BEHAVIORAL CHANGES AND USER ACCEPTANCE OF ADAPTIVE CRUISE CONTROL (ACC) AND FORWARD COLLISION WARNING (FCW): KEY FINDINGS WITHIN AN EUROPEAN NATURALISTIC FIELD OPERATIONAL TEST

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ABSTRACT

In the euroFOT project multiple Advanced Driver Assistance Systems (ADAS) were tested within a large-scale Field Operational Test (FOT) in Europe. Main objective of the project was the impact assessment of different ADAS on safety, traffic efficiency, environment, driver behaviour and user-acceptance in real life situations with normal drivers. The needed data was gathered by means of instrumented vehicles. Altogether, about 1000 vehicles from different manufacturers and with different advanced driver assistance systems took part in the FOT. The Institute of Automotive Engineering (ika) of the RWTH Aachen University analysed the effects of Adaptive Cruise Control (ACC) usage in combination with Forward Collision Warning (FCW) under normal driving conditions of 100 passenger cars. The results of the data analysis show positive effects on traffic safety and fuel consumption. In terms of traffic safety a reduction in number of incidents, harsh braking and critical time-headways were determined. These reductions can be attributed to changed distance behaviour of the drivers.

INTRODUCTION

One of the main challenges of road transport is the reduction of fatalities. The worldwide number of fatalities exceeds more 1.2 million per year (1). To identify possible approaches to improve traffic safety various initiatives were launched in Europe within the last years. One of these approaches is the wide deployment of Advanced Driver Assistance Systems (ADAS).
These systems are designed to support drivers in their daily driving routine by increasing driving comfort, safety and efficiency with regard to traffic flow as well as fuel consumption. In addition to different studies (2) Field Operational Tests (FOT) were conducted within the last few years that aim to investigate short- and long-term effects of ADAS under normal driving conditions. The first large-scale FOT for investigating effects of ADAS was started within the seventh framework program of the European Commission. Objective of the euroFOT project was to assess the impacts of eight different ADAS with regard to driver acceptance, traffic safety and efficiency as well as fuel consumption. All tested functions are in production and are integrated as such in the vehicles. Overall, about 1000 vehicles were used for data collection in the project.
This paper presents the results of the conducted analysis of the collected data of 100 passenger cars equipped with an Adaptive Cruise Control (ACC) and a Forward Collision Warning (FCW) function.

STATE OF THE ART

Field operational tests belong to experiments under realistic settings and are an important method to assess the impact of ADAS because of low controlling factors. This allows investigating the naturalistic driving behaviour under real driving conditions which is highly important for the assessment of ADAS. Based on the collected data the analysis answers predefined research questions to assess the impact. To gather a sufficient amount of data, an experiment duration of several months is necessary.
In the U.S. large-scale FOTs are used as an evaluation method since 1996 (3). In addition to FOTs of Intelligent Speed Adaptation Systems (ISA) (4), Forwards Collision Warning (FCW) (5), Lane Departure Warning (LDW) (6), Adaptive Cruise Control (ACC) (7), and naturalistic driving studies were conducted (8). The following table highlights some of the conducted FOTs in Europe and the U.S.

	Tested Systems	Number of vehicles	Number of particpants	Duration [Months]	Mileage [km]
NHTSA ICC FOT (1996 – 1998)	ICC	10	108	13	108,000
VOLVO IVI FOT (2001 – 2004)	ACC, CWS, AdvBS	100	> 1000	> 24	16,300,000
ACAS FOT (2003 2004)	ACC, FCW	14	66	9	158,000
Mack IVI FOT (2004 – 2005)	LDW	22	31	12	1,400,000
IVBSS FOT (2008 – 2010)	FCW, LDW, CSW, LCM	26	108	10	1,394,000
ISA Sweden (1999 – 2002)	ISA	5000	10,000	12	75,000,000
ISA GB (2001 – 2008)	ISA	20	20	5	570,000
The assisted driver (2006 – 2007)	ACC, LDW	20	20	5	n.a.
SeMiFOT (2008 – 2009)	ACC, FCW, LDW, BLIS	14	39	6	171,440
euroFOT (2008 – 2012)	ACC, CSW, FCW, LDW, SRS, BLIS, FEA, IW	971	1038	12	34,868,000
TeleFOT (2008 – 2012)	NAV, SL, SA, SC, GD, TI, eCall, FCW, ACC, LKA, LDW	n.a.	2986	12	n.a.

AdvBS: Advanced Braking System, CWS: Collision Warning System, CSW: Curve Speed Warning, GD: Green Driving, FEA: Fuel Efficiency Advisor, IW: Impairment Warning, ICC: Intelligent Cruise Control, ISA: Intelligent Speed Adaptation, LCM: Lane Change Merge, LKA: Lane Keeping Assist, NAV: Navigation System, SA: Speed Alert, SC: Speed Camera, SL: Speed Limiter, SRS: Speed Regulation System, TI: Traffic Information

Figure 1. Overview of FOTs in Europe and the U.S.

METHODOLOGY

In the following, the data management process as well as the analysis approach for the ACC and FCW used in euroFOT is presented. To that end, first the data management process is presented. Afterwards the defined experimental design of both systems and the data analysis approach of the collected data is described.

Data management

The participants of the FOT are non-professional drivers that were recruited by different car dealerships in Germany. They were contacted by the dealerships after buying a vehicle of the specific manufacturer equipped with ACC and FCW. This vehicle is used afterwards for the FOT. To collect all relevant data (CAN data and GPS data) data loggers (Data Acquisition System (DAS)) were installed in all 100 customer vehicles. The data loggers are able to record, temporarily store and transmit the data afterwards to a centralized server system. Overall, about 100 CAN signals were recorded. In addition to dynamic measures (velocity, acceleration, yaw rate, steering angle, wheel speed etc.) status information of different systems were considered (e.g. state of turn indicator, wiper, ADAS). To avoid modifications of the customers' vehicles and influences to the driving behavior no additional data sources like video systems were used. Figure 2 presents an overview of the process stages for data management.

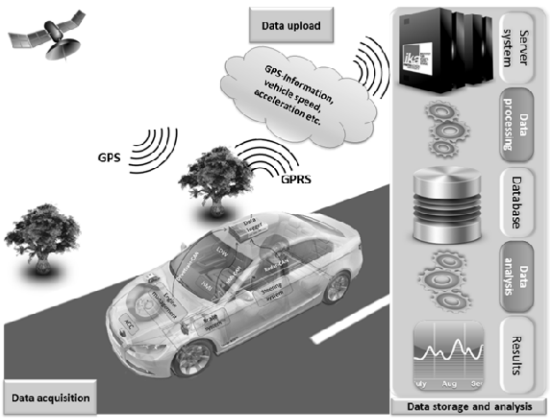

Figure 2. Data acquisition and processing

The data measured on the connected CAN-channels will be stored in a first stage on a FLASH storage device installed on the DAS. The DAS offers the possibility to communicate with the device during operational time of the field test using an integrated GPRS module. This allows wireless uploading of recorded information to a centralized server system, while the DAS is collecting data simultaneously. Therefore the data is compressed and encrypted. By means of a GPRS connection the DAS status and operation on board of the vehicle can also be checked and monitored during the entire operation time.

The upload procedures are designed and implemented to work fully autonomously. Autonomous operation means that no user interaction – neither on the driver side nor on the operator side – is required. Hence the drivers are totally kept out of the data retrieval loop. No training of the drivers participating in the field test is needed and the loss of data due to maloperation is excluded. Besides the event recognition and data retrieval steps the entire process chain for data management has been automated (11). Figure 3 presents the structure of the software architecture that has been developed at ika for this purpose.

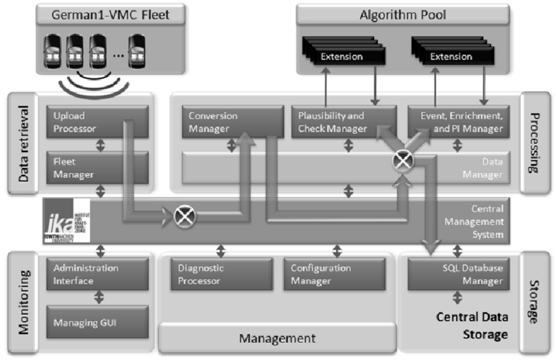

Figure 3. Software architecture of data management process

The architecture for data management on the server side consists of several different software components. The coordination of the interaction between the software components is performed by the Central Management System (CMS). After data has been successfully uploaded on the server, the CMS is responsible for passing the data to the Data Manager, which subsequently manages the data processing. Data is passed between these software elements each time one process step is accomplished. The processed data is stored on an SQL based server at the end, in order to make the data available for the analysis. For configuration management and diagnostic purposes as well as operator access, additional software components (e.g. diagnostic processor etc.) complete the infrastructure for the automation of the whole process chain.

Experimental design

For the impact assessment it is necessary to assess also trips without the influence of the system as a reference (baseline) besides trips with activated system (treatment). The comparison of the collected data in both phases (baseline/treatment) forms the basis for the assessment of the systems' impact. Based on these research questions hypotheses to be tested (e.g. ACC decreases the number of incidents) have been defined. By means of the hypotheses the required signals and data sources for data collection have been identified.

The experimental duration of the FOT for the vehicle fleet of 100 passenger cars was twelve months of which the first three months served as a baseline. During this baseline period the ADAS were deactivated, while all necessary data was collected from the vehicle's CAN-Bus. By means of the baseline the naturalistic driving behavior of the participants was analyzed. In the following treatment period the systems were activated and the drivers were free to use the systems as desired. Neither further instructions were given to the drivers nor were they accompanied by a supervisor. Drivers used the vehicles in their daily routine (e.g. way to work). The experimental design for the 100 passenger cars is shown in Figure 4.

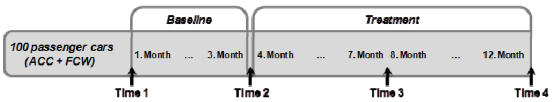

Figure 4. Experimental design for the vehicle fleet of 100 passenger cars

In addition to the selection of relevant driving events (e.g. incidents, lane change maneuvers) different indicators are necessary for the impact analysis. Especially for the hypothesis testing the so called performance indicators (e.g. number of harsh braking events, average speed) are required for the statistical analysis. Moreover, so called situational variables such as weather conditions or road type are relevant for the hypothesis testing in order to ensure that the comparison of baseline and treatment is done under similar circumstances to avoid influences from external effects. By combining the relevant events with the situational variables scenarios for the comparison of baseline and treatment were determined. An example for detection of relevant scenarios is presented in Figure 5.

