DEVELOPMENT PLAN FOR ASSESSMENT TECHNOLOGY OF ADVANCED SAFETY VEHICLE

Jae-Wan LEE
Gyu-Hyun KIM
Korea Automobile Testing and Research Institute
Korea
Byeong-Kee HAN
Hongik University
Korea
Yun-Yeong JO
Ministry of Land, Transport and Maritime Affairs
Korea
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ABSTRACT

Although an automobile is a necessity and a convenience in the modern era, traffic accidents take a great toll on the society, both economically and socially. Korea has the unenviable record being one of the highest traffic accidents and fatality rates. In 2009, there were 5,838 fatalities on the roads. A new and systematic approach to safety policy development is necessary to reduce traffic casualties.

The goal of this research is the development of advanced safety vehicles and relevant assessment technologies. The results will make a contribution to Korea's national goal of "Reducing Traffic Casualties by Half." There are four objectives in this research; the first objective is to develop technology that can reduce casualties in vehicle accidents, the second one is to establish advanced safety standards, the third one is to develop assessment technology for safety features integrated with information technology and the last one is to support the establishment of policies that can stimulate the commercialization and market penetration of these vehicles. The development plan was established with following criteria, such as the economic feasibility, safety enhancement, timeliness and redundancy under the above goal.

The research priorities were set after many elements were taken into consideration, such as target population to be protected, fatality reduction effects, technical feasibility and prospects. The planned timeline spans 7 years and 9 months, from December 2009 through September 2017 [1]. The research is divided into three stages; to reflect market variations and other development that cannot be foreseen at this moment the latter two stages will be finalized in the final year of the 1st stage which will end in 2012. The research subjects in the Stage 1 are as follow; vehicle compatibility, speed-sensitive active head restraint, commercial vehicle automatic emergency brake system, lane departure warning system, blind spot warning system, adaptive front light system and emergency rescue system.

The results of this research will eventually lead to the standardization, establishment of laws/regulations, safety criteria and vehicle safety ratings. This research could be used as resources the development of global technical regulations in UN/ECE/WP.29. It is hoped that this project will stimulate the growth of advanced safety vehicle market and have a synergy effect with the integration of the latest information technology. This project was supported by the Ministry of Land, Transport and Maritime Affairs of the Republic of Korea. Eleven research institutes, including the Korea Automobile Testing and Research Institute, Hyundai Motor Company and Seoul National University take part in this project.

BACKGROUND

The damages caused by car accidents, not only injure people and their finances, but are also very detrimental to society at large; in order for a country to join the ranks of the most industrialized nations, car accidents should be dealt with as an issue at the social level. The "Accident Free Driving" vision has been established in all the leading industrialized countries and various policies and cutting edge auto technology have been put in place over the past 10 years to reduce the number of casualties. For example, in the past 10 years, the U.S. has set a reduction of 30% in casualties as their stated goal, as have the EU with a 50% reduction target and Japan, also slated for 50%.

While the necessity to create vehicles with advanced safety features to reduce the number of casualties through the convergence of intelligent technologies is currently being proposed, a new assessment method for advanced safety devices for automobiles should be developed to test the latest technology, thereby reducing the negative effects to boost Korea's entry into the high-tech safety market.

Although improvements in auto safety, road infrastructure and driver education are needed in order to successfully reduce accidents, the development of assessment technology for advanced safety vehicles is necessary for better auto safety standards. Thus, the characteristics of accidents both in Korea and overseas need to be examined first. Then, it is necessary to discover the technology that can drastically reduce accidents based on this examination, allowing us to come up with detailed measures to commercialize the new technology.

By integrating safety with IT, a field Korea excels in, and an advanced safety vehicle that can greatly contribute to the government's aspiration to "Reduce Traffic Casualties by Half" should be developed. Accordingly, an assessment method for testing vehicles with advanced safety features should be organized and developed. The two developments could synergistically create new jobs and accelerate entry into the market for this new technology. The movement to establish an international set of standards for automobiles has been moving forward lately. Moreover, as one of the leading car manufacturing countries, Korea should conduct basic research to have an active voice in UN/ECE/WP.29 ECE Regulations and Global Technical Regulation (GTR).

ANALYSIS OF VEHICLE ACCIDENTS

Vehicle Accidents Data

According to 2007 figures, the number of traffic accidents per 100,000 people in major Organization for Economic Co-operation and Development (OECD) countries are 651.5 for Japan, 580.5 for the U.S., 436.8 for Korea, 407.6 for Germany, 308.5 for the UK and 132.1 for France (Figure 1). The trend between 1990 and 2006 for the same figure has been drifting downward on an overall basis, but the rate of traffic accidents for the U.S. has had the biggest reduction. This is a surprising finding, since the U.S. has the lowest dependence on public transportation and thus has a concomitant high car accident rate. Japan's figure was on the rise until 2000, but it has recently been decreasing mainly due to the increased ratio of elderly people.

The number of deaths from car accidents per 100,000 people is: 13.7 for the U.S., 12.7 for Korea, 7.5 for France, 6.0 for Germany, 5.2 for Japan, 5.0 for the UK and 5.1 for Switzerland. The OECD average is 9.1 deaths. Although the number of auto accidents per 100,000 in Korea is lower than in Japan or the U.S., the number of deaths from these accidents in Korea is double the Japanese figure and slightly lower than those for Americans. While the UK has a similar population density with Korea, the figures for fatal car accidents are far lower, which is an indication of advanced accident prevention measures; the low figures for France and Germany, where high-speed driving is common, are noteworthy (Figure 2) [2],[3].

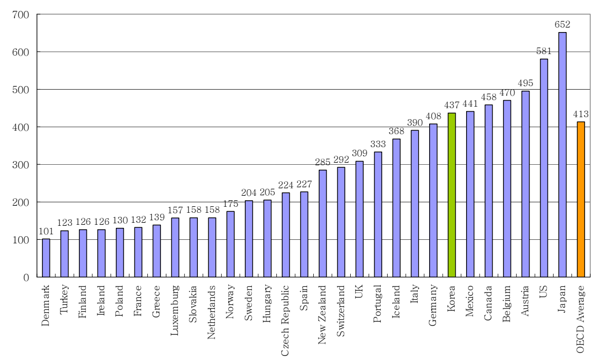

Figure 1. Number of Traffic Accidents per 100,000 People (OECD) [2],[3].

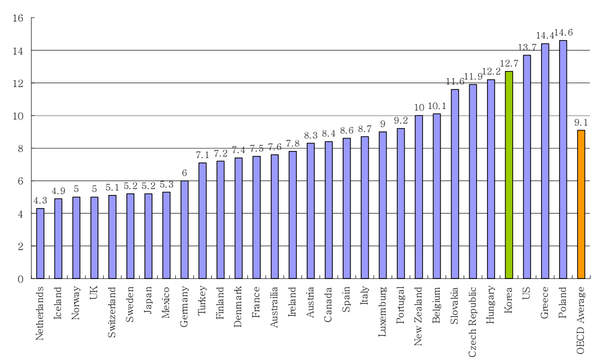

Figure 2. Number of Death from Car Accidents per 100,000 People (OECD) [2],[3].

Vehicle Accidents in EU 15

Road fatalities per 1 billion vehicle-km for Korea are about double the OECD average; compared to the UK, which has the lowest such figure, Korea has 3 times the number of fatalities. Road fatalities are too high relative to the number of accidents and hint at the gravity of the levels of fatal accidents on the road. Road fatalities of children under 14 per 100,000 people are 2.3 for Korea, 2.8 for the U.S., 0.9 for the UK, 1.0 for Germany, 0.8 for Japan. The OECD average is 2.1 children and Korea's figure is nearly 2 times as high compared to the others. The Korea's pedestrian death rate is much higher than any industrialized nation at 37.4%. Poland follows with a 34.9% rate. This is because the number of vehicle-to-people accidents is relatively higher.

Single vehicle accidents cause the highest death toll in absolute numbers and are accountable for more than one third of all fatalities. About 5% of all single vehicle accidents result in the death of an occupant, significantly more than the 3.4% average for all collision types. Pedestrians are also at a higher risk during a crash. Crashes at crossings or during turning bear a relatively low risk and result in a death in less than 2% of all collisions of this type. Similarly, rear-end collisions rarely cause fatalities and only account for 6% of all deaths, significantly less than their 15% share in the total accident number (Figure 3).

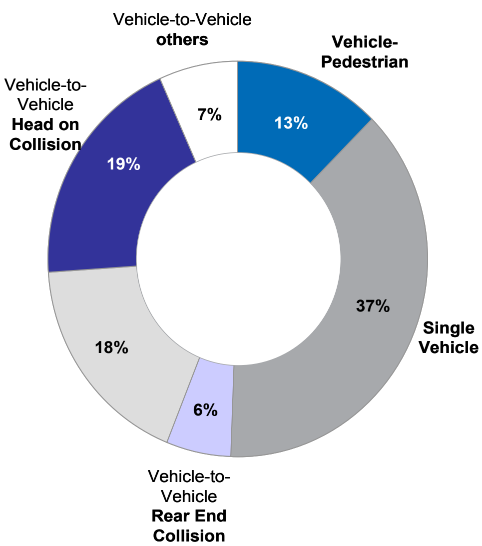

Figure 3. Number of Fatalities by Collision Type in EU15 [1].

Vehicle Accidents in Korea

Fatal crashes have been reducing over the past few years, but the rate of reduction itself has been at a relative standstill lately. In addition, the number of people injured from crashes has been increasing in investigations conducted by insurance companies, but the same figure has stayed the same according to police records. In 2007, there were 6,166 fatalities on the road; but the government reports 340,000 injured people, while insurance company reports 1.2 million injured (Figure 4).

Pedestrian accidents cause the highest death toll in absolute numbers and are accountable for 36.2% of all fatalities. Crashes at crossings or during turning bear a relatively high risk. Single vehicle accidents are also at a higher risk during a crash. Rear-end collisions are account for 11.8% of all deaths. Head-on collisions are comparatively rare and account for 8.7% of all deaths (Figure 5).

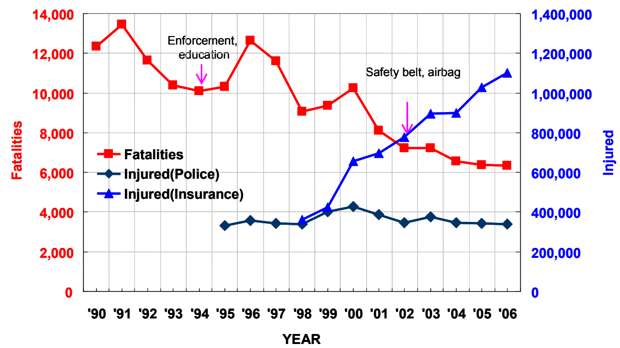

Figure 4. Trend of Accident Casualties in Korea [2].

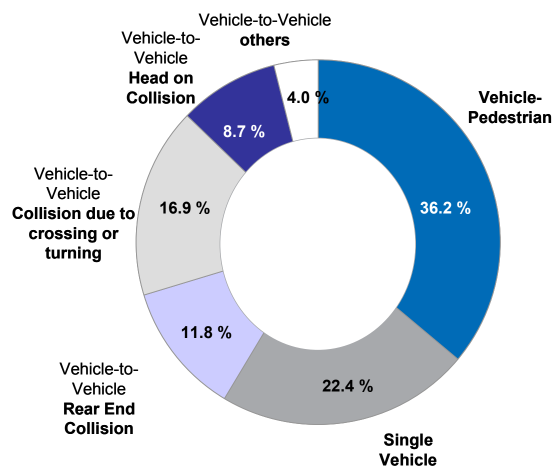

Figure 5. Number of Fatalities by Collision Type in Korea [1],[2].

With the increase in the number of Sport Utility Vehicles and Recreational Vehicles, the ratio of compact cars per SUV+RV has been increasing as well: from 0.08 in the late 1990s to 0.68 in mid-2000's. This also suggests the need to secure vehicle-to-vehicle safety measures as well. The highest number of deaths occurs for side impact, rear-ending and head-on collisions respectively, while the number of pedestrian deaths still make up a high percentage at 40. Also, as night activities are on the rise, the number of nighttime fatal crashes is also increasing. Although intersections take up only a small percentage of the entire road, accidents occur most frequently at intersections (44%) due to the concentration of traffic in urban centers. There are fewer fatalities at the site of the accident (1,488 people) compared to deaths while in treatment (2,443 people), which demonstrates the need for prompt after-care. As for injuries from crashes, cervical (46%) and lumbar (29%) spine injuries from vehicle-to-vehicle rear-end collisions are occurring at an alarming rate. This calls to attention the importance of reducing neck injuries from rear impacts.

TECHNOLOGICAL ADVANCES

So far, advances in collision safety devices, such as seatbelts, airbags, improvements in the frame and ABS (Anti-lock Braking System) have greatly helped to reduce the number of casualties in traffic accidents. The focus of new research is on preventative safety devices like driver assistant functions and on reducing or avoiding the collision in case of an accident. At present, safety integrated with IT is advancing at an exponential rate and developed countries are on the verge of commercializing the new technology based on rather extensive research.

Many countries are coming up with policies and other ways to increase their overall safety levels, such as putting together databases on accidents and injuries, to help determine the cause and device response measures to reduce casualties in traffic crashes. By applying advanced safety technology in the development process, cars are now lighter and could alleviate traffic congestion, even potentially reducing exhaust and greenhouse gases (CO2).

The adaptive front lamp system, Adaptive Cruise Control (ACC), blind spot detection systems and other functions can help the driver in normal driving conditions. The ACC uses a laser mounted on the radiator grill that can detect the distance from the car ahead, so that a safe buffer distance can be maintained. In case of a problem while driving, the ABS and the ESC can keep the vehicle stable. The ESC reduces or controls the momentum of the vehicle if the wheels lose bearing power or the chassis is unstable.

Functions to alarm the driver include the Tire-Pressure Monitoring System (TPMS), Lane Departure Warning System (LDWS) and the Lane Keeping System (LKS). Functions that can avoid collision or reduce the impact, as well as the Automatic Emergency Braking System (AEBS) have increased driver safety by enhancing safety and convenience. Research on the Human Machine Interface (HMI), which can equip the driver with information for convenience and safety, is being actively carried out in leading industrialized countries.

Recently, the power of IT has been added to all this and cars can now play the role of moving offices. The biggest characteristic of an advanced safety vehicle technology is that it prevents accidents or reduces injuries by reducing the collision speed. The effects of advanced safety features are also great, as an 18% reduction in accidents was reported for AEBS and 12% for LDWS [5]. To meet consumers' expectations who seek proactive safety and convenience, vehicles with electronic and IT integrated safety features are rapidly being developed. Vehicle-to-vehicle information exchange (infrastructure needed) systems are currently being developed so that data could be exchanged via satellite or a nearby network to prevent accidents.

As such, vehicles have advanced to the point that they can detect dangers on the road and are becoming intelligent enough to control themselves. However, this is only possible as long as the sensors and various high-tech devices on the vehicle are properly functioning. If they were to malfunction, smart vehicles could be at even greater risks on the road than conventional ones. Safety standards for AEBS and LDWS are currently being drafted in the U.S., Europe and UN/ECE/WP.29 and discussions on diverse safety features will gain momentum in the future.

RESEARCH OBJECTIVES AND TOPICS

Research Objectives

The vision of this research is to make a contribution to Korea's national goal of "Reducing Traffic Casualties by Half" through the development of advanced safety vehicles and relevant assessment technologies. The objective of the research is to develop technology that can reduce casualties in car accidents, to establish advanced safety standards, to develop assessment technology for safety features integrated with IT and prepare policies that can stimulate market penetration and practical uses for these vehicles. The development plan proposed here is based on the above vision and on such objective criteria as the economy, safety, timeliness and redundancy.

Research Topics

Mitigation of Casualties

- Vehicle compatibility

- Speed-sensitive active head restraint to protect neck injuries in rear-end collisions
- Protecting passengers in rollover accidents
- Injury criteria database
- Protecting pedestrians and bicycle riders through active hood and bumper technology

Improved Active Safety Technology

- Passenger vehicle ACC
- Commercial vehicle AEBS
- Lane Departure Warning System
- Blind Spot Warning System
- Adaptive Front Lamp System
- Passenger vehicle AEBS
- Commercial vehicle ACC
- Lane Keeping System
- Detecting pedestrians at nighttime
- Human factor for active safety

Safety Integrated with IT

- Emergency rescue
- V2X Infrastructure communication
- Intersection based on V2I communication
- Stability of integrated electromagnetic compatibility
- V2X control system

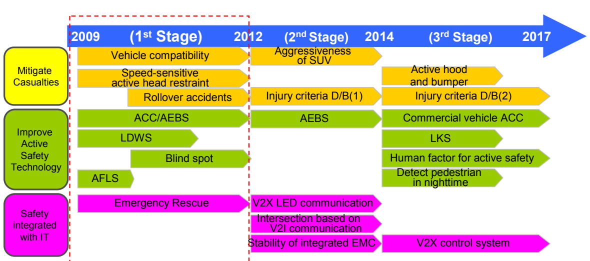

Figure 6. Development Plan for Assessment Technologies of Advanced Safety Vehicle.

The selected research priority took many elements into account, factoring in target population, reduction effects for number of fatalities, potential, concreteness and prospects. About 11 research institutes will participate, including the Korea Automobile Testing and Research Institute, Hyundai Motor Company and Seoul National University. The planned timeline spans 7 years and 9 months, from December 2009 through September 2017. The estimated budget is at 20.6 billion KRW (18 million US$). The research will be divided into stages 1, 2 and 3; the latter two stages will be planned in the future, after 3 years into stage 1, to reflect market variations and other situations that cannot be foreseen at the moment (Figure 6).

Research Stage 1

The details of Stage 1 of the research, which runs from December 2009 to September 2012, are as follow.

Mitigation of Casualties

- Vehicle compatibility: compatibility enhancement measures for frontal/side collisions between a passenger vehicle and an SUV/RV
- Speed-sensitive active head restraint: preventative measure for neck injuries in rear-end collisions
- Protecting passengers in rollover accidents: minimize injuries to passengers due to roof crush in rollover accidents by finding design constraints of roof

Improved Active Safety Technology

- Passenger vehicle ACC: support the driver to take on some of the driver's responsibility
- Commercial vehicle AEBS: enhance driving safety of commercial vehicles
- Lane departure warning system: prevent accidents by alarming the driver when the vehicle moves out of the lane due to drowsiness or inattentiveness
- Blind Spot Warning System: detect obstructions in blind spots and notifies the driver to prevent accidents
- Adaptive Front Lamp System: control the lower beam depending on speed and adapt to highway driving

Safety Integrated with IT

- Emergency rescue: in case of an accident, automatically sends information on location and time of accident, vehicle data, and passenger's vital signs to allow for rapid emergency rescue response

CONCLUSIONS

Developing assessment technology for advanced safety vehicles that can contribute to the agenda of Korean government to "Reduce Traffic Casualties by Half" will not only reduce accidents in Korea but also enhance automobile technology in the future. Furthermore, lower numbers for traffic crash casualties can be expected with AEBS (18%) and LDWS (12%) technologies. This research could be used as basic material for the enactment of WP.29 global technical regulations stimulate the growth of advanced safety vehicle markets and have a synergistic effect with the integration of the latest IT technology.

The results of this research could also contribute to the founding of a new traffic environment with the expertise that affect real life, with standardization, enactment/amendment of laws/regulations, safety criteria and car safety ratings. By putting together a comprehensive body injury database, the results of the accident analysis could be used as basic material for the development of advanced safety vehicles and assessment technologies. Finally, an enhanced national image from the drastic reduction of auto accidents and road fatalities can also be expected.

ACKNOWLEDGEMENTS

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REFERENCES

[1] B.K. Han, Y.J. Jeong and J.W. Lee, Report of Development Plan for assessment technology of advanced safety vehicle, Korea Ministry of Land, Transport and Maritime Affairs, Gwacheon city, September 2009

[2] IRTAD http://cemt.org/IRTAD/Irtad_Database.aspx, 2009.10

[3] OECD Statistics http://www.oecd.org/statsportal/0,3352,en_2825_293564_1_1_1_1_1,00.html,2009.10.

[4] Traffic accident analysis center, Road traffic accidents in Korea, Road Traffic Authority, Seoul city, 2008

[5] An Introduction to the New Vehicle Safety Regulation, http://www.unece.org/trans/doc/2008/wp29/WP29-145-08e.pdf

LDWS PERFORMANCE STUDY BASED ON HUMAN FACTORS

Hong Guk, Lee
Kyung Hee University
Republic of Korea
Hwan Seo, Park
Kyung Hee University
Republic of Korea
Song Min, Yoo
Kyung Hee University
Republic of Korea
Paper Number 11-0147

ABSTRACT

In order to reduce the fatality of traffic accident up to 50%, various tools are being developed for safer operation of vehicles on the road. Serious portion of accidents are believed to be the result of driving across the lane due to either negligence or drowsiness of the driver. As a prior step to lane keeping system (LKS) which enforces a vehicle to run within its current lane, lane departure warning system (LDWS) is developed to warn a driver before it moves over to next lane unintentionally and is being widely installed by a vehicle manufacturer or sold as an aftermarket product. Even though LDWS is believed to prevent accident and reduce fatalities by 25% and 15% respectively, its effectiveness in performance is yet to be confirmed in many aspects.
LDWS is designed to issue a warning within the tolerance limits defined on both side of the lane boundary so that the driver would take evasive maneuver back to original lane securing a safe gap against vehicles moving in the adjacent lane. Since the driver may not perceive and respond properly due to human delay in recognition and in response, the warning may not be triggered early enough.
In this study, the vehicle lateral locations relative to warning zone envelop (earliest and latest warning zone defined in International Organization for Standardization (ISO) standard, Economic Commission for Europe (ECE) and National Highway Traffic Safety Administration (NHTSA) regulations) are compared with respect to various factors including delays, vehicle velocity, vehicle heading angle with respect to the lane.
Since LDWS is designed to be activated at the velocity over 60 km/h, vehicle velocity range for the study is set to be from 60 to 100 km/h.
The vehicle heading angle (yaw angle) is set to be up to 5 degree away from the lane (abrupt lane change) considering standard for lane change test using double lane-change test specification.
There are no solid guideline for human perception and response delay for imminent accident. Tentative delay up to 2.0 second is found from emergency braking case study for accident perception while 0.54 to 0.73 second range actuation delay is necessary.
Even though further study may follow as for the assessment for human delays in more systematic approach, preliminary study still suggests that LDWS might not be sufficient enough to issue a proper warning for drivers. Thorough knowledge of human factors to the system is needed in order to understand the limit of LDWS and to facilitate the technology like LKS.

INTRODUCTION

The most of vehicle accident occurs due to carelessness of driver. Therefore, concept of active safety technologies to perform evasive action prior to hazardous environment different from passive safety technologies that lessen the aftermath of the crash is being developed aiming at reducing traffic accidents and ensuring the safety of vehicle. The earlier version of active safety technology as ADAS(Advanced Driving Assistance Systems) facilitating the minimal safety tactics eliminating unsafe factors has been introduced with the aids of sensors to improve safety and convenience of the vehicle driving environment. Gradually, the proportion of these support devices is expected to increase. Among various ADAS, the readily developed ones which can effectively prevent vehicle accidents are being actively commercialized and corresponding regulations and standards are widely discussed. These systems can be categorized with the longitudinal and the lateral control system depending on the orientation of the control activity applied to the corresponding vehicle maneuvering[1].

Longitudinal control system includes Adaptive Cruse Control (ACC), Advanced Emergency Brake Systems (AEBS) and Front Collision Warning System (FCWS). The systems which assist the lateral control of the vehicle are Lane Departure Warning System (LDWS) and Lane Keeping Assist System (LKAS). LDWS is designed to detect the unintentional lane departure possibly from drowsiness or inadvertently leaving the lane while driving and alert the driver through various ways including alarming. LDWS currently is being installed in commercial vehicles and its convenience in use and effectiveness in alerting driver against possible danger due to monotonous driving environment is reported. In addition, there have been many discussions on international standards leading to the finalized agreement[2].

In the process of ensuring the product quality and enhancing the performance of the controller, more thorough studies were made in the perspective of various factors affecting the outcome of the system including roadway environment, hardware specification and driver characteristics. In recent studies, the human factors in ADAS warning system such as LDWS or ACC were the most actively discussed ones which could alter the performance of the system[3].

Thiffault and Bergeron studied steering behavior data on the monotony road environment using the simulator[4]. The analysis result shows that as the driver's fatigue level increases the steering angles become large (from 6 to 10°) and extreme (more than 10°) values.

Sleepiness ratings and reaction time increase along with driving time. The research on driver fatigue on highway driving using simulator[5].

Suzuki studied changes of the vehicle driver's steering behavior depending on 4 types of lane-departure warning system when vehicles depart from lane using a driving simulator[6]. As for the form of warning, if the driver has the prior knowledge of the warning, the sound beep was more effective in reducing the response time compared to that with other types of warning. However, without the prior information given to the driver against the upcoming warning, the alert delivered through the vibration with the steering wheel was most effective.

Type of the lane departure warning is classified as early and last warning. The first or early warning is given when the vehicle is confronting the first stage of entering the lane departure mode which could be developed into the accrual crash of the vehicle with the one move in the adjacent lane. The last warning is occurred when the vehicle is still in a dangerous situation after the early warning possibly from the driver negligence against the first warning. The visual type of warning aid provide as the first warning signal is not effective enough and often triggers more second or last warning delivered in the more alarming type of signal as beep. In comparing the performance between a visual and an auditory warning method, the auditory warning appears be better compared to the visual warnings in terms of maximum deviation distance and recovery time[7].

In determining the performance of the vehicle active safety system, the reaction time is found to the most importance factor. The reaction time, often referred as response delay is defined to be the lapse until it takes to the driver to recognize objects and perform appropriate actuation against the detected situation. It becomes the crucial criteria in deciding how fast the driver recognizes and reacts to the given incidents. Reaction time varies depending on individual characteristics and the way situation is perceived. In addition, the reaction time can be reduced through the driver's prior knowledge or alertness of the upcoming danger. The driver's react time in ACC and LDWS appears to be different depending on various aspects like alert type, alert methods, driver control actions and the surrounding environment during driving.

