycle and those crashes in which the other road-user did not pay enough attention.

Traction Control systems (TC) on motorcycles were considered to be effective in crashes in which the critical event was a power skid or the rider pulling a "wheelie". This potential was considered to be certain as Traction Control systems could prevent this kind of situations.

Airbags on motorcycles were considered to be effective in crashes in which the motorcycle rider remained seated on the motorcycle during the collision and in which the speed was not in excess of 70 km/h. The potential was considered to be uncertain, since no evaluations based on real-life crashes have been carried out yet.

Intelligent Speed Adaptation (ISA) on motorcycles is not common. However, it was considered that this system could theoretically prevent all crashes in which the motorcycle speed was a critical factor for the crash. This assessment was uncertain, possibly even very uncertain, since no evaluations based on real-life crashes have been carried out yet. Moreover, at the moment it is not possible to assess the (probably large) potential in form of injury mitigation. It is reasonable to assume that reduced impact speed would have a considerable injury mitigating effect in all types of motorcycle crashes, and therefore the calculated potential is likely to be an underestimation.

Immobilizers and alcolocks on motorcycles would eliminate crashes involving stolen motorcycles and crashes in which motorcyclists who were under the influence of alcohol were killed due to their own mistakes. Both potentials were considered to be certain, since the riders in these crashes would not have had access to road traffic (see Figure 3) if the motorcycles had been fitted with immobilizer and alcolock systems.

E-call on motorcycles was considered to be effective in single crashes in which the killed motorcyclist was found more than one hour after the crash and in which the forensic examination estimated that they did not die immediately after the collision. However, the potential was somewhat uncertain, since it was difficult to estimate how many of these fatalities could have been prevented if the crash had been reported earlier.

Improved visibility in other vehicles (i.e. A-pillar etc.) had a potential in crashes in which the driver of another vehicle stated that the motorcycle was concealed by the vehicle structure itself (i.e. A-pillar) or by some other vehicle. This potential was considered to be somewhat uncertain, since it was impossible to guarantee that the crash could have been avoided if the visibility had been improved.

Approved motorcycle technical inspections were considered relevant in those crashes in which the motorcycle had significant technical faults (i.e. malfunctioning brakes) that could be expected to be detected in a technical inspection.

The infrastructure

Median barriers were considered to be effective in preventing head-on crashes. Crashes in which the motorcyclist lost control and collided with oncoming traffic were excluded, since it is highly unlikely that a conventional median barrier would have mitigated the injury outcome. A Swedish study [6] has shown that serious and fatal motorcycle crashes have been substantially reduced on newly built roads with cable median barriers. However, the possible effect based on analysis of in-depth studies was considered to be somewhat uncertain, since it was impossible to exclude the possibility that the fatal crash would still have occurred if a median barrier had been present. While the type of barrier and its position are also important for the crash outcome, this aspect could not be taken into account.

Improved sight distance in the road environment had the potential for preventing crashes in which limited visibility due to obstacles in the road environment was a decisive factor. However, the potential was somewhat uncertain, since sight distance does not necessarily improve the driver's attention, although this would most probably improve the chances of detecting the motorcycles.

Intersections in urban areas: rebuilding ordinary intersections into roundabouts was considered to be effective in preventing all fatal crashes that occurred in an intersection in urban areas, excluding those crashes involving excessive speeding. In certain cases, it was difficult to assess the speed at which the crash could have been prevented, and the potential was therefore somewhat uncertain.

Safe roadsides: with this term it was meant that the area immediately adjacent to the road is cleared of any fixed object (such as poles, trees or rocks) that could be dangerous in a collision. This intervention area was considered to be relevant in single crashes in which the motorcyclist was killed in a collision with some fixed object in the roadside. However, it was difficult to exclude that the motorcyclist could not have continued out into the terrain and collided with some other object if the roadside had been cleared. This potential was therefore uncertain.

Motorcycle-friendly side barriers were considered to be relevant in crashes in which a conventional barrier was the primary collision object. However, in crashes in which the impact speed was very high, the design of the barrier may be insignificant to the possibility of survival. The potential was somewhat uncertain, since it would be necessary to carry out a larger evaluation based on real-world crashes with conditions that comparable to Swedish ones.

A clean and regular road surface was expected to prevent crashes in which the poor condition of the road surface was a certain cause for the crash. This potential was considered certain.

Proper road repairs had the same criterion as clean and regular road surface. This potential was considered certain too.

Safe intersections on rural roads could have a great potential, since many crashes at intersections occurred on rural roads. However, crashes involving excessive speeding were not considered, for the same reason as for intersections in urban areas. The potential was uncertain, principally because there is no known specific road design that has been tested and evaluated with respect to motorcyclists.

The users

A number of countermeasures or intervention areas that related to the user have effect on the same crashes as countermeasures related to the vehicle. Their potentials were therefore assessed in the same manner.

Speed limit compliance had therefore the same potential as Intelligent Speed Adaptation (ISA).

Improved motorcycle rider conspicuity had the same potential as improved motorcycle conspicuity.

No drunk-driving was considered to be effective in the same crashes as alcolocks on motorcycles. However, this potential was somewhat uncertain as the road traffic could still be accessed (see Figure 3).

Motorcycle riders' proper risk judgment or capability applied to crashes in which the rider's assessment of the traffic situation, risky behavior or poor riding knowledge (such as braking or cornering techniques) were considered to be critical factors in the crash. The potential was not certain, since it was difficult to determine to what extent a crash could have been avoided or mitigated with, for instance, a less risky behavior.

Use of a helmet and full-body protective clothing were considered certain in those crashes in which a killed motorcyclist without helmet or full-body protective clothing would have survived with them, according to the forensic examinations.

No motorcycle lending: there are indications that riders who do not drive their own motorcycle are generally overrepresented in fatal crash involvement. No motorcycle lending was therefore considered to have an effect in preventing crashes, excluding those cases in which the motorcycle was stolen. However, this effect was uncertain, since it may sometimes be difficult to assess in in-depth studies when the motorcycle had been loaned or not. Moreover, in fatal crashes lending was often combined with alcohol and lack of helmet or other protective equipment. Consequently, the potential could be regarded as very uncertain.

More strict medical requirements for motorcycle driving were also difficult to assess. This countermeasure is not related to the actual motorcycle use, but rather to the access to the road traffic (see Figure 3). This assessment was based on cases in which serious illness could have caused the crash. Such assessment was also difficult to make and the potential of this intervention area was therefore considered to be uncertain.

Other road-users' proper risk judgment or capability had the same approach as for motorcyclists. The assessment in these cases was also relatively certain.

No use of unregistered motorcycles on the road was considered relevant in crashes in which an unregistered motorcycle was involved in the fatal crash. This potential was certain, as access to road traffic would be denied, although there is no known way to effectively achieve this.