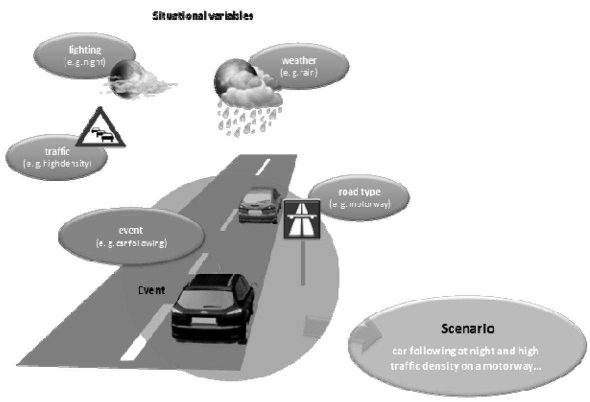

Figure 5. Procedural steps to cluster data for analysis purposes

The combination of the car following event (relevant event for ACC) with different situational variables provides the scenario of a car following event under the relevant weather, traffic, lighting and road type conditions, e.g. car following on a motorway, in day light and high traffic density.

Furthermore subjective data is collected by means of four time-based (Time 1 to Time 4) questionnaires to analyze the effect on user acceptance. The first two questionnaires (Time 1 and Time 2, see Figure 4) were spread during the baseline phase. The remaining questionnaires (Time 3 and 4) were distributed at half-time and at the end of the treatment phase.

Data analysis

The required signals were recorded with defined sampling rate. By means of the installed data loggers the collected data were transmitted wirelessly to the centralized server system at the ika (see Figure 6). After the successful transmission of the data to the server (within the data management) the data processing is conducted. Firstly, the data quality analysis includes the assessment of missing data parts and plausibility checks of the recorded signals. In a second step, the gathered data was enriched with map attributes (e.g. road type, speed limits) from a digital map based on the recorded GPS information. Afterwards, additional information (e.g. time-headway, time-to-collision (TTC), average speed) was calculated from the collected data. Finally, situational variables and relevant driving events were identified by means of an automated recognition process (12).

The data analysis starts with the calculation of the performance indicators that are necessary for the hypothesis testing. Afterwards, the processed data was stored on a database, which served as a basis for the data analysis. The results of the hypothesis testing were used as input for the impact assessment, see Figure 6.

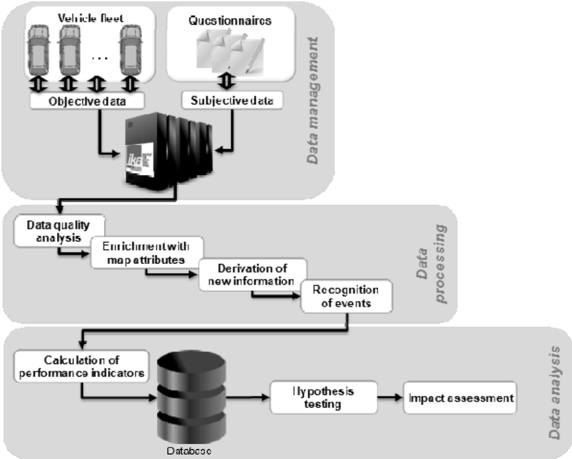

Figure 6. Processing steps between data collection and impact assessment

The processing of the raw data led to an increase in the data amount due to the enrichment and derivation process. Overall, about 1 TB of data is available for the impact assessment, see Figure 7.

	Mileage [km]	Number of drivers	Number of trips	Data amount
Raw data	1,954,329	98	144,280	493 GB*
Data processing	1,954,329	98	144,280	990 GB
Impact assessment				
Baseline	233,071	84	6048	100 GB
Treatment	747,296	84	18,268	293 GB

* compressed

Figure 7. Overview of data amount

RESULTS OF THE IMPACT ASSESSMENT

The magnitude and the experimental set-up of the conducted FOT allow detailed insights into various aspects of the daily use of ACC and FCW by normal customers. In the following some of the main outcomes of the conducted statistical analysis are presented. Thereby, the analysis focuses on changes in traffic safety, driver behavior and environment while driving on motorways. For the safety impact assessment various indicators are used to determine the impact of ACC and FCW. An assessment by means of accidents occurred within the FOT is not a feasible approach. Only a few accidents (< 4) occurred within the data collection phase, which are not sufficient to provide any statistical valid conclusions.

Safety

The combination of ACC and FCW show a positive impact on driving safety. While there was no decrease in average speed (an indicator previously linked to increase in safety (13)), the average time-headway (THW) shows an increase of about 16% (see Figure 8) and leads therefore to larger/greater safety margins. Due to the predefined settings of the ACC time-headway the number of (intended or unintended) close approaching maneuvers is highly reduced and prevents therefore critical driving situations. The analysis of critical time-headways (< 0.5 s) reveals a reduction of 73% on motorways. As a consequence of the safer distance behavior the frequency of harsh braking maneuvers is lower when driving with active ACC. Two out of three harsh braking events (67%) can be avoided by the use of ACC. Like for the harsh braking events the number of incidents is lower when using ACC and FCW. The incidents based on vehicle kinematics show more than 80% reduction. Details on the incident definition can be found in (14).

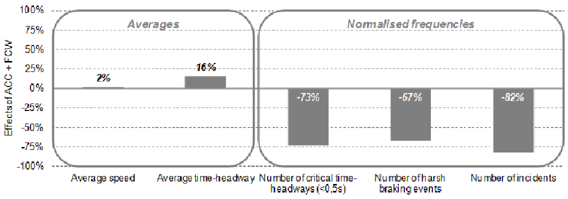

Figure 8. Overview of safety indicators for driving with active ACC and FCW on motorways

Explanations for the increase in average time-headway and the reduction of critical time-headways, harsh braking events and incidents can be found in the selectable ACC settings that can never be lower than the legally prescribed value which is not always considered by drivers in their normal driving behavior. Resulting from the increase in average time-headway the reaction time to avoid (unintended) close approaching events is higher. If the driving situation exceeds the braking capacities of the ACC because of a highly decelerating vehicle in front, the presented warnings (by the ACC and FCW) give the driver appropriate time to react on the driving situation. It could be shown in the analysis that this effect can be mainly attributed to the ACC by comparing situations where only one of the functions was active.

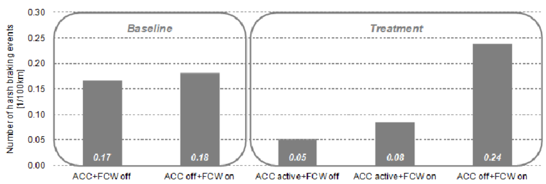

Figure 9. Number of harsh braking events within different experimental phases

In phases of active ACC (independent on the FCW status) a significant decrease of harsh braking events was observed, see Figure 9. In case of deactivated ACC and activated FCW no such effect could be shown. To specify the contribution of each individual function the change in issued FCW warnings was investigated. To that end, it can be seen in Figure 10 that the highest reduction during the treatment period was found in phases when the

ACC was active. The number of warnings was significantly decreased by about 80%.

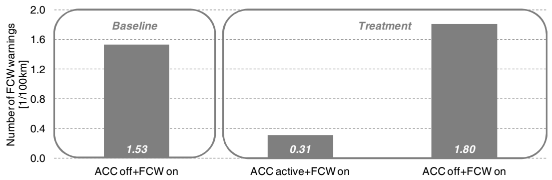

Figure 10. Number of FCW warnings in different experimental phases

Driver behavior

ACC related changes in the driving behavior can be deduced from the same performance indicators that are associated with safety. Those are mainly based on objective data and indicate especially a safe distance behavior which leads to safety benefits. Additionally, the questionnaire data indicates that the expectations of drivers to the ACC are not affected, i.e. the scores on satisfaction and usefulness that drivers gave before gaining access to the systems match those given during and after the trial.
In Figure 11 it can be seen that the acceptance rating on the Van der Laan scale (scaling from -2 to +2) shows low variation.

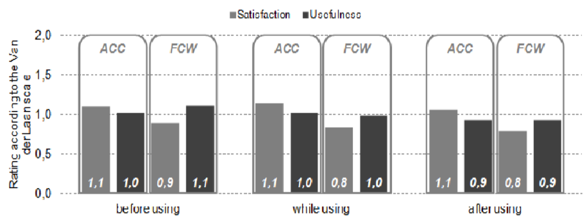

Figure 11. Acceptance rating for ACC and FCW

The acceptance is based on the average of the questionnaire items related to satisfaction and usefulness. In terms of usage, drivers mainly use ACC on motorways. Here, the proportion of kilometers driven with active ACC reaches almost 50%. The increase in the usage frequency can be confirmed by evaluating the travel time and distance with and without active ACC. Comparing the first months to the last months of the FOT there is a significant increase of ACC usage in terms of travel time with active ACC (31%) and frequency of ACC activations (53%). The drivers seem to get used to the positive perception of the ACC and use the system longer and more often over time even though they do not indicate a change in their usage behavior within the questionnaires. This increased use of ACC is in line with the perceived increase of safety and comfort which is self-reported by the drivers. In contrast, self-reported ratings on trust do not change over time and thus do not reflect the positive perception related to safety and comfort.
The majority of the drivers (close to 70%) perceive the FCW as safety increasing and most helpful on motorways in normal traffic conditions. The ratings on satisfaction and usefulness remain high throughout the study, but are in general slightly lower than those of ACC. The slight decrease in the ratings can be interpreted by high expectations of the drivers at the project start. In addition, drivers are not uniformly positive to the investigated FCW's audio-visual interface. Some reported that they perceive the timing of the warnings as to early and therefore annoying. This can be attributed to varying individual comfort zones in terms of following distances and reinforces the need for investigating new and creative ways of offering individual adaptations possibilities. Acceptance is a key parameter for the effectiveness of ADAS since unsatisfied drivers tend to switch of the system and therefore no benefit can be achieved.

Fuel consumption

Based on a lower variation in speed when driving with active ACC, it is hypothesized that there are also positive effects on environment in terms of fuel consumption and CO_2 emission. The analysis of the fuel consumption shows a significant reduction of 2.77% while driving on motorways. This system related change in fuel consumption and the measured average fuel consumption of 7.3 l/100km is combined with the usage rate of 49.4% that is reached during the FOT on motorways and projected to the EU-27 level (see Figure 12).