In order to find the effect of preventing accidents in US, the field test was performed to analyze a reduction in accidents rate during 10,000 miles driving on each cargo vehicle. As a result, LDWS equipped vehicle showed better enhanced results with reduction rate of 25% in vehicle accidents and 15% in accident severity[8].

Unlike field test research, few results were found in simulating the effectiveness of active safety system since it is difficult to determine the key factors altering the performance of the system especially human induced parameters like response delay. In the process of estimating the human factors, it is hardly possible to observe human reaction since it is difficult to construct similar situation with actual driving environment without informing the driver against the test environment. If the driver acknowledge the empirical environment, it is difficult to induce natural lane departure situation from the driver's drowses or unknown mistakes and identify to source of the lane departure.

In this study, the reaction time among human factors will be considered for the simulation. It is also studied to confirm how reaction time affects accident probability after LDWS alert is triggered. A single reaction time is assessed to estimate the possibility leading to the catastrophe. Distributed reaction time with Gaussian distribution is introduced to facilitate the variation of the actual driver.

LANE DEPARTURE WARNING SYSTEM (LDWS)

LDWS consists of sensing module detecting lanes and additional portion determining the vehicle location with respect to relevant lanes, warning function to the driver if necessary, visual aid to be displayed in front of the driver (Figure 1)[9]. LDWS takes images of traveling direction using camera, recognizes current lane and determines the location of vehicles on the road. Considering the velocity of a moving vehicle and vehicle departure angle, LDWS determines whether the vehicle leaves off the lane and endangers adjacent vehicles. Various types of alarming method are executed to deliver the imminent environment effectively to the driver.

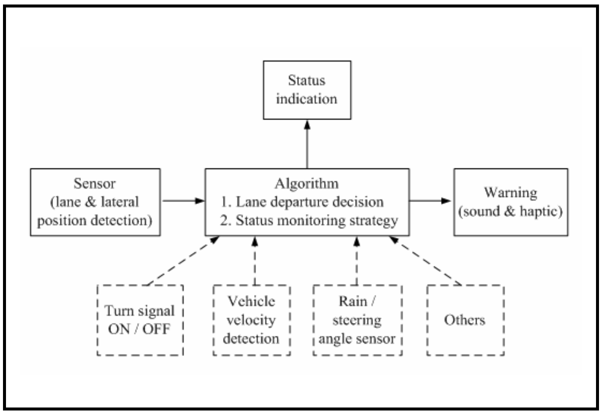


Figure 1. Functional elements of LDWS

SIMULATION

Simulation Factors

Assumption Following assumptions are introduced for the simulation:

1) Roadway is 3.5 m-wide two-lane straight road
2) No malfunction in LDWS device operation
3) Both the subject vehicle in the current lane and the target one in the adjacent lane run in the same velocity
4) Both vehicles are commercially operated ones

In order to simulate the accident due to the inadvertent lane change along with the vehicle running in the lane next, two lane roadways are necessary. The assumption of commercially operated vehicle might play better role in the curvature road.

Selection of factors Key parameters used for LDWS simulation to evaluate its benefit in terms of reducing traffic accident are as follows:

1) The vehicle velocity range is 60~100 km/h.
2) Yaw angle range involved in the lane departure of the subject vehicle is 1~10 degrees.
3) The reaction time is between 0.38 and 1.5 seconds.

Since the operating range of the most LDWS device is 60-100 km/h, same velocity condition is selected in the simulation. In simulating lane departure involved accident, fictitious vehicle as target one is assumed to exist in the adjacent lane.
The vehicle yaw angle is 1~5 degree for mild lane departure while that would be extended up to 10 degrees in the abrupt change[10]. Human reaction delay includes time it would take to perceive the imminent danger from the warning alarm and actuate the steering wheel in order to maneuver back to the original lane. This type of delay range is found to be between 0.38 and 1.5 seconds.

Simulation Procedures

The subject vehicle leaves the current line due to drowsiness or inattention. LDWS detect the lane departure and warning is issued. The hardware delay is neglected. The driver recognizes the warning and turns the steering wheel back towards to original driving lane after the designated response delay. The subject vehicle's maneuvering distance (lateral distance) from the initial location which is the middle of two lane boundary until the last position where it returns would be calculated. Either the leftmost or the rightmost location of the subject vehicle would decide the collision between the subject vehicle and the target one. Depending on the level of delay, the subject vehicle might be exposed to accident with the target vehicle or safely return to the initial lane. The reaction time of driver is different depending on various conditions (driver's age, driving conditions, environmental conditions, etc.).

The human reaction delay is the most difficult and uncertain factor to apply. A fixed value and distributed ones with Gaussian distribution are assumed for the simulation. The simulation process calculated the lateral distance using factors including reaction time with a Gaussian distribution and yaw angle. Three exclusive zones as safe, transient and accident zone are defined depending on the vehicle's last location in the roadway relative to each lane before it moves back to its original position (Figure 2). The transient zone is introduced since the subject vehicle might impose threat to the target vehicle's operation due to close distance in between even though there would not be any accident.

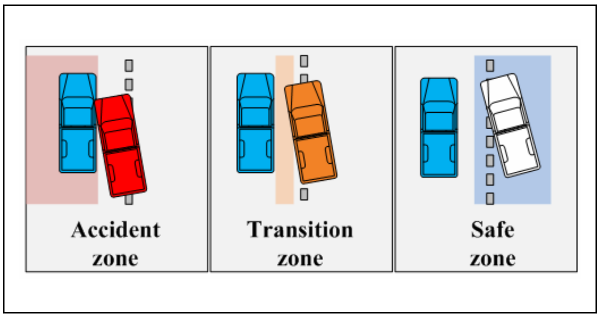


Figure 2. Schematic diagram of three zones

RESULTS

Figure 3 shows the yaw angle defining three characteristic zones for specific fixed reaction delay of 0.38 second with respect to vehicle velocity variation. The upper boundary separates accident zone from transient one while the lower one

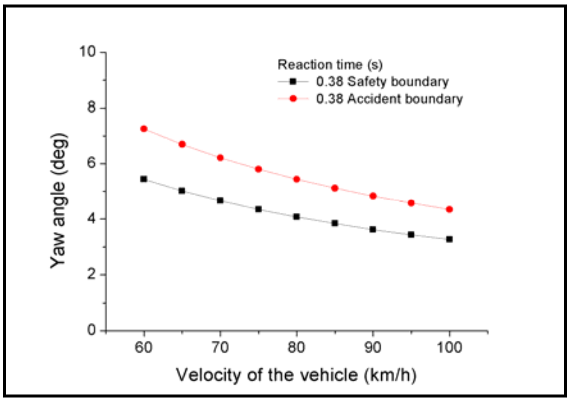


Figure 3. Yaw angle for three zones (reaction delay of 0.38 second)

classifies transient zone from the safe one. As the vehicle runs faster, it reaches easily to transient and accident zone.

Figure 4 shows yaw angle boundaries among three zones revealing for various driver's reaction time. As the reaction delay becomes larger accident zone increases. Generally, the yaw angle is inversely proportional to the vehicle velocity. The slope gets steeper for smaller reaction time, thereby the yaw angle variation becomes insensitive for larger reaction delay.

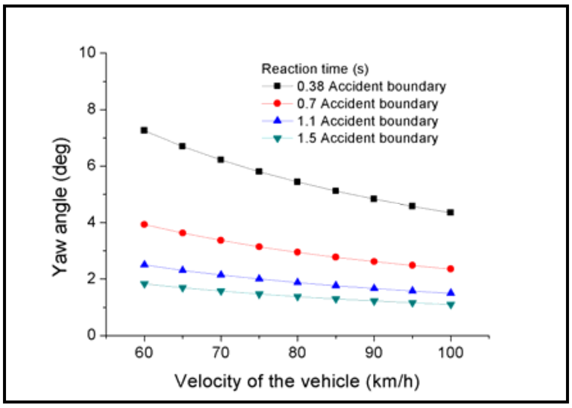
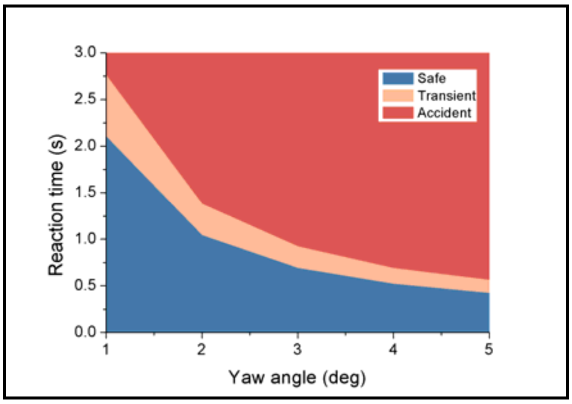


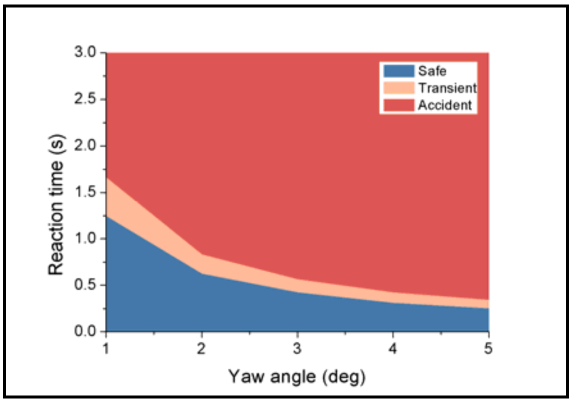
Figure 4. Accident zone variation for reaction time

Figure 5 compares boundaries of three zones for two different vehicle velocities. As velocity becomes higher accident zone increases.

Figures 6 and 7 show collaborated comparisons and trends displayed for various velocity and delay times. Similar trends are observed as in previous figures.



(a) Velocity of the vehicle : 60 km/h



(b) Velocity of the vehicle : 100 km/h

Figure 5. Boundary comparison(V=60, 100 km/h)

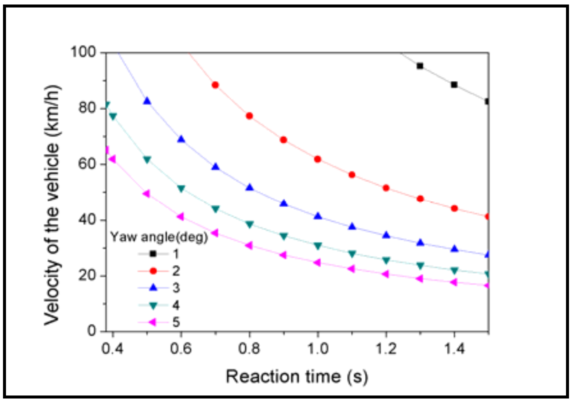


Figure 6. Safety boundary trend

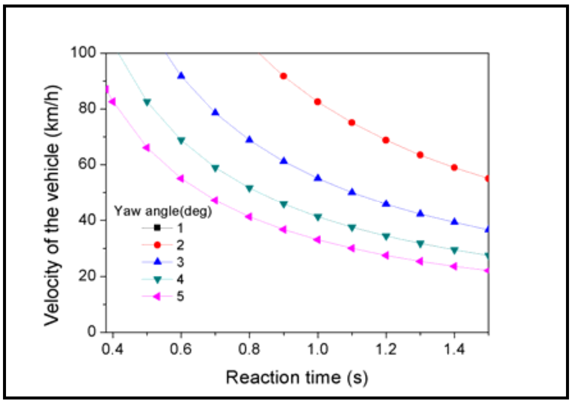
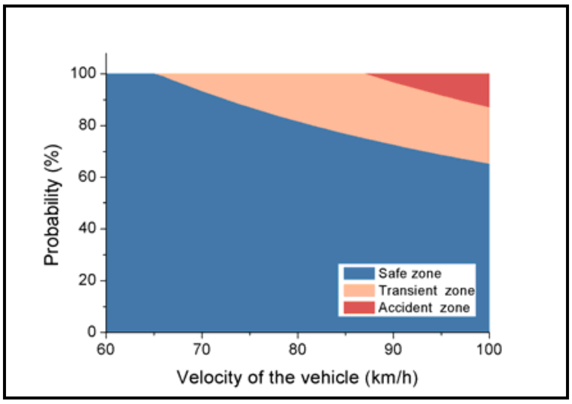
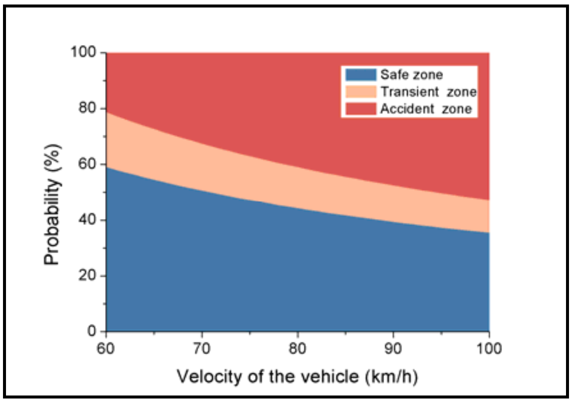


Figure 7. Accident boundary trend

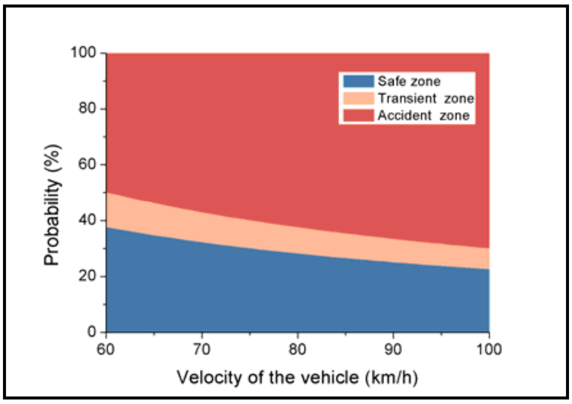
Figure 8 shows the probability of vehicle reaching three zones as safe, transient and accident region accounted for yaw angles ranging from 1 to 5 degrees as mild lane change. As the reaction delay increases, safe and transient zones decrease along with their decreasing rate trend.



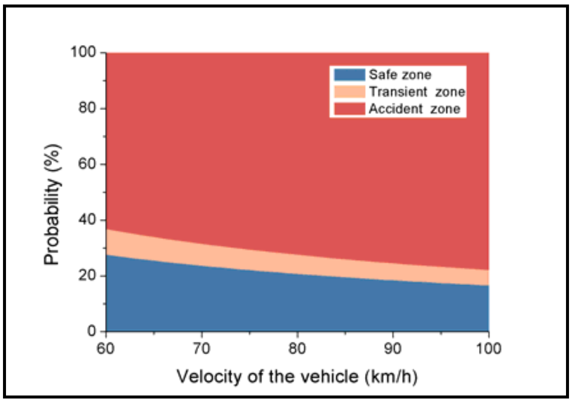
(a) Reaction time : 0.38 second



(b) Reaction time : 0.7 second



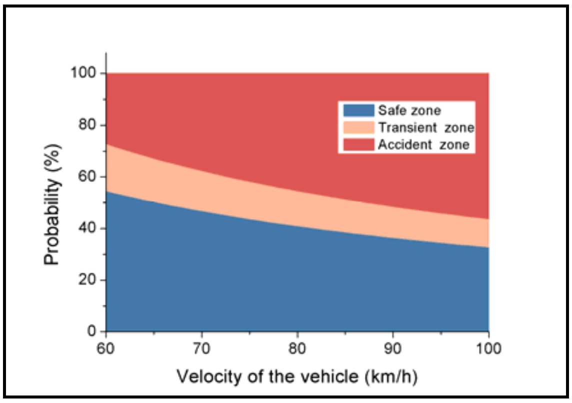
(c) Reaction time : 1.1 second



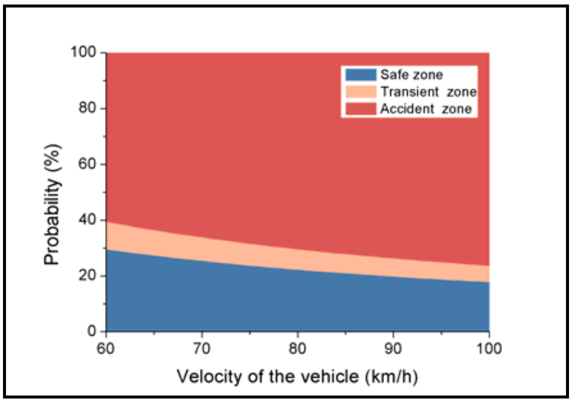
(d) Reaction time : 1.5 second

Figure 8. Accident probability trend variation (mild lane change)

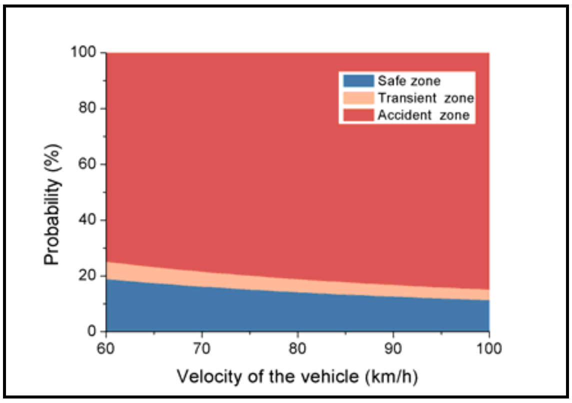
Figure 9 shows the probability of accidents due to vehicle velocity, vehicle angle 1~10 degrees is a result of simulation. When compared to Figure 8 there are big differences in accident area. The reason for this difference is because of vehicle's angle (larger than 5 degrees) due to the sudden departure. Only accident zone can be found with reaction time of 0.7 seconds and angle larger than 5 degrees in figures 8 and 9
Figure 10 shows the probability of vehicle reaching three zones. Results are also from the accumulated simulation outcomes accounted for yaw angles ranging from 1 to 10 degrees which include abrupt lane change.
It can be naturally confirmed that incidents including the abrupt lane change display more unsafe region. For example, probability of safe zone for mild steering is 80% while that of wider steering range is 40% for vehicle velocity of 80 km/h and



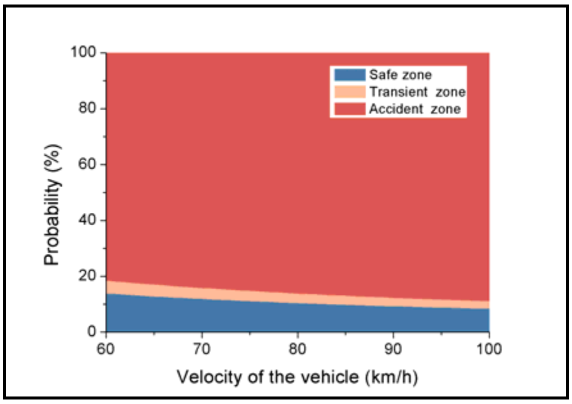
(a) Reaction time : 0.38 second



(b) Reaction time : 0.7 second



(c) Reaction time : 1.1 second



(d) Reaction time : 1.5 second

Figure 9. Accident probability trend variation by velocity of the vehicle (1~10 degree)

minimal reaction delay of 0.38 s (Figures 8 and 9). This can be explained from different perspective as in Figure 10. For mild lane change, as reaction time delay increases, hazardous results are obtained.

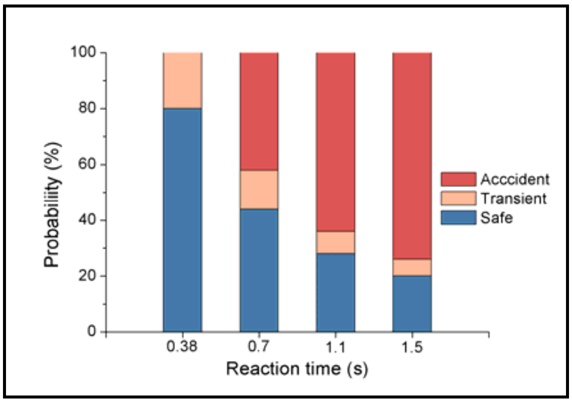


Figure 10. Probability variation by reaction time (mild lane change)

Figure 11 is a probability graph accumulated for all velocity range(60~100 km/h) and yaw angles designating mild lane changes.

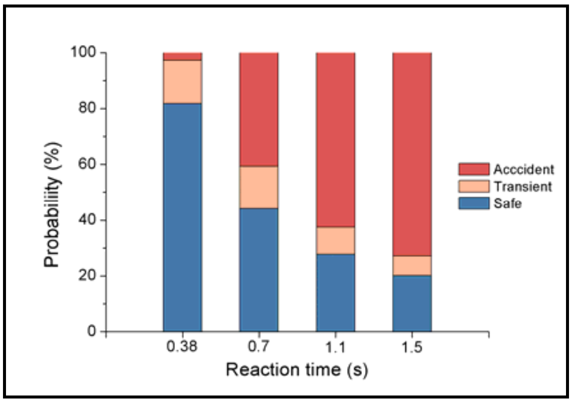


Figure 11. Accident probability variation by reaction time(yaw angle : 1~5 degree, velocity of the vehicle : 60~100 km/h)

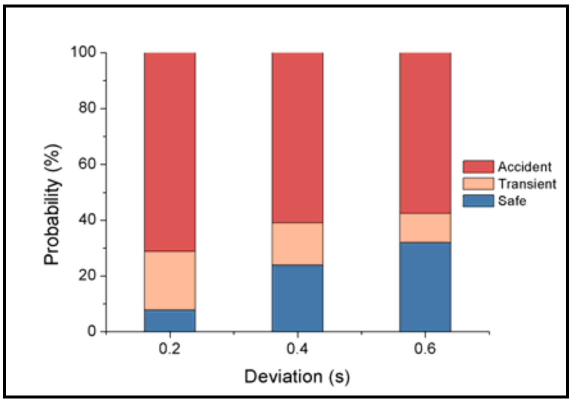
RESULT OF GAUSSIAN DISTRIBUTION REACTION TIME

Unlike the results observed in the previous section, driver's characteristics are different and varying depending on various sorts of factors. In this study, drivers with different reaction time are all considered by collaborating results. The probability of an accident was estimated using Gaussian distribution reaction time. Since the consequence of the lane departure is decided by the level of the specific reaction delay as has been observed in the previous section, the probability of the three zones would be decided by the area under the distribution function within each specific interval that classify each regions.

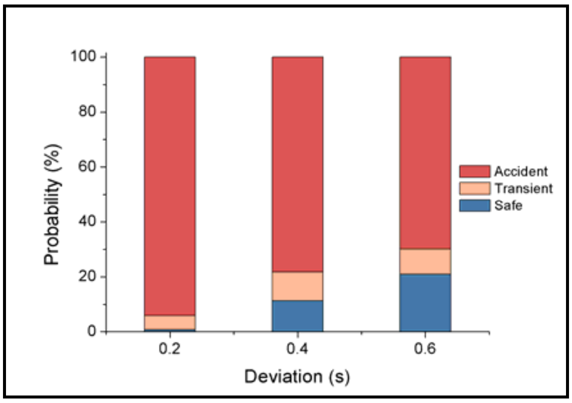
Figure 12 shows the result of simulation when vehicle's velocity and yaw angle are 80 km/h and 3 degree using Gaussian distribution assumption for driver's reaction delay.

The result has been estimated, using mean of various reaction time distribution and relevant deviation. The higher deviation decreases the probability of an accident. As the deviation gets smaller, it displays similar feature with that from a fixed reaction delay at the very mean value.

In figure 12, as deviation becomes smaller, the accident zone gets larger. It can be naturally decided that the mean value of the distribution contributes more to cause accident as can be observed in smaller deviation results.



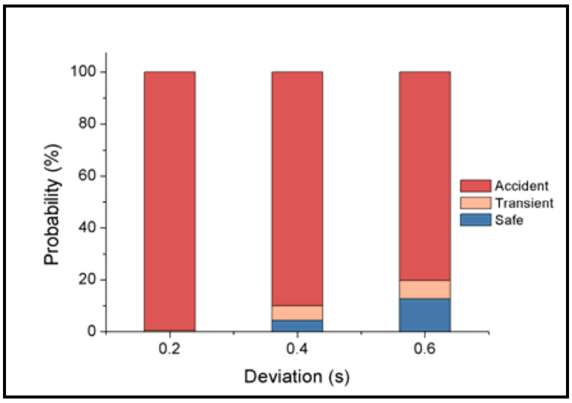
(a) Mean of reaction time : 0.8 second



(b) Mean of reaction time : 1.0 second

CONCLUSIONS

Through this study, the effect of driver's perception reaction time with various types at lane departure affecting the performance of the system is studied.



(c) Mean of reaction time : 1.2 second

Figure 12. Probability trend for varying mean and deviation in Gaussian distribution(yaw angle : 3 degree, velocity of the vehicle : 80 km/h)

1. Specific reaction delay is identified to specify safe, transient and accident zone. The level of accident probability is also evaluated through driver's reaction time and vehicle condition at lane departure.

2. It is found that faster reaction time is needed to properly respond to the accident for larger vehicle deviation angle and velocity as vehicle departs current lanes.

3. The possibility of accident occurrence probability increases as vehicle velocity and deviation angle increases.

4. The accident probability rapidly increases up to 1 second of reaction delay and the rate of increase would subside afterwards.

5. Gaussian reaction time distribution is effectively used to approximate the general behavior of the driver against predicting the accident probability for LDWS equipped vehicle maneuver.

A thorough and detailed work will follow regarding the effect of roadway curvature. Other characteristics including vehicle dimension, steering characteristics and LDWS hardware specifications related to the commercially operated vehicle would be more thoroughly studies.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Yoo, S. M. 1993. “Safety Study of Intervehicle Headway for Vehicle Longitudinal Control System.” SAE Technical Paper #931922

[2] National Highway Traffic Safety Administration. “Lane Departure Warning System NCAP confirmation Test December 2008”

[3] Kwon, S. J., Chun, J. h., Koo, T. y., Cho, k. y. and Suh, M. W. 2005. “Design of the Forward Vehicle Collision Warning Algorithm Considering Human Factors.” KSAE Conference Proceedings, pp.1713-1718.