Safe motorcycle riding in groups was considered relevant in those crashes in which the poor assessment of the traffic situation by one of the motorcycle rider of the group could have caused the crash. However, the potential was uncertain, since it was difficult to assess the extent to which safer group riding could have prevented these crashes.

Rested motorcycle riders: in general, an assessment of whether fatigue is the cause of a crash is difficult and particularly difficult in the case of motorcycle crashes. The potential of rested motorcycle riders was therefore somewhat uncertain, although every year in Sweden a number of crashes occur in which it is suspected that the rider could have fallen asleep on his motorcycle.

Motorcycle riders' appropriate driving license category was based on those crashes in which the motorcycle rider had no motorcycle driving license. Purely hypothetically, the crash could have been avoided if the rider had had the right driving license category and thus better competence. However, the potential was uncertain or even very uncertain, since it is doubtful whether holding a motorcycle driving license by itself would have been sufficient to avoid the crash or not.

Improved motorcycle riders' attention was based on the number of crashes in which the rider's inattention was considered to be a cause of the crash. This assessment was considered to be fairly certain.

RESULTS

Analysis of in-depth studies of fatal motorcycle crashes in Sweden showed that all killed motorcyclists who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license (see Figure 4).

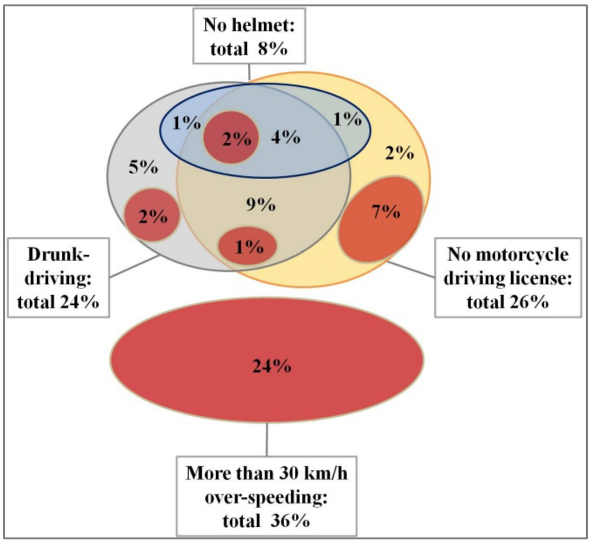

Figure 2. Relationship between influence of alcohol, use of helmet, motorcycle driving license, and estimated driving speed in fatal motorcycle crashes in Sweden 2005-2008.

As shown in Figure 4, it was found that 58% of all motorcyclists killed were either under the influence of alcohol, or did not use a helmet, or had no motorcycle driving license or drove more than 30 km/h over the speed limit. Besides, more than half of the killed motorcyclists killed who had no motorcycle driving license were under the influence of alcohol.
It was also found that in more than one third of the fatal crashes the motorcyclists' driving speed was judged to be at least 30 km/h over the speed limit. It was also shown that excessive speeding did not correlate with any other analyzed risk factor in two thirds of the crashes in which over-speeding by more than 30 km/h was present.
However, it was also found that that in only 2% of the cases all risk factors (rider under the influence of alcohol, not wearing a helmet, no motorcycle driving license and more than 30 km/h over-speeding) were present at the same time. In practical terms, this meant approximately one case per year in Sweden.

The results for the analysis of the potential of different countermeasures are presented depending on which element of the road system they related to: the vehicle (see Table 2), the infrastructure (see Table 3) and the user (see Table 4). The potentials are shown as number of lives per year that could have been saved in Sweden (in average, 53 motorcyclists were killed every year in Sweden during the period 2005-2008). The potentials were also grouped depending on the reliability of the assessment, as explained above.

Table 2.
The potential of vehicle countermeasures or intervention areas in reducing motorcycle fatal crashes in Sweden, in number of saved lives per year

The vehicles	**Certain potential** (relationship is known or the assessment was certain)	**Somewhat uncertain potential** (relationship is missing or the assessment was somewhat uncertain)	**Uncertain potential** (further research is needed)
Antilock brake systems (ABS) on motorcycles	21 (40%)		
Improved motorcycle conspicuity			6 (11%)
Traction Control systems (TC) on motorcycles	5 (9%)		
Airbags on motorcycles			7 (13%)
Intelligent Speed Adaptation (ISA) on motorcycles			>15 (>28%)

Immobilizers on motorcycles	3 (6%)		
Alcolocks on motorcycles	8 (15%)		
E-call on motorcycles		4 (8%)	
Improved visibility in other vehicles (i.e. A-pillar etc.)		3 (6%)	
Approved motorcycle technical inspection	2 (4%)		

Table 3.
The potential of infrastructure countermeasures or intervention areas in reducing motorcycle fatal crashes in Sweden, in number of saved lives per year

The infrastructure	**Certain potential** (relationship is known or the assessment was certain)	**Somewhat uncertain potential** (relationship is missing or the assessment was somewhat uncertain)	**Uncertain potential** (further research is needed)
Median barriers		6 (11%)	
Improved sight distance in the road environment		6 (11%)	
Safe intersections in urban areas		4 (8%)	
Safe roadsides			6 (11%)
Motorcycle-friendly side barriers		5 (9%)	
Clean and regular road surface	2 (4%)		
Proper road repairs	<1 (<2%)		
Safe intersections on rural roads			8 (15%)

Table 4.
The potential of user countermeasures or intervention areas in reducing motorcycle fatal crashes in Sweden, in number of saved lives per year

The users	**Certain potential** (relationship is known or the assessment was certain)	**Somewhat uncertain potential** (relationship is missing or the assessment was somewhat uncertain)	**Uncertain potential** (further research is needed)
Motorcyclists' speed limit compliance			>15 (>28%)
Motorcycle riders' proper risk judgment or capability		16 (30%)	
Use of helmets	4 (8%)		
No drunk-driving		8 (15%)	
Use of full-body protective clothing	3 (6%)		
No motorcycle lending			9 (17%)
More strict medical requirements for motorcycle driving			7 (13%)
Other road-users' proper risk judgment	2 (4%)		
No use of unregistered motorcycles on the road	3 (6%)		
Safe motorcycle riding in groups			4 (8%)
Rested motorcycle riders		3 (6%)	
Motorcycle riders' appropriate driving license category			14 (26%)
Improved motorcycle rider conspicuity / other road-users' attention			6 (11%)
Improved motorcycle riders' attention	5 (9%)		

As shown in Tables 2, 3 and 4, the most promising countermeasures with a certain assessment were Antilock brakes (40%) and alcolocks (15%) on motorcycles. Among those countermeasures or intervention areas with a somewhat uncertain assessment, motorcycle riders' proper risk judgment or capability (30%), no drunk-driving (15%), median barriers (11%) and improved sight distance in the road environment (11%) were the most promising ones. Other countermeasures or intervention areas with great potential were speed limit compliance or ISA systems on motorcycles (at least 28%) and motorcycle riders' appropriate driving license category (26%). In these cases, however, the assessments were uncertain and further research is therefore needed.