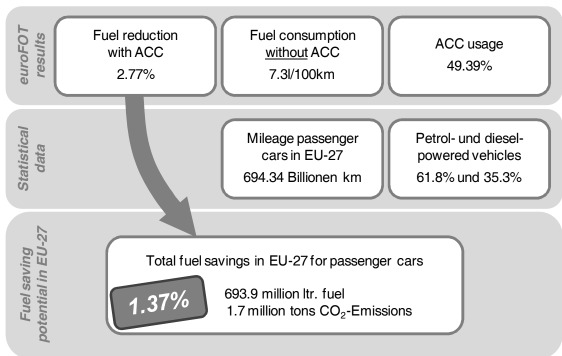

Figure 12. Fuel saving potential of ACC for driving on motorways

For the European passenger car fleet which consists of approximately 62% petrol and 35% diesel powered vehicles the overall fuel saving potential of 1.37% accounts for almost 700 million liters of fuel every year and 1.7 million tons of CO_2 based on the average fuel consumption that is evaluated with the objective data. The statistical data on the total mileage of passenger cars and the fleet composition can be found in (15) and (16). The final results of the impact assessment including statistical information can be found in ().

CONCLUSIONS AND RECOMMENDATIONS

During the euroFOT project data of about 1000 vehicles was collected. With the help of the gathered data the impact of eight different ADAS was evaluated. The analysis of the effects of ACC and FCW usage showed positive effects on traffic safety, driver behavior and driver acceptance as well as fuel consumption.

The relevant factor for the reduction in harsh braking events, incidents etc. can be attributed to changed distance behavior. The analysis shows that the average time-headway was increased at about 16%. In addition to the usage rate of 50% the analysis of acceptance rating revealed a positive perception of the ACC and FCW. Furthermore, a reduction in fuel consumption of 2.8% was observed which results in less CO_2 emissions.

Based on the gathered insights with regards to how drivers use the systems valuable input for the various stakeholders (suppliers, vehicle manufacturers, and research institutes) for improving system design and promoting product development is provided. Moreover the positive results are a powerful tool to raise public awareness about the potential of ADAS. These will provide further impulses for consideration of ADAS in the customer's purchase decision. By means of increased penetration rates a major contribution for improving traffic safety can be achieved.

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SAFETY CHANGES IN THE US VEHICLE FLEET BY VEHICLE MODEL YEAR

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ABSTRACT

NASS/CDS 1995-2009 was the basis for evaluating safety changes in the vehicle fleet with model year. The analysis shows that the mean AIS 3+ HARM for belted drivers in 1996-2009 model year vehicles had decreased injuries in side and frontal crashes. Head injuries were the most reduced body region in frontal crashes, decreased by 40%; however, there was an increase in lower extremity injuries. Chest injuries were most reduced in side crashes, decreased by 25%. For rollovers, reduction in injuries for all body regions were observed in 2000 to 2009 model years compared to models up to five years earlier. For the most recent model years, a larger fraction of the AIS 3+ HARM occurred in severe rollover (more than 7 quarter-turns).

INTRODUCTION

Recent models of passenger vehicles have incorporated numerous safety features. The objective of this research was to determine how the injury environment has changed in recent vehicles compared to older vehicle models. More specifically, for recent model vehicles, how has the distribution of crashes and injuries changed for belted drivers by crash mode and injured body region.

There are a variety of ways to examine the frequency and rate of injuries in the available databases. Frequently, Maximum Abbreviated Injury Scale (MAIS) 3 and above injuries are combined. Alternatively, the HARM weighting scheme is applied to injuries of different severity. The latter has the advantage of weighting injuries in proportion to their cost (Malliaris 1982). The HARM method will be the primary focus of this paper. The change in Mean HARM for different vehicle model years is used as a surrogate for changes in injury rates.

The model year period from 1985 through 2009 is of principal interest. During the past 25 years there have been a number of changes in safety testing to encourage safety improvements in passenger vehicles. Although the first commercial airbags were introduced in limited numbers during the 1970's, it was not until1984 that Federal Motor Vehicle Safety Standard (FMVSS) 208 mandated a phased introduction of the driver airbags for passenger cars produced after 1989, with light trucks phased-in by 1997. It was not until the early 1990 model years that air bags penetrated the fleet in large numbers. In 1998, FMVSS 208 mandated the second generation airbag, also with phased enforcement. In addition, the evolution of New Car Assessment Program (NCAP) to add a star rating system in 1992, and the 1995 entrance of the Insurance Institute for Highway Safety (IIHS) crash testing for consumer information increased the incentives to improve frontal crash safety. In 1997 NCAP initiated a side impact test program, followed by IIHS and in 2004 a Motor Vehicle Safety Standard was strengthened to require a side crash test.

Electronic stability control (ESC) entered the market in 1995 and became standard on approximately 38% of the cars and SUV's by model year 2005. By model year 2009, the ESC was standard equipment on 100% of SUV's, 74% of cars and 38% of pickups (IIHS 2013).

METHODS

The source for exposure and injury data was the NASS/CDS (National Automotive Sampling System/Crashworthiness Data System) years 1995 to 2009. NASS/CDS is a weighted estimate of tow-away crashes occurring in the United States. The NASS/CDS weighted data contains approximately 23 million drivers of passenger cars, SUV's, passenger vans or light trucks (pickups) who were exposed to crashes. NASS/CDS data were disaggregated by vehicle model year and crash mode. Since this study focused on the safety changes for belted drivers, only vehicles with belted drivers were included. The resulting population of vehicles was 22,541,582.

The resulting data permitted the assessment of changes in injury distributions and rates by model year, crash mode and body region for belted drivers. The front, side and rear crash mode categories excluded all rollovers. The rollover crash mode contains all rollovers including those with planar impacts as an earlier event.

The HARM calculations for the body regions were based on the approach introduced by Fildes and Digges [Fildes 1992]. This methodology applies a weighting factor to each AIS 3+ injury in the database. The weighting factor is proportional to the cost of the occupant's most serious injury. In general, minor and moderate injuries (AIS 1 and 2) are high frequency, events that tend to cloud the analysis of serious injury reduction by safety systems. For this reason, AIS 1 and 2 injuries were excluded from the HARM calculations. The AIS 3+ HARM, measured in equivalent fatalities, was based on NHTSA's data on average cost of injuries. The equivalent fatality measurement is obtained by normalizing the average cost of a given injury by the cost of a fatality. The average cost of each injury severity was obtained from a Table E-1 in the 1995-1997 NASS/CDS Summary (NHTSA 2001). The injury cost values are: MAIS 3, 98,011; MAIS 4, 221,494; MAIS 5, 697,533; and MAIS 6, 822,328. The Mean HARM for each category was calculated by dividing the HARM suffered by drivers by the number of drivers exposed to that category. The Mean HARM results were multiplied by 100 to simplify the presentation. The HARM values were applied to the maximum injury per body region.

RESULTS

The distributions of belted drivers by crash mode and AIS 3+ HARM from NASS/CDS 1995-2009 are displayed in Table 1. Since the principal interest was in the newer vehicles, the model years 2000 to 2009 were aggregated. This group contained 5,339,833 belted

TABLE 1.
Distribution of Exposed Vehicles and Driver 3+ HARM by Crash Mode for Vehicle Model Years 2000 to 2009

CRASH MODE	FRONT	NEAR SIDE	ROLL	FAR SIDE	REAR
EXPOSURE	55%	14%	12%	11%	8%
3+ HARM	38%	28%	22%	10%	2%

Figure 2 separates the model years into three groups – 1985-1989; 1990-1995 and 1996-2009. Figure 1 suggests that the model years 1985 to 1989 have fewer vehicles, but the number in each model year are fairly constant. However, the 1990-1995 group is biased by larger numbers of vehicles in the later years. The 1996 - 2009 group is biased by a larger number of vehicles in the earlier years. Consequently a comparison of the two latter groups is closer to a comparison of vehicles in the late 1990's to those in the early 2000's.

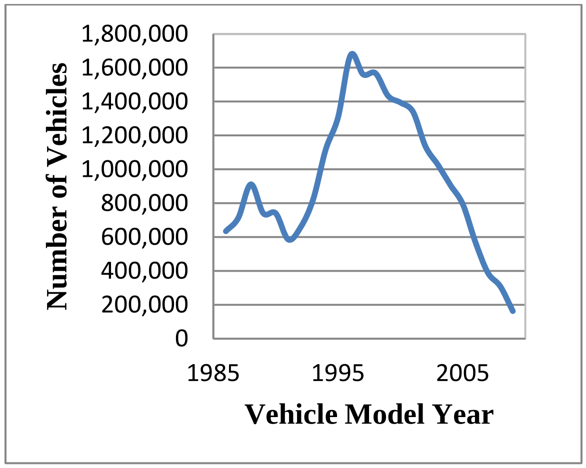

Figure 1. Distribution of light vehicles with belted drivers in 1995-2009 NASS/CDS by model years.

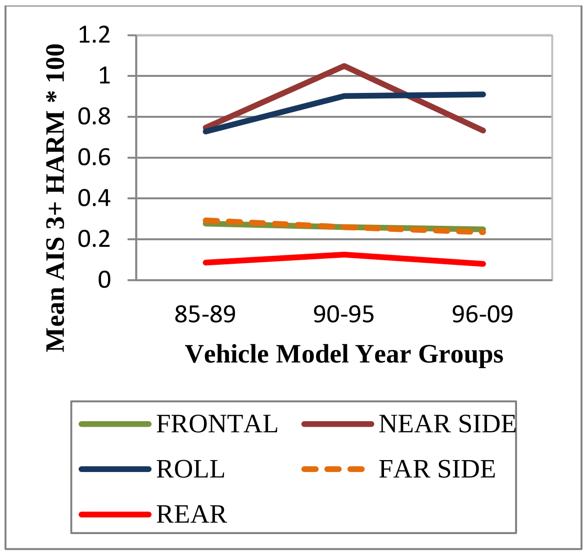

Figure 2. Mean AIS 3+ HARM for belted drivers in 1995-2009 NASS/CDS by crash mode for three model year groupings.

Frontal Crash Mode Results

The frontal crash mode was disaggregated to determine the exposure of belted drivers and the injuries received by belted drivers. Injuries were determined for each body region, with the restriction that only the most serious injury per body region was included. AIS 3+ HARM for each model year grouping was calculated for each body region and the distribution of HARM was determined. The resulting distributions are plotted in Figure 3.