[4] Thiffault,P. and Bergeron, J. 2003. “Monotony of road environment and driver fatigue: a simulator study.” Accident Analysis & Prevention, Volume 35, Issue 3, May: 381-391

[5] Tinga, P. H., Hwanga, J. R., Doongb, J. L. and Jenga, M. C. 2008. “ Driver fatigue and highway driving: A simulator study.” Physiology & Behavior, Volume 94, Issue 3, June: 448-453

[6] Keisuke, S. and Hakan, J. 2003. “An analysis of driver`s steering behavior during auditory or haptic warnings for the designing of lane departure warning system.” JSAE Review 24, pp.65-70.

[7] Song, J. H., Sung, D. H., Lee, D. H. and Lee, W.S. 2008. “Evaluation of a Lane Departure Warning System Using a Driving Simulator.” KSAE Conference Proceedings, pp.1709-1714.

[8] Evaluation of the Mack Intelligent Vehicle Initiative Field Operational Test Final Report, US DOT, 2006

[9] ISO Standard. 2007. “Intelligent transport system – Lane departure warning systems – Performance requirements and test procedures.” ISO 17361.

[10] ISO Standard. 2008. “Passenger cars – Test track for a severe lane-change maneuver – Part 1: Double lane-change.” KSR ISO 3888-1

ONE SIZE DOESN'T FIT ALL

Donald Friedman
Center for Injury Research
USA
Paper No. 11-0401

ABSTRACT

Modern passenger cars and trucks are designed for the young 50th percentile male and adjustments are provided to accommodate the 5th to 95th percentile occupant. However, the accommodating seating and occupant protection systems are grossly inadequate for the smaller people and the 30% of the U.S. population who are obese as well as those with the diminished muscular strength and increased fragility of age. The same considerations apply to the optional inclusion of driver aids.

Automotive design staffs rarely include professionals over the age of sixty because mass marketing focuses on the young to middle aged population. But the population is aging and life expectancy now reaches to the eighties. Cars can now be purchased with a myriad of options but none include a senior package. Aftermarket sales of sunroofs, electronics, etc., and even limousine conversions are commonplace but no design effort has focused on an occupant protection package for these smaller, aging, older, fragile, obese people. This paper highlights what can be done technically.

INTRODUCTION

The safety act of 1965 initiated the concepts of structural crashworthiness and occupant protection. Cars didn't have seatbelts and these concepts were not quantified. The Department of Transportation was born with aircraft industry and academic staff. Research and experimentation were based on physics and iterative testing. The fundamentals of crashworthiness focused on structural integrity, maintenance of the occupant survival zone and 50 mph frontal impacts. The concept of occupant protection focused on the second collision between the occupant and the dash and means to avoid acceleration injury. People refused to use their belts and a worldwide effort to develop airbags was initiated. The idea was to rapidly insert a soft air cushion between the occupant and the instrument panel as a substitute for the belts.

The problem became whether the airbag energy produced more injury than it prevented. As a result the combination of belts and supplemental restraint airbags was born. The belts would work in low-level crashes (where the energy in the collision was less than the energy in the bag) and the bag would supplement the belts in high-energy collisions. Then injury criteria and anthropometric dummies were developed and the idea of dynamic compliance tests was implemented. Since then the ground rules haven't changed much in that vehicles must be designed to protect a 50th percentile male dummy in 30 mph compliance tests to established injury criteria and must <u>accommodate</u> a 5th female and 95th percentile male dummy.

The consequence of regulations (as estimated by NHTSA) has been to save 15% of the 40,000 lives that would have been lost each year. The tragedy is that government and industry have agreed that they have done and are doing all they can in crashworthiness and occupant protection and have turned their attention to driver aids to avoid or reduce the number of accidents and thereby reduce casualties. A testament to that position is that by international accounts the U.S. now ranks about 14th in the world in fatality and casualty rates. Countries who have adopted the Swedish Government's "Vision Zero" policy (striving for zero accident deaths) have reduced their casualty rates to 1/4 of ours and getting better without high tech driver aids.

The U.S. economy in GDP terms is four times our nearest competitor, our consumption per capita is rising at about 7% per year and the quality of life is among the highest in the world. On the other hand life is not simple anymore. The same technology that makes life good, is for the most part beyond our comprehension and impossible to fix without special knowledge and tools.

The social network revolution which is the result of personal interactive instantaneous communication is likely to change our political, economic, environmental, health care, theological and corporate governess way of living. Those changes will hopefully be in time since, our rate of consumption is unsustainable. On the automotive front we need to get back to basics.

One Size Fits All

Modern passenger cars and trucks are designed for the 50th percentile male driver and adjustments are provided to accommodate the 5th to 95th driver. Accident avoidance standards like vision (day and night; front, rear and side), handling, steering and braking are accommodating but far from optimal for drivers other than the 50th percentile male. The CarFit educational program is the best of the available adjustments [1].

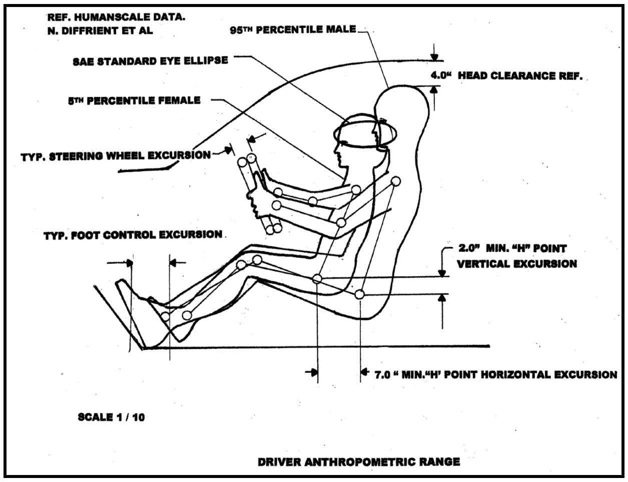

Figure 1. Driver anthropometric range.

Custom or Customizing Vehicles

Driver safety would be improved by installing crash avoidance and convenience feature and/or crashworthiness improvements. There are at least two categories of devices which can aid drivers. One category is anti-lock brakes and its derivative, electronic stability control, and it works for everyone to limit the severity of crashes [2]. Likewise development is underway for sophisticated aids like blind spot detection, adaptive cruise control and lane wander and departure systems [3]. The second category includes after-market-additions currently available like: pedal extenders, wide angle rear view mirrors, seat belt load distributors and limiters, seat adjusters, proximity warning sensors, hand controls, back-up and low light level vision cameras, etc. These devices are after-market additions or options on certain models which customize and can optimize the special needs driver/vehicle interface.

Recent Analytical and Experimental Research

Experiential data and needs For the past three years, the author (Don Friedman) has lived at a full service (independent and assisted living) senior residential community of about 400 people in 300 apartments whose average age is 80. The resident assigned parking lot is full with about one car per apartment. The facility provides all reasonable amenities including scheduled event bus service. A frequent subject of dining room dinner conversation is health, children and grandchildren, transportation, driving confidence and travel. Of particular interest to this study is the strong desire for independence and reluctance to accept aid which burdens family. My observations are that given the status quo in driver/vehicle interaction, confidence and confusion in driving safely erodes with age. However, my conclusion is that significant improvements in driver/vehicle interaction would dramatically improve confidence and safety, and reduce confusion. Those improvements should not involve sophisticated electronic manipulation or interpretation (older people prefer a "one button" or person to person interface).

In a group of environmentally influenced safety conscious drivers (like my own large extended family), my observations indicate they follow the statistical pattern of carelessness in youth, developing respect for the consequences of accidents in middle age, and deteriorating confidence in their and their parents driving as they age. Figure 2 shows NHTSA's plot of accident fatality rate as a function of age. This retrofit of an optimized vehicle and driving interface would benefit any person impaired by their stature, health, and age.

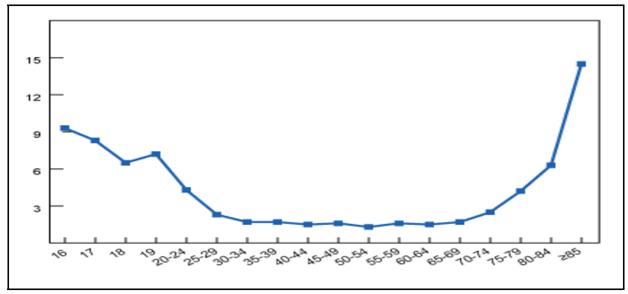

Figure 2. Passenger vehicle crash deaths per 100 million miles traveled by driver age.

Previous studies, analyses, efforts and reports
Previous studies have drawn similar conclusions and suggestions for what might be done, such as CarFit, MIT's AgeLab [4], the 2007 Conference of the American Society on Aging, and the National Council on Aging [5] and IIHS Status Report [6-11].

Silverstein of U of Mass. states that, "by the year 2030, 70 million Americans will be 65 or older. Current estimates suggest that, 2% of the population ages 65-74, 19% of the population ages 75-84, and 47% of the population age 85+ are likely to suffer from Alzheimer's disease or a related disorder translating into about 4.5 million Americans today. By the year 2050, the number of American's with Alzheimer's disease could range from 11.3 million to 16 million (Alzheimer's Association, 2005). Most persons with Alzheimer's disease reside in the community with their families and about 20% live alone. As with many older adults, without appropriate interventions, the primary mode of transportation for persons with dementia is likely to be driving [12]."

Certainly a dialog on what to do about driving with impairments and providing alternate transportation is important. A team of experts, uniquely qualified to address the specific question of customizing and retrofitting an existing vehicle with an optimized safety interface to the individual driver's and/or occupant's physique, health and mental characteristics is the first step.

As an active, working octogenarian living in a senior community, I firmly believe that the proposed benefit prioritized approach will significantly aid the aging society at a very reasonable cost (less than 10% of the original cost of the car). Likewise, this approach is sufficiently flexible, yet thorough; to apply to the unique needs of physically and/or mentally challenged individuals.

As examples, in a recent dinner table conversation a widow explained that her husband usually drove but she couldn't see over the wheel without a thick cushion and it made it difficult to reach the pedals. Repositioning the seat upward and rearward and adding pedal/wheel extenders would make a big difference.

My wife, who is 78 years old and has been driving since she was 18 without a significant accident, recently took a driver's test to renew her California state driver's license. She did not know about, have or read the California manual for taking a driver's test [13]. She failed the test for "cognitive" reasons, specifically because in the first 11 instructions to make a turn or proceed through an intersection with a stop sign she failed to come to a complete stop, wait three seconds and look in both directions before proceeding. She was demoralized and willing to accept a limited to local streets driver's license. However, because I felt she was a competent driver, we hired a retired inspector from a driver training service and retraced the instructions. She did everything right, except she did a California stop i.e. a virtual stop without a three second pause. An automated verbal prompt would have saved the day. We have appealed the limited license and are awaiting an appointment for a new test. If I hadn't interceded she would have been miserable for giving up her independence.

The premise of this paper is that vehicles need to be designed or retrofitted to fit the user and its intended purpose. Safety for the accommodated population in previously purchased vehicles would be improved by retrofit installations of crash avoidance and convenience features and/or crashworthiness improvements for the elderly. There are at least two categories of devices which can aid elderly or impaired drivers: One is electronic stability control and sophisticated aids like blind spot detection, adaptive cruise control and lane wander and departure systems. The second includes after-market-additions like: pedal extenders, wide angle rear view mirrors, seat belt load distributors and limiters, inflatable belts, three dimensional seat adjusters, proximity warning sensors, hand controls, back-up and low light level vision cameras, etc.

Some new small car production designs need to adjust their size, capacity, and performance for single purpose use and be custom tailored to fit the owner. The laws need to be adjusted to allow such designs and define their operating territory. No fault insurance may eliminate the need for tort reform and litigation. The myths and half truths about safety must be dispelled to support consumer confidence. The approach to convince new car production manufacturers will have to be preceded by mass retrofit demonstrations. This paper then will focus on retrofit.

What Can Be Done

As previously mentioned for the past three years, the author has lived at a full service (independent and assisted living) senior residential community of about 400 people in 300 apartments whose average age is 80. The resident assigned parking lot is full with about one car per apartment. The facility provides all reasonable amenities including scheduled event bus service. A frequent subject of dining room dinner conversation is health, children and grandchildren, transportation, driving confidence and travel. Of particular interest to this study is the strong desire for independence and reluctance to accept aid which burdens family. My observations are that given the status quo in driver/vehicle interaction, confidence and confusion in driving safely erodes with age. However, my conclusion is that significant improvements in driver/vehicle interaction would dramatically improve confidence and safety, and reduce confusion. Those improvements should not involve sophisticated electronic manipulation or interpretation (older people prefer a "one button" or person to person interface).

One approach would be to establish a dialog on what to do about driving with impairments and providing alternate transportation. The focus should be to address the specific question of customizing and retrofitting existing vehicles with an optimized safety interface to the individual driver's and/or occupant's physique, health and mental characteristics. The expected result is to extend the opportunity to drive and ride safely with advancing age and it has the associated advantage of ride sharing with people in the same community.

There are two main approaches: Safety Aids and Improved Occupant Protection. Both require addressing and correcting the "one car fits all drivers and passengers" provisions of modern vehicle performance regulations. Then the accident avoidance and occupant protection features of existing vehicles may be significantly improved, by customized retrofit to fit individuals who are not scaled from alert 27 year old male solders with physically trained and tempered musculature.

Driver safety aid Recent safety studies, injury data and readily available enhancement devices to improve a 5th, 50th, or 95th percentile individual's driving performance, confidence and mobility are available. A key consideration will be the positioning of 5th and 50th drivers to match the eye ellipse of the 95th percentile (full rear seat and 4” headroom) for improved Occupant Protection enhancements. Such an investigation would involve installing selected or previously developed aids for each size driver in one of three vehicles. A fourth unmodified vehicle would serve as the comparative base vehicle. Evaluating driver performance enhancements should be by human factor interviewing of potential users for comfort, convenience and acceptability as well as conducting comparative tests in the base and enhanced vehicles by a state licensed driving instructor using the California scoring form. The test population should include a significant number of people in each size, weight and health category.

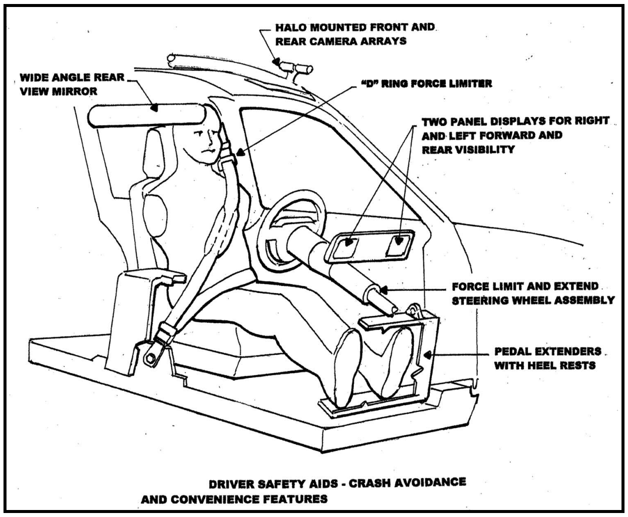

Figure 3. Driver safety aids – crash avoidance and convenience features.

Improved occupant protection Using a finite element vehicle and occupant model, assess the proposed and expected improvement in injury potential performance between baseline and modified vehicle safety devices. An estimate of the injury benefit payoff from available statistics for all combinations of occupant stature, health, enhancement device and crash mode should be made. The next step would be to combine and sled test the selected enhanced devices to significantly reduce a 5th, 50th, or 95th percentile occupant’s injury potential for normal, obese and fragile levels of health and strength in all medium severity crash modes (frontal, side, rear and rollover).

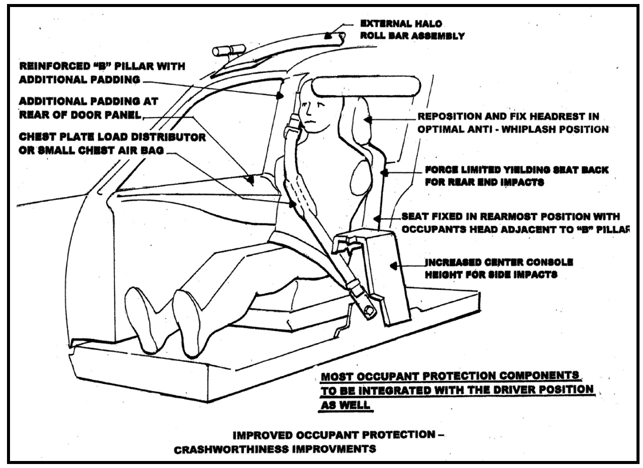

Figure 4. Improved occupant protection – crashworthiness improvements.

Experimental examples
In an effort to demonstrate the effect of reduced musculature in frontal and side impact accidents a simple modification to the stiffness of the Hybrid III dummy was made. The stiffness was reduced to 30% of the original dummy neck, but was still three times stronger than the musculature which keeps our heads erect in normal activities. The results were:

Frontal impact protection The reduction in musculature and orientation of the Hybrid III neck as developed for rollover testing appears to explain anomalies in frontal and side impact protection. For instance the IIHS reported an increase in fatalities with advanced airbags compared to the immediately previous designs. An identical set-up for frontal impacts at typical airbag deployment initiation speeds of 15 mph is shown with the Hybrid III dummy with its original and reduced musculature neck in Figures 5 and 6, respectively. The flexibility of the reduced musculature puts the dummy’s head in close proximity to the deploying airbag with serious injury consequences if the airbag fires and from striking the wheel hub if it doesn’t.

Figure 5. Hybrid III dummy with original musculature neck.

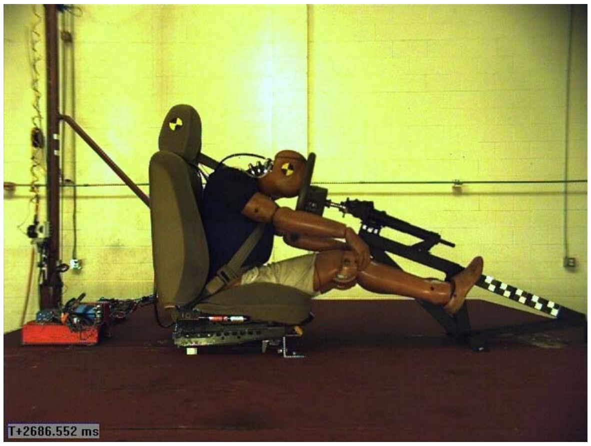

Figure 6. Hybrid III dummy with reduced musculature neck.

Side Impact Protection Window curtain airbags are now in use as head impact protection for side impacts and as such deploy at 100 to 120 mph. Rollover activated window curtain airbags for ejection protection deploy at 25 to 50mph. If the side impact airbag is activated during a rollover because of the vehicle side being in proximity to the ground while the occupant is "up and out" against the roof rail the result may be head and brain trauma, diffuse axonal injury, and coma. A solution would be to have two or variable inflators and change the rollover sensing algorithm to override and inhibit the side impact deployment gas generator.

CONCLUSIONS

Conceptually, subject to an injury payoff benefit analysis and the specific occupant and car to be modified, the retrofit modifications could consist of some or all of the following in order of relative cost:

1. Driver Safety Aids - Crash Avoidance and Convenience Features:

- Add pedal extenders and heel rests to fit the subject size occupant.
- Add a wide angle rear view mirror.
- Add rear and curb proximity sensors with audio warning.
- Add oral warning prompts keyed to braking and turn signals to stop, look right/left, etc.
- Install a rotating contoured all-belts-to-seat for safety, easy access and positioning.
- Install two rear low light level camera arrays*
- Install two frontal low light level camera arrays*
- Install two panel displays for right and left forward or rear visibility.*
- Add a retrofit ESC to the anti-lock braking system if available.
- Add a GPS transmitting speaker cell phone to emergency road service for person to person location and directions to destination.

*Conduct human factors tests to see if the elderly can handle such displays.

2. Improved Occupant Protection - Crashworthiness Improvements:

- Move and fix the seat to its rearmost position.
- Recline the seat back so the occupant's head is next to the B-pillar.
- Reinforce and add padding to the B-pillar.
- Place a shoulder bolster on the rear of the door.
- Reposition and fix the headrest to the optimal anti-whiplash position.
- Adjust the seat to allow 4" of headroom for the subject size occupant.
- Force limit the D-ring and/or the latch anchor of the restraint system.
- Add a chest plate fitted load distributor to the shoulder belt or
- Add an inflatable belt air bag as a 4 point shoulder belt or to the underside of the existing belt.
- For occupants with spinal bone degeneration (spondylosis) it may be necessary to wear a tethered hat.
- Force limit and extend the steering wheel.
- Add a D-ring to D-ring belt to effect a yielding seat back for rear collisions.
- Increase by 8" the height of the center console by standoffs to provide far side occupant protection in near side impacts. [An example is the Camry console which starts at the elbow and goes back. Instructions say to raise the whole console and extend/move it forward to provide separation between the driver and front seat passenger.]
- Add an external roof crush limiting Halo which can also support the cameras.

LIMITATIONS

There are some limitations to what can be done without violating Certification to FMVSS [14]. Indications are that the anticipated devices satisfy the requirements but we need to pay attention to this restriction. Very recent studies of IIHS indicate 15% increased mortality to women over 62 with advanced air bags [9]. This has been considered in our occupant protection task proposal but may require additional tests. We are aware of the economic factors which have reduced accident and fatality rates, but believe this research compensates because it is applicable to those with obese and injury prone physiques and health issues other than seniors.

REFERENCES

[1] CarFit Brochure, 2009. http://www.car-fit.org/
[2] NHTSA 49cfr571.126 (10-1-06 Edition)
[3] Stein, J. 2010. "Continental Sees Shift to Affordable Safety Technology." Automotive News, June 21, 2010.
[4] http://agelab.mit.edu/
[5] Finn, J and N.M. Silverstein. 2007. "Transportation and Community Mobility Track", Joint Conference of the American Society on Aging and the National Council on Aging, Chicago, IL, March 2007.
[6] IIHS Status Report. 2001. "Special Issue Older Drivers," Vol. 36 No. 8, September 2001.
[7] IIHS Status Report. 2007. "Special Issue Older Drivers." Vol. 42 No. 3, March 2007
[8] IIHS Status Report. 2008. "Older Drivers Fatal Crashes Trend Down." Vol. 43 No 11, December 2008
[9] IIHS Status Report. 2010. "Airbags Have Evolved." Vol. 45 No 1, February 2010.
[10] IIHS Status Report. 2010. "Senior Drivers Aren't Causing More Crashes." Vol. 45 No 6, June 2010.
[11] Preusser Research Group 2010. "Restricted Licensing Among Older Drivers." Trumbull, CT, March 2010.
[12] Silverstein, N.M. 2006. "Overview of Issues Associated with Dementia, Driving, and Community Mobility Options." International Conference on Aging, Disability and Independence." February 1, 2006.
[13] California Driver's Handbook
[14] Federal Regulations, Title 49 C.F.R. part 567 Certification http://law.justia.com/us/cfr/title49/49-6.1.2.3.32.html

POTENTIAL EFFECTIVENESS OF INTEGRATED FORWARD COLLISION WARNING, PRE-COLLISION BRAKE ASSIST, AND AUTOMATED PRE-COLLISION BRAKING SYSTEMS IN REAL-WORLD, REAR-END COLLISIONS

Kristofer D. Kusano
Hampton C. Gabler
Virginia Tech
United States

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ABSTRACT

This study examines the potential effectiveness of a Pre-Collision System (PCS) that integrates Forward Collision Warning (FCW), Pre-crash Brake Assist (PBA), and autonomous Pre-crash Braking (PB). Real-world rear-end crashes were extracted from NASS/CDS years 1993 - 2008. The sample of 1,396 collisions, corresponding to 1.1 million crashes, was simulated as if the striking vehicle had been equipped with PCS. A stochastic framework was developed to account for the variability in driver response to the warning system. The result was an estimate of PCS benefits in terms of crash severity (change in velocity during the collision, ΔV), injury reduction for drivers, and prevented collisions. The results indicate that PCS reduced the median ΔV by 34%. The number of moderately to fatally injured drivers wearing their seat belt was reduced by 50%. Finally, 7.7% of collisions were prevented.

INTRODUCTION

Active safety systems that can prevent or mitigate forward crashes are a promising method of reducing crash-related injuries and property damage. Forward collision warning (FCW), pre-crash brake assist (PBA), and autonomous pre-crash braking (PB) systems are systems being implemented in current and near-term passenger vehicles. All three of these systems often depend on millimeter-wave radar scanning technology to track vehicles and objects in front of the equipped vehicle. These systems can also use input from other sensors or otherwise interact with other systems such as speed sensors, steering angle sensors, and airbag control modules. FCW systems warn the driver through visual, audio, and/or tactile means of an impending collision. FCW has been designed to warn the driver close to the last possible moment before driver corrective action can possibly avoid the collision. As with other systems, nuisance or false positive alarms reduce the acceptance by the driver [1]. PBA is triggered when the vehicle recognizes an emergency braking scenario and amplifies driver braking input when the driver applies the brake. In systems with multiple PCS components, PBA is designed to activate following the warning. Finally, PB is intended to autonomously add to the vehicle's braking deceleration, even if there is no driver input. In systems with multiple components PB is triggered last, closest to the collision. Therefore, most PB systems are being designed to trigger only when a collision is unavoidable. Therefore, the main focus of PB is crash mitigation, not necessarily crash prevention.

One of the crash modes that is anticipated to be applicable to PCS is the rear-end collision. A rear-end collision is one in which the front of one vehicle (the striking vehicle) impacts another vehicle traveling in the same direction of travel as the first vehicle (the struck vehicle). The struck vehicle can be decelerating, stopped, or moving at a lesser speed than the striking vehicle. Rear-end collisions are one of the most frequent multi-vehicle crash modes. Although in general many of these collisions are low in severity, rear-end collisions can result in serious or fatal injuries. The combination of a high frequency crash mode and the relative ease at which radar systems can track vehicles traveling in the same direction compared to other crash scenarios makes rear-end collisions a promising crash mode for PCS application.