DISCUSSION

This study analyzed motorcycle fatal crashes in Sweden and showed that some risk factors such as no helmet, drunk-driving, no motorcycle driving license and excessive speed may often occur in the same crash. For instance, it was found that all killed motorcyclists in Sweden during the period 2005-2008 who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license. This suggested that, in those crashes, the lack of a helmet could be related to a certain type of behavior, that is, this was likely to be a conscious violation rather than a simple error. It is therefore important to take this into account when planning campaigns or other countermeasures to address this issue.

In this study, assessments were made on whether certain countermeasures could have prevented motorcycle fatal crashes or mitigated the injury outcome. However, it is clear that the reliability of these assessments may vary depending on the problem area. While the STA's in-depth studies contain very comprehensive material, in some cases it was difficult to assess the potentials of certain countermeasures due to the lack of information.

In the present study, the possibility of preventing fatal crashes has been assessed in the first place, since the material was based on in-depth studies of fatal crashes. While countermeasures that are effective in reducing the number of fatalities among motorcyclists could also be appropriate for reducing the number of seriously injured, further research is needed to determine whether this is the case.

Among all analyzed countermeasures or intervention areas, Antilock brakes (ABS) on motorcycles were estimated to have the largest effect in terms of saved lives per year. Intelligent Speed Adaptation (ISA) on motorcycle could have also saved many lives, at least 28%. The same potential applied to speed limit compliance for motorcyclists. While ISA has shown promising results on passenger cars [7], no evaluations on motorcycles have been carried out yet. A recent Swedish survey [8] showed that approximately 10% of the two-thousand participants were positive to implementing ISA on motorcycles.
However, it should be noted that, while the potentials of ISA or motorcyclists' speed limit compliance were uncertain, this was most likely an underestimation as no effects on injury mitigation were taken into account.

The most promising infrastructure countermeasure was safe intersections on rural roads, although the potential was considered to be uncertain due to the lack of a specific road design. Median barriers and improved sight distance in the road environment were also found to have significant potentials in reducing motorcycle crashes (11% reduction), although these assessments were somewhat uncertain. Motorcycle-friendly barriers were found to have the same potential, even though the assessment was uncertain due to the lack of real-life evaluations.

Among user countermeasures, motorcycle riders' proper risk judgment or capability was found to be a promising intervention area with a large potential (30%). However, this potential was considered somewhat uncertain as it may be difficult to determine to what extent a crash could have been avoided or mitigated with, for instance, a less risky behavior.

Motorcycle riders' appropriate driving license category had a great potential as well, as 26% of the motorcycle riders involved in these fatal crashes did not have one. However, this potential was uncertain too as it was impossible to exclude that the crash would have occurred anyway, even if the rider had had a proper driving license, as riding without a motorcycle driving license was often associated with other risky behaviors (see Figure 4).

The potentials shown in Table 2, 3 and 4 were calculated separately and no interactions were taken into account. For instance, it could be argued that increased speed limit compliance would enhance the effectiveness of helmets, full-body protective clothing and motorcycle-friendly barriers. On the other hand, it could be expected that, with the implementation of Antilock brakes on a large scale, fewer motorcyclists would fall prior to collision, thus reducing the number of crashes in which motorcycle-friendly barriers may be effective. Besides, it should be noted that in many cases the potentials presented in this study may overlap. For instance, a motorcyclist under the influence of alcohol who was killed in a collision with a conventional side barrier could have been saved by both alcolocks and motorcycle-friendly barriers.
At the same time, the potential of some countermeasures may be added to each other, for

instance ABS and Traction Control System, as they act on different types of critical situations.

This study may constitute a suitable basis for developing local and national strategies aimed at reducing the number of fatalities among motorcyclists, as interventions should be objectively prioritized depending on the expected effects. While certain intervention areas may already be included in other action plans (i.e. safe intersections on urban and rural roads, improved sight distance, median barriers and roundabouts), this study showed that those intervention areas may be effective in reducing fatal motorcycle crashes too.
However, it is also important to keep in mind that the potentials of the analyzed countermeasures or intervention areas shown in this study were based on Swedish crash data. While the material was fully representative for Swedish conditions, possibly for Scandinavian conditions at large, it should be noted that Sweden is a small country with particular weather conditions. The use of motorcycles and the infrastructure may therefore differ in other regions of the world. For instance, the calculated potential of use of helmets and fully-body protective clothing, approved motorcycle technical inspection, clean and regular road surface or proper road repairs was relatively low in Sweden due to the relatively limited number of relevant crashes. In the same way, median barriers and roundabouts are getting more and more frequent on the Swedish roads and it could therefore be argued that the potential of those intervention areas could be bigger elsewhere.

Furthermore, most of the motorcycles included in this study were heavier models (see Table 1) which may reflect the fact that motorcycling is a somewhat seasonal activity in Sweden. Clearly, lighter motorcycles (i.e. scooters) are rather uncommon in fatal crashes in Sweden, which may not be the case in other countries in which motorcycle are used as a mean of transportation as well. Further studies should therefore be carried out in other countries as well.

A possible limitation of this study is that the calculations did not take into account any behavioral effects that could conceivably follow from certain countermeasures or intervention areas. In most cases, the findings of this study could be seen as an assessment of the maximum benefit. While risk compensation would naturally affect the actual effectiveness of a certain countermeasure, further studies need to address this issue using real-world crash data after the implementation of a countermeasure. However, it should also be noted that no behavioral adaptation seems to have occurred with the implementation of Antilock brakes (ABS) on motorcycles [3, 4, 5].

CONCLUSIONS AND RECOMMENDATIONS

- All killed motorcyclists in Sweden during the period 2005-2008 who did not use a helmet were either under the influence of alcohol and/or had no motorcycle driving license.

- 58% of all motorcyclists killed were either under the influence of alcohol, or did not use a helmet, or had no motorcycle driving license or drove more than 30 km/h over the speed limit.

- Antilock brakes (ABS) on motorcycles were estimated to have the largest effect in terms of saved lives per year. Intelligent Speed Adaptation (ISA) on motorcycle could have also saved many lives, at least 28%. The same effect applied to speed limit compliance for motorcyclists.

- The most promising infrastructure countermeasure was safe intersections on rural roads, although the effect was considered to be uncertain due to the lack of a specific road design. Median barriers and improved sight distance in the road environment were also found to have significant effects in reducing motorcycle crashes (11% reduction).

- Among user countermeasures, motorcycle riders' proper risk judgment or capability was found to be a promising intervention area with a large potential (30%). However, this effect was somewhat uncertain. Motorcycle riders' appropriate driving license category had a great potential as well, as 26% of the motorcycle riders involved in these fatal crashes did not have one.

- This study may constitute a suitable basis for developing local and national strategies aimed at reducing the number of fatalities among motorcyclists, as interventions should be objectively prioritized depending on the expected effects. However, it is also important to note that Swedish conditions may differ from other countries. Furthermore, these calculations did not take into account any behavioral effects that could conceivably follow from certain countermeasures.