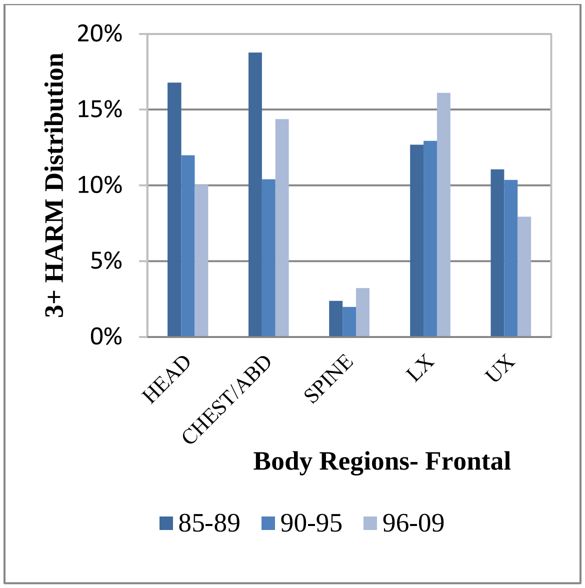

Figure 3. Body region distribution of AIS 3+ HARM for 1995-2009 NASS/CDS belted drivers involved in frontal crashes for three model year groups.

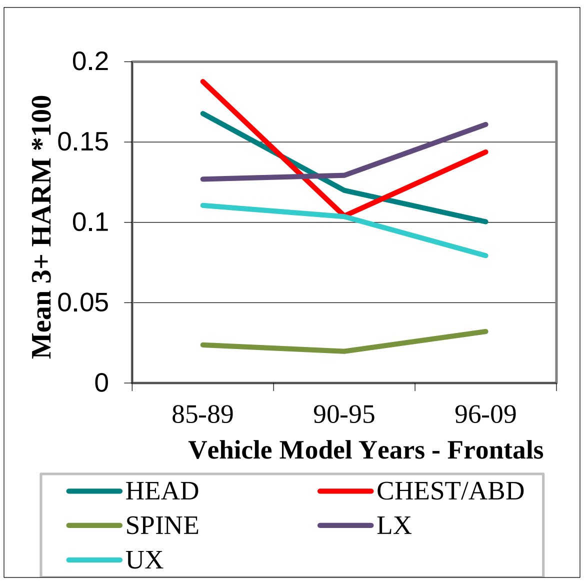

Figure 4. Body region distribution of AIS 3+ Mean HARM for 1995-2009 NASS/CDS belted drivers involved in frontal crashes for three model year groups.

Figure 4 displays the trends in frontal crashes by model year groupings for mean AIS 3+ HARM by body region.

Near-side Crash Mode Results

The near-side crash mode was treated in a manner similar to that described for the frontal mode. The resulting distribution of AIS 3+ HARM by body region for three model year groupings is displayed in Figure 5.

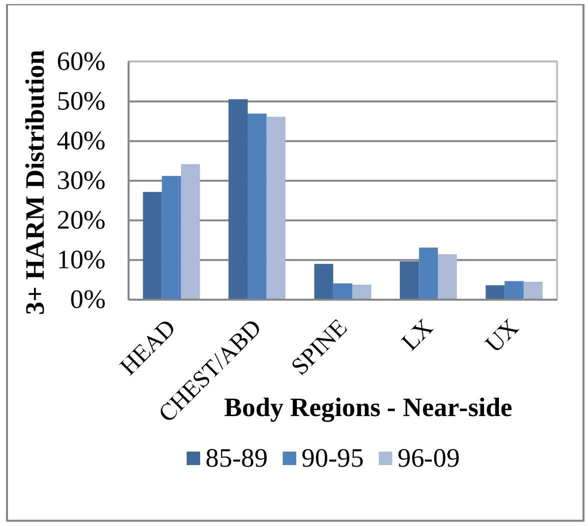

Figure 5. Body region distribution of AIS 3+ HARM for 1995-2009 NASS/CDS belted drivers involved in near-side crashes for three model year groups.

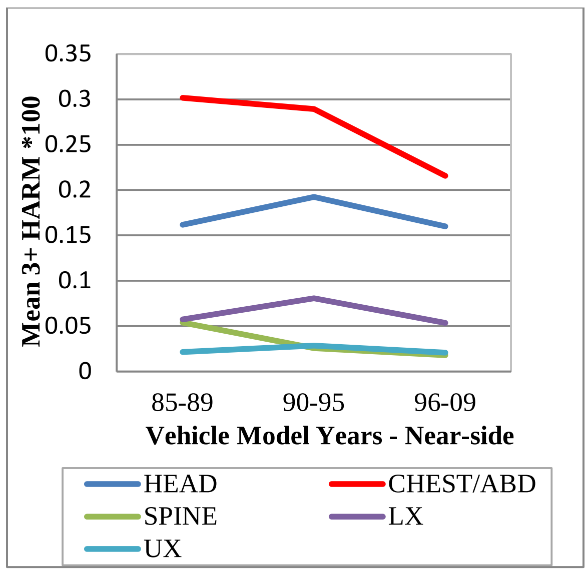

Figure 6. Body region distribution of AIS 3+ Mean HARM for 1995-2009 NASS/CDS belted drivers involved in near-side crashes for three model year groups.

Figure 6 shows the trends by model year groupings for mean AIS 3+ HARM by body region applied to the near-side crash mode.

Rollover Crash Mode Results

Data analysis similar to that described for the frontal crash mode was applied to rollovers. Figure 7 shows the AIS 3+ HARM distribution for rollovers. This figure displays the distributions for three model year groupings and five body regions.

Figure 8 shows four model year groupings for the mean rollover AIS 3+ HARM by body regions. For the rollover, the 1996-2009 model year grouping was split into two. The early group included the years 1996-1999 and the later group 2000-2009. This grouping was done because ESC did not arrive in the fleet in significant numbers until after model year 1999. The split was intended to investigate changes in rollovers as ESC penetrated the fleet. The latest model year grouping exhibited a downturn in the mean AIS 3+ HARM for all body regions.

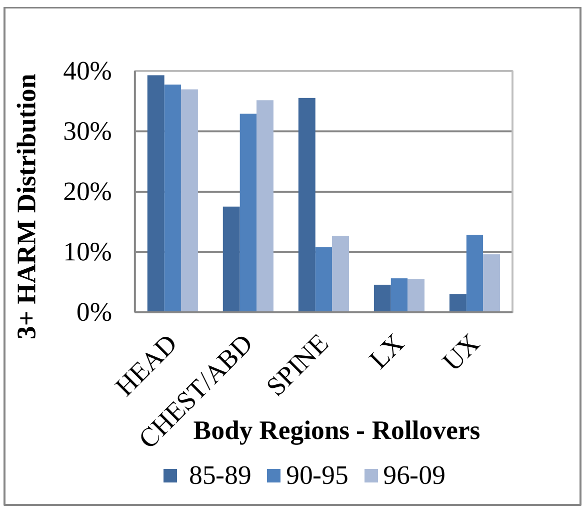

Figure 7. Body region distribution of AIS 3+ HARM for 1995-2009 NASS/CDS belted drivers involved in rollover crashes for three model year groups.

Figure 9 shows the distribution of belted drivers exposed to rollovers and the distribution of their AIS 3+ HARM by number of quarter-turns. Because the quarter-turns further divides the data, the entire range of model years was included in the plots. It is evident that quarter-turns 1, 2, 4, 6 and 8 are most frequently represented in both exposure and AIS 3+ HARM. Subsequent plots will apply quarter-turn groupings that cluster the data around these numbers.

In view of the benefit of ESC to reduce rollovers, it is of interest to examine how the HARM distribution has changed with rollover severity for the recent models of vehicles. The number of quarter-turns is a generally accepted measure of the initial rollover energy and it was used as a measure of severity.

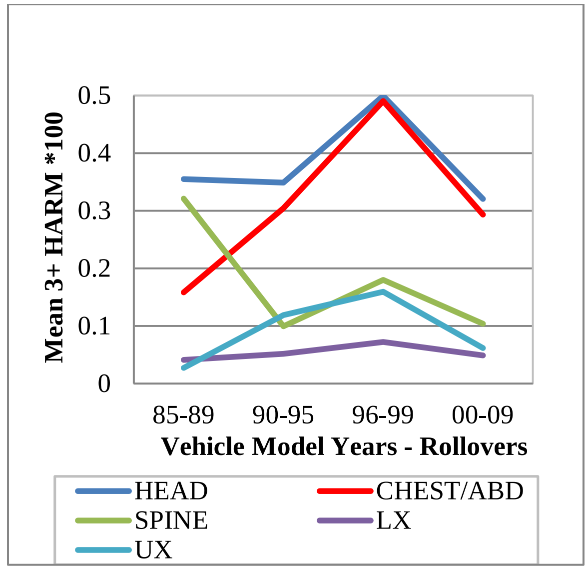

Figure 8. Body region distribution of AIS 3+ Mean HARM for 1995-2009 NASS/CDS belted drivers involved in rollover crashes for three model year groups.

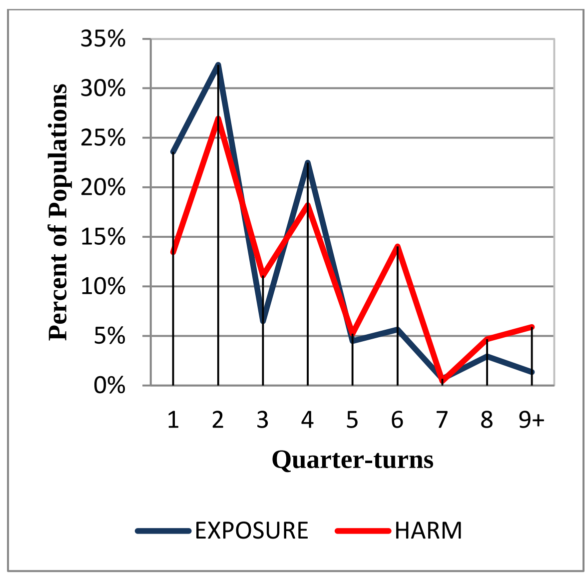

Figure 9. Distribution of model year 1985 to 2009 vehicles in rollover crashes and AIS 3+ Mean HARM for their belted drivers in NASS/CDS 1995-2009 by number of quarter-turns.

However, when the data was separated by number of quarter-turns it became necessary to group larger numbers of model years. For the data to follow, two groups of ten model years were used. The model year groups are: 1990-1999 and 2000-2009.