A review of Intelligent Transport Systems by Bayly *et al.* summarizes the results of studies of expected fleet-wide benefits for individual PCS components [2]. Forward collision warning systems were the most frequently studied PCS component. Studies pertaining specifically to rear-end collisions reported a range of crashes prevented from as low as 7% to as high as 80%. Studies focusing on PBA found a reduction in the number of applicable crashes from 26% to 75%. These PBA studies, however, aggregated several crash modes; rear-end impact was not broken out separately. Benefits in these studies were often implied from an assumed proportion of a target population that would benefit from the PCS component. Although every collision is different, this traditional effectiveness methodology does not treat each collision individually and cannot predict the effectiveness of PCS on a case-by-case basis.

Driving simulators are also commonly used to assess potential benefits of PCS. For example, Lee *et al* exposed driving simulator users to a lead vehicle stopped scenario and found that FCW reduced the number for that scenario by 80.7% [3]. This and other driving simulator based studies often only examine a small set of collision scenarios and thus cannot be extended to the overall system benefits expected throughout the fleet.

Many studies that have examined PCS related components have focused on only one feature. However, vehicles both in production and near-production are combining PCS components into an integrated system. In these integrated systems, the effectiveness of one PCS component is influenced by the other components. The effectiveness of the integrated PCS components is not simply the linear combination of each individual PCS component.

This study will examine the effectiveness of an integrated PCS containing FCW, PBA, and PB. The study uses the unique approach of determining the effectiveness of PCS on a case-by-case, or microscopic, basis for thousands of crashes and then aggregating these individual crash outcomes to determine the overall, or macroscopic, effectiveness of PCS. The approach developed examined a nationally representative sample of moderate to severe collisions, and simulated each case as if the vehicle was equipped with a functioning PCS.

OBJECTIVE

The objective of this study is to estimate the safety benefits for the striking vehicle in rear-end collisions which are equipped with a pre-collision braking system consisting of forward collision warning, pre-crash brake assist, and pre-crash brake. Benefits will be estimated in terms of reduction in the number of collisions, collision severity (ΔV), and the number of injured drivers.

METHODOLOGY

Case Selection

Real-world collisions were extracted from the National Automotive Sampling System / Crashworthiness Data System (NASS / CDS) from year 1993 to 2008. NASS / CDS is a U.S. Department of Transportation sponsored, representative sample of minor to severe crashes that occurred in the United States. Teams throughout the country investigate approximately 5,000 crashes per year in detail. This investigation includes visiting the scene of the accident, collecting information from police and medical records, photographing and diagraming the scene, conducting interviews with the occupants, and measuring damage to the vehicle(s). In order to be investigated, crashes must feature at least one passenger vehicle and at least one vehicle must have been towed from the scene due to damage. NASS / CDS is released yearly and is publically available for download from the National Highway Safety Administration (NHTSA). Each case in a year of NASS / CDS is assigned a national weight factor. This weight represents the number of similar collisions that occurred annually throughout the entire U.S. In this study all analyses used the weighted values of cases from NASS / CDS.

Target vehicles were the striking vehicles in rear-end collisions. Rear-end collisions were identified by using a method adapted from Eigen and Najm [4]. Pre-crash variables in NASS / CDS such as accident type (*ACCTYPE*), critical pre-crash event (*PREEVENT*), and pre-crash movement (*PREMOVE*) were used to classify crashes as a rear-end collision. Furthermore, only collisions involving 2 vehicles (*VEHFORMS* = 2) and involving a single collision event (*EVENTS* = 1) were included. The crash event must have resulted in frontal damage to the striking vehicle. Both striking and struck vehicles were either a car, light truck, or van. To accommodate reconstruction of each case, both vehicles were required to have values recorded for total ΔV, vehicle curb weight, and vehicle length. To compute the reduction in injured drivers, a known driver seat belt use was required.

Modeling PCS Function

Activation of each of the PCS components varies by manufacturer and system. A simple metric that many PCS use to judge collision threat is Time to Collision (TTC). TTC is the ratio of range, x, to range rate, or relative velocity, V_{12}:

$$TTC = \frac{x}{V_{12}} \qquad (1).$$

TTC has been shown to directly relate to driver's threat recognition in frontal collisions and is readily measured by radar sensors [5]. A PCS that has the three components described earlier (FCW, PBA, and PB) is presented by Aoki *et al* [6]. The activation times for the PCS components in this system are shown in Table 1..

Table 1.
Activation Timing for PCS Components.

PCS Component	TTC Activation (s)	Effect
Forward Collision Warning (FCW)	1.7	Warns the driver through audio, tactile, and/or visual warning
Pre-crash Brake Assist (PBA)	0.8	Doubles driver braking effort
Pre-crash Brake (PB)	0.45	Increases vehicle deceleration by a level of 0.6 g

To assess the benefit of PCS components in reducing crash severity, crashes were simulated for every striking vehicle involved in rear-end collisions as if they were equipped with FCW, PBA, and PB.

ΔV Estimates in NASS/CDS

The ΔV (delta-V) is defined as the change in velocity of a vehicle during a crash event, i.e. the difference between the velocity at impact and the separation velocity. ΔV is a standard metric of the severity of a collision and has been found to be well correlated to occupant injury risk [7, 8]. The ΔV is reconstructed when possible in cases from NASS / CDS by correlating vehicle damage in a crash to the energy absorbed by the vehicle body. Vehicle crush depth is measured by the NASS / CDS investigator, as shown in Figure 1. Using conservation of momentum the ΔV is computed from the energy absorbed during the collision. This approach is often referred to as the "CRASH3" method for computing ΔV after an algorithm developed by McHenry [9]. A version of the CRASH3 algorithm is used by NASS / CDS investigators to reconstruct collisions. Full derivations of this method can be found elsewhere [9-11].

Figure 1. Photograph of Vehicle Being Measured for Crush Damage.

A schematic representation of the collision is shown in Figure 2. The resultant force of the collision is assumed to pass through a common point, P. The location of P is found using the crush depth and width of the damage area. The Principal Direction of Force (PDOF) is the direction of the resultant force with respect to the heading of the vehicle. The moment arm of the resultant collision force, *h*, is found geometrically from the location and direction of the resultant force.

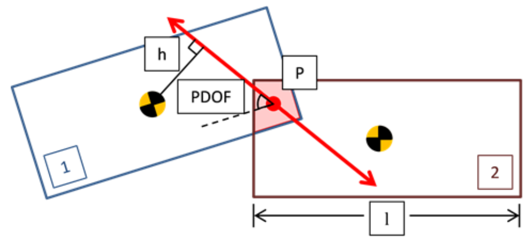

Figure 2. Schematic Representation of Non-central Collision.

The change in velocity for vehicle 1, ΔV_1, can be derived as:

$$\Delta V_1 = \sqrt{\frac{2E_T\gamma_1}{m_1\left(1+\frac{\gamma_2 m_2}{\gamma_1 m_1}\right)}} \quad (2).$$

where E_T is the total energy absorbed in the crash, γ is the effective mass coefficient, and m is the mass of the vehicle. To account for the rotational effects of the vehicle, an effective mass coefficient, γ, is computed for each vehicle:

$$\gamma = \frac{k^2}{k^2+h^2} \quad (3).$$

where k is the radius of gyration for the vehicle. The effective mass coefficient can fall between zero and unity and is representative of the proportion of the mass that contributes to the change in velocity along the vehicle's heading; the other proportion of the mass contributes to rotational acceleration of the vehicle. The concept holds true when the moment arm of the resultant crash force stays constant during the collision, which is a reasonable assumption for relatively short collisions [12].

Computing Reduced ΔV due to Pre-crash Braking Impulse

To compute the benefit of PCS, rear-end collisions were reconstructed using the information in NASS / CDS to estimate the crash severity which would have occurred if the vehicle had been equipped with PCS. A similar momentum approach to the CRASH3 method was used so that the ΔV recorded in NASS / CDS could be directly modeled. Consider a rear-end collision where the striking vehicle (vehicle 1) collides with a vehicle that is standing still (vehicle 2). The ΔV for this collision for vehicle 1 is defined as

$$\Delta V_1 = V_{12,0} - V_C \quad (4).$$

where $V_{12,0}$ is the velocity of vehicle 1 with respect to vehicle 2 at impact and V_C is the common velocity achieved following the collision. The change in velocity of vehicle 2 is simply V_C. Therefore, the sum of the two ΔVs yields the impact velocity:

$$\Delta V_1 + \Delta V_2 = V_{12,0} - V_C + V_C = V_{12,0} \quad (5).$$

Now consider a collision where the driver of vehicle 1 increases the braking magnitude from a_0 to a_1 and again to a_2 prior to the collision. This scenario is akin to how drivers using a PCS experience an increase in braking in response to a warning and again prior to the collision via autonomous pre-crash braking. A diagram of the vehicle deceleration before and after increased braking is shown in Figure 3. The increases in braking level occur at a jerk authority of j. The jerk authority is the maximum rate at which deceleration can be increased by the braking system. The first braking pulse starts at a time to collision TTC_1 and the second at TTC_2. The first braking pulse has duration of t_1, and the second braking pulse has duration of t_2.

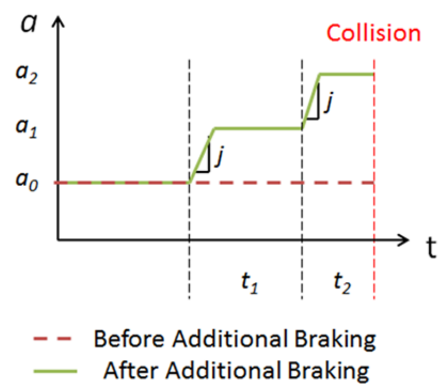

Figure 3. Graph of general, two-pulse braking deceleration. braking deceleration, *a*, increases from a_0 to a_1 and again to a_2 at a jerk authority of *j*.

The speed of vehicle 1 at the time of the first brake activation (TTC_1), $V_{12,1}$, can be found using a kinematic relationship:

$$V_{12,1} = a_0 TTC_1 + \sqrt{(a_0 TTC_1)^2 + (V_{12,0})^2} \quad (6).$$

Examining the first braking pulse and integrating the acceleration of the vehicle yields the velocity of the vehicle at t_1, which is equal to the vehicle velocity at the start of the second braking pulse, $V_{12,2}$:

$$v(t_1) = V_{12,2} = -a_1 t_1 + \frac{(a_1-a_0)^2}{2j} + V_{12,1} \quad (7).$$

Integrating once more yields the position at t_1:

$$x(t_1) = -\frac{1}{2}a_1 t_1^2 + \left(\frac{(a_1-a_0)^2}{2j} + V_{12,1}\right)t_1 - \left(\frac{(a_1-a_0)^3}{6j^2} + V_{12,1}TTC_1\right) \quad (8).$$

The second braking pulse starts at an activation time of TTC_2, which corresponds to a position, x_1:

$$x_1 = -V_{12,2}TTC_2 \quad (9).$$

Due to symmetry, the kinematics of the vehicle are described similarly to (7) and (8) for the second braking pulse. The resulting equations are quadratic, allowing for the braking times of the first and second pulses, t_1 and t_2, to be solved algebraically.

The reduction in velocity created by the braking can be found by integrating the deceleration pulse:

$$\mathrm{P_{brake}} = \frac{a_2^2 - a_0^2}{2j} + a_1\left(t_1 - \frac{a_1 - a_0}{j}\right) + a_2\left(t_2 - \frac{a_2 - a_1}{j}\right) \quad (10).$$

Using conservation of momentum, the change in velocity after braking, ΔV_1^*, can be derived in terms of the change in velocity without additional braking, ΔV_1, using an approach similar to the CRASH3 algorithm:

$$\Delta V_1^* = \Delta V_1 - \frac{\gamma_1\gamma_2 m_2}{\gamma_1 m_1 + \gamma_2 m_2}\mathrm{P_{brake}} \quad (11).$$

This method is based on the velocity of vehicle 1 relative to vehicle 2. This method can be used if the struck vehicle is accelerating or decelerating at a constant rate. The accelerations (a_0, a_1, and a_2) simply become the relative accelerations:

$$a_{12} = a - a_s \quad (12).$$

where a is the acceleration of vehicle 1, a_s is the acceleration of the struck vehicle, and a_{12} is the acceleration of vehicle 1 with respect to vehicle 2.

Modeling Driver Input and Vehicle Dynamics in Response to PCS

The effectiveness of PCS with FCW is dependent upon the response of the driver to the warning. A simplified driver model was developed to describe the reaction time of the driver to the FCW. The time from the issue of the warning to the time that the driver applies the brakes is a driver's reaction time. Reaction time is important for PCS algorithms because it determines what systems will activate. For example, consider four scenarios of drivers applying the brakes in response to a warning, shown in Figure 4. FCW warns the driver 1.7 s before the collision. A fast reaction time (scenario 1) will cause the driver to apply the brakes before the threshold for PBA resulting in only driver braking effort. However, a medium reaction time (scenario 2) will cause PBA to activate once the driver starts braking, doubling the driver braking effort. A slow reaction time (scenario 3) will still cause PBA to activate, but braking time will be shorter. Finally, if the reaction time is greater than 1.7 s, the crash will occur before the driver applies the brake (scenario 4).

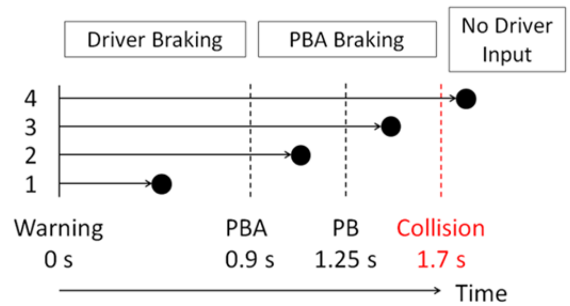

Figure 4. Schematic of PCS component activation based on reaction time for fast (1), normal (2), slow (3), and no response (4). Filled circles indicate the time of driver brake application.

To determine the expected fleet-wide benefits of PCS algorithms, a distribution of driver brake reaction times was used as developed by Sivak *et al* [13]. This study collected reaction times to visual warnings of 1,644 drivers on a test track and found a mean reaction time of 1.21 s with a standard deviation of 0.63 s. Assuming a lognormal distribution of reaction times, this distribution has been used to investigate PCS warning response [14].

Figure 5 shows the probability distribution function of driver response times. For all drivers in the population, 17% would have a reaction time greater than 1.7 s, thus having no response prior to the collision. Characteristic "fast", "medium", and "slow" response times were found from the remaining 83% of drivers. Characteristic "slow" and "fast" responses were found which corresponded to 20% of the population. The median response time, 1.07 s, was used as the "medium" response time, which was used to characterize the remaining 43% of the population.

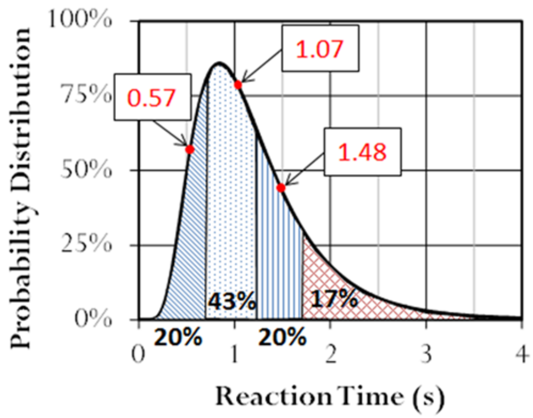

Figure 5. Probability distribution of driver reaction times and characteristic reaction times used for PCS simulations.

From the crash investigation, the speed at impact can be estimated using (Equation 5); however, the maneuvers of the driver prior to the collision without PCS affect the vehicle speeds when PCS components activate. Drivers were separated into 3 groups based on pre-crash maneuver (*MANEUVER*): 1) not braking, 2) braking, or 3) accelerating. The "Not Braking" group was assumed to not apply the brakes at all prior to the collision. The "braking" group could apply the brakes in two ways: late and hard braking, as a driver who was inattentive and realized a collision risk too late to avoid the collision, or early and weak braking, as a driver who applies the brakes to avoid a collision but misjudges the brake magnitude necessary to avoid the collision. The "braking" group was simulated with both late, hard braking and early, weak braking. The accelerating group was assumed to apply a constant acceleration.

Similarly, braking or acceleration by the struck vehicle was separated into the same three pre-crash maneuver classes. When the MANEUVER variable was missing or unknown for the striking vehicle, the crash was reconstructed using all three pre-crash maneuver classes. If the MANEUVER variable was missing for the struck vehicle, ACCTYPE was used in its place. ACCTYPE records the struck vehicle maneuver (moving, decelerating, or accelerating) in rear-end crashes but does not specify the striking vehicle maneuver.

Driver braking magnitude was set at constant levels. Hard braking produced a 0.4 g vehicle deceleration, while weak braking created 0.2 g of deceleration. The maximum vehicle deceleration possible was limited to 0.8 g. If the struck vehicle was braking, it was assumed they were braking at 0.2 g and PCS equipped vehicle deceleration was found using (12). Simulations with PCS assumed the driver would apply the brakes at the hard level (0.4 g) in response to the warning.

The combination of the four pre-crash maneuvers and four response times created 16 possible braking pulses after PCS implementation for each algorithm. A schematic of the 16 possible braking pulses by pre-crash maneuver and response time is shown for the FCW + PBA + PB system in Figure 6. The large dashed line shows the driver braking without PCS and the solid line shows the vehicle braking with PCS in response to the driver braking input with PCS.

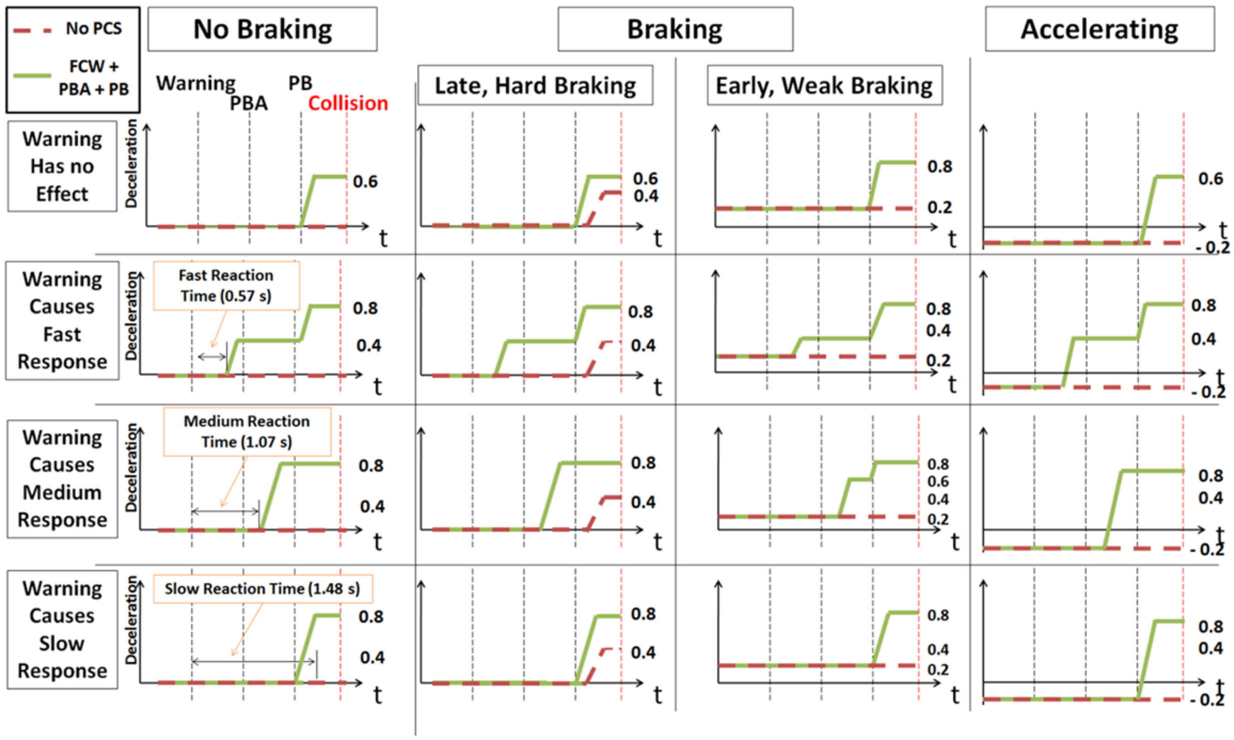

Figure 6. Schematic Representation of PCS Braking Pulses for Pre-crash Maneuver and Response Time for a FCW, PBA, and PB Algorithm. Magnitudes (*g*) and delay times (*s*) are labeled.

Overall System Performance

To estimate overall algorithm effectiveness, the NASS / CDS national weighting factor for each case was split between simulations to generate a single distribution of effectiveness after PCS activation. For cases where the driver was not braking or accelerating, 17% of the case weight was assigned to the no effect simulation, 20% to the fast response simulation, 43% to the medium response simulation, and 20% to the slow response simulation. For cases that reported driver braking it was assumed that the late-hard and early-weak braking scenarios had equal probability of occurring. Therefore, 8.5% of the case weight was assigned to the no response simulation, 10% to the fast response, 21.5% to the medium response, and 10% to the slow response for each maneuver. Splitting the weighting factor insured that the overall system performance reflected the distribution of driver reaction times.

A large number of cases (13.5%) had a missing or unknown pre-crash vehicle maneuver. This is coded in NASS / CDS when the investigator is unable to determine the pre-crash maneuver with confidence. For cases with unknown or missing pre-crash vehicle maneuver, simulations for all the maneuvers were performed. To determine overall system performance, the distribution of reaction times was combined with the distribution of pre-crash maneuvers observed in the known population. Of rear-end collisions with known braking status, 29% were not braking and 71% were braking, with almost none (<1%) accelerating. As such, accelerating simulations were not considered for unknown maneuver cases. Multiplying the response time probability with the maneuver probability gave the proportion of the case's weighting factor assigned to each simulation, shown in Table 2.

Table 2.
Distribution of Case Weight for Cases with Unknown Pre-Crash Maneuver prior to PCS.

			Maneuver[b]		
			NB	HEB	WLB
			29%	35.50%	35.50%
Response Time[a]	NR	17%	5%	6%	6%
	FR	20%	6%	7%	7%
	MR	43%	13%	15%	15%
	SR	20%	6%	7%	7%

[a]NR – no response, FR – fast response, MR – medium response, SR – slow response
[b]NB – no braking, HEB – hard, early braking, WLD – weak, late braking.

Injury Risk after PCS Activation

To estimate the number of injured drivers after PCS activation, an injury risk curve was used to predict the number of injured drivers. An injury risk curve, which relates the probability of injury to crash severity and seatbelt use, was used from a previously published study [15]. Injury was defined as a maximum Abbreviated Injury Score (MAIS) of 2 or greater (MAIS2+), representing moderately to fatally injured drivers. The Abbreviated Injury Score is a measure of an injury's threat to life, with 0 being no injury and 6 fatal injury [16]. In the previous study, logistic regression was used to fit an injury risk curve to a similar population of rear-end collisions. The resulting risk curve had the form:

$$P(\Delta V, belt\ use) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 \Delta V + \beta_2 (belt))}} \quad (13).$$

where β_0, β_1, and β_2 are coefficients determined by the regression analysis. For belt use, the quantity $belt$ was set to 1 for belted drivers, and -1 for unbelted drivers. The coefficients for the injury risk curve are listed in Table 3.

Table 3.
Injury Risk Curve Coefficients from Kusano and Gabler (2010).

Parameter		Value
Intercept	β_0	-6.068
ΔV	β_1	0.1000
Belt Use	β_2	-0.6234

The total number of injured drivers, N, was estimated as:

$$N = \sum_{i=1}^{N} w_i \, P(\Delta V_i, belt\ use) \quad (14).$$

where w_i and ΔV_i, is the weight and simulated ΔV assigned to each simulation. To compare the PCS outcome to the outcome without PCS, the number of injured drivers without PCS was estimated in the same way. Injury reduction was computed only for belted drivers. Because the relatively high levels of braking involved in PCS, there is possibility of unbelted occupants being thrown out of position prior to the collision. Out of position front seat occupants in airbag equipped vehicles are more likely than belted occupants to suffer serious injury due to airbag deployment. Because of this unknown aspect of potential increase in driver injury, unbelted occupants were excluded.

System Limitations

The maximum vehicle braking deceleration is restricted by the road surface type and conditions. Table 4 lists nominal maximum braking deceleration for different surfaces and conditions [17-19]. Surface type and condition were determined from the variable *SURTYPE* and *SURCOND*, respectively. Vehicles were determined to be sliding based on pre-crash maneuver (*MANEUVER*) and pre-crash impact stability (*PREISTAB*). Unknown surface types were assumed to be pavement / asphalt / concrete and unknown surface condition was assumed to be dry. If vehicle stability was unknown, it was assumed the vehicle was tracking prior to the collision. Because vehicles with PCS would feature an Anti-Lock Brake System (ABS), striking vehicles were assumed to achieve the maximum possible braking deceleration with PCS activation. The braking decelerations for each simulation were adjusted to reflect the maximum braking deceleration based on surface type, condition, and stability. Furthermore, if striking vehicles were sliding prior to the collision, it was assumed that the ABS would allow them to maintain tracking when PCS activated.

Table 4.
Maximum Braking Deceleration in g for Different Surface Types and Conditions [17-19].

Surface Condition	Braking (no lockup)	Sliding (wheels locked)
Dry Pavement / Asphalt / Concrete	0.8	0.65
Wet Pavement / Asphalt / Concrete	0.7	0.55
Snow	0.4	0.25
Ice	0.15	0.075
Dry Gravel/Dirt	0.7	0.6
Wet Gravel/Dirt	0.6	0.5

Most PCS do not activate at low vehicle speeds. The FCW and PB systems were assumed to activate at relative vehicle speeds greater than 15 kmph (9.32 mph). The PBA component was assumed to activate at relative vehicle speeds greater than 30 kmph (18.6 mph). If the warning threshold was not met at the time of system activation, the case had no system activation and thus no benefit. If the PBA threshold was not reached, braking was adjusted accordingly to match the driver's input. If the PB threshold was not reached, the braking level was maintained at its previous level until the collision.