ACKNOWLEDGEMENTS

This study was conducted as part of the work for the joint strategy for improved safety for motorcycle and moped riders in Sweden for the period 2010-2020 [2]. This project was coordinated by the Swedish Transport Administration (STA) in collaboration with other stakeholders such as the Swedish Moped and Motorcycle Industry Federation (McRF), the National Society for Road Safety (NTF), the National Police Board (RPS), the Swedish Association of Local Authorities (SKL), the Swedish Motorcyclist Association (SMC), the Swedish Motor Insurers (TFF) and the Swedish Transport Agency (Transportstyrelsen). Many thanks also to Jörgen Persson at STA for valuable input during the entire project.

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Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW)

Dr.-Ing. Achim Kuschefski

Dipl.-Päd. Matthias Haasper

André Vallese, B.A.

Institut für Zweiradsicherheit e.V. (ifz)

Germany

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ABSTRACT

The results of a survey by the Institut für Zweiradsicherheit e.V. (ifz) on the topic "Advanced Rider Assistance Systems for Powered Two-Wheelers (ARAS-PTW)" carried out by ifz in the year 2009 triggered the study at hand. In fact the survey showed that both male and female motorcycle riders have knowledge deficiencies as regards rider assistance systems.

Against this background we explored the matter and found out that the respective literature offers a wide variety of definitions of assistance systems. This variety was the reason for a first attempt to clearly define the term "Rider Assistance Systems for Powered Two-Wheelers" – taking into account all the relevant specific requirements.

Furthermore, the study offers a general synoptic view (updated September 2010) of current rider assistance systems for powered two-wheelers.

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Results of an ifz-survey

The results of an ifz poll among 2,317 motorcycle riders (male and female) in the year 2009 revealed that only few riders have knowledge about what "Driver Assistance Systems" are.

20.9 percent of those questioned were not able to answer the question "Please tell us three different advanced rider assistance systems for powered two-wheelers." They did not know even one of these systems or could not see the connection between the device and the question asked. Furthermore, 19.5 percent could give one example, 23.3 percent could name two, but only 36.4 percent were able to name three different driver assistance systems at all (see figure 1).

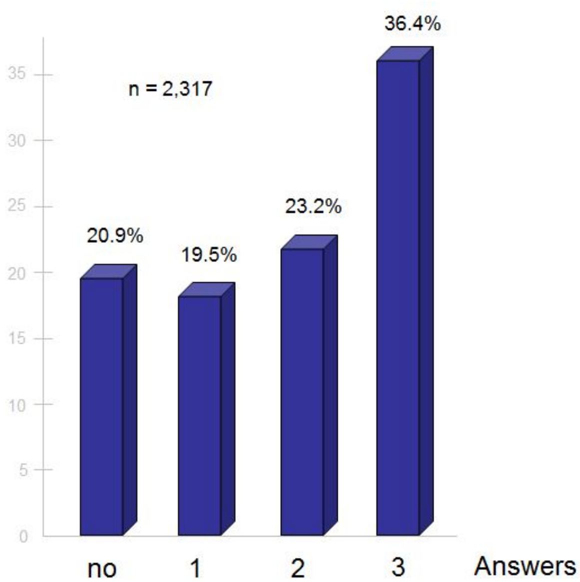

Figure 1: "Please tell us three different rider ADAS for powered two-wheelers." – Frequency of naming

Anti-lock braking systems (ABS) have been sufficiently known in wide sections of the population for quite some time, and since 1988 many motorcycles have been equipped with it. This might be the reason for the fact that "ABS" was the most frequent answer (96 percent) in this context (driver assistance systems for powered two-wheelers).

93 percent of those who only knew one assistance system mentioned ABS. If the interviewees knew two or three systems, they also designated ABS in most cases (94.1 and 98.8 percent respectively).

The familiarity with ABS can also be deduced from the fact that the first of three answers given in 75.6 percent of all cases was "ABS".

Figure 2 shows other systems mentioned and their frequency of naming.

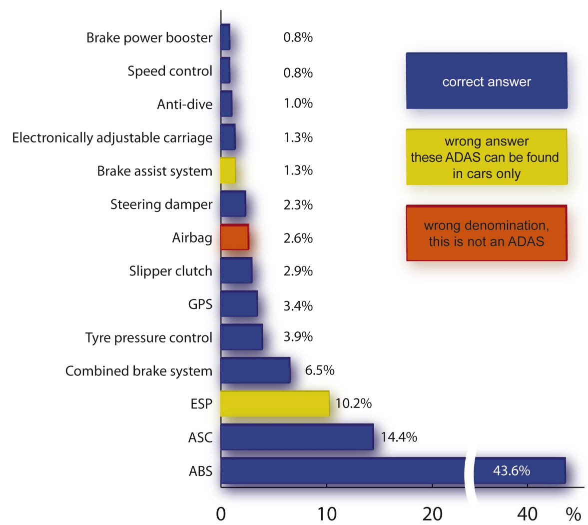

Figure 2: Frequency of driver assistance systems for powered two-wheelers mentioned by the interviewees

Another interesting result was the fact that airbags as a means of passive driver protection were mentioned in 2.6 percent of cases although they are definitely not part of a driver assistance system. Also, the interviewees brought up systems that up to now only have been fit to cars, trucks or coaches.

Thus it is important to keep in mind that only about one third of the interviewed persons were able to name three driver assistance systems. One fifth of the interviewees could not mention even one system although the example of ABS and its widespread familiarity with it would have suggested this. Maybe the difficulty lies in the term “driver assistance”. Due to the results of the survey we took a closer look at the subject and found the different definitions of driver assistance systems. This is why we try to shape a first definition of “Rider Assistance Systems for Powered Two-Wheelers” in the paper at hand – in due consideration of the requirements characteristic of two-wheelers.

The Driving Task

In this context it is necessary to give a brief explanation of the term “driving task”, as this term will be referred to at a later stage in this study in order to give a further differentiation of driver assistance systems. Furthermore this is important for a classification of these systems.

For more than 40 years scientists have dealt with driving tasks, a term that designates the requirements and operations that are necessary to drive a motorized vehicle. Again, there are a lot of definitions of the term in use, some of which are rather complex ones. In the study at hand we have chosen the model according to R. Bernotat, a basic and clear approach that is quite easy to understand. It can be outlined in the following way:

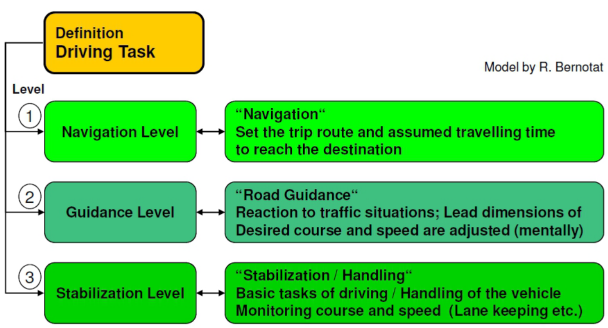

Figure 3: Classification of driving tasks into three levels (according to [1])

Roughly speaking, the driving task consists of three levels: The navigation level, the guidance level and the stabilization / handling level. While the navigation level means the determination of the trip route and maybe also the length of the trip, level number 2, the guidance level, already includes tasks such as reactions to diverse road traffic situations. These induce a mental determination of the set course and the desired speed in due consideration of existing traffic regulations. Level 3, the so-called stabilization or handling level, covers basic driving tasks and the monitoring of course and speed. The Levels 2 and 3 require constant interaction, whereas the interaction between Level 1 and 2 is less frequent.