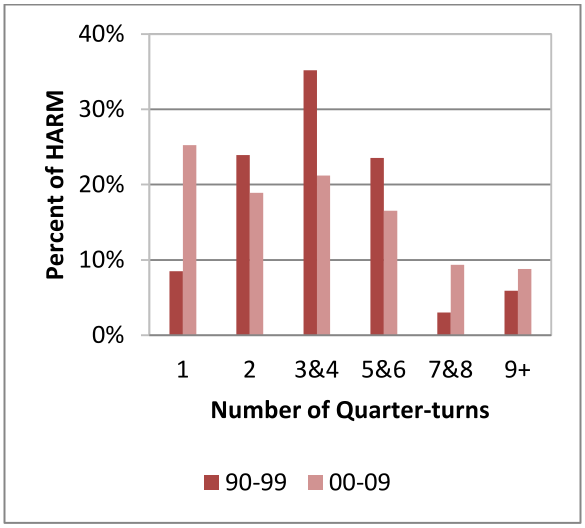

Figure 10. Distribution of AIS 3+ HARM for belted drivers in NASS/CDS 1995-2009 for Model Years 1990-1999 and 2000-2009 by number of quarter-turns.

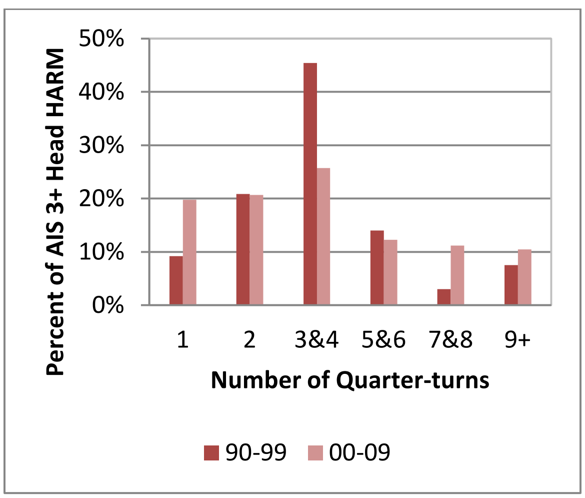

Figure 11. Distribution of AIS 3+ Head HARM for belted drivers in NASS/CDS 1995-2009 for Model Years 1990-1999 and 2000-2009 by number of quarter-turns.

Figure 10 displays the AIS 3+ HARM distribution for belted drivers in the two model year groupings by rollover severity. Figure 11 is a further disaggregation of the data that shows the distribution of AIS 3+ head HARM. Figure 12 is similar to Figure 11, but shows the AIS 3+ chest HARM distribution.

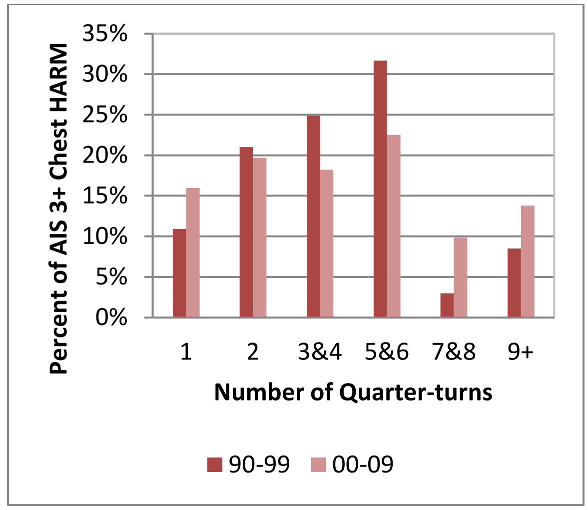

Figure 12. Distribution of AIS 3+ Chest HARM for belted drivers in NASS/CDS 1995-2009 for Model Years 1990-1999 and 2000-2009 by number of quarter-turns.

DISCUSSION

The purpose of the analysis presented was to examine how the population of NASS vehicles has changed with particular emphasis on changes in the protection of different body regions. This study was not an attempt to examine the effectiveness of the countermeasures that have been introduced. Consequently (except for rollovers,) there was no attempt to control for crash severity, vehicle age at the time of the crash, and driver factors. However, the study shows how the populations of belted drivers in vehicles of different model years are being injured, according to NASS/CDS.

Table 1 shows that for belted drivers in the NASS model year grouping 2000-2009, frontal crashes retained the largest fraction of AIS 3+ HARM at 38%. Near-side accounted for 28% and rollovers accounted for 22%. It should be noted that unbelted occupants were not included in these calculations.

Figure 2 shows that the most recent model year grouping has reduced mean HARM in all modes except rollover. However, when the 1996-2009 grouping is further divided, as in Figure 8, a reduction of rollover mean HARM in the latest model years is evident. The near-side experienced an increase in mean HARM for the mid years (1990-1995). This period was before the most recent side protection standards and consumer information tests were advanced. In addition, the passenger cars of this period may have been subjected to more severe crashes from an increasing population of light trucks and SUV's.

Figures 3, 5 and 7 show the distributions of AIS 3+ HARM for three model year groupings. The bars for each model year grouping add to 100%. Consequently, reductions in one body region may lead to increases in other regions. The mean HARM calculation shown in Figures 2, 4 and 6 divides the HARM by the exposure and consequently reductions in all categories may be possible.

Figures 3 and 4 show a dramatic reduction in head injury HARM for the most recent grouping of model years. The mean HARM is down 40% from the early model years and 16% from the mid-model years. However, offsetting this gain is an increase in chest/abdominal and lower extremity injury - up 36% and 25% from the mid-years. As shown in Figure 2, the overall mean HARM for frontal crashes decreased for the recent model years.

Figure 6 shows that the most recent vehicles exhibit a reduction in the near-side mean HARM for all body regions. The reduction of chest HARM is most apparent – down 25% from the mid-model years.

The rollover results in Figure 8 show increases in head and chest mean HARM for the 1996-1999 model year groupings. However, dramatic reduction for all body regions occurred for the latest model years. The penetration of ESC into the fleet is a possible explanation for this effect.

To further investigate changes in AIS 3+ HARM with rollover severity, the rollover data was disaggregated by quarter-turns. Figure 9 suggests clustering the quarter-turn data as follows: 1, 2. 3&4, 5&6, 7&8 and 9+. In order to achieve sufficient cell sizes, ten model years were grouped. The results of the HARM distribution with quarter-turns are shown in Figures 10, 11 and 12. These Figures indicate that the later models of vehicles have lower AIS 3+ HARM in the mid quarter-turn ranges from 2 through 6. Their HARM is higher at 1 and 7+ quarter-turns. The higher HARM at 1 quarter turn may be caused by a planar crash with another vehicle prior to the rollover. The fraction of HARM at the higher quarter-turns is 8.9% for the early model years and 18.2% for the later model years. This higher HARM fraction at high severities is present in both head and chest injuries.

CONCLUSION

The NASS/CDS analysis shows that the mean HARM for belted drivers in 1996-2009 model year vehicles had decreased in side and frontal crashes. Head injuries were the most reduced body region in frontal impacts and chest injuries were most reduced in side impacts.

Consumer information testing and regulatory initiatives in the early and mid 1990's may have contributed to encouraging the improvements in the frontal and side crash mode.

For rollovers, there was an increase in the mean HARM for the model years 1996 -1999. However, for the model year grouping 2000-2009 the mean HARM of all body regions decreased dramatically. The penetration of ESC into the vehicle fleet may have contributed to this decrease in HARM.

ACKNOWLEDGMENTS

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Impact assessment of enhanced longitudinal safety by Advanced Cruise Control Systems

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ABSTRACT

This paper presents an impact assessment of enhanced safety by Advanced Cruise Control (ACC) systems. The objective of our study is to assess of the enhancement of the driving safety between with and without the ACC system. For the impact assessment of the ACC system, the system performance test data as well as the usual driving data should be used to assess direct and indirect safety impacts.

Therefore the proposed methodologies were developed by using the collected data from the Field Operational Test (FOT) and the evaluation scenario based test for conducting the safety impact assessment of the ACC system.

First, 5 vehicles equipped with ACC system will take part in the field operational test so that we can make the FOT database. By using the collected database, Changes of crash risk between with and without ACC system are used to quantify the impact of the ACC system.

Second, to make up for the missed the FOT data, test scenario based ACC performance test was conducted. From the scenario based test, system's physical performance in the specific driving situations can be evaluated.

Finally, impact assessment of the ACC system can be obtained by combining FOT based analysis and scenario based test results. By using the proposed assessment methods, the impact assessment with respect to impacts on safety by the ACC system can be assessed scientifically.

INTRODUCTION

Road safety is a major concern in most countries and the attention is turning towards active safety system that is not only developed to reduce the consequences of accidents but also to reduce the number of driver errors and thereby the number of accidents. In case of Korea, there is the unenviable record being one of the highest traffic accidents and fatality rates. In 2009, there were 5,838 fatalities on the road.[1] Therefore, a new and systematic approach to safety system is necessary to reduce traffic casualties.

In this point of view, an Adaptive Cruise Control (ACC) system for the passenger vehicle had entered the market to mitigate the consequences of an accident and to reduce the number of fatalities among car occupants.

As market of such various new technology entries goes, research about effectiveness and necessity by new system are conducted. Also, estimating the benefits of advanced safety systems before introducing to markets is useful to develop and enhance systems effectively.

A research of safety effect by an integrated vehicle-based crash warning system was developed and tested under the Integrated Vehicle-Based Safety System (IVBSS) initiative of the United States Department of Transportation's (U.S. DOT) Intelligent Transportation System program [2][3].

In case of Europe, SEiSS(Socio-Economic Impact of intelligent Safety Systems)[4] project and euroFOT project[5] are conducted to develop harmonized and standardized assessment procedures as well as to improve related tools for commercially available pre-crash sensing system.

General research method to assess the safety effect of the system is using an accident data which is relative to safety system. From the accident data, we can simulate the safety system's performance in a same driving situation to determine whether accidents could have been avoided with the system or not. The problem of this method is that it cannot represent every relative situation of the system. Besides, it is difficult to obtain cases with detailed kinetic information for the simulation.[6]

Another approach is using of a Field Operational Test (FOT) data. By using the test vehicles equipped with the safety system, driving data was collected by 'with' and 'without' the safety system. From the analysis of the collected data, safety enhancement can be assessed as change of the crash rate 'with' and 'without' safety system. In case of FOT based approach, it also has a problem that accidents seldom occur in actual traffic.

Therefore, in this paper, assessment of enhanced longitudinal safety of the ACC system is conducted by using not only the FOT data based, but also test scenario based. First, by using the collected FOT database, the assessed safety impact of the ACC system is conducted. Next, by using the scenario based test result, expected safety effect of the ACC system can be assessed in selected driving scenarios.

Finally, impact assessment of the ACC system can be obtained by combining FOT based analysis and scenario based test results. By using the proposed assessment methods, the impact assessment with respect to impacts on safety by the ACC system can be assessd scientifically.