RESULTS

Selected Cases

Of all rear-end collisions in NASS / CDS 1993-2008, 1,396 cases met all the requirements of this study. These cases accounted for approximately 1,080,000 rear-end collisions. Table 5 shows pre-crash braking maneuvers for striking and struck vehicles. The most frequent striking vehicle maneuver was applying the brakes (61.4%) followed by not applying the brakes (25%). Of striking vehicles, 13.5% had missing or unknown maneuver status. For struck vehicles, 92% of vehicles were not applying the brakes and 7% of vehicles were braking.

Table 5.
Distribution of Pre-crash Maneuvers.

Braking Type	Strik. Veh.	% Strik. Veh.	Struck Veh.	% Struck Veh.
No Braking	271,259	25.0%	994,505	92%
Braking	468,346	43.2%	78,588	7%
Braking with Lockup	197,453	18.2%	1,062	0%
Accel.	1,591	0.1%	10,371	1%
Missing / Unknown	145,877	13.5%	-	-

Almost all cases (99.7%) occurred on concrete, asphalt, or pavement. The remaining occurred on dirt or gravel roads. Table 6 shows the distribution of surface conditions in the selected cases. A majority, 80.5%, of crashes occurred on dry roads, followed by wet roads with 17.6%. Snow and ice combined to account for approximately 2% of cases, with only a fraction of a percent being unknown.

Table 6.
Distribution of Road Surface Conditions.

Surface Condition	Number of Crashes	% of Crashes
Dry	872,614	80.5%
Wet	191,267	17.6%
Snow or Slush	16,242	1.5%
Dirt, Mud, Gravel	4,355	0.4%
Missing	50	0.0%

Algorithm Performance

Figure 7 shows the overall distribution of crash severity after PCS activation compared to without PCS. The additional PCS components reduced the distribution of ΔV and the number of collisions prevented.

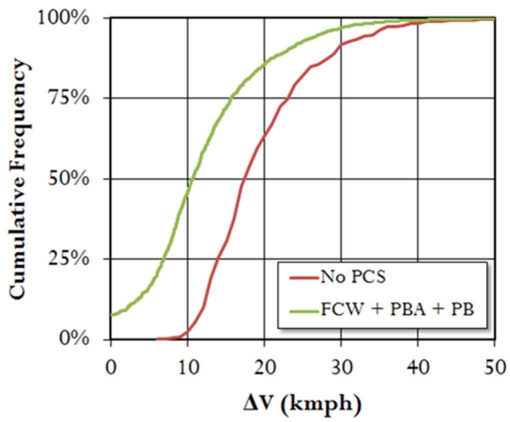

Figure 7. Cumulative Distribution of Crashes after PCS Algorithm Implementation.

Table 7 summarizes the percentage of crashes avoided and the reduction in median ΔV of non-prevented collisions due to PCS algorithm activation.

Table 7.
Median Reduction in ΔV and Prevented Collisions for Each PCS Algorithm.

Algorithm	Percentage of Crashes Prevented	Median ΔV (kmph)	Percent Reduction of Median ΔV
No PCS	-	17.0	-
FCW + PBA + PB	7.7%	11.3	34%

Table 8 shows the predicted reduction in the number of moderately to fatally injured, belted drivers for the three PCS algorithms.

Table 8.
Predicted Number of Moderately to Fatally Injured Drivers for PCS Algorithms.

Algorithm	Predicted Number of Injured Drivers	Percent Reduction
No PCS	12,338	-
FCW + PBA + PB	6,123	50%

Table 9 shows the percentage of all weighted collisions where various PCS components did not activate due to system limitations. Of drivers who braked early enough to activate PCS, 0.1% did not activate FCW because the relative vehicle velocity at FCW activation was below the 15 kmph threshold. This is a reflection of the fact that NASS/CDS only includes cases which at least one vehicle was towed due to damage. Of cases with FCW activation, 12% of all cases did not have PBA activate because the 30 kmph relative velocity condition was not met. Finally, 11% of cases had FCW and PBA activate but not PB due to the 15 kmph relative velocity threshold.

Table 9.
Percentage of Collisions with No PCS Component Activation due to System Limitations.

Component	% Collisions with no Activation
FCW	0.1%
PBA	12%
PB	11%

DISCUSSION

Implication of Results

This study shows the potential effectiveness an integrated PCS algorithm with forward collision warning, pre-crash brake assist, and autonomous pre-crash brake. The simulation takes into account a range of potential driver inputs using population distributions to describe likely results. In this way, this study provides an explicit estimate of the expected fleet-wide PCS algorithm effectiveness for rear-end collisions.

PCS shows large potential effectiveness for mitigating crash severity and injury. PCS reduced the median ΔV 34% and the number of moderately to fatally injured drivers by 50%. Fortunately, most injuries in rear-end collisions are relatively minor. Of drivers in rear-end collisions, 30% sustained minor injuries (e.g. MAIS1, cervical spine injury, abrasions). These occupants would also see benefits from reduced crash severity, which were not estimated here. Also not considered were the economic benefits (e.g. property damage or societal costs of injuries) from prevented and mitigated collisions.

Using real-world data, such as that from NASS / CDS, is advantageous to predicting safety benefits. The crashes simulated here are a nationally representative set of rear-end collisions that all resulted in a collision without PCS implementation. The impact severities are a distribution of minor to severe collisions that have historically been experienced in the field. By accounting for the distribution of possible driver responses, the results estimate the expected overall system benefits for each algorithm. Because crashes in NASS / CDS must involve at least one vehicle towed due to damage, very minor collisions are not included. However, since these collisions occur at low impact speeds, it is unlikely that all of the PCS components would activate.

Limitations

Although this study presents a possible range for PCS algorithm performance, it still provides an ideal case. This analysis assumed that the successive stages of PCS would activate successfully. In practice, one or more systems may not activate due to tracking and sensing limitations. Actual field performance of systems may be less effective.

The driver model was greatly simplified due to the limited information available for the driver's state prior to the collision. The simulation process did not include any effect of PCS on driver maneuvers other than braking, such as steering, prior to the collision. Also, the driver model assumed that driver's braking increased at a constant rate and remained constant at a specified magnitude. In practice, driver deceleration can change in magnitude during a braking period. Without instrumentation in real-world collisions, further simulation of driver braking deceleration was not feasible beyond simple constant magnitudes. Although the driver model included a range of possible driver reactions, it did not capture all possible driver braking inputs.

The reconstruction techniques used to compute the ΔV in each simulation were limited by the information available from crash investigations. The CRASH3 damage method of computing ΔV used by investigators in NASS / CDS was derived out of the need to estimate ΔV without significant knowledge of pre-crash conditions of the vehicles. The CRASH3 method estimates absorbed energy based on an empirical correlation between residual crush and absorbed energy. These correlations are found by obtaining vehicle stiffnesses from crash tests. Although this method has been validated and studied in the past, it relies on vehicle stiffness data from a relatively small number of crash tests extrapolated to the entire vehicle fleet [11]. Therefore, ΔV estimates derived from the CRASH3 method are known to vary depending on the vehicles involved in the collision [20]. The reconstruction methods also assume that the lever arm of the resultant collision force does not change after the application of PCS braking. Although the position of the damage may change slightly after PCS braking, because rear-end collisions feature damage that is often along a majority of the vehicle width and are at shallow angles the change in moment arm will be slight.

CONCLUSIONS

This study identified the potential effectiveness of an integrated PCS algorithm with forward collision warning (FCW), brake assist (PBA), and autonomous pre-crash braking (PB). This unique study used approach of determining the effectiveness of PCS on a case-by-case, or microscopic, basis for thousands of crashes and then aggregating these individual crash outcomes to determine the overall, or macroscopic, effectiveness of PCS. In this way, the expected fleet wide safety benefits of PCS were estimated. PCS reduced the median ΔV by 34% and prevented 7.7% of crashes. The number of moderately to fatally injured belted drivers was reduced by 50%.

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REFERENCES

[1] J. P. Bliss and S. A. Acton, "Alarm mistrust in automobiles: how collision alarm reliability affects driving," *Appl Ergon,* vol. 34, pp. 499-509, Nov 2003.

[2] M. Bayly, *et al.*, "Review of Crash Effectiveness of Intelligent Transportation

Systems," TRACE Project, Deliverable D4.1.1 - D6.2, 2007.
[3] J. D. Lee, *et al.*, "Collision Warning Timing, Driver Distraction, and Driver Response to Imminent Rear-End Collisions in a High-Fidelity Driving Simulator," *Hum Factors,* vol. 44, pp. 314-334, Summer 2002.
[4] A. M. Eigen and W. G. Najm, "Problem Definition for Pre-Crash Sensing Advanced Restraints," U.S. Department of Transportation DOT HS 811 114, April 2009.
[5] D. N. Lee, "A Theory of Visual Control of Braking Based on Information about Time-to-Collision," *Perception,* vol. 5, pp. 437-459, 1976.
[6] H. Aoki, *et al.*, "Safety Impact Methodology (SIM) for Effectiveness Estimation of a Pre-Collision System (PCS) by Utilizing Driving Simulator Test and EDR Data Analysis," SAE Technical Paper Series 2010-01-1003, 2010.
[7] D. J. Gabauer and H. C. Gabler, "Comparison of roadside crash injury metrics using event data recorders," *Accid Anal Prev,* vol. 40, pp. 548-58, Mar 2008.
[8] G. T. Bahouth, *et al.*, "Development of URGENCY 2.1 for the Prediction of Crash Injury Severity," *Top Emerg Med,* vol. 26, pp. 157-165, 2004.
[9] "CRASH3 User's Guide and Technical Manual," National Highway Traffic Safety Administration, Department of Transportation, Wasington, D. C. DOT HS 805732, April 1982.
[10] T. Day and R. Hargens, "An Overview of the Way EDCRASH Computes Delta-V," SAE Technical Paper Series Paper 870045, 1987.
[11] D. Sharma, *et al.*, "An Overview of NHTSA's Crash Reconstruction Software WinSmash," in *Proceedings of the 17th Annual International Enhanced Safety of Vehicles Conference*, Lyon, France, Paper Number 07-0211, 2007.
[12] N. A. Rose, *et al.*, "An Examination of the CRASH3 Effective Mass Concept," SAE Technical Paper Series 2004-01-1181, 2004.
[13] M. Sivak, *et al.*, "Radar-measured Reaction Times of Unalerted Drivers to Brake Signals," *Perceptual and Motor Skills,* vol. 55, p. 594, 1982.
[14] S. J. Brunson, *et al.*, "Alert Algorithm Development Program NHTSA Rear-End Collision Alert Algorithm Final Report," DOT HS 809 526, 30 September 2002.
[15] K. D. Kusano and H. C. Gabler, "Potential Occupant Injury Reduction in Pre-Crash System Equipped Vehicles in the Striking Vehicle of Rear-end Crashes," *Ann Adv Automot Med,* vol. 54, pp. 203-14, 2010.
[16] T. A. Gennarelli and E. Wodzin, "AIS 2005: a contemporary injury scale," *Injury,* vol. 37, pp. 1083-91, Dec 2006.
[17] P. J. Blau, *Frictional Science and Technology: from Concepts to Applications*, 2nd ed. Boca Raton, FL: CRC Press, 2009.
[18] H. Franck and D. Franck, *Mathematical Methods for Accident Reconstruction: A Forensic Engineering Perspective*. Boca Raton, FL: CRC Press, 2010.
[19] J. S. Baker, *Traffic Accident Investigation Manual*, 1st ed.: The Traffic Institute, Northwestern University, 1975.
[20] C. E. Hampton and H. C. Gabler, "Evaluation of the Accuracy of NASS/CDS Delta-V Estimates from the Enhanced WinSmash Algorithm," *Ann Adv Automot Med,* vol. 54, pp. 241-52, 2010.

PROGRESS REPORT ON EVALUATION OF A PRE-PRODUCTION HEAD-ON CRASH AVOIDANCE ASSIST SYSTEM USING AN EXTENDED "SAFETY IMPACT METHODOLOGY" (SIM)

R. M. Van Auken
J. W. Zellner
J. Y. Silberling
Dynamic Research, Inc.
United States of America
Yoichi Sugimoto
Yoshihiro Urai
Honda R&D Co., Ltd.
Japan
Paper Number 11-0270

ABSTRACT

NHTSA reported that in 2006, 9.8% of fatal crashes and 4.1% of injury crashes were head-on crashes (Traffic Safety Facts 2006). Honda has developed a pre-production Head-on Collision Avoidance Assistance System (H-CAAS) intended to detect, warn and mitigate specific crash types, including a severe, primary crash type in which the subject vehicle drifts laterally into the path of an on-coming vehicle, typically as a result of driver inattention (due to, e.g., distraction, drowsiness or alcohol impairment). The goal of this research is to estimate H-CAAS safety benefits, at a national level, focusing on both primary and secondary technology relevant crash types (TRCT's). This paper provides a progress report on the evaluation of US-level safety benefits of H-CAAS, based on the Safety Impact Methodology (SIM) tool developed by Honda and DRI and extended under Cooperative Agreements with NHTSA, as well as a description of recent extensions of the SIM itself. The SIM developed by Honda and DRI applies computer simulations of the driver-vehicle-environment, involving time-space relationships between the subject vehicle and a collision partner, and predicts crash, injury and fatality outcomes, with and without the Advanced Collision Avoidance Technology (ACAT) countermeasure, for a sample of NASS/CDS cases; and a systems model to extend the sample results to the national level, in order to estimate effectiveness and safety benefits of the countermeasure in terms of crash, injury, and fatality reductions. Data sources include NHTSA FARS, NASS/CDS, GES, and PCDS accident data; vehicle parameter and exposure data (e.g., from Polk vehicle registration data); and countermeasure-specific data from objective tests. For the H-CAAS evaluation, results from previous driving simulator objective tests involving n=9 distracted drivers and n=10 drowsy drivers were used to parameterize, calibrate and validate the SIM tool. The SIM was then used to estimate US-level safety benefits of H-CAAS. Results of extending the SIM include the addition of a simplified head-on accident reconstruction module which takes into account the generally large closing speeds, approximately 180 degree relative heading angles and the relatively small lateral offsets and drift rates of sampled head-on crashes; and substantial upgrades of the Guided Soft Target collision partner test system, in terms of a more realistic 2nd generation soft body and greater operating speed and range. The extensions to the SIM have resulted in a more robust, accurate and widely applicable suite of tools for estimating safety benefits of advanced safety technologies at a national level. A limitation of the SIM tool is that the uncertainty bounds associated with the estimates include some but not all sources of uncertainty.

INTRODUCTION

NHTSA has reported that 9.8% of fatal crashes and 4.1% of injury crashes in 2006 were head-on crashes [1]. Therefore Honda has developed a pre-production Head-on Collision Avoidance Assistance System (H-CAAS) to address this crash problem. The H-CAAS is intended to detect, warn and mitigate specific crash types, including a severe, primary crash type in which the subject vehicle drifts laterally into the path of an on-coming vehicle, typically as a result of driver inattention (due to, e.g., distraction, drowsiness or alcohol impairment).

In parallel, Honda and Dynamic Research Inc. (DRI) have been developing and applying Safety Impact Methodology (SIM) tools to evaluate the effectiveness and benefits of various advanced technologies in avoiding and mitigating specific types of crashes [2][3]. These methods were recently extended and refined under two Cooperative

Agreements with NHTSA, entitled Advanced Crash Avoidance Technologies (ACAT) series I and II. The objectives of the ACAT-I program were: 1) to develop a standardized Safety Impact Methodology (SIM) tool to evaluate the effectiveness of advanced technologies in mitigating specific types of vehicle crashes; and 2) to develop and demonstrate objective tests that are used in the SIM to verify the safety impact of a real system. The objectives of the ACAT-II program were: 1) to extend the previously developed Safety Impact Methodology (SIM) tool used to evaluate the effectiveness of advanced technologies in avoiding or mitigating specific types of vehicle crashes; and 2) to further define, develop and demonstrate objective tests that are used in the SIM to verify the safety impact of a real system.

Final results from the ACAT-I program were reported in [4], with mid-term progress and final results summarized in [5] and [6].

This paper provides a mid-term progress report on the ACAT-II research program to refine the Honda-DRI ACAT-I SIM tool and to use this tool to estimate the H-CAAS safety benefits, at a US level. The final results from the ACAT-II program are planned to be reported in [7].

The Honda-DRI SIM, developed in response to these objectives comprises the following key steps and assumptions:

1. Access US crash databases such as NASS/Crash Data System (CDS), Pedestrian Crash Data System (PCDS) and naturalistic driving databases (e.g., [8]);
2. Using these databases, reconstruct the pre-crash, crash, and post-crash vehicle trajectories and driver control time histories of real crash and non-crash cases using an Automated Accident Reconstruction Tool (AART);
3. Based on the specific ACAT being evaluated, and using the typologies in these databases and a Technology-Relevant Case Specification tool, the ACAT designer identifies Technology-Relevant Crash Types (TRCTs);
4. Sample real reconstructed cases from within each TRCT for simulation and testing purposes, using a Case Sampling Tool;
5. From this sample, select "representative" cases for testing, using a Test Selection Tool;
6. Use the reconstructed time histories to specify each of the selected tests;
7. Use a Guided Soft Target (GST) as the collision partner (CP) in the Track tests to follow precisely the reconstructed CP trajectory [9];
8. Measure (the change in) impact conditions due to actions of the ACAT (both in tests and in computer simulations with the test sample), including the effects of drivers' interactions (which are modeled in the simulations based on the drivers' reactions in the tests);
9. Calibrate and validate the simulation results by correlating them with the test results, using quantitative criteria;
10. Refine the simulation to the extent necessary to meet the criteria as appropriate (i.e., refining parameters based on the collected test data);
11. Run the calibrated/validated simulations for all TRCT cases sampled in Step 4, above;
12. Based on the calibrated/validated simulation results, estimate the effectiveness (i.e., safety benefit) of the ACAT at the US level, in terms of indices such as Accident Ratio, Fatality Ratio, and Effectiveness, among others.

Within the ACAT programs, these steps are organized under several tasks including: definition of the SIM, definition of the advanced technology and the related safety area to be addressed, and development of objective tests for predicting safety benefits. Each of these tasks and highlights of the novel and comprehensive Honda-DRI SIM are described subsequently.

THE SAFETY IMPACT METHODOLOGY

NHTSA's Safety Impact Methodology framework [10] is illustrated in Figure 1. This framework comprises 22 different Functions (e.g., "Archival Data"). These functions are grouped into nine different activities illustrated by the large open boxes (e.g., "Data Usage"), which are also grouped into four main areas indicated by the box color coding (i.e., red, yellow, blue, and purple). Of the 22 different Functions, 11 Functions were implemented by the Honda-DRI SIM tool (Figure 2), the other 11 Functions would be accomplished "off-line".

Overview of the Honda-DRI SIM

The Honda-DRI SIM comprises four main modules as illustrated in Figure 2. The color coding of each module in Figure 2 corresponds to the color shading of the functions in Figure 1. The main SIM modules comprise:

1. Crash scenario database development tools to accomplish NHTSA Framework Functions 1, 2, 5, and 6;
2. Technology relevant case specification and case sub-sampling tools to accomplish Function 7;
3. A Crash Sequence Simulation Module (CSSM) to accomplish Functions 17 to 21; and
4. An Overall Safety Effects Estimator (OSEE) to accomplish Function 22.

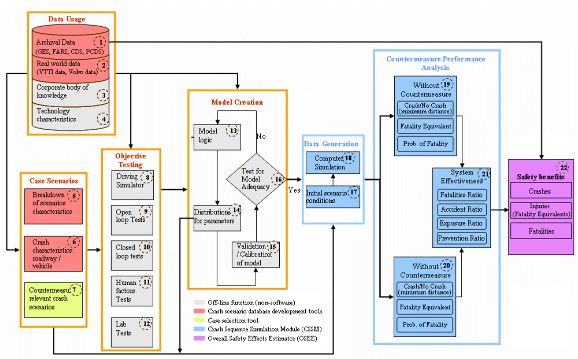

Figure 1. NHTSA ACAT SIM Framework [10]

Each of these modules in turn comprises a dozen or more sub-modules, within which the related functionalities and methods are implemented. The following describes some highlights and features of the main modules and some of the sub-modules.

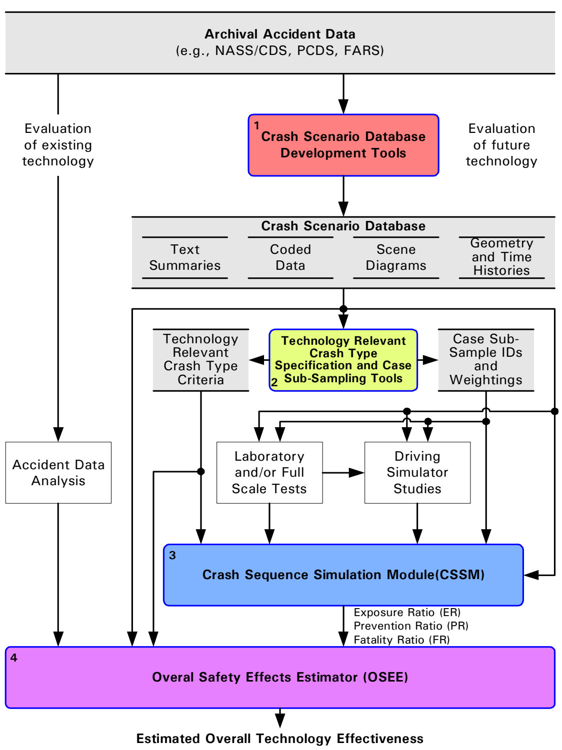

Figure 2. Honda-DRI SIM Tool Modules

Crash Scenario Database Development Tools (Module 1)

There are three main steps that are used to construct the crash scenario database from the archival US DOT accident data (Module 1) as illustrated in Figure 3. The "Crash Scenario Data Extraction and Assembly Tools" extract a set of crash scenarios weighted to US annual levels, comprising text summaries and coded data, from hierarchical US DOT accident data [11][12][13][14]. The resulting coded dataset comprises one record for each vehicle involved in a crash. A "Scene Diagram Download Tool" is then used to extract scene diagrams from the NASS website for each of the CDS and PCDS crash cases. Finally, the geometry and trajectory time histories of the vehicles, collision partners, and occluding objects are digitized and reconstructed using the scene diagrams and an "Automated Accident Reconstruction Tool" (AART) and ancillary digitizing tools. The latter are further described subsequently.

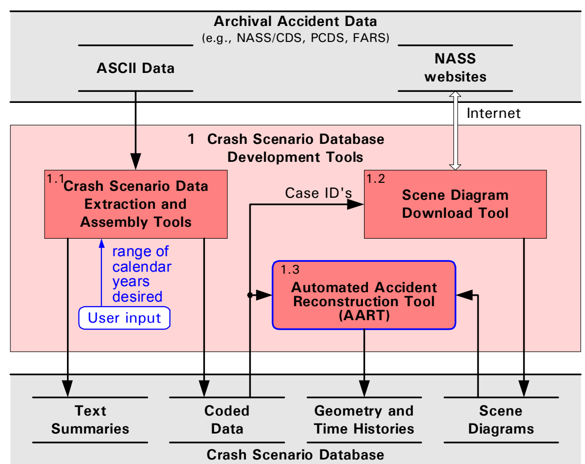

Figure 3. Crash Scenario Database Development Tools

Automated Accident Reconstruction Tool (Module 1.3)

The unique AART estimates plausible pre-crash, crash and post-crash time-space relationships of the crash involved vehicles and fixed objects based on the coded data and scene diagram for each accident. It comprises an interactive Graphical User Interface (GUI) which enables the user to digitize the pre-impact, point-of-impact, and point-of-rest locations for the crash involved vehicles. Specialized versions of the AART were developed for 1) NASS CDS and PCDS crashes involving one or two vehicles, or one vehicle with a pedestrian, with 3-dof (planar) motions and a single impact event; 2) a simplified AART for head-on crash cases that are assumed or known to involve a low lateral acceleration drift; and 3) a version to reconstruct the subject vehicle trajectories in VTTI near-crash cases based on the available GPS, speed, and acceleration data.

The AART assumes that the ground plane is horizontal and the vehicles do not pitch or roll and remain in contact with the ground with force equal to their respective weights. Therefore the vehicles move in a horizontal plane with 3 degrees-of-freedom (2 horizontal transitional degrees of freedom and 1 rotational (i.e., yaw) degree-of-freedom) each. It is further assumed that the dynamic motions of each vehicle during the crash sequence comprise three phases. These phases are as follows:

- Pre-impact phase where the vehicle dynamics are dominated by lateral and longitudinal forces produced by rolling tires under quasi-steady state neutral steer conditions and where the steering rate is assumed to be a stochastic random variable; which can be approximated by a quasi-steady 4th order vehicle directional control model;
- Impact phase where the vehicle dynamics are dominated by forces resulting from contact with a single vehicle or fixed object; which can be reconstructed using the WinSMASH Damage Algorithm based on vehicle damage information [15] (provided sufficient information is available) and/or fit to the US DOT Crash Victim Simulator/US Air Force Articulated Total Body (ATB) program [16][17]. The ATB program can then be used to simulate and predict changes in the crash Delta-V based on changes in the crash geometry and vehicle speeds;
- Post-impact phase where the vehicle dynamics are assumed to comprise constant translational and angular deceleration until the vehicle comes to rest (i.e., the translational and angular velocities immediately after impact decrease to zero at a constant rate).

These three phases are separated in time by the initial point-of-impact ($POI^{(-)}$), point-of-separation ($POI^{(+)}$), and point-of-rest (POR), as illustrated in Figure 4.