The hierarchy in the classification of driving tasks is obvious: Level 1 is superior to Level 2 which is superior to Level 3. The navigation level, which roughly determines the trip route, always plays a superior role among the driving tasks as a whole. In the same way the guidance level is superior to the stabilization level, since without a set course and without a desired speed there is no need for action on this level.

Advanced Driver Assistance Systems – what is the idea behind it?

Since 1966 there has been an official classification into *active* and *passive safety systems* [2]. According to this classification all systems and technologies that help prevent accidents are classified as *active* safety devices. Systems and technologies that help reduce accident results are classified as *passive* safety systems. Meanwhile the boundaries between active and passive safety have become fluent and were softened by driver assistance systems in many different fields.

The term “driver assistance system” derives from the field of automobiles and originally was defined as “Advanced Driver Assistance Systems” (ADAS) in English-speaking countries. Where and when this term was mentioned for the first time in the corresponding professional literature could not be exactly sorted out, probably this was the case shortly before the turn of the millennium.

In the respective publications one finds countless reports and studies on driver assistance systems (ADAS). As well, there are several different definitions since different criteria were taken as a

basis for classification.
At the beginning a lot of systems that relieved or supported the driver were assigned to be an ADAS, such as the electric starter because this made starting the engine a lot easier. At the time this device was invented, however, nobody talked about driver assistance systems at all.

As more electronic equipment was fitted to vehicles, it was possible for the first time to realize complex systems. At times of purely mechanical equipment such systems were unimaginable. Thus traffic news has been broadcasted since 1969; and since 1978 many cars have been equipped with anti-lock braking systems (ABS) as standard. Other systems followed.

Due to the fact that the great number of ADAS according to these criteria would be hardly comprehensible or understandable, some sources refer to driver assistance systems only at the guidance level, whereas others see them at the stabilization level. At the navigation level, one frequently uses the term information systems.

To give just one example: "They act as a sort of electronic pillion passenger discreetly from the background", as one could read in a brochure about driver assistance systems of Continental Teves AG & Co oHG published in the year 2008.

The general meaning of the word "assistance" is *to render help*. In our context the aim of this help is to relieve and support the driver from his operation tasks in some way or other by different systems. This first and foremost refers to *active safety*, which means the reduction of the probability of the occurrence of dangerous road traffic situations. If a critical situation occurs, the driver gets support for the driving task by one or more assistance systems; pre-crash systems can even reduce potential accident results. Very occasionally post-crash systems in order to improve the rescue management (e-Call) are also included into ADAS.

At present driver assistance systems are developed mainly with respect to self protection and to a lesser extent in order to protect other road users. Thus ADAS only support the driving tasks of the driver whose vehicle is equipped with it. As a consequence they do not have supporting effects on other road users, although a certain correlation (i.e. accident results) cannot be denied.

From the field of civilian air traffic, for example, the so-called TCAS (Traffic Alert and Collision Avoidance) is well known. This system prevents a collision of two aircrafts by calculating an evasive manoeuvre for both planes in mutual adjustment. A transfer of this system to the road traffic system seems aptly conceivable.

Within the framework of the European research project SAFERIDER (January 1, 2008 – December 31, 2010) the term ADAS ("Advanced Driver Assistance System") which originates from the field of automobile driving, was renamed into ARAS "Advanced Rider Assistance Systems" for the very first time. At that time the focus was on using the correct English term and not yet on an adjusted definition.

But no matter which view or classification is under consideration: for a motorized two-wheeler both are inadequate as the very specific features of operating a powered two-wheeler are not taken into consideration at all. This is especially true when taking into account that motorcycle riders belong to the group of vulnerable road users.

Even motorcycle manufacturers normally do not label their equipment "Rider Assistance Systems". Thus one finds terms such as "active safety equipment" or "an important step towards more riding safety" (source: BMW Motorrad). The reason for this is probably the fact that the numerous definitions of assistance systems derive from the field of automobiles.
This is why we hope that this study will provide new definitions of rider assistance systems for motorized two-wheelers and will thus enable a better designation of the corresponding equipment. In the end the amount of safety features influences the purchase decisions of motorcycle riders [3].

Advanced Driver Assistance Systems in the field of automobiles can be classified into five categories:

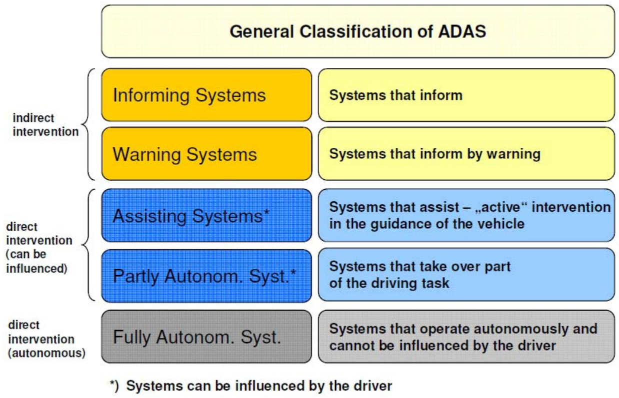

Figure 4: General Classification of ADAS

According to Figure 4 the systems are classified with respect to informing, warning, assisting, and partly and fully autonomous. The informing and warning systems only have an indirect influence on the driving task. They can but they do not necessarily have to be observed by the driver and/or induce him/her to a corresponding activity. In contrast to them, the assisting and partly autonomous systems do mean a direct intervention into the driving task. However, they can be adjusted by the driver at any time.

The assisting systems are systems that indicate driving errors while operating the vehicle. The indication happens directly and in a haptically perceptible way to those steering elements of the vehicle which should be operated in order to prevent an accident. Optical and audible warning signals are also possible. Take for example the active lane keeping assistance for automobiles and trucks. If a driver is inobservant and leaves the lane – for whatever the reason is – there is an automatic counter steering which alerts the driver and is supposed to make him leave the false lane. If the driver, however, decides against the counter steering, it is possible to adjust the automatic steering by a slightly raised exertion of force.

An example of a partly autonomous system is ACC (Adaptive Cruise Control), an automatic vehicle distance and speed regulator. After having set one's desired speed and vehicle distance the ACC takes over this part of the driving task. The driver still has to monitor this function but can switch it off or readjust at any time.