FIELD OPERATIONAL TEST DATA BASED SAFETY IMPACT ASSESSMENT

To assess the safety impact of the ACC system on real driving condition in Korea, Field Operational Test data based safety impact assessment was conducted.

1. System Definition

Test vehicles equipped with ACC system will take part in the field operational test so that we can make the FOT database. The FOT data was collected using a test vehicle equipped with various sensors, e.g., a laser-radar sensor, a CCD camera, a three axis inertial sensor, and a GPS.

By using the test vehicles, control input of ACC system and driver's inputs (steering, throttle, brake) are collected. Also, vehicle's driving information (velocity, longitudinal and lateral acceleration, yaw rate, etc.) and information of preceding vehicle (relative speed, clearance) are stored with GPS data.

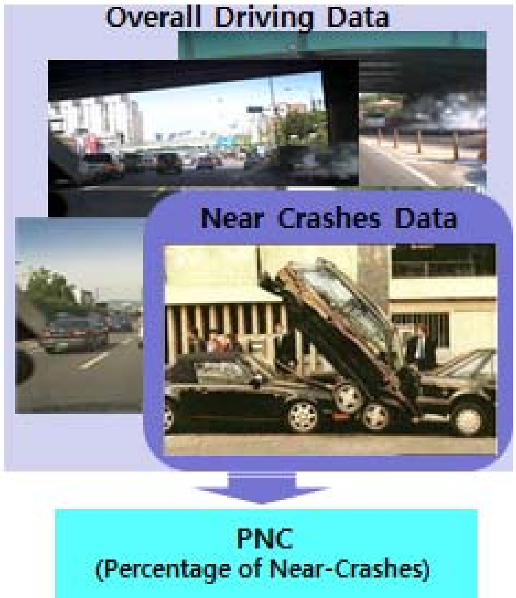

Fig.1 Overview about FOT based safety impact assessment

2. Manual FOT data base

The field test was conducted in April 2012. The test was implemented for two test conditions over a period of 1 month. During the first condition, drivers drove the instrumented vehicle for about 1 week with the ACC system turned off. In the second condition drivers drove the vehicle for about 3 weeks with the ACC system enabled. The driving road type is mix of urban and non-urban roads around the city of Seoul (Korea).

Throughout the course of the field test, drivers accumulated over 6604 km of driving – 21% by manual driving and 79% by ACC system were operated.

Table.1 Field Operational Test Data Overview

No	ACC		Manual	
	Time (sec)	Distance (km)	Time (sec)	Distance (km)
1	103271.6	667.2	12552.5	111.0
2	72229.9	825.9	26691.7	226.3
3	37241.6	697.2	13791.3	220.2
4	103060.5	1356.6	33920.7	318.2
5	177686.5	1961.7	39905.4	219.4
Total	493489.8	5508.6	126861.5	1095.1
Portion	79.6%	83.4%	20.4%	16.6%

3. Near Crashes Definition

To evaluate whether ACC system increases the safety, near-crash thresholds were selected. Threshold values consist of 3 parameters: Time To Collision (TTC) and minimum clearance between subject and target vehicle and longitudinal deceleration of the subject vehicle. If all of these three values of the FOT data are over each value's threshold, it is considered as near-crash driving situation. Near-crash thresholds were determined using distributions of intensity measures recorded in the field test.

Time To Collision(TTC)

TTC means time that is expected to collide when present relative speed and distance are kept.

By using the ECE regulation No.48 (Rear end collision Alert Signal)[7] and driver's reaction delay (1.0sec), , TTC threshold can be determined as follow:

$$TTC_{NearCrash} = \begin{cases} 1.0 \text{ sec} & if \ \ V_{rel} < 12.5kph \\ \dfrac{2.4}{30_{[kph]}} \cdot V_{rel} & if \ \ 12.5kph < V_{rel} < 30kph \\ 2.4 \text{sec} & if \ \ 30kph < Vrel \end{cases} \quad (1)$$

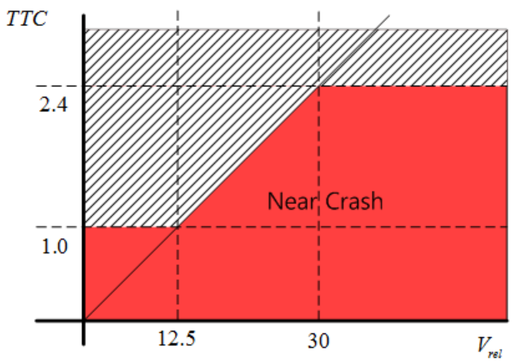

Fig.2 Threshold of the TTC

Minimum Clearance

From the experimental test data, we confirm that vehicles clearance about preceding vehicle had tended to maintain linear combination of velocity and normal time-gap.

$$c = c_0 + \tau \cdot v_p \quad (2)$$

Where, C0 means minimum clearance and τ is the linear coefficient.

By analysis of the manual driving data in normal car-following situation, the linear coefficient can be obtained as Table.2

From the under 5 percentile's linear coefficient, Table.3 Near crash rates of the FOT database the threshold value of the minimum clearance can be obtained as:

$$c_{\min} = 0.7 \cdot v_s + 1.0 \quad (3)$$

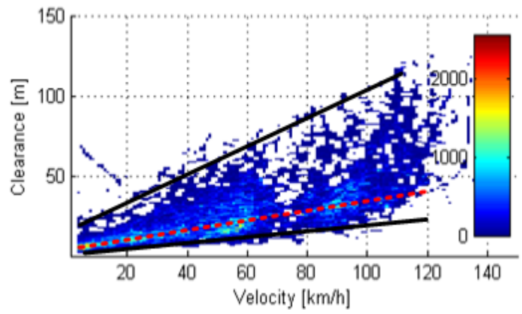

Fig.3 Clearance and Velocity relation in car-following situation

Table.2 Linear coefficient of the Time gap in Car following situation

Following-Data (15 person, 342min)					
Index-Percentile	5%	25%	Mean	75%	95%
Linear coefficient [s]	0.72	1.07	1.36	1.69	2.27

Longitudinal Deceleration

As shown in Fig.4, mainly uses area of the longitudinal accelerations were close to zero, which means that the majority of the motion occurred at nearly uniform speed. About 90% of acceleration and decelerations occurred within –2.0 and 2.0 m/s2.

Therefore, values that driver seldom used area (under -2.0m/s) are mainly selected as threshold values of longitudinal deceleration.

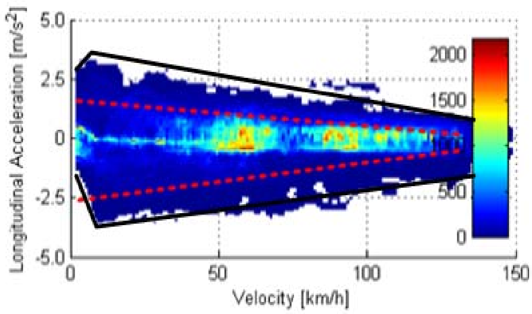

Fig. 4 Longitudinal Acceleration and Velocity Relation

4. Test Results

The exposure to near crashes in the manual and ACC driving periods provides a measure to assess the

No.	ACC				Manual			
	Distance (km)	Near Crash			Distance (km)	Near Crash		
		Total	Deceleration	Cut In		Total	Deceleration	Cut In
1	667.2	2	1	1	111.0	0	0	0
2	825.9	2	1	1	226.3	1	0	1
3	697.2	1	0	1	220.2	0	0	0
4	1356.6	7	1	6	318.2	1	1	0
5	1961.7	2	1	1	219.4	3	1	2
Total	5508.6	14	4	8	1095.1	5	2	3
Near Crash Rate (No./100km)	0.25/100km				0.46/100km			

potential safety benefits of the ACC system. By using the collected database, changing of crash risk between with and without ACC system is used to quantify the impact of the ACC system.

The number of near crash per 100 km in the manual driving period is 0.46 and in the ACC case was 0.25. In case of three vehicles (number 1, 3 and 4), the near crash rate are increased in ACC driving period. As shown in Table 3, it is caused by other vehicle's cut in. It means that the ACC system cannot guarantee the vehicle's safety in case of cut in case as much as in case of deceleration case. However, average of the near crash rates decreased during the ACC driving period.

Safety impact of the ACC can be assessed based on driver exposure to near crashes with and without the ACC system by using equation (4) [2]

$$E(S_i) = 1 - \frac{PNC_w(S_i)}{PNC_{wo}(S_i)} \quad (4)$$

$$where,\ PNC_w(S_i) = Near\ crash\ rate\ with\ System$$

$$PNC_{wo}(S_i) = Near\ crash\ rate\ without\ System$$

From the result of the near crash rate of the manual and ACC driving case with equation (1), expected safety benefit of the ACC system in the Korean road condition is that 45% of longitudinal crash can be reduced by the ACC system.

TEST SCENARIO BASED SAFETY IMPACT ASSESSMENT

To make up for the missed FOT data, test scenario based ACC performance test was conducted. From the scenario based test, system's physical performance in the specific driving situations can be evaluated. By using the scenario based test result, expected safety effect of the ACC system can be assessed in selected driving scenarios.

1. Scenario Definition

To construct the test scenario, important component of the system should be defined first. In this research, the main component of the ACC system are defined as 'Detection', 'Decision' and 'Control'.

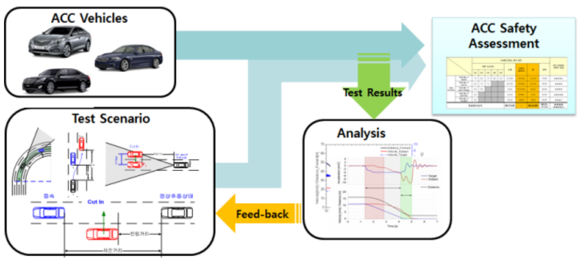

Fig. 5 Overview of the Scenario based Safety Assessment

From the main component of the ACC system, the test scenario is composed to represent ACC related accident situation which are mainly occurred in daily driving situation, i.e. subject vehicle's lane-change, cut-in or sudden decelerations of the target vehicle.