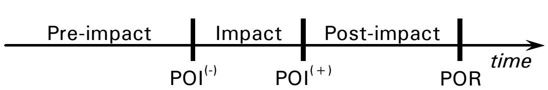

Figure 4. Assumed Crash Phases for Vehicle Dynamics

It is also assumed that the longitudinal vehicle acceleration and corresponding speed vs time can be separated into phases as illustrated in Figure 5. It was assumed that the longitudinal pre-crash acceleration during pre-impact phases can be approximated by up to three different constant acceleration levels which are functions of the coded CDS data for "attempted avoidance maneuver." "pre-event movement", and "road-surface condition." It is also assumed that the initial speed is either the "police reported travel speed" if it is known, or the "speed limit" plus 7 km/h if the police reported travel speed is unknown (based on data in [18]).

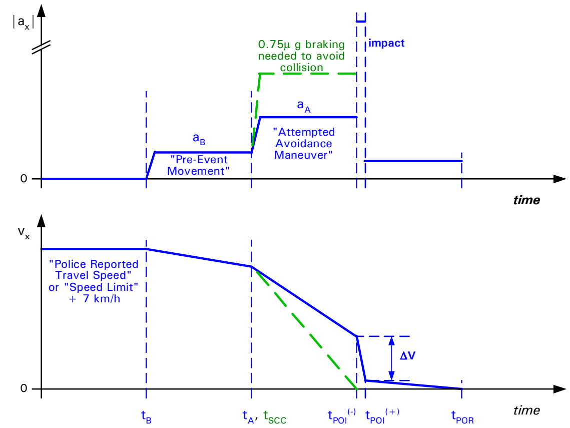

Figure 5. Assumed speed profile (NASS AART)

The change in acceleration is assumed to occur at times t_B and t_A as illustrated in Figure 5. The t_A time nominally corresponds to the Safety Critical Conflict time (t_{scc}). The t_{scc} was defined for the purpose of this tool as the time at which if the driver began braking and/or steering at 0.75 g times the coefficient of friction (mu) then the crash could be avoided.

Pre-crash Phase It is assumed during the pre-crash phase that each vehicle is neutral steering (i.e., has zero cornering compliance and understeer gradient) and the quasi-steady equations of motion for each vehicle are therefore [19]:

$$\begin{aligned} \dot{X} &= u\cos\psi - v\sin\psi \\ \dot{Y} &= u\sin\psi + v\cos\psi \\ \dot{\psi} &= r = \frac{u}{a+b+u^2K_u}\delta_w \end{aligned} \quad (1.)$$

and

$$v = u\beta \approx r\left(b - u^2D_r\right) \quad (2.)$$

where

$$K_u = D_f - D_r \tag{3.}$$

and where

X and Y are the coordinates of the vehicle cg in the inertial (ground) frame,
ψ is the heading of the vehicle in the inertial frame,
u and v are the longitudinal and lateral components of the vehicle velocity in the vehicle frame,
r is the yaw rate of the vehicle,
δ_w is the average steer angle of the front wheels,
a and b are the distances between the vehicle c.g. and the front and rear axles respectively,
D_f and D_r are the front and rear cornering compliances, and
K_u is the understeer gradient.

It is furthermore assumed for the current evaluation that the vehicles have neutral steering with no lateral slip, therefore D_f, D_r and K_u are zero.

It is also assumed that the time derivative of the front wheel angle ($\dot{\delta}_w(t)$) is a stochastic random (white noise) process such that

$$\begin{aligned} E\left(\dot{\delta}_w(t)\right) &= 0 \\ E\left(\dot{\delta}_w(t)\dot{\delta}_w(t+\tau)\right) &= \delta(\tau) \end{aligned} \tag{4.}$$

where $E(x)$ is the expected value of x and $\delta(\tau)$ is the Dirac function. This assumption means that the front wheel angle has a $1/s^2$ power spectral density, which is typical of human operator control activity. Therefore the assumed steering angle tends to have relatively large low frequency components and small high frequency components necessary to follow the reconstructed path.

Impact Phase The impact phase is assumed to be a single impact event beginning at $POI^{(-)}$ and ending at $POI^{(+)}$, which is ultimately modeled by a time-domain ATB crash simulation. Therefore the time between $POI^{(-)}$ and $POI^{(+)}$ is typically a small finite value, and the distance the vehicles travels in this period is also a small finite value. The ATB simulation also assumes that each vehicle has a single mass segment with an 8th order hyper-ellipsoid shape (i.e., rectangular solids with slightly rounded corners). All vehicles and objects are constrained to move without vertical, pitch, or roll degrees-of-freedom.

The 3-DOF AART also closely fits the Delta-Vx and Delta-Vy results to the WinSMASH Delta-V values in the CDS database (i.e., a "Delta-V Constraint"), provided there is sufficient coded information (e.g., damage data) to calculate the WinSMASH collision force moment arm (h) as illustrated in Figure 6. The WinSMASH damage algorithm assumes that: the time between $POI^{(-)}$ and $POI^{(+)}$ is very short and can be neglected, and the distance the vehicles travel in this period is small and can be neglected, and each vehicle is rectangular in rectangular plan view. It is further assumed that the net effects of the differences in the ATB and WinSMASH assumptions are relatively small, and can be addressed by varying the vehicle-vehicle contact friction and coefficient-of-restitution in the ATB simulation to fit the WinSMASH result. This fitting process is accomplished in a "batch" preprocessor for a user selected range of calendar years. Detailed equations are in [7].

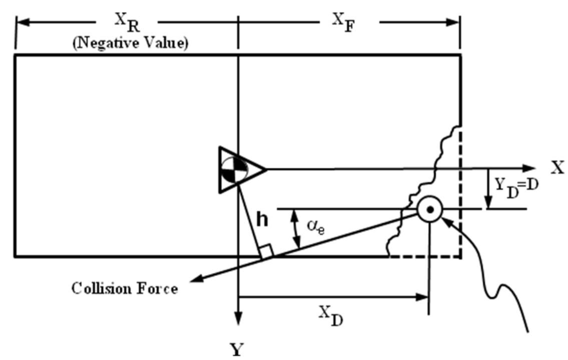

Figure 6. WinSMASH Damage and Collision Force Moment Arm

Post-Impact Phase It is assumed that the tires of each vehicle after impact separation are sliding without rolling (e.g., locked or damaged wheels or suspension) during the post-impact phase, resulting in constant horizontal forces and yaw moments acting on the vehicle. Therefore the vehicle has constant translational and angular deceleration from $POI^{(+)}$ to POR (i.e., the translational and angular velocities after impact decrease to zero at a constant rate).

3-DOF NASS AART – Based on the assumed equations of motion for each phase, the solution steps are as follows:

1. Fit an initial "reference trajectory" for the vehicles ($\mathbf{x}_0(t)$) comprising a pre-impact phase with constant steer angles and speeds

(i.e., the $\delta_{w,0}(t)$ for each vehicle are constant, resulting in constant turn radius for each vehicle with neutral steering), impact phase (using the pre-computed ATB results from the WinSMASH/ATB batch preprocessor if available), and post-impact phase.

2. Determine the linearized state-space equations of motion of the vehicles ($\mathbf{x}(t)$) relative to the reference trajectory $\mathbf{x}_k(t)$, i.e.,

$$\Delta\mathbf{x}_k(t) = \mathbf{A}_k(t)\Delta\mathbf{x}_k(t) + \mathbf{B}_k(t)\Delta\dot{\delta}_{w,k}(t) \qquad (5.)$$

where, $\Delta\mathbf{x}_k(t) \hat{=} \mathbf{x}(t) - \mathbf{x}_k(t)$, $\Delta\delta_{w,k}(t) \hat{=} \delta_w(t) - \delta_{w,k}(t)$, and k is an iteration number.

3. Estimate a trajectory innovation ($\hat{\delta}_w(t)$, $\Delta\hat{\mathbf{x}}_k(t)$) using a Kalman Filter-Smoother with the pre-impact, POI, and POR locations as "measurements" [20].
Update the reference trajectory based on the trajectory innovation according to the equations:

$$\hat{\mathbf{x}}_{k+1}(t) = \hat{\mathbf{x}}_k(t) + \alpha_k \Delta\hat{\mathbf{x}}_k(t) \qquad (6.)$$

$$\hat{\delta}_{w_{k+1}}(t) = \hat{\delta}_{w_k}(t) + \alpha_k \Delta\hat{\delta}_{w_k}(t) \qquad (7.)$$

where α_k is a relaxation factor for the k th iteration.

4. Repeat steps 2 through 4 for 10 iterations.
5. Estimate the safety critical conflict time and pre-impact speed profile based on the reconstructed vehicle paths, impact speeds, and coded CDS data (e.g., attempted avoidance maneuver, road surface condition), as illustrated in Figure 5.

Simplified H-CAAS AART – One of the requirements of the AART is that it should reconstruct plausible crashes. It was found that the 3-DOF AART tended to reconstruct head-on crashes with large lateral accelerations that were above the perceptual thresholds for typical drivers and likely to alert an inattentive driver before the crash. This is attributed to the typical placement of the vehicle symbols on the scene diagrams, which appeared to underestimate the pre-crash drift travel distance, and therefore overestimate the lateral drift acceleration. Therefore the pre-crash lateral g levels reconstructed by the 3-DOF AART, using the digitized pre-crash vehicle positions, were not considered plausible in head-on crashes involving low lateral drift accelerations which are typically assumed to occur in inattentive driver "drifting" into other lanes (i.e., they are sub-perceptual threshold).

The Simplified H-CAAS AART was therefore developed with the key assumption that the lateral acceleration is 0.05 g. This value was chosen because it is not noticeable kinesthetically in the absence of visual cues [21]. This small lateral drift acceleration was modeled as a constant external force acting on the vehicle, which would represent a crowning or super-elevation of the roadway, inadvertent steer input, crosswind, or any number of other events
The Simplified H-CAAS AART in effect reconstructs head-on crashes with 1 degree-of-freedom because the lateral acceleration and yaw rate are assumed to be constant during such an inattentive drift. This AART uses the subject vehicle's intended path in conjunction with the point-of-impact to determine the drift trajectory, as illustrated in Figure 7.

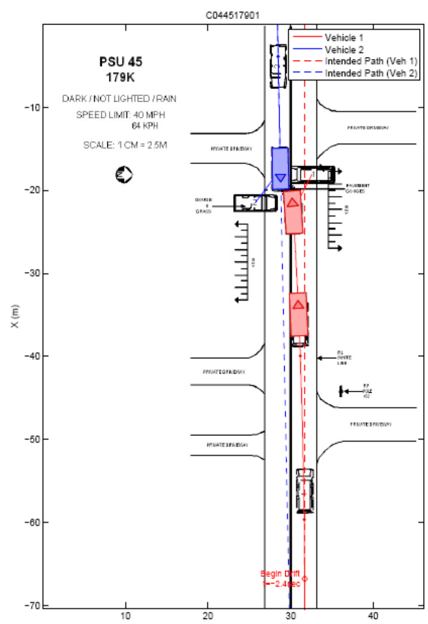

Figure 7. Scene Diagram with Intended Path and Subject Vehicle Drift using the Simplified H-CAAS AART

The Simplified H-CAAS AART determines the impact speed of the vehicles by fitting the longitudinal Delta-V, points-of-impact, and points-of-rest.

This version of the AART also estimates the pre-impact speeds of the vehicles using the data, in order of priority, listed in the second column of Table 1. The Simplified H-CAAS AART uses different data priorities in order to obtain more plausible timing of the collision partner driver emergency braking in response to the subject vehicle drifting across the lane boundary. The main difference from the 3-DOF AART algorithm is the assumption that each vehicle was traveling at the coded travel speed (if available) or at the speed limit plus 7 km/h is more reliable than the coded avoidance maneuver or pre-event movement.

Table 1.
3-DOF and Simplified H-CAAS AART Data Priority

3-DOF AART Data Priority Order	H-CAAS AART Data Priority Order
1. A crash occurred	1. A crash occurred
2. Inattentive driver or other cause	2. Inattentive driver or other cause
3. Delta-V	3. Delta-V
4. POI and POR locations	4. POI and POR locations
	5. Initial speed is: a) coded travel speed or b) speed limit + 7 km/h
5. Coded avoidance maneuver	6. Coded avoidance maneuver
6. Coded pre-event movement	7. Coded pre-event movement
7. Initial speed is: a) coded travel speed or b) speed limit + 7 km/h	

Promoting the initial speed data above the coded avoidance and pre-event movement allows the AART to reconcile apparent inconsistencies in the coded data by changing the assumed acceleration levels for the pre-event and avoidance maneuvers.
The Simplified H-CAAS AART has the ability to reconstruct head-on crashes where the vehicles are originally traveling on either a straight or curved path. However, the 3-DOF AART is recommended for reconstruction of cases with more complicated vehicle trajectories.

Technology Relevant Case Specification and Case Sub-Sampling Tools (Module 2)

The "technology relevant case specification" and "case sub-sampling" tools illustrated in Figure 8 enable the user to formalize the descriptions of the technology relevant crash categories based on the technical description and intent of the ACAT and select a sub-sample of cases for simulation and testing purposes. The result of applying these tools is a set of criteria in terms of NHTSA Universal Descriptors [22] and other coded variables and vehicle specific values (e.g., the Critical Precrash Event= "This vehicle traveling over the lane line on left side of travel lane" and the NASS Accident Type = "Same Trafficway Opposite Direction") that describe each ACAT-specific technology relevant category. A list of cases and resulting weightings is then automatically randomly sampled and generated that comprise a representative sub-sample of cases for each technology relevant category, for which scene diagrams existed and geometry and time histories had been reconstructed, for simulation purposes.

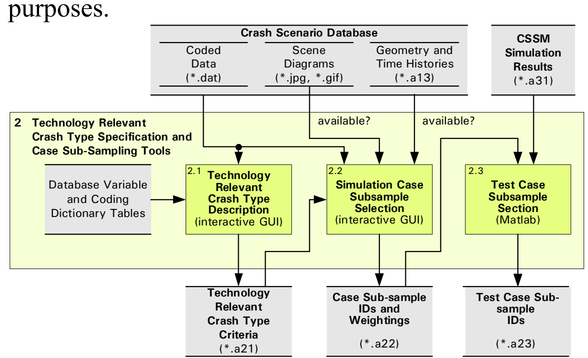

Figure 8. Technology Relevant Crash Type Specification and Case Sub-Sampling Tools

Crash Sequence Simulation Module (Module 3)

The "Crash Sequence Simulation Module" (CSSM) illustrated in Figure 9 is a unique time domain simulation of the driver, the vehicle (with and without ACAT) and the environment, in order to predict the relative effects of the ACAT and assumed driver behaviors on crash occurrence and injury consequences in real-world crash scenarios.

One of the main elements of the CSSM is the NASA MIDAS-based driver model [23], which is indicated as Module 3.6 in Figure 9. This driver model comprises long term memory, sensing/perception, working memory, and motor response functions, as illustrated in Figure 10 and implemented in NASA's APEX programming environment [24]. Long term memory comprises declarative knowledge and procedural knowledge, such as vehicle steering and speed control procedures. Some of these procedures have vehicle, situation, and behavior specific knowledge (e.g., vehicle-dependant feedback gains and open-loop responses) that it is assumed the driver has "learned" prior to each simulation being run and which is based on experimental data.

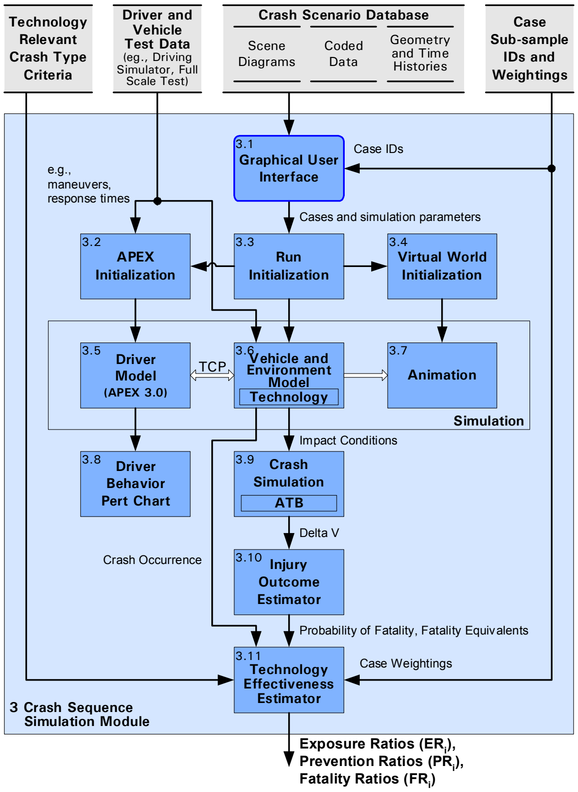

Figure 9. Crash Sequence Simulation Module

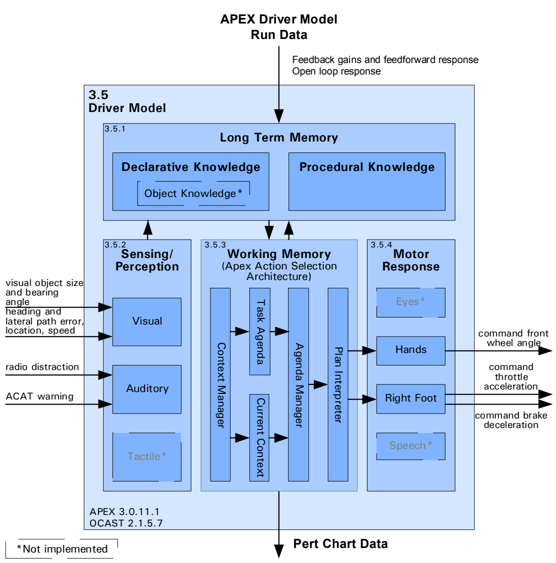

Figure 10. NASA MIDAS-based Driver Model

Other CSSM submodules are the

- ATB crash simulation to compute the crash Delta-V based on the impact speeds and geometry (Module 3.9);
- Injury Outcome Estimator to estimate the Subject Vehicle (SV) and CP driver injury Fatality Equivalents (FE) and Probability of Fatality (POF) (Module 3.10); and a
- Technology Effectiveness Estimator (3.11)

The Technology Effectiveness Estimator estimates the Exposure, Prevention, Injury and Fatality Ratios (ER, PR, IR, and FR) for each technology relevant crash category based on the simulation results as follows:

$$ER_i = \frac{\tilde{S}_{W_i}}{\tilde{S}_{WO_i}} \qquad (8.)$$

$$ER_i \times PR_i = \frac{\tilde{A}_{W_i}}{\tilde{A}_{WO_i}} \qquad (9.)$$

$$ER_i \times PR_i \times IR_{p,i} = \frac{\widetilde{FE}_{p,W_i}}{\widetilde{FE}_{p,WO_i}} \qquad (10.)$$

$$ER_i \times PR_i \times FR_{p,i} = \frac{\tilde{F}_{p,W_i}}{\tilde{F}_{p,WO_i}} \qquad (11.)$$

where

$\tilde{S}_{W_i}$ and $\tilde{S}_{WO_i}$ are the estimated number of conflicts with and without the ACAT,

$\tilde{A}_{W_i}$ and $\tilde{A}_{WO_i}$ are the estimated number of crashes with and without the ACAT,

$\widetilde{FE}_{p,W_i}$ and $\widetilde{FE}_{p,WO_i}$ are the estimated number of injury Fatality Equivalents for person type "*p*," with and without the ACAT, and

$\tilde{F}_{p,W_i}$ and $\tilde{F}_{p,WO_i}$ are the estimated number of fatalities for person type "*p*," with and without the ACAT,

ER_i is the estimated Exposure Ratio,

PR_i is the estimated Prevention Ratio,

$IR_{p,i}$ is the estimated Injury Ratio for person type "*p*,"

$FR_{p,i}$ is the estimated Fatality Ratio for person type "*p*,"

for TRCT "i." Ratios less than 1 are desirable.

The *p* person types are the subject vehicle driver and collision partner person, which is either the driver of the other vehicle or a pedestrian (Note: the H-CAAS does not address pedestrian crashes).

In the current example evaluation, it was assumed that the H-CAAS does not affect the number of conflicts (i.e., it is not intended to be a conflict avoidance system), and therefore $ER_i = 1$.

The number of crashes with and without the ACAT in each TRCT was estimated from the CSSM Driver-Vehicle-ACAT-Environment simulation results according to the equations:

$$\widetilde{A}_{W_i} = \sum_{k \in \{TRCT_i\}} w_k \left(\sum_j P_{W_j} n_{W_{k,j}} \right) \quad (12.)$$

$$\widetilde{A}_{WO_i} = \sum_{k \in \{TRCT_i\}} w_k \left(\sum_j P_{WO_j} n_{WO_{k,j}} \right) \quad (13.)$$

where

- w_k is the US level case weighting for the *k*th simulated crash scenario,
- P_{W_j} and P_{WO_j} are the probabilities of the *j*th driver-behavior combination occurring (e.g., Driver "273a") with and without the ACAT, determined by Driving Simulator test results,
- $n_{W_{k,j}}$ and $n_{WO_{k,j}}$ are the crash outcomes in the *k*th crash scenario with and without the ACAT for the *j*th driver-behavior combination.

This module is described in further detail in [4][7].

Overall Safety Effects Estimator (Module 4)

The Overall Safety Effects Estimator is a uniquely powerful, integrated tool for estimating the combined effects of multiple, complimentary or redundant ACATs on the number of crashes and fatalities based on technology effectiveness functions, crash scenarios, and retrospective and forecasted data [3]. The technology effectiveness functions describe the exposure, prevention, and fatality ratios (ER, PR, FR) vs technology relevant category criteria. These functions are based on results from the CSSM and other a-priori knowledge (e.g., published literature and statistical accident data analyses for existing technologies such as side airbags [25]) expressed as mathematical functions of the relevant human, vehicle, environment and accident factors. Retrospective data sources include FARS and GES accident databases [11][14] and R.L. Polk & Co. National Vehicle Population Profile® vehicle registration data [26].

The results from the OSEE are used to estimate the size of the problem, technology effectiveness, and benefits according to the equations [22]:

$$B = N_{WO} - N_W \quad (14.)$$

$$B = \sum_i B_i = \sum_i N_{WO_i} \times E_i \quad (15.)$$

where

- B is the benefit (which can be the number of crashes, number of fatalities, or other such measures);
- N_{WO} is the value of this measure (e.g., the number of crashes) that occurs without the system;
- N_W is the value of the measure with the system fully deployed;
- "i" is an index referring to individual scenarios;
- E_i is the effectiveness of the system in reducing the value of the measure (e.g., fatalities) in a specific crash-related scenario;
- N_{WO_i} is the baseline value of the measure in individual scenario "i" ; and
- B_i is the benefit in each of the individual scenarios.

The OSEE also estimates the uncertainty in the results due to some, but not all, sources of variation as follows:

- The number of fatalities from the FARS databases, for a given make, model, body type, model year, and calendar year.
- The number of vehicles involved in accidents from the GES databases, for a given make, model, body type, model year, and calendar year.

These uncertainty calculations are described in further detail in [4].

Extensions of the SIM in the ACAT-II Program

The Honda-DRI SIM tools described herein includes several modifications and refinements as part of the NHTSA-DRI-Honda ACAT-II program. These modifications and refinements include initially planned extensions and additional extensions identified during the program in order support the H-CAAS evaluation.

The refinements that were made to the crash scenario database development tools in Module 1 include:

- Extending the data extraction modules to support more recent data (e.g., 2007 calendar year CDS data);
- Add vehicle parameter data for more recent calendar year vehicles;
- Add Universal Descriptor variables for TRCT description;
- Add "DOCTRAJ" and other variables to the crash scenario dataset, as needed for the reconstructable case criteria;
- Calculate and add the WinSMASH moment arm and other supporting variables to the crash scenario dataset, as needed for the "Delta-V constraint."

Refinements made to the AART (Module 1.3) include:

- Add "DOCTRAJ" check to the reconstructable case criteria;
- Develop a "Delta-V constraint" preprocessor for the NASS 3-DOF AART based on WinSMASH Delta-V, moment arm; integrate solution into the 3-DOF AART; and numerous other minor refinements;
- Develop a new Simplified H-CAAS AART in order to reconstruct head-on crashes involving inadvertent drifting;
- Expansion of Safety Critical Conflict (SCC) Time to include braking and/or steering maneuvers.

Refinements made to Module 2 include:

- Adding support for Universal Descriptors

Refinements made to the CSSM (Module 3) include:

- Extending the vehicle steering model to include steering wheel torque
- Implemented driver behavior data for drowsy and/or impaired drivers;
- Implemented an unintentional lateral drift as determined by the H-CAAS AART
- Added a driver "intended path" feedback control recovery phase after the avoidance maneuver.

Refinements made to the OSEE (Module 4) include:

- Update FARS and GES data to the 2008 calendar year;
- Update vehicle parameters for newer model year Honda and Acura vehicles;
- Develop an MS Excel workbook to extend the OSEE modeled fleet results for a given model year and calendar year to the entire US light passenger vehicle fleet in the same calendar year; and to estimate the technology effectiveness by H-CAAS TRCT and by non-technology specific crash types. (Also used in ACAT-I).

ADVANCED TECHNOLOGY AND SAFETY AREAS THAT THE H-CAAS ADDRESSES

The Head-on Crash Avoidance Assist System (H-CAAS) illustrated in Figure 11 is an active safety technology that automatically predicts particular types of head-on collisions, warns the driver, and applies gentle steering torque in order to help the driver to avoid the collision, as illustrated in Figure 12. The current speed, brake pressure, steering angle, steering torque, and yaw rate of the driver's vehicle are used in combination with radar data giving the position of other objects and vehicles in the environment, to determine whether a collision seems imminent.