The fifth and last category of ADAS consists of fully autonomous systems. The oldest and best known systems in this category are anti-lock braking systems (ABS). These systems operate fully autonomously and cannot be influenced by the driver.

The increasing automation of operating tasks and the increasing autonomy of driver assistance systems means a growing influence and taking over by technology; the driver's share in the driving task decreases which results in a decrease of alertness on the part of the driver. In this context some researchers even have a vision of fully autonomous driving in the near future (cf. figure 5).

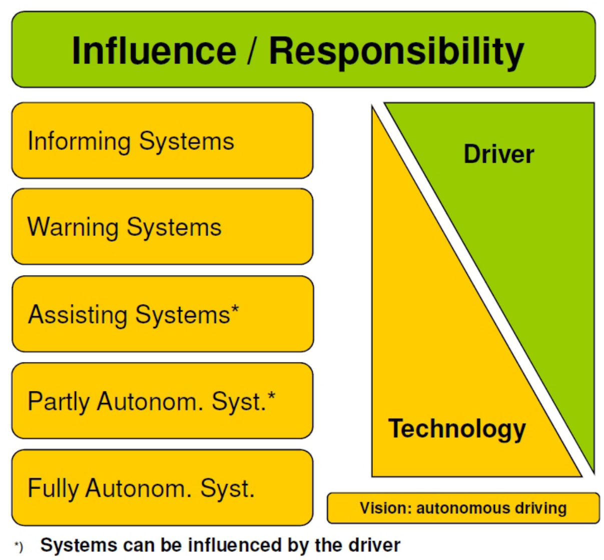

Figure 5: Influence and Responsibility of Driver Assistance Systems

The reason for the fact that this vision will remain a vision for the years to come is due to legal circumstances, although this matter is being worked on currently.

According to the Vienna Convention on Road Traffic (1968) the following requirements must be met:

Article 8: Driver

(1) Every moving vehicle or combination of vehicles shall have a driver.

(4) Every driver of a power-driven vehicle shall possess the knowledge and skill necessary for driving the vehicle. …

(5) Every driver of a power-driven vehicle shall at all times be able to control … his vehicle.

(6) Every driver of a vehicle must avoid all other activities and concentrate on the operation of his/her vehicle. National law must have prescriptions for the use of mobile phones while steering a motor vehicle. In any case these regulations have to prohibit the use of mobile phones or hands-free speaking systems for motorists of motorized vehicles in motion.

Article 13: Speed and distance between vehicles

(1) Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be able to exercise due and proper care and to be at all times in a position to perform all manoeuvres required of him. He shall, when adjusting the speed of his vehicle, pay constant regard to the circumstances, in particular the lie of the land, the state of the road, the condition and load of his vehicle, the weather conditions and the density of traffic, so as to be able to stop his vehicle within his range of forward vision and short of any foreseeable obstruction. He shall slow down and if necessary stop whenever circumstances so require, and particularly when visibility is not good.

The contents of the Vienna Conventions make clear that Driver Assistance Systems can only work in a limited sense as fully autonomously. Still, the motorist himself has to be in control of his vehicle and thus of his driving.

Figure 6 shows the classification of Advanced Driver Assistance Systems in the field of automobiles taking into consideration the three levels of driving tasks. Some ADAS are exemplarily catalogued.

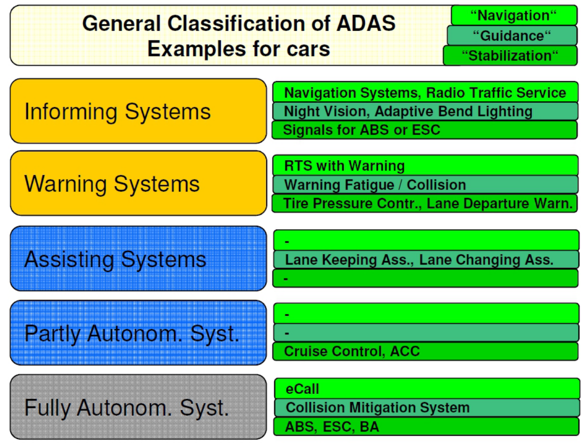

Figure 6: Classification of driver assistance systems for automobiles considering the three-level model for driving tasks

Specifics of powered two-wheelers and implications

As chapter “Advanced Driver Assistance Systems – What is the idea behind it?” showed, there are many different driver assistance systems for car drivers. Equipment that seems to be normal for car drivers, however, is not necessarily commonplace for motorcycle riders. One simple example in this context is traffic news. Information about the current road traffic situation (i.e. about wrong-way drivers) are withheld from motorcycle riders, since there is no space for radios or because communication turned out to be rather difficult at least until some years ago.

In contrast to car drivers, motorcycle riders are much more exposed to the environment. There is no bodywork that protects them from outside influences (such as weather conditions) which is also the reason why there is much more sensory strain on motorcycle riders than on car drivers. This important matter, however, has not been given a lot of attention up to now; in our view, though, this aspect plays an important role in the evaluation of assistance systems for motorcycles and should be taken into consideration when a classification is to be set. The reasons for this will be shown in the following “Pyramid of Convenience”.

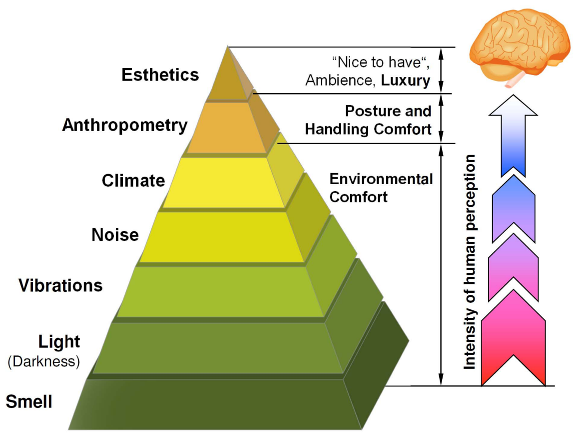

Figure 7: Pyramid of Convenience (according to /4/)

As figure 7 shows, sensory impressions such as odour, light, vibration, noise, climate and anthropometry (determination and application of physical dimensions of the human body) and aesthetics are hierarchically structured.

One interesting aspect of the pyramid is that higher-level sensory impressions are felt as a lack of comfort only when the needs from lower-level impressions have been satisfied. In concrete terms, this means for example that noise is being perceived as disturbing only when the rider does not feel affected negatively by odour, light or vibrations.

This hierarchical structure of human sensations reveals the big difference in the strain of car drivers and motorcycle riders. Today, impairments such as smell, light, vibrations, noise and climate are for car drivers more or less eliminated, which leads to the fact that requirements in the field of anthropometry and aesthetics ("nice to have") have gained more and more importance.

And the motorcycle riders?