Table.4 Main component of the ACC system

Performance Factors	Assessment Elements
Detection	In-lane Vehicle Detection
	Side-lane Vehicle Detection
	Mult-vehicle Detection
Decision	Following Performance: Curved Road
	Following Performance: Multi-Vehicle
	Following Performance: In-path Vehicle
Control	Control Performance: Deceleration
	Control Performance: Cut-In Vehicle
	Control Performance: Lane Change

Tabel.5 Test Scenario for Assessment of the ACC system

Driving Situation		**Scenario**	
Curved Road	**Entrance**	In-path Vehicle (No.1-1)	Side-lane Vehicle (No.1-2)
	Following	In-path Vehicle (No.1-3)	Side-lane Vehicle (No 1-4)
Cut In		Straight Road (No.2-1)	Curved Road (No.2-2)
Lane Change		Subject Vehicle's Lane Change (No.3)	
Straight Road		Detection Range (No.4)	Distance Control (No.5)

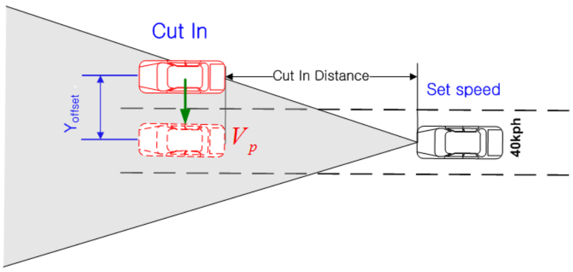

Fig. 6 Test Scenario: No.2-1, Straight Road Case

Table.6 Test Condition of Scenario No.2-1

V_s (Set Speed)	**Vp (Cut In Vehicle)**	**Cut In Distance**	**Cut In Speed**
40 kph	40 kph	8 (m)	Slow (4sec)
			Fast (2sec)
	35 kph	8 (m)	Slow (4sec)
			Fast (2sec)

2. Test System Definition and Test Results

To evaluate the ACC system's safety performance on the test scenario, test vehicles construct by preceding vehicle and subject vehicle. The following measuring instruments were used during the experiment: DAQ system, CCD camera, three axis inertial sensor, and a GPS.

In order to warranty sufficient safety and the repeatability of the test results, Steering and Throttle/Brake robot were selected to perform the preceding vehicle.

In case of the subject vehicle, 4 kinds of passenger vehicles (which are included the ACC system) were used.

By using the test system, each vehicle's driving information (velocity, steering, acceleration and Driver's input) and relative motion (clearance, lateral offset, relative velocity, etc.) can be collected simultaneously.

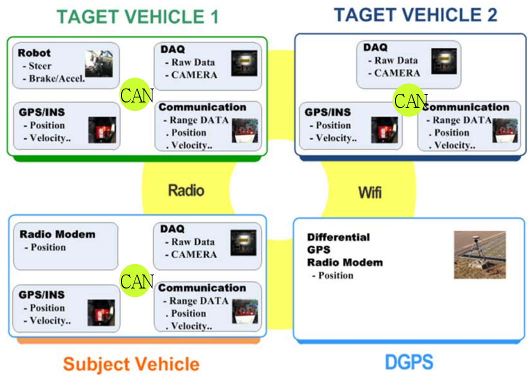

Fig. 7 Test System composition for the scenario based safety assessment

3. Safety Grade Definition

Safety level of the ACC system can be determined from the test result. To grade the performance quality of the ACC system, it should evaluate its main component which defined in previous chapter, such as detection, decision and control. Also, the longitudinal safety index (equation 5) [8] which was proposed in our previous research is used to evaluate the safety level of the ACC system's control performance.

$$I_{longitudinal} = \max\left(\frac{|x_{\max} - x|}{|x_{\max} - x_{th}|}, \frac{|TTC^{-1}|}{|TTC_{th}^{-1}|} \right) \quad (5)$$

Therefore, every scenario has an appraisal standard to make an objective evaluation. For instance, in case of 'Cut-in scenario in the straight road', the appraisal standard is composed as follow:

1) Detection component

- A point of the time to target selection

- Lateral offset between subject vehicle and cut-in vehicle when the preceding vehicle was selected as the target

2) Decision component

- Delay time of the warning signal

(If the driving came to near crash situation)

3) Control component

- Minimum clearance during preceding vehicle's

cut-in motion
- Clearance control after cut-in
- Safety index during overall driving

4. Test Results

From the scenario based test, the ACC system's safety grade can be obtained as Table.7. As shown in the Table.7, all of vehicles got over 80% of grade in total point. Especially, all of ACC system had a greate score in detection range test. Even though test vehicles had different system and control algorithm, test result was very similar to each other. However, in case of cut in test scenario, grade of some ACC system is little lower than other case.

The effect of the ACC system can be assessed by using the test result with real accident data. In this research, we referred the Pre-crash scenario from NTHSA. [9] By matching between the longitudinal related pre-crash scenario and test scenario of the ACC system, reduction rate of accidents can be estimated as Table.8. From the estimation, it is expected that 35% of the accidents can be reduced by the ACC system based on safety assessment by using the test scenario.

Table.7 Test Result of 'Test scenario based safety assessment of the ACC system'

Test Result : Test Scenario based Safety Assessment of the ACC system						
	Test No. 1 Curved Road	**Test No. 2 Cut In**	**Test No. 3 Lane Change**	**Test No. 4 Detection Range**	**Test No. 5 Distance Control**	**Sum**
Vehicle A	13.8/15	21.2/24	9.75/15	5.64/6	30/40	80.4/100
Vehicle B	11.5/15	17.3/24	11.55/15	5.8/6	36.4/40	82.5/100
Vehicle C	12.3/15	17.4/24	13.5/15	5.8/6	33.6/40	82.6/100
Vehicle D	12.3/15	15.7/24	12.9/15	5/6	36.2/40	82.1/100
Average	12.5/15 (0.83)	17.9/24 (0.75)	11.9/15 (0.80)	5.6/6 (0.93)	34.1/40 (0.85)	81.9/100 (0.82)

Table.8 Safety Assessment based on Scenario test

Pre-crash Scenario (Longitudinal related Case)	**Rate**	**Matching Scenario**	**Test Result**	**Estimated Reduction Rate of Accidents**
Following Vehicle Approaching a Decelerating Lead Vehicle	7.2%	Distance Control (No.5)	0.85	6.1
Following Vehicle Approaching Lead Vehicle Moving at Lower Constant Speed	3.5%			3.0
Following Vehicle Approaching an Accelerating Lead Vehicle	0.3%			2.6
Following Vehicle Approaching a Stopped Lead Vehicle	16.4%			13.9
Vehicle Taking Evasive Action Without Prior Vehicle Maneuver	0.95%			0.8
Vehicle(s) Changing Lanes – Vehicles Traveling in Same Direction	5.7%	Cut In (No.2)	0.75	4.3
Vehicle Taking Evasive Action With Prior Vehicle Maneuver	0.2%			0.1
Vehicle(s) Turning – Vehicles Traveling in Same Direction	3.7%			2.8
Following Vehicle Making a Maneuver and Approaching Lead Vehicle	1.4%	Lane Change (No.3)	0.80	1.1
Vehicle(s) Parking – Vehicles Traveling in Same Direction	0.8%	None (Low Speed Case)	-	-
Total	40.15%			34.9%

CONCLUSIONS

In this paper, the impact assessment method of enhanced safety by Advanced Cruise Control (ACC) system was proposed. For the impact assessment, the scenario based system performance tests as well as the usual FOT data were used to assess direct and indirect safety impacts.

By using the FOT data, expected safety impact of the ACC system can be obtained from changing of near crash rate between with and without ACC system. Based on the reduction of near crashes, the integrated system could help prevent from near crashes approximately 45%.

Test scenario based ACC performance test was conducted to make up for the missed case in the FOT data. From the scenario based test, system's physical performance in the specific driving situations can be evaluated. Finally, impact assessment of the ACC system can be obtained by combining real accidents data and scenario based test results. By using the proposed assessment methods, the impact assessment with respect to impacts on safety by the ACC system can be assessed scientifically. From the estimation result, the ACC system can reduce the accident by 35%.

As a conclusion, the ACC system can reduce the car accidents significant in car following near crashes when the system was enabled. However, in case of the cut in of other vehicle, the system cannot be guaranteed the safety as well as other case.

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PEDESTRIAN BEHAVIOR ANALYSIS USING 110-CAR NATURALISTIC DRIVING DATA IN USA

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ABSTRACT

The research objective of this work was to understand pedestrians' behavior and interaction with vehicles during pre-crash scenarios that provides critical information on how to improve pedestrian safety.

In this study, we recruited 110 cars and their drivers in the greater Indianapolis area for a one year naturalistic driving study starting in March 2012. The drivers were selected based on their geographic, demographic, and driving route representativeness. We used off-the-shelf vehicle black boxes for data recording, which are installed at the front windshield behind the rear-view mirrors. It records high-resolution forward-view videos (recording driving views outside of front windshield), GPS information, and G-sensor information.

We developed category-based multi-stage pedestrian detection and behavior analysis tools to efficiently process this large scale driving dataset. To ensure the accuracy, we incorporated the human-in-loop process to verify the automatic pedestrian detection results. For each pedestrian event, we generate a 5-second video to further study potential conflicts between pedestrians and vehicle. For each detected potential conflict event, we generate a 15-second video to analyze pedestrian behavior.

We conduct in-depth analysis of pedestrian behavior in regular and near-miss scenarios using the naturalistic data. We observed pedestrian and vehicle interaction videos and studied what scenarios might be more dangerous and could more likely to result in potential conflicts.

We observed: 1) Children alone as pedestrians is an elevated risk; 2) three or more adults may be more likely to result in potential conflicts with vehicles than one or two adults; 3) parking lots, communities, school areas, shopping malls, etc. could have more potential conflicts than regular urban/rural driving environments; 4) when pedestrian is crossing road, there is much higher potential conflict than pedestrian walking along/against traffic; 5) There is an elevated risk for pedestrians walking in road (where vehicles can drive by); 6) when pedestrians are jogging, it is much more likely to have potential conflict than walking or standing.; and 7) it is more likely to have potential conflict at cross walk and junction than other road types.

Furthermore, we estimated the pedestrian appearance points of all potential conflict events and time to collision (TTC). Most potential conflict events have a TTC value ranging from 1 second to 6 seconds, with the range of 2 seconds to 4 seconds being associated with highest percentages of all the cases. The mean value of TTC is 3.84 seconds with standard deviation of 1.74 seconds.

To date, we have collected about 65TB of driving data with about 1.1 million miles. We have processed about 50% of the data. We are continuously working on the data collection and processing. There could be some changes in our observation results after including all data. But the existing analysis is based on a quite large-scale data and would provide a good estimation.