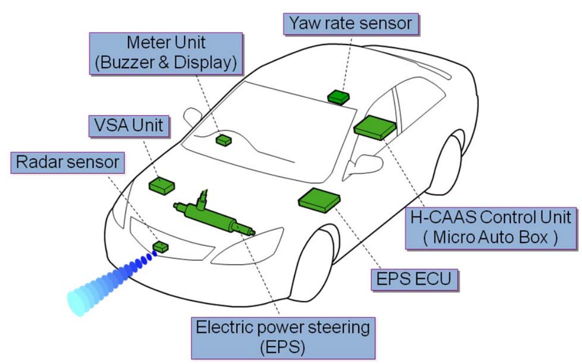

Figure 11. H-CAAS System Configuration

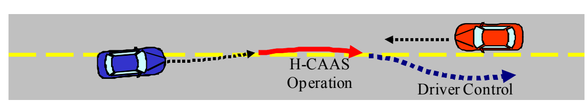

Figure 12. Operation of the Proposed H-CAAS

The operation scenario for the H-CAAS is illustrated in Figure 13. The system differentiates between what it estimates to be intentional driver actions and what it estimates to be unintentional "drifting" of the Subject Vehicle. If the Subject Vehicle begins drifting left into opposing traffic, possibly as the result of inattentive (e.g., distracted, drowsy and/or impaired) driving, and if an oncoming vehicle is sensed, then the H-CAAS applies a small steering torque to the right (away from opposing traffic) and provides an audible sound, both of these being intended to warn the driver, and which cannot directly control the vehicle. The driver then reacts to these warnings and steers the vehicle back onto its intended path in order to avoid the collision. The H-CAAS also provides steering torque to assist the driver's avoidance maneuver. Note that the system does not operate for drifting rightward into opposing traffic, which is not typical in the US.

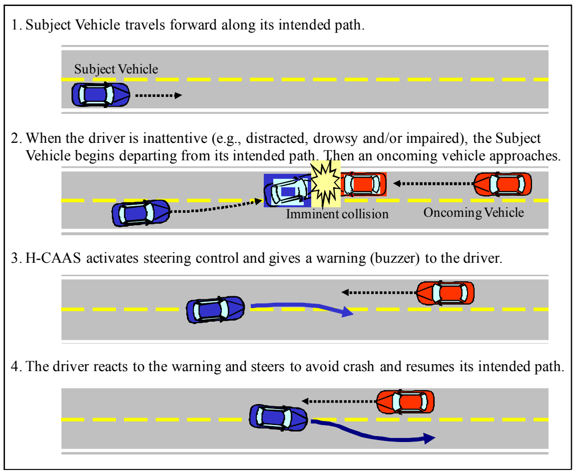

Figure 13. Proposed H-CAAS Operation Scenario

In addition to the steering torque and warnings (audible, visual, and tactile), the H-CAAS can apply automatic braking using an integrated Head-on Collision Mitigation Braking System (H-CMBS). The H-CMBS is a part of the H-CAAS and will be treated as an integrated feature of the H-CAAS. The H-CMBS is designed to apply braking, when it is determined that a collision cannot be avoided, in an effort to reduce the impact speed of the Subject Vehicle.

Note that the H-CAAS is still undergoing pre-production tuning and testing. The specification and performance of the production system may vary from the settings of the pre-production system being evaluated in this project.

For this evaluation the Honda H-CAAS designers have identified one Primary and six Secondary Technology Relevant Crash Types (TRCTs) in terms of coded database variables for which the system is expected to have some benefit. All of the H-CAAS TRCTs are crashes involving:

- two vehicles,
- the Weather is not Snow,
- the Road Condition is not Ice,
- the Initial Speeds of the subject vehicle (SV) and collision partner (CP) (if known) are both greater than or equal to 30 km/h,
- the Attempted Avoidance Maneuver of the subject vehicle is any except no driver present,
- the NASS Accident Type is Same Traffic Way, Opposite Direction, and
- any First Harmful Event.

The Primary TRCT is further specified as:

- the SV Movement Prior to the Critical Event is going Straight, and
- the Critical Precrash Event is the SV traveling over the lane line on the left side of the travel lane.

The six secondary TRCTs are similar to the primary TRCTs, but have more allowable coded values for the SV Movement Prior to the Critical Event, and the Critical Precrash Event, as described in [7].

OBJECTIVE TESTS FOR PREDICTING SAFETY BENEFITS

This section provides an overview of the innovative objective tests proposed for the purposes of ACAT SIM model parameterization, calibration and validation.

Test Case Selection Criteria

The objective of the Driving Simulator and Track tests is to parameterize, calibrate and validate the driver, vehicle and ACAT models over the range of conditions for which the ACAT is expected to function and to be effective. This is accomplished by selecting test cases from within each primary TRCT. The test case selection criteria for driver-not-in-the-loop and driver-in-the-loop tests are based on the value of several key variables at the Safety Critical Conflict time as described in [4] and [5]. However, for the H-CAAS evaluation, the definition of the Safety Critical Conflict time was extended to include steering and braking, such that it is defined herein to be the last time in the period before impact that the subject vehicle can brake and/or steer at 0.75 g x the coefficient of friction (mu) of the road surface and either avoid the collision or stop.

Description of Objective Tests

There are 3 categories of objective tests, each of which is designed to provide the information needed for the evaluation of the ACAT (Table 2). These objective tests include laboratory tests, vehicle tests, Track tests, and Driving Simulator tests. For the H-CAAS evaluation, the Driving Simulator test data from a previous study of a similar technology were used.

Table 2.
Summary of Categories, Purposes and Approximate Number of Tests

Category of test	Type of test	Facility	Key indices to be measured	Number of Tests
ACAT Warning	Compo-nent	Lab	Warning locations, magnitudes and spectra	10 tests (5 luminance, 3 audible, 15 steer pulse tactile, 2 safety belt pretension)
Vehicle	Compo-nent	Lab	Vehicle dimensions, weight, etc.	3 tests(a
	Driver-not-in-The-loop	Track	Vehicle response to driver controls	37 tests(a
Driver-Vehicle-ACAT	Driver-in-the-loop	Driving Simulator	Typical drivers response delays and magnitudes	20 typical drivers x 5 conditions x 3 repeats = 300 tests

Laboratory Test – A series of laboratory tests were conducted for the ACAT-I program to measure the characteristics of the ACAT warnings as they are experienced by a vehicle driver during a potential conflict event. The results of these tests were used to calibrate and validate the driving simulator setup, as well as to provide parameters for the CSSM warning and display model that is sensed by the CSSM driver model. These tests include audible, visual, and tactile warning tests. These tests are further described in [4].

Vehicle Tests – These tests include vehicle parameter tests, which are designed to measure the vehicle parameters including mass, wheelbase, track, length, and longitudinal CG location. The vehicle tests also include vehicle dynamics tests, which are used measure the vehicle response characteristics to various driver and ACAT inputs. For the H-CAAS evaluation, these tests were expanded to include measurements of steering torque as a function of vehicle speed and steering wheel angle. These tests are further described in [4] and [7].

Track Tests – These tests would typically include driver-not-in-the-loop and driver-in-the-loop test. Driver-not-in-the-loop tests are vehicle/ACAT tests which are used to calibrate the Driving Simulator models. Driver-in-the-loop tests are driver/vehicle/ACAT tests which measure the expert driver's response to the ACAT and are used to calibrate the Driving Simulator. For the H-CAAS evaluation, this testing was not necessary to accomplish because there were no H-CAAS Driving Simulator tests to calibrate. However, the foam vehicle body of the Guided Soft Target (GST) test system was refined to achieve a more realistic vehicle form as show in Figure 14. In addition, the associated inter-vehicle communications network was upgraded so as to have a greater operational range, to at least 1 km.

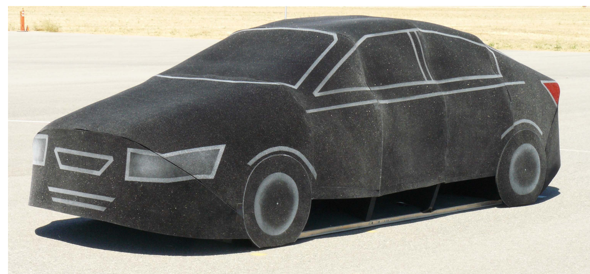

Figure 14. Guided Soft Target Foam Vehicle Body and Dynamic Motion Element

Driving Simulator Tests – In lieu of new Driving Simulator testing based on H-CAAS specific scenarios, Driving Simulator data from a previous study were used to generate driver parameters for use in the CSSM. Honda R&D Company, Ltd. made available the test data and results of a previous Driving Simulator study (Figure 15) for a prototype Collision Avoidance Assist System (CAAS) which operates in a manner similar to H-CAAS and which considered the effects on both distracted drivers and drowsy drivers. Since the CAAS and H-CAAS systems are very similar, the previous Driving Simulator study provided the best available data for identifying emergency driving parameters for use in the CSSM.

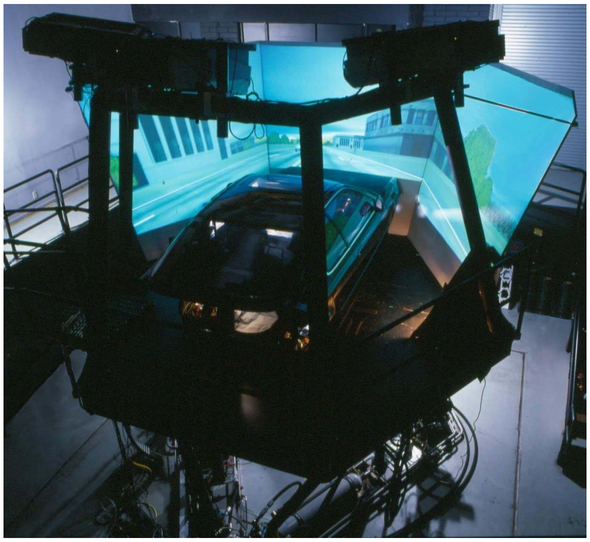

Figure 15. DRI Driving Simulator

The CAAS Driving Simulator study consisted of a sample of 20 typical driver participants. Half of the participants were in the "distracted" driver group and the other half were in the "drowsy" driver group. Both distracted and drowsy driver participants experienced the same conflict scenario, in which the subject vehicle is leaving the lane into oncoming traffic, on a trajectory which would lead to a head-on collision. This lane departure was induced by instantaneously re-positioning the subject vehicle while the participant was inattentive. The CAAS operation would then alert the driver to the impending collision and the driver would react accordingly as illustrated in Figure 16.

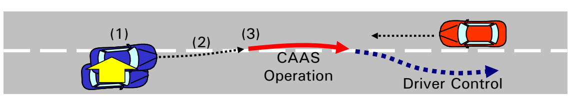

Figure 16. CAAS Conflict Scenario

<u>Driver Behavior Model Parameter Extraction</u> – The emergency braking and steering maneuvers for the Driving Simulator participants were parameterized in order to implement them into the CSSM in a repeatable manner. This was accomplished by first parameterizing the braking and steering maneuvers as illustrated in Figure 17 and Figure 18. The typical steering emergency maneuver consisted of an emergency steering response and then a recovery phase during which the driver re-positioned the vehicle in the center of the initial travel lane. This response is the reason for the asymmetric steering profile in Figure 18.

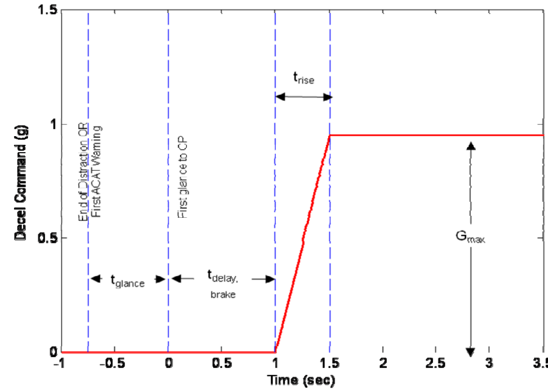

Figure 17. Parametric Form of the Assumed Driver Emergency Braking Procedure

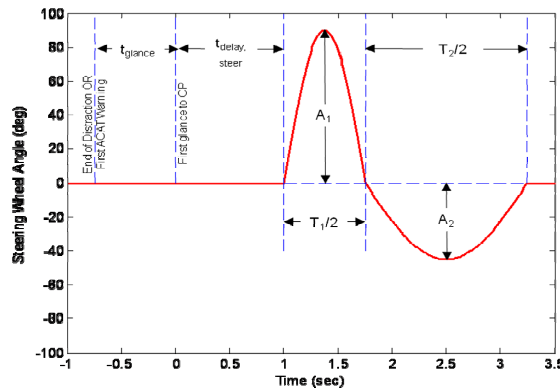

Figure 18. Parametric Form of the Assumed Driver Emergency Steering Procedure

After the responses were parameterized, the responses for the first two valid exposures for each participant were selected to be used in the H-CAAS evaluation. An exposure was classified as invalid if the participant glanced at the roadway before the CAAS warning, or if the parameterized fit was poor ($r^2 < 0.85$). If a driver did not have two valid exposures, the results from that driver were not used. This process resulted in 26 emergency responses consisting of two runs each for 8 of the distracted participants and 5 of the drowsy participants.

A review of published literature was also conducted in order to determine the feasibility of determining parameters for an alcohol impaired driver. This review concluded that there was insufficient published data available to determine the driver parameters with the detail required for the CSSM.

CONCLUSIONS

The Advanced Crash Avoidance Technology (ACAT) programs are proof-of-concept efforts that seek to determine the feasibility of developing estimates of effectiveness for specific safety technologies in the absence of data from real world crashes or field operational tests. The progress to date in this ACAT-II program has substantially extended and refined the methodology that could be used to estimate the safety benefits of the particular crash countermeasure evaluated in this research project.

The extended and refined Safety Impact Methodology (SIM) tool is planned to provide an estimate of safety benefits of a prototype Honda Head-On Crash Avoidance Assist System (H-CAAS) in terms of reduction in crashes and fatalities. The SIM methodology and overall safety benefits and effectiveness results are planned to be described in more detail in the ACAT-II final report [7].

REFERENCES

[1] Anon., Traffic Safety Facts 2006.

[2] Sugimoto, Y., and Sauer, C.W., "Effectiveness Estimation Method for Advanced Driver Assistance System and its Application to Collision Mitigation Brake System," Paper No. 05-0148-O, 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington, June 6-9, 2005.

[3] Suzuki, H., et al., "Development of a Prototype Safety Analysis System to Assess and Forecast Vehicle Safety," Technical Paper 2006-01-0718, SAE, Warrendale, PA, 2006.

[4] Van Auken, R.M, et al., Advanced Crash Avoidance Technologies (ACAT) Program – Final Report of the Honda-DRI Team, Volume I: Executive Summary and Technical Report, DOT HS 811 454, Accomplished by Honda and DRI for the National Highway Traffic Safety Administration, Washington, Forthcoming.

[5] Zellner, J.W., et al., "Extension of the Honda-DRI "Safety Impact Methodology" (SIM) for the NHTSA Advanced Crash Avoidance Technology (ACAT) Program and Application to a Prototype Advanced Collision Mitigation Braking System," Technical Paper 2009-01-0781, SAE, Warrendale, PA, 2009.

[6] Van Auken, R.M., et al., "Extension of the Honda-DRI Safety Impact Methodology for the NHTSA Advanced Crash Avoidance Technology (ACAT) Program and Application to the Evaluation of an Advanced Collision Mitigation Braking System – Final Results of the ACAT-I Program," Technical Paper 2011-01-0581, SAE, Warrendale, PA, 2011.

[7] Zellner, J.W., et al., Advanced Crash Avoidance Technologies (ACAT) II Program – Volume I: Executive Summary and Technical Report, Accomplished by Honda and DRI for the National Highway Traffic Safety Administration, Washington, Forthcoming.

[8] Dingus, T. A., et al., The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment, DOT HS 810 593, Accomplished by Virginia Tech Transportation Institute, for National Highway Traffic Safety Administration, Washington, April 2006.

[9] Kelly, J., Broen, P., Silberling, J., Bozin, N., Zellner, J., "Development of a Guided Soft Target for Crash Avoidance Technology Evaluation," SAE Technical Paper 2011-01-0580, 2011.

[10] Carter, A.A., Burgett, A., Srinivasan, G., Ranganathan, R., "Safety Impact Methodology (SIM): Evaluation of Pre-Production Systems," Proceeding of the 21st International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 09-0259, Stuttgart, June 2009.

[11] Tessmer, J.M., FARS Analytic Reference Guide 1975 to 2006, National Highway Traffic Safety Administration, Washington, DC, 2006

[12] Anon., National Automotive Sampling System Crashworthiness Data System, 2000 Coding and Editing Manual, National Highway Traffic Safety Administration, Washington, 2000.

[13] Anon., National Automotive Sampling System (NASS) Pedestrian Crash Data Study, 1996 Data Collection, Coding, and Editing Manual, National Highway Traffic Safety Administration, Washington, 2002.

[14] Anon., National Automotive Sampling System (NASS) General Estimates System (GES), Analytical Users Manual (1988-2008), National Highway Traffic Safety Administration, Washington, 2009.

[15] Tsongos, N., Crash 3 Technical Manual, National Highway Traffic Safety Administration, Washington, 1986.

[16] Fleck, J.T., and Butler, F.E., Validation of the Crash Victim Simulator, Vol. 1: Engineering Manual – Part 1: Analytical Formulation, DOT HS 806 279, US DOT, Washington, 1981.

[17] Obergefell, L.A., Gardner, T.R., Kaleps, I., and Fleck, J.T., Articulated Total Body Model Enhancements, Harry G. Armstrong Aerospace Medical Research Laboratory, AAMRL-TR-88-009, January 1988.

[18] Anon., "Special Issue: Speed," Status Report, Vol. 43, No. 1, 31, Insurance Institute for Highway Safety, January 2008.

[19] Bundorf, R.T., and Leffert, R.L., "The Cornering Compliance Concept for Description of Vehicle Directional Control Properties," Technical Paper 760713, Society of Automotive Engineers, Warrendale, PA, 1976.

[20] Bryson, A.E., and Ho. Y.C., Applied Optimal Control, Revised Printing, Hemisphere Publishing, Washington, 1975.

[21] Young, L.R., "On Adaptive Manual Control," Ergonomics, Vol. 12, No. 4, pp. 635-675, 1969.

[22] Burgett, A., Srinivasan, G., and Ranganathan, R., A Methodology for Estimating Potential Safety Benefits for Pre-Production Driver Assistance Systems, DOT HS 810 945, National Highway Traffic Safety Administration, Washington, May 2008.

[23] Hart, S.G., Dahn, D., Atencio, A., and Dalal, K.M., "Evaluation and application of MIDAS v2.0," Technical Paper 2001-01-2648, SAE, Warrendale, 2001.

[24] Anon., APEX Reference Manual 3.0 Beta, NASA Ames Research Center, 2005.

[25] Braver, E., Kyrychenko, S., Efficacy of Side Airbags in Reducing Driver Deaths in Driver-Side Collisions, Insurance Institute for Highway Safety, August 2003.

[26] Anon., "National Vehicle Population Profile®," Source: Copyright © 2002, R. L. Polk & Co., 2004.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AART	Automated Accident Reconstruction Tool
ACAT	Advanced Crash Avoidance Technology
APEX	NASA software for human behavioral modeling
ATB	Articulated Total Body (computer program)
CAAS	Crash Avoidance Assist System (a predecessor to the H-CAAS)
CDS	Crashworthiness Data System (accident database)
CP	Collision Partner
CSSM	Crash Sequence Simulation Module
Delta-V	Change in velocity
ER	Exposure Ratio
FARS	Fatality Analysis Reporting System (fatal accident database)
FE	Fatality Equivalent (injuries)
FR	Fatality Ratio
GES	General Estimates System (accident database)
GST	Guided Soft Target
H-CAAS	Head-on Crash Avoidance Assist System
H-CMBS	Head-on Crash Mitigation Braking System
IR	Injury Ratio
MIDAS	Man-machine Integration Design and Analysis System (NASA human operator model)
OSEE	Overall Safety Effects Estimator
PCDS	Pedestrian Crash Data System (accident database)
POF	Probability of fatality
$POI^{(-)}$	Point-of-impact
$POI^{(+)}$	Point-of-separation
POR	Point-of-rest
PR	Prevention Ratio
NASS	National Automotive Sampling System
SIM	Safety Impact Methodology
SV	Subject Vehicle
TRCT	Technology Relevant Crash Type

Proposal for a Test Procedure of Assistance Systems regarding Preventive Pedestrian Protection

Walter Niewöhner
DEKRA Automobil GmbH, Accident Research Stuttgart
Germany
Franz Roth
Audi
Dr. Johann Gwehenberger
Allianz Center for Technology
Christian Gruber
BMW
Matthias Kuehn
German Insurers Accident Research
Raimondo Sferco
Ford Motor Company Europe
Claus-Henry Pastor
Federal Highway Research Institute
Uwe Nagel
Daimler
Michael Stanzel
Volkswagen

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ABSTRACT

This paper is showing a proposal for a test procedure regarding preventive pedestrian protection based on accident analysis.

Over the past years pedestrian protection has become an increasing importance also during the development phase of new vehicles. After a phase of focusing on secondary safety, there are current activities to detect a possible collision by assistance systems. Such systems have the task to inform the driver and/or automatically activate the brakes. How practical is such a system? In which kind of traffic situations will it work? How is it possible to check the effectiveness of such a system? To test the effectiveness, currently there are no generally approved identifiable procedures. It is reasonable that such a test should be based on real accidents. The test procedure should be designed to test all systems, independent of the system's working principle. The vFSS group (ad**v**anced **F**orward-looking **S**afety **S**ystems) was founded to develop a proposal for a technology independent test procedure, which reflects the real accident situation. This contribution is showing the results of vFSS.

The developed test procedure focuses on accidents between passenger cars and pedestrians. The results are based on analysis results of in-depth databases of GIDAS, German insurers and DEKRA and added by analysis of national and international statistics. The in-depth analysis includes many pre-crash situations with several influencing factors. The factors are e. g. speed of the car, speed of the pedestrian, moving direction and a possible obscuration of the pedestrian by an object. The results comprise also the different

situations of adults and children. Furthermore, they include details regarding influence of the lighting conditions (daylight or night) especially with respect to the accident consequences. In fact, more accidents happen at daylight, but fatal accidents are more often at night.

A clustering of parameter combinations was found which represents typical accident scenarios. There are six typical accident scenarios which were merged in four test scenarios. The test scenarios are varying the starting position of the pedestrian, the pedestrian size (adult or child) and the speed of the pedestrian, whereas the speed of the car will not be varied. To ensure the independency from used sensing technologies it is necessary to use a suitable dummy. For example, if sensors are based on infrared, the dummy should emit the temperature of a human being.

The test procedure will identify the collision speed as the key parameter for assessing the effectiveness of the tested system. The collision speed is defined as the reduction between initial test speed of the car and impact speed. The assessment of the speed reduction value regarding the safety benefit, however, will be part of a separate procedure.

INTRODUCTION

The pedestrian protection has become an increasing importance. In the first phase there was a focus on secondary safety which led to intensified activities in this area at the front of the vehicles. The extended possibilities of sensing technologies and improved performance of data processors in combination with better knowledge about the accident causes allows the development of driver assistance systems also for pedestrian accidents.

An advanced driver assistance systems (ADAS) is not only designed to avoid an accident. It includes also the possibility to reduce accident consequences by e.g. reducing the impact speed. There are different possibilities which could be the warning of an inattentive driver or an automatic braking manoeuvre. The action of an ADAS depends on the traffic situation and also on the implemented philosophy. Just the philosophy of the ADAS is an important point.

Depending on the time to collision the system has the task to inform the driver and/or to activate the brakes. How practical is such a system? In which kind of traffic situations will it work? Is such a system fulfilling the expectations of a driver?

So far an independent test standard to verify the system reliability and effectiveness is missing. Specific tests for special systems cannot generate comparable results. Thus a test standard mirroring real accidents is required.

In the future there will be definitely procedures to test ADAS. Based on this fact several companies decided to work together to develop proposals for test procedures for selected ADAS. The companies Allianz Center for Technology (AZT), Audi, Federal Highway Research Institute of Germany (BASt), BMW, Daimler, DEKRA, Ford, GDV, Honda, KTI, Opel, Porsche, Toyota and Volkswagen work together in the working group vFSS (Ad**v**anced **F**orward-looking **S**afety **S**ystem). The target of the group is to develop proposals for test procedures for forward-looking safety systems based on the results of accident analysis. The test procedure should be independent from used sensing technologies. The first focus of vFSS is on preventive pedestrian protection and forward collision warning/avoidance systems. This contribution is explaining how the proposal of test protocol regarding preventive pedestrian protection was developed.

DATABASIS

The results of the vFSS accident analysis are based on different sources. vFSS used published from European projects as well as public available statistics from Germany. The used In-Depth databases were GIDAS, UDV, and AZT supplemented by analysis of the DEKRA Database. These are described below.

Official Road Traffic Accident Statistics

Federal statistics are continuously maintained on accidents in which fatalities or material damage have been caused as a consequence of road traffic on public roads and open spaces. They serve to produce an up-to-date, comprehensive and reliable database on the structure and development of road accidents; Section 1 (Law on Statistics of Road Traffic Accidents) [1]. The published German statistics are prepared by the Federal Statistical Office of Germany (StBA).

GIDAS Database

GIDAS (German In-Depth Accident Study) is a joint project conducted by the Federal Highway Research Institute (BASt) and the Research Association of the Automotive Technology (FAT) of the VDA. The project makes available detailed and statistically representative data of real-life road accidents in Germany. The accident location is in the conurbation of Hanover or Dresden. The accidents are collected during a survey shift (specific random sample scheme) if at least one person injured.

The GIDAS project has recorded around 3,000 individual facts on each of approximately 2,000 accidents annually since 1999. The GIDAS Database currently comprises 19,000 accidents with 33,500 involved vehicles and a total of 47,500 persons.

The defined random sampling procedure and the use of weighting factors enables the GIDAS Database to give a representative reflection of those national accident statistics involving personal injury. The number of cases is so high that statistically significant results can be achieved. The high level of detail of the cases also enables in-depth investigations.

Accident Database of German Insurers Accident Research

The evaluated case material of the UDV is primarily comprised of the claim files of the insurers that are routinely drawn on a random sampling basis from the total number of all liability damage cases in Germany for the purpose of conducting accident research. The accidents here are accidents involving personal injury and damage of at least €15,000. They took place during the period 2001 - 2006.

The accident database (UDB) of the UDV contains 4,500 accidents with 8,200 victims.