In order to answer this question, we carried out a survey on the occasion of the Dortmund trade fair "Motorräder Dortmund 2010", which revealed the following results. The interviewees were asked to make a direct comparison between their "own motorcycle" and their "own car" and evaluate the different sensory strains. In doing so the aim was not to control the ranking as revealed in the pyramid of convenience but to evaluate the different sensory impressions for both vehicles. Figure 8 shows the results of this survey.

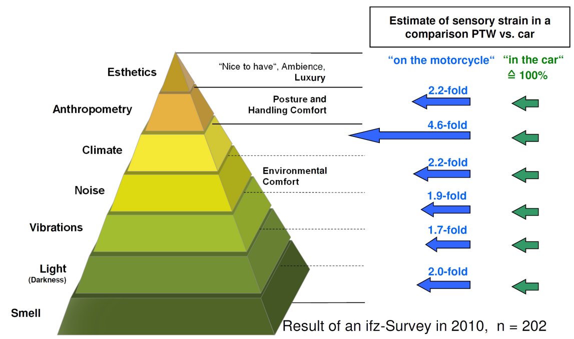

Figure 8: Sensory strain: A direct comparison car – motorcycle within a pyramid of convenience

The figure clearly shows that the sensory strain among motorcycle riders is considerably higher than among car drivers. In all categories the car was taken as being the standard (100%). The obtained data are mean scores obtained from the answers of 202 persons interviewed. The smallest difference with only 70% additional strain was reached for the aspect strain by light, the biggest difference was obtained for the aspect "climate" with 360% additional strain felt among motorcycle riders. All the other feelings of straining sensory impressions when riding a motorcycle ranked about twice as high compared to driving a car.

As the amount of the sensory strain in the pyramid shows, it is especially the environmental-comfort systems and the posture and handling comfort systems that play a significant role for motorcycle riders, a role that should not be underrated. These systems exert a significant influence on Level 2 (guidance level) and on Level 3 (stabilization / handling) of the driving task (cf. Figure 9).

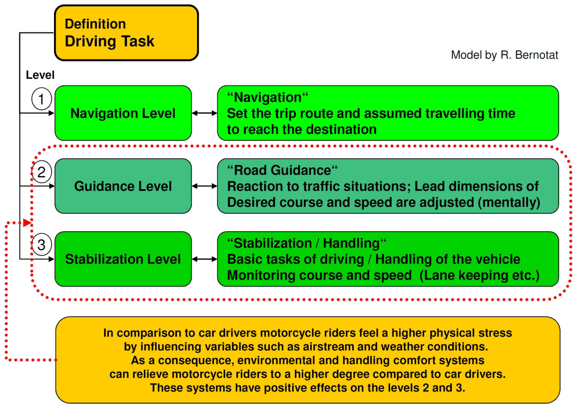

Figure 9: Positive effects of environmental and handling comfort systems

The directly influencing variables on the physical strain for motorcycle riders are:

- Vibration ("sitting directly on the motor / engine")
- Noise (no encapsulation of the engine, airstream)
- Direct exposure to airstream and precipitation
- Direct exposure to sun and heat (no roof, no air conditioning)
- Additional physical strain by heat of engine
- Additional physical strain by motorcycle gear

Being exposed to these factors may lead to the following negative impacts after a certain amount of time:

- decline in physical condition (bodily fatigue)
- decline in coordination (steering, banking)
- decline in concentration (mental fatigue)
- decline in alertness (environment, road traffic, street /road)
- decline in reaction
- increased accident risk

These are reasons enough to include environmental-comfort systems into assistance systems for motorized two-wheelers. Just as well as the fact that the sensory strain when riding a motorcycle is at least twice as high as when driving an automobile, which supports the importance of furnishing motorized two-wheelers with environmental-comfort systems. But what exactly are these?

"Environmental-comfort systems" means assistive equipment that eases the operation of motorized two-wheelers for the rider with regard to odour, light, vibration, noise and climate / weather conditions.

In addition, the "posture and handling comfort systems", which can be classified among the "ergonomic systems", play an important role.
In general, "ergonomics" is considered to be the science of the regularity of human work with the aim to improve the interaction of user and machine in order to reduce the strain for the user which results in a more efficient and safer operation.
The influence on the driving task is well recognized so that explanations that go more into detail are not necessary at this point.

Both systems, the "environmental-comfort systems" as well as the "posture and handling comfort systems" can be seen as included in the term "comfort assisting systems". Comfort in this context means rather a relief of strain and support of the rider and to a lesser extent the idea of pleasure or luxury. Following this allocation it becomes clear that with this in mind comfort systems should definitely be classified into the devices of assistance systems for powered two-wheelers. If there is a lack of comfort, this inevitably will lead to discomfort which leads to increased strain, going along with growing fatigue but also a decline in alertness. This is a circle with subsequent effects which is the reason why comfort systems indeed can be considered as supportive safety devices for motorized two-wheelers.
In a direct comparison with cars, the above mentioned systems are usually taken for granted in the equipment for automobiles.

Definition of "Advanced Rider Assistance Systems for Powered-Two-Wheelers (ARAS-PTW)"

As could be seen in the previous chapters there is no standardized definition for rider assistance systems. In order to meet the requirements of motorized two-wheelers and their specific features the study at hand shaped a new definition of assistance systems for powered two-wheelers.

The following definition refers solely to the vehicle level, thus to systems that can be allocated to the vehicle.

The differentiation was made deliberately, although a lot of equipment that improves the active safety for the riders do exist. The background for this decision is the reference to automobiles, for their drivers no special equipment is necessary.

Definition:

The term "Advanced Rider Assistance Systems for Powered Two-Wheelers (abbr. ARAS-PTW)" denotes equipment which supports and assists the operator of a powered two-wheeler and / or reduces the stress and strain for the rider.

It is a means of active safety (accident avoidance) but also influences accident results during a pre-crash-phase in a positive way.

An ARAS-PTW should be assigned to at least one of the three levels of rider tasks.

According to the above mentioned definition, rider assistance systems for motorized two-wheelers predominantly serve the purpose of *active safety*. This is the reason why systems such as e-call or those that reduce fuel consumption and thus emission or an electrical motor starter do not fit among ARAS-PTW.

One important feature according to the definition of ARAS-PTW above is that the physical strain for the rider can be reduced by the comfort assisting systems. This is why systems which have been taken for granted in automobile equipment [windshield, windshield wiper (if they existed for motorized two-wheelers), heating, etc.] for a long time already now do class among "rider assistance systems for powered two-wheelers".

Systems that call attention to the motorized two-wheeler and its unprotected and exposed rider (self-protection) by audible or optical means, do also fit among ARAS-PTW. Among them are vehicle-to-vehicle systems which at present, however, are still in the process of development.

Based on the already known classification of driver assistance systems, these will be enhanced by comfort assisting systems which can be subdivided into systems supporting the handling and posture comfort and the environmental comfort (see Figure 10).

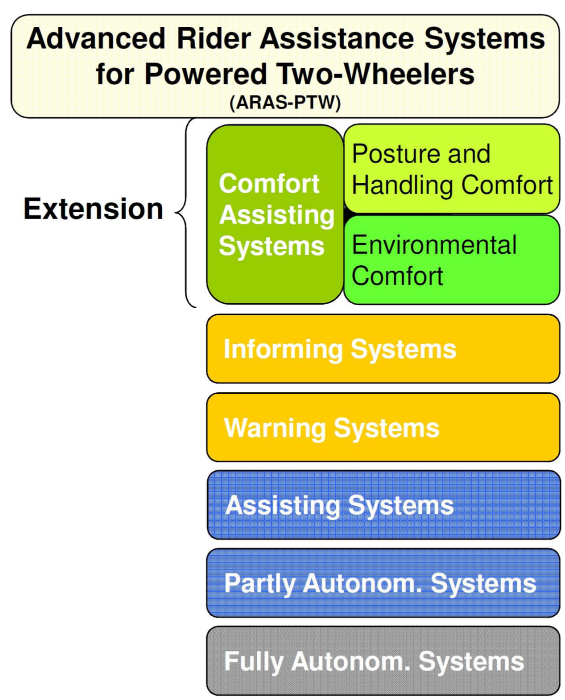

Figure 10: Classification of ARAS-PTW

Synopsis of present on-bike assistance systems for powered two-wheelers (as of 9/2010)

According to the definition and classification of rider assistance systems, the following elements can be listed as ARAS-PTW. Categories are classified according to their support of driving tasks. In order to avoid multiple entries, the boundaries between some systems are fluid.

Comfort assisting systems:

- Posture and handling comfort
  - Handling/Stabilization level
    - Gear Shift Assistance
      - Full automatic transmission (stepless too)
      - Half automatic transmission
      - Dual-Clutch
      - Quickshifter (1)
    - Reverse Gear (2)
    - Electro-hydraulic main stand (2)
    - Automatic turn signal off-switch (3)
    - Radial brake master cylinder (4)
    - Adjustable seat
    - Adjustable handlebars
    - Adjustable footrests
    - Adjustable levers
- Environmental comfort
  - Guidance level
    - Xenon headlight
    - Adaptive cornering light
  - Handling/Stabilization level
    - Adjustable chassis
      - Spring pre-load adjustable
      - Adjustable damping
      - Leveling systems
    - Electronically adjustable chassis
      - "ESA", "DES; Spring pre-load and damping adjustable
    - Wind/Airflow/Weather protection
      - Fairing
      - Mechanically/electronically adjustable windshield
    - Heated grips
    - Heated seat
    - Any other heating or cooling system

Informing systems:

- Navigation level
  - Radio with traffic service
  - GPS
- Guidance level
  - Fuel gauge
- Handling/Stabilization level
  - Neutral indicator light (gear) (5)
  - Gear display (6)
  - Shift timing indicator light (7)

Warning systems:

- Guidance level
  - Fuel reserve (8)
  - Ambient air temperature (ice warning)
  - Brake pad wear indicator
  - Tyre pressure control
  - Daytime running light (9)
  - Hazard warning light (10)

Assisting systems:

- ---

Partly autonomous systems:

- Handling/Stabilization level
  - Cruise control
  - Hill start assist (11)

Fully autonomous systems:

- Handling/Stabilization level
  - Integral (combined) braking systems
    - Single- / Dual-
    - Mechanic/electronic brake balance
    - Adaptive brake balance
  - ABS
    - Integral ABS (Single- / Dual-)
    - "Brake-by-wire" C-ABS
  - Real-Wheel Lift-Off Protection
  - Brake booster
  - Traction control
  - Wheelie protection
  - Mapping

- Drive mode switch
- Slipper clutch (Anti-hopping)
- Electronic steering damper
- Side stand switch (12)

(This list is not intended to be exhaustive.)

Annotations:
(1) Quickshifters prevent fatigue of the hand that holds the clutch and induce reduced carriage strokes while shifting the gears.

(2) In contrast to two-track vehicles, heavy one-track vehicles are difficult to park and manoeuvre and need a high amount of physical exertion. This is why a reverse gear as well as an electro-hydraulic main stand provide safety and prevent the vehicle from toppling over.

(3) The automatic turn signal off -switch ensures a turning-off of the indicator and thus prevents unintentional indicating after having turned (which in fact happens quite often). Not to switch off the signals can lead to dangerous situations with other road traffic users, as they get wrong information.

(4) The radial brake master cylinder fit to motorcycles that are not equipped with ABS offers a much better pressure point compared to common systems which reduces the probability of overbraking the front wheel.

(5) The neutral indicator light (gear) is very helpful when operating a motorized two-wheeler because of the sequential gearbox.

(6) Due to the sequential gearbox the rider never knows exactly whether he/she is riding in top gear already. This is why there is often "void" shifting of gears which would be obsolete in case of gear displays.

(7) Although the shift timing indicator light originally comes from racing, it can be useful for riders in road traffic as well. The reason for this is that the necessary look at the revcounter is no longer necessary and thus the concentration is focused at 100% on the road and the road traffic.

(8) Since the introduction of displays for fuel reserves, the manual opening of the fuel tap has become unnecessary. In the past this sometimes led to dangerous situations, for example when opening the tap during an overtaking manoeuvre.

(9) Daytime running lights are a form of self-protection by warning others or catching other road users' attention that a motorcycle is approaching.

(10) Hazard warning lights are important for the self-protection of motorcycle riders, for example in order to warn other road users at the tail end of traffic jams; thus they won't be unnoticed and hit by the next vehicle.

(11) Up to now motorcycles have not been equipped with hill start assist systems. In order to use this device, integral braking systems will be necessary.

(12) A side stand switch indeed is a true rider assistance system as it indicates the position of the side stand and allows a start-up only when the stand has been retracted. In addition, a spring fracture would be recognized immediately during the trip which would lead to an immediate cut off of the ignition. Without this safety device a lot of accidents happened in former times.

Summary & conclusion

A survey carried out by ifz on the topic of advanced driver assistance systems revealed that male and female motorcycle riders lack the knowledge of driver assistance systems.

The subsequent research in literature definitions of driver assistance systems clearly showed that on one hand there are a lot of very different definitions, and on the other there is none which meets the requirements of motorized two-wheelers. The reason for this fact is relatively simple: The term "driver

assistance systems" originates from the field of automobiles.
This is why – taking into consideration the specific requirements of motorized two-wheelers – the well-known classification of advanced driver assistance systems was enhanced and a new definition of advanced rider assistance systems for motorcycle riders was developed (ARAS-PTW). This definition is intended to provide a more direct classification of systems as well as a generally accepted labeling.

The definition derives with reference to the three levels of driving tasks as well as requirements specific to two-wheelers which have become particularly clear in the so-called "pyramid of convenience".

The study ends with a list of ARAS-PTW which have already been in existence for some time.

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