Accident Database of Allianz Center of Technology

The Accident Database of the Allianz Technology Center (AZT) is comprised of the claim files of the Allianz insurance. The claims files are selected on a random sampling basis from the total number of the 1.5 million yearly liability damage cases. The cases used are accidents involving personal injury.

The accident database of the AZT contains more than 20,000 accidents containing 1,750 with involved passenger cars.

DEKRA Accident Database

DEKRA maintains a national network of road accident analysis experts. Accident reconstruction reports are prepared primarily for the courts, public prosecution services, police and insurance companies. DEKRA Accident Research has access to these reports. The cases were selected on a random basis, analysed and added to an accident database..

The database currently contains about 3,000 accidents.

ACCIDENT ANALYSIS

The accident analysis is primarily based on German accident data. The results of the analysis are supplemented by existing results from the UK and results of publications coming from the European project SafetyNet [3].

General Statistics

In 2008 in Germany all together 320,614 accidents leading to personal injuries were registered. 413,524 persons were injured within these accidents (4,477 fatally injured + 70,644 severely injured + 338,403 slightly injured persons). Most of the accidents occurred at daylight (Figure 1, n=299,526). The share of persons injured during the night is accounting for less than one third (Figure 2, n=113,237). Thus three out of four persons get injured during daylight. A view to the pedestrians shows a ratio of two injured pedestrians at daylight to one during night time (22,272 at daylight in relation to 11,151 at night). An additional view to the fatally injured pedestrians shows a differing ratio. There were 256 fatalities at daylight in relation to 397 under dark lighting conditions (Figure 3 + Figure 4).

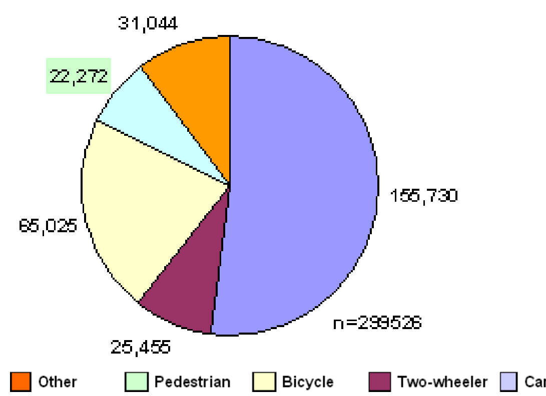

Figure 1 Persons injured by road accidents under daylight conditions in Germany 2008[2]

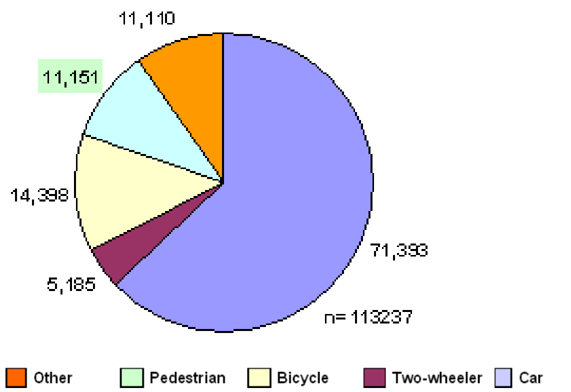

Figure 2 Persons injured by road accidents under night conditions in Germany 2008, source StBA

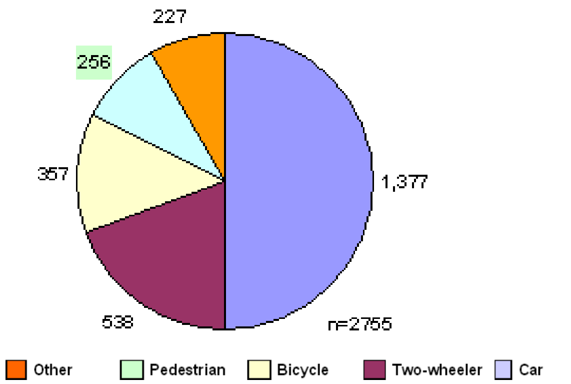

Figure 3 Road accident fatalities under daylight conditions in Germany 2008, source StBA

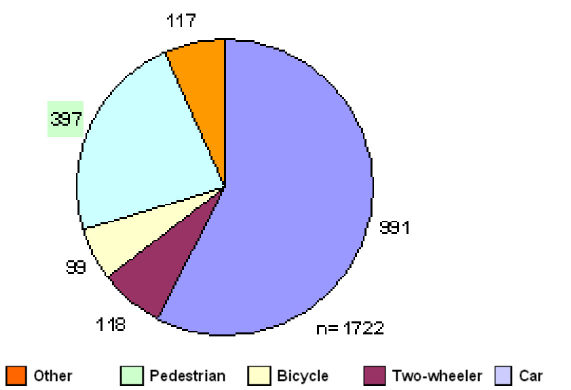

Figure 4 Road accident fatalities under night conditions in Germany 2008, source StBA

Analysing the German 2008 road accident statistics for the location of the fatal accidents under night conditions the rural areas show the highest frequency (Figure 6 + Figure 5, n=1,000). The number of fatalities in urban areas is accounting for 490 and thus roughly half of the urban figures. 231 persons were killed on motorways. They add to approximately one quarter of the urban figures. Looking to the pedestrian fatalities they show a clearly differing pattern. Nearly 50% of all fatalities in urban areas under night conditions are pedestrians (241 of 490), whereby the share in rural areas is less than one seventh (130 of 1,000).

The German figures of 2008 also show the significantly higher share of fatal injured pedestrian in the winter months from November to January with long nights and short days, Table 1. In the monthly average 82 pedestrians were fatally injured in November, December and January. This is nearly twice the figure of the remaining months with 45 fatalities. 182 of the 246 November to January accidents occurred under night conditions (74%).

The European pedestrian accident statistics show a similar correlation. The mean value of 18 European countries for pedestrians killed under night conditions is 52.6%, Figure 7.

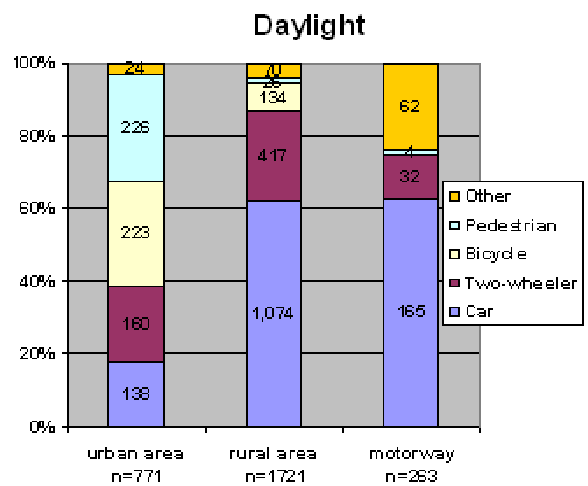

Figure 5 Road accident fatalities under daylight conditions split to the different locations in Germany 2008, source StBA

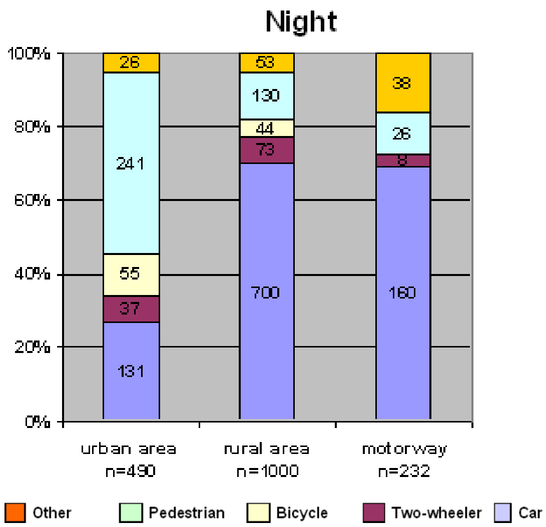

Figure 6 Road accident fatalities under night conditions split to the different locations in Germany 2008, source StBA[2]

Table 1 Distribution of fatally injured pedestrians in Germany 2008, source StBA

	2008	
Total	653	100%
Nov … Jan	246	38%
Monthly mean value Feb … Oct	45	
Monthly mean value Nov … Jan	82	
Nov … Jan	246	100%
Darkness	182	74%
Age >65y.	135	55%

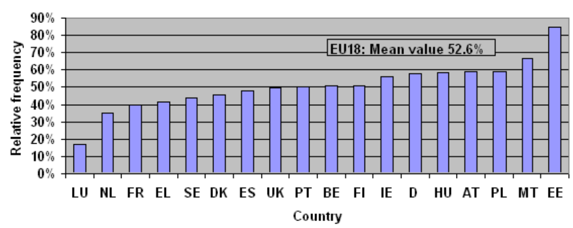

Figure 7 Share of fatally injured pedestrians under night conditions for 18 European Countries [3]

In-Depth Analysis

The results of GIDAS, UDB, AZT and DEKRA complete the knowledge given by the reports.

All sources show nearly the same typical scenarios for the accidents between passenger cars and pedestrians. These scenarios include crossing with and without obstruction. Some also mention "Turning accidents" and/or "Accidents along the carriageway". All results show that the "crossing accidents without obstruction" include the highest share,Table 2. The crossing accident with obstruction is on the second rank in most analysed sources.

As shown above the lighting conditions play an important role. Roughly 60% of the GIDAS and UDV car against pedestrian accidents occurred under daylight conditions, as shown in Figure 8. The higher level of accident severity under night conditions is corroborated by the GIDAS data. Looking at the crossing accidents the share of fatalities doubles from daylight to night conditions, Figure 9. The total number of crossing accidents under daylight accounts for about twice the figure as under night conditions.

Table 2 Shares of selected accident situations of different data sources (100% all frontal collisions between passenger cars and pedestrians), source GIDAS, UDB, AZT [4].

	GIDAS n=1,065	UDV n=243	AZT n=30	UK (APROSYS)
Crossing without obstruction	60	59,8	71	58,6
Crossing with obstruction	27	11,0	13,2	17,9
Turning	7	21,2	10,5	
Along carriageway in/against direction	3	8	5,3	11,1

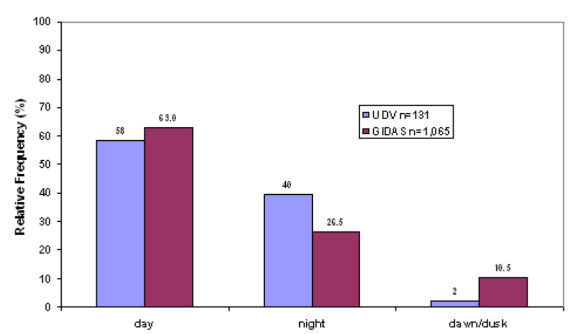

Figure 8 Distribution of lighting conditions of UDV and GIDAS car-pedestrian accidents

The most frequent contact area in car to pedestrian collisions is the vehicle's front (60%). The left (right) side of the car is hit in 11% (12%). The rear end collisions account for 13%. Most of the pedestrians (92%) hit by the vehicle's front are crossing a road, 59.8% without a view obstruction and additional 11% with a view obstruction. Some pedestrians (8%) are hit by a car while they are walking along the carriageway. The remaining 21.2% of the pedestrians collide with a turning car. The working group vFSS is focusing the frontal collisions, which are the basis for the following analysis. The analysis of the UDB led to the accident scenarios displayed in Figure 10.

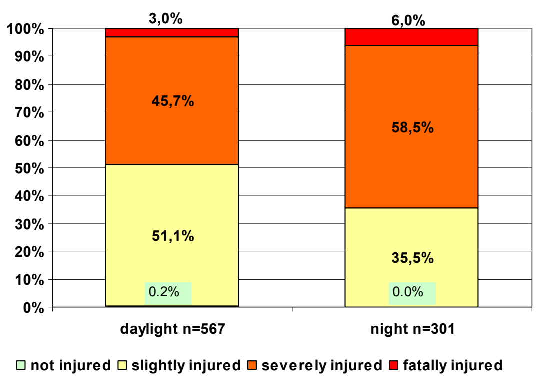

Figure 9 Injury severity of the pedestrians in crossing accidents, source GIDAS

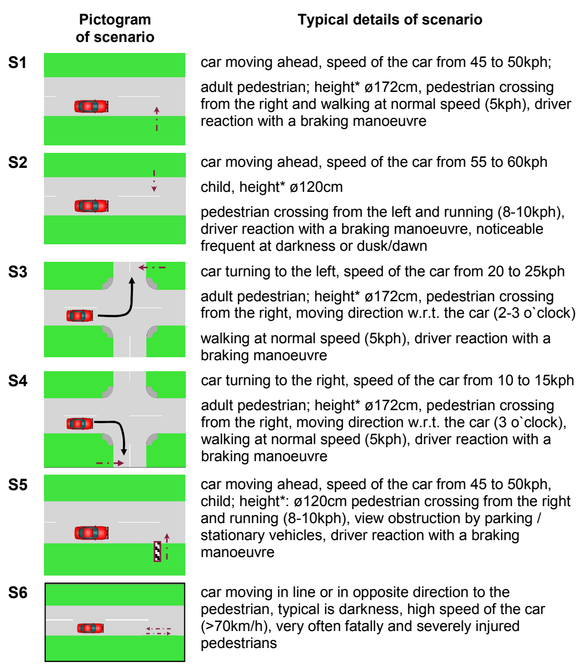

Figure 10 Typical car to pedestrian accident scenarios, source UDB

A special analysis carried out within the German "AKTIV" project resulted in three typical accident scenarios. The GDV scenarios S1 and S2 are summarized in AKTIV scenario F1, the scenarios S3 and S4 in F3. The scenario S5 is included in F2.

Remarkable is the high proportion of scenario S2 occurring under night conditions, Figure 10. The details of the scenarios mentioned in are a summary of the total results. The mentioned figures for speeds and body heights are the typical values. The spread of course is a lot larger.

The risk of injury severity varies from scenario to scenario, Table 3. This table is only showing the shares of the listed scenarios. There are missing figures, which are caused by not listed scenarios. The scenario S2 includes 60% of the fatally, 30% of the severely and 18% of the slightly injured of the pedestrians. Together the scenarios S1 and S2 cover two third of all severe or fatal injuries caused by a frontal collision with a passenger car.

Table 3 Share of accident scenarios subdivided into the accident consequences, source UDB

	share of injuries		
Scenario	fatally injured	severely injured	slightly injured
S1	16	39	24
S2	60	30	18
S3	0	13	13
S4	0	3	0
S5	15	6	4

The kind of obstruction is often another vehicle. The GIDAS data show a share of 42.5% of accidents with a sight obstruction including 30.5% obstructions by a vehicle, Figure 11. There is an important question. Was the driver able to brake and if yes how strong? The analysis show roughly the same share of braking manoeuvres at day and night, but the achieved deceleration is lower during the night, Figure 12. Combined with the higher initial speeds (Figure 13) the impact speeds at night are clearly higher, Figure 14. This is of course one important influencing factor regarding the higher accidents consequences at night.

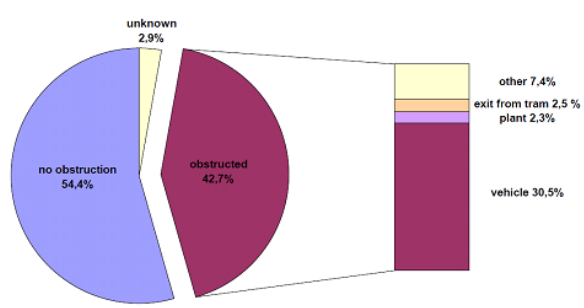

Figure 11 Share and kind of obstructions of car against pedestrian accidents, source GIDAS.

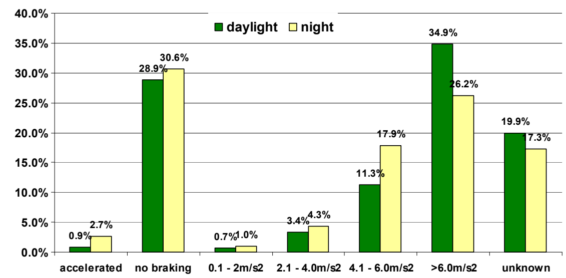

Figure 12 Deceleration of passenger cars in crossing accidents (n=868), source GIDAS

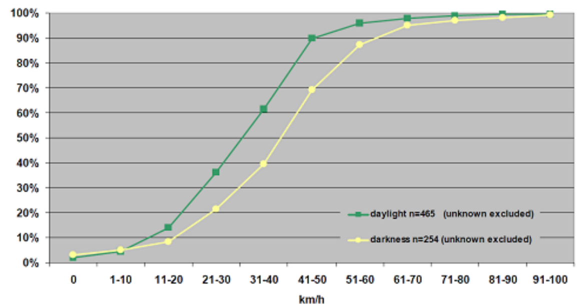

Figure 13 Initial speed of passenger cars in crossing accidents, source GIDAS

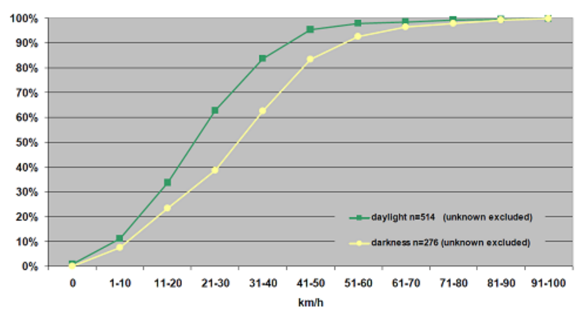

Figure 14 Impact speed of passenger cars in crossing accidents, source GIDAS

The analysis of the pre-crash movement of the pedestrians displays that they are using several ways to reach the crossing point, Figure 15. Many of the pedestrians were standing at the borderline (41% on the right + 27% on the left side). Some walked along the sidewalk (right 7% + left 2%) and a small percentage (5%) moved at right angles to the lane. An important value for a possible sensing system is the time of the first visibility of the pedestrian and the collision (Time to Collision=TTC), Figure 16. It is obvious, that many of the just mentioned standing pedestrians are visible for a long time. Therefore a high percentage for TTC=3.0s is comprehensible. Spreading the TTC-values to covered and uncovered pedestrians leads for uncovered pedestrians to a share of 70% visible pedestrians at TTC=3.0s, Figure 17.

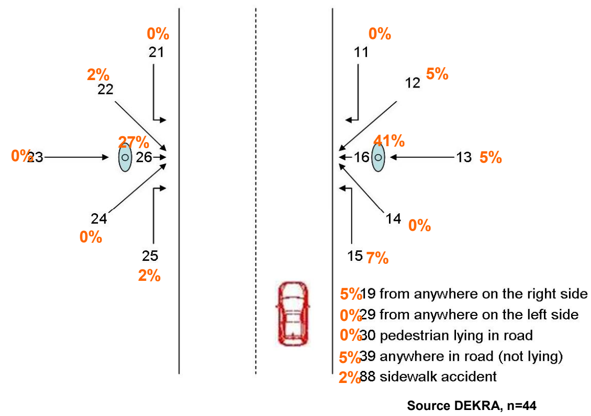

Figure 15 Pre-crash movement of pedestrians in car to pedestrian accidents, source DEKRA

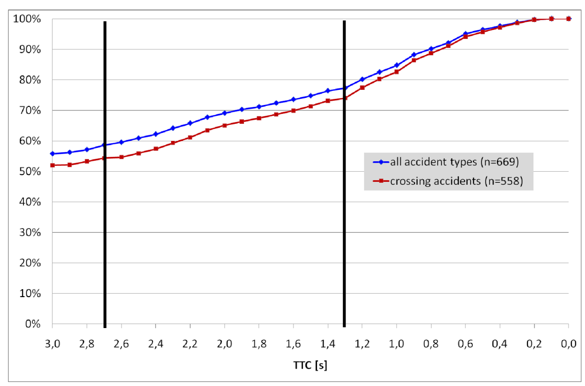

Figure 16 Cumulative frequency of TTC from the first point of pedestrian's visibility, source GIDAS

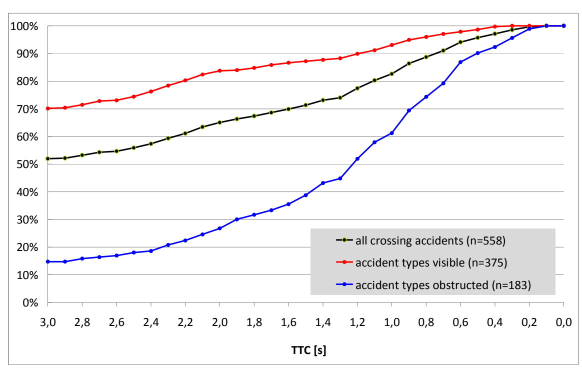

Figure 17 Cumulative frequency of TTC from the first point of pedestrian's visibility split in accident situations with and without obstruction, source GIDAS

TEST PROCEDURE

The accident analysis includes many interesting results. The task is to transfer these results in a proposal for a test procedure. The accident scenarios shown in Figure 10 are the basis of this procedure. The first point is to filter the most important ones.

An ADAS regarding pedestrians will get a symmetric layout, therefore the scenario S2 (pedestrian crossing from the left side) can be included in S1 (pedestrian crossing from the right side). The turning scenarios S3 + S4 are included in S5, because the sensing system will work as if the pedestrian is covered on a straight road. Due to the large variety of single situations covered by scenario S6 and the comparable small absolute figures the scenario S6 was not included in the test procedure.

The main factors to be considered within the test scenarios are the pedestrian's body height, walking speed and the presence or absence of an obstacle. This results in the four test scenarios (TS1 to TS4) shown in Figure 18 to Figure 21. The speed of the passenger car is fixed to 40km/h.

The TTC values of TS1 + TS2 are fixed to 1.3s, the TTC for TS3 + TS4 are 2.7s. The values were won within the accident analysis.

It is important to ensure that the procedure is independent from the sensing technology. This includes that the used pedestrian dummy is visible e.g. for a radar or an infrared sensor. It implements not, that there is one dummy which is covering all sensor systems. It is only necessary, that the testing institute has a dummy with the questioned attribute(s).

To avoid a systems application targeting a good test performance additional tests are foreseen. Those are developed in the scope of covering side influences like night conditions, other pedestrians walking along the side walk, or another car speed. The tested systems have to work reliable within these parameters.

The system test of the vehicle should be done 10 times for each proposed test scenarios I to IV. The system has to warn or to brake. The tests will deliver 10 valid measured values of the collision speed. The result of the test procedure will be the speed reduction (V_{RED}), which is the difference between test speed (40 km/h) and impact speed. The results of the V_{RED} will be used in a separate assessment procedure to receive a comparative value.

TS1

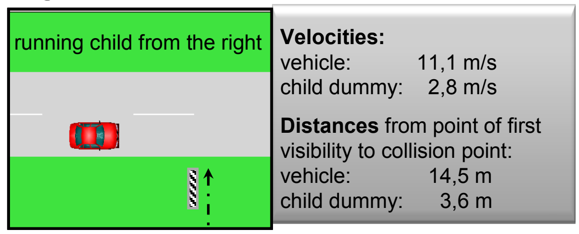

Figure 18 proposed procedure for covered running child

TS2

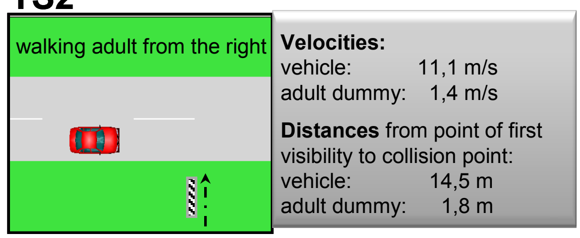

Figure 19 proposed procedure for covered walking adult

TS3

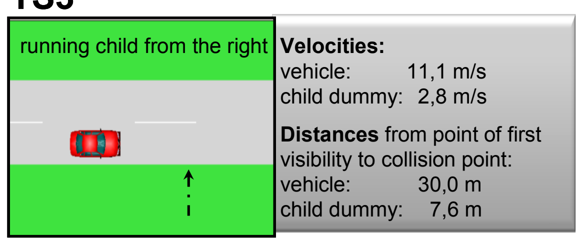

Figure 20 proposed procedure for uncovered running child

TS4

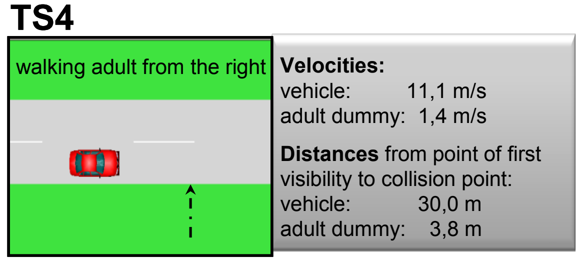

Figure 21 proposed procedure for covered walking adult

SUMMARY

Driver assistance systems have an important impact on road safety. With different system concepts and new working principles an independent test procedure is required to verify the benefit potential and to get comparable values.

To define such a test procedure several vehicle manufacturers, insurance companies, KTI and DEKRA, BASt found the vFSS working group. One main focus was set on systems for preventive pedestrian protection. A comprehensive analysis of the accident occurrence was carried out to figure out high risk situations to be covered by the test procedure.

Within the working group four test scenarios were defined. The test layout was designed in a way the full range of the different systems can be assessed. Thus also systems with a comparable low performance can pass the test albeit with a lower ranking. This is to not limit the tests to the premium class systems only. That way the systems can enter all vehicle classes and thus ensure a broad market penetration.

REFERENCES

[1] Gesetz über die Statistik der Straßenverkehrs-unfälle (Straßenverkehrsunfallstatistikgesetz – StVUnfStatG) vom 15. Juni 1990, (BGBl. I S. 1078)

[2] Statistisches Bundesamt (Federal Statistical Office of Germany), Fachserie 8 Reihe 7, yearly published.

[3] Traffic Safety Basic Facts 2007, Pedestrians, ERSO Safety Net, published Feb. 2008, Project co-financed by the European Commission, Directorate-General Energy and Transport

[4] APROSYS SP3, Definition of vehicle and pedestrian/cyclist impact location, technical report AP-SP31-001R-BASC, March 2005

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