INTRODUCTION

In this project, the goal is to determine detailed pre-crash scenarios for vehicle-to-pedestrian collisions in the United States. With the support from Toyota Motor Corporation and Toyota Engineering & Manufacturing North America Inc., we recruited 110 cars and their drivers in the greater Indianapolis area for a one year naturalistic driving study starting in March 2012. The Transportation Active Safety Institute (TASI) at IUPUI is located in the heart of downtown Indianapolis. In addition, within the 30 mile radius around Indianapolis, where many people commuting daily, there is a variety of urban streets, highways, freeways, suburban areas, and rural areas. This makes it possible to collect driving and vehicle data from very diverse driving conditions. We used off-the-shelf vehicle black boxes for data recording, which are installed at the front windshield behind the rear-view mirrors, which record high-resolution forward-view videos (recording driving views outside of front windshield), GPS information, and G-sensor information.

We designed and developed a suite of tools to process the data, perform automatic pedestrian detection, and pedestrian behavior analysis. This paper describes our approach and highlights the findings of the pedestrian behavior analysis. This project involves human subjects and received approval from the Indiana University Institutional Review Boards (IRB).

RELATED NATURALISTIC DATA COLLECTION PROJECTS IN USA

In 2002, with the support from National Highway Traffic Safety Administration (NHTSA), Virginia Tech Transportation Institute (VTTI) performed 100-car naturalistic driving data collection [1]. The focus of VTTI's 100-car study was to obtain data on driver performance and behavior in the moments leading up to a crash. Recently, the National Academies of Science-Strategic Highway Research Program 2 sponsored the SHRP 2 Naturalistic Driving Study [2]. The objective of SHRP 2 is to address the role of driver performance and behavior in traffic safety. For both projects, the study focuses are on the driver's performance and behavior.

METHODS

Apparatus

In this project, we installed a DOD GS600 DVR in each vehicle to collect the naturalistic driving data that consists of the driving scene video, GPS information, and vehicle acceleration in X, Y, and Z directions. The DOD GS600 DVR can collect data continuously and save the data into a micro SD card. We used 32GB micro SD cards which can hold up to 10 hours of driving data. The SD card can be easily accessed and switched at the bottom of the camera. *Figure 1* shows the specification of the DOD GS600 DVR. It includes one 120^{o} wide angle lens video camera, a GPS with internal antenna, and G sensor. We set the DOD GS600 DVR to record video at 30 frames per second with 1280x720 resolution.

Sensor	5 Mega pixels CMOS
Wide Angle Lens	120○
Focus	10cm - infinity
GPS	Internal antenna
Video output	MINI HDMI : Support 1080i/720p output mode Composite : NTSC/PAL
Recording format	mov
Recording resolution	1920 x 1080(30fps) 1280 x 720(30fps) 848 x 480(60fps)
Video Code	H.264
Recording media	Micro Card(Upto 64G SDHC Card)

Figure 1 The specification of DOD GS600

Figure 2 shows the example installation to the subject's vehicle. It is installed behind the rear view mirror on the front windshield via its suction cup to record the driving scene. The power cable of the DVR is connected to the vehicle's cigarette charger. The camera will be turned on when vehicle is on; and will be off when the vehicle is off. (note: Due to this constrains, we only select the vehicles that their cigarette charger will be off when the vehicle is off.) To protect the subjects' privacy, we disabled the audio recording capability. To ensure the quality of data collection, we also disabled the "reset" and "format" buttons in the device.

Figure 2 An example installation

Figure 3 shows an example collected video frame, GPS and G sensor data. Video data in .mov format which is encoded using H.264. In the generated video, the GPS location and vehicle speed is displayed on the top left corner of the video. At the same time, it outputs a separate data file in text format with GPS location, speed, and G sensor information. Each second, it would output the GPS information along with calculated moving speed. Every 0.1 second, it would output the G sensor information.

Figure 3 Example collected data (video, GPS, and G sensor data).

Subjects

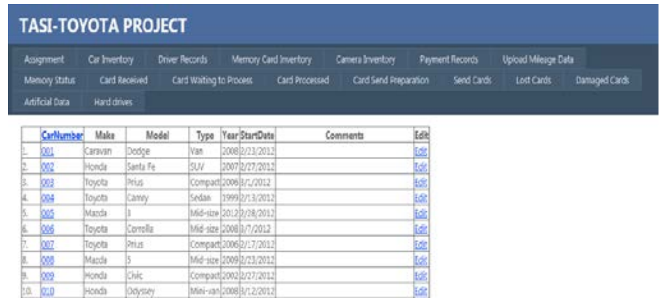
Subjects were recruited through a variety of outlets in the Greater Indianapolis area. 865 people responded to the ads and all were sent an electronic pre-screening form. 580 people returned the pre-screening form. Of those, 350 were eligible for the study. A second screening was done by phone and 270 people participated in the second screening. Of those, 116 people were chosen to participate in the study based on their demographic and geographic representation. Each subject has his/her own vehicle.

Of our 116 subjects, 78% are Caucasian, 10% are Asian, 6% are African American, 2% are Latino/Latin American, 1% are Middle Eastern, 1% are Indian and 2% are of unknown ethnicity. The high percentage of Caucasians compared to the other groups is representative of the population of Indiana where 78.1% of the population is Caucasian. 57 of our subject are female and 59 are male. 72% of our subjects are between the ages of 24-60, 20% are 18-24 and 8% are 60+.

Data Collection

In general, each subject is assigned 4 micro SD cards. For some subjects with high mileage driving, we assign 5 or more micro SD cards. At any given time, each subject had 2-3 micro SD cards available on hand to switch out the cards as needed. Subjects were instructed on how to put in and remove the micro SD cards without changing the angle of the camera. The subjects deliver the card(s) with data to our data collection coordinator via mail or direct drop-off. Our data collection coordinator would send empty cards to the subject upon receiving their data cards.

To manage this process, we designed the subject data management system (Figure 4). With this data management system and method, we can easily pinpoint to the status of any card at any given time. The management system automatically provides warning for the data collection coordinator in following two situations: requests the coordinator to send SD cards to a subject if he/she has only one card on hand; and requests the coordinator to contact a subject if he/she has not send any card in a 3-week period. To ensure the security of the data management system, we have three-level of access authorization to investigator of this task, the data coordinator, data documentation specialist.



	CarNumber	Make	Model	Type	Year	StartDate	Comments	Edit
1.	001	Caravan	Dodge	Van	2008	2/23/2012		Edit
2.	002	Honda	Santa Fe	SUV	2007	2/27/2012		Edit
3.	003	Toyota	Prius	Compact	2006	3/1/2012		Edit
4.	004	Toyota	Camry	Sedan	1999	2/13/2012		Edit
5.	005	Mazda	3	Mid-size	2012	2/28/2012		Edit
6.	006	Toyota	Corolla	Mid-size	2008	3/7/2012		Edit
7.	007	Toyota	Prius	Compact	2006	2/17/2012		Edit
8.	008	Mazda	5	Mid-size	2009	2/23/2012		Edit
9.	009	Honda	Civic	Compact	2002	2/27/2012		Edit
10.	010	Honda	Odyssey	Mini-van	2008	3/12/2012		Edit

Figure 4 The subject data management system

To assist the data documentation process, we designed the data documentation tool. Figure 5 shows the graphical user interface for data documentation, which can help to efficiently organize the data collected. The capabilities include: 1) copy and organize information, such as hard drive location, data type, process date, etc. 2) record, calculate and organize information related to each vehicle such as recorded mileage, recorded time, etc. 3) provide accurate information for subject management system. 4) create logs, such as mileage log, daily log, car log, overall log and etc. 5) automatically change the filename of each file while copying using our defined file name structure as shown in Figure 6. To minimize human errors during the card ID input process, the system would require double input of card ID and the ID number is also designed to help identify typos. This tool allows copying of multiple SD cards to two hard drives at the same time.

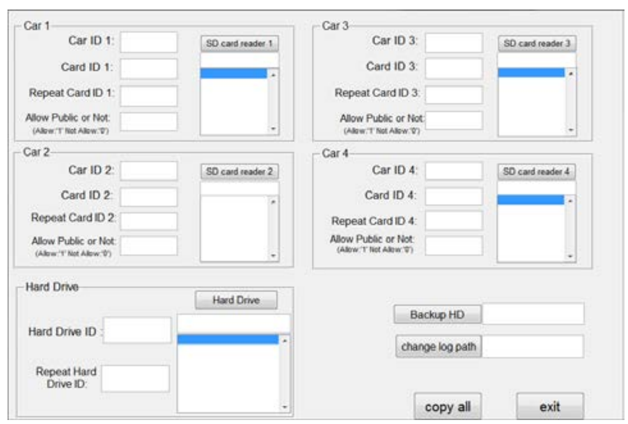


Figure 5 Data management tool

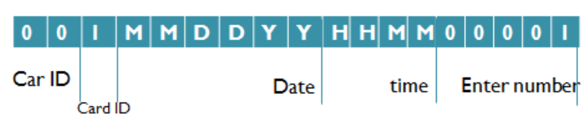


Figure 6 Filename structure

To collect one year data from over 110 subjects is not a trivial task. During the data collection process, we dealt with different kinds of incidents: SD card lost in mailing process, SD card damage, DVR damage, DVR drop off, DVR angle change, subject operation error, etc. We have a team of

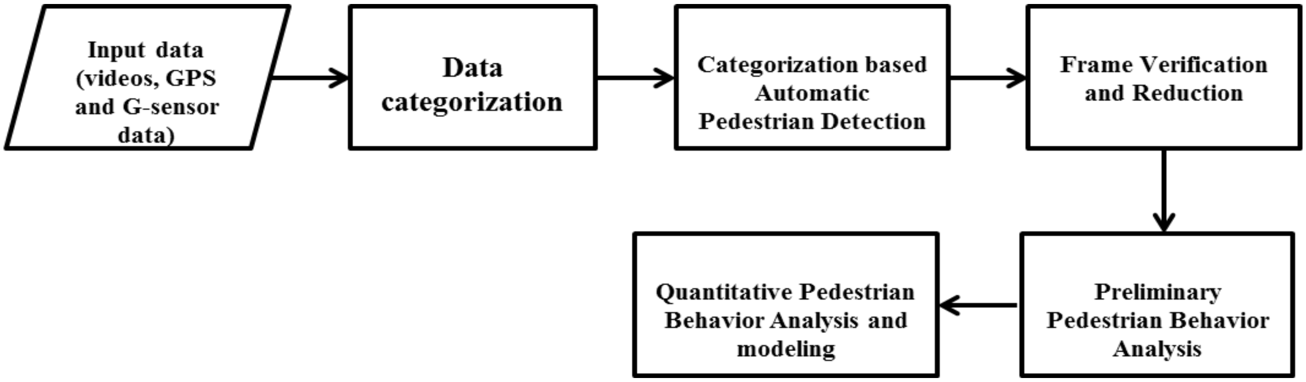


Figure 7 Overview of the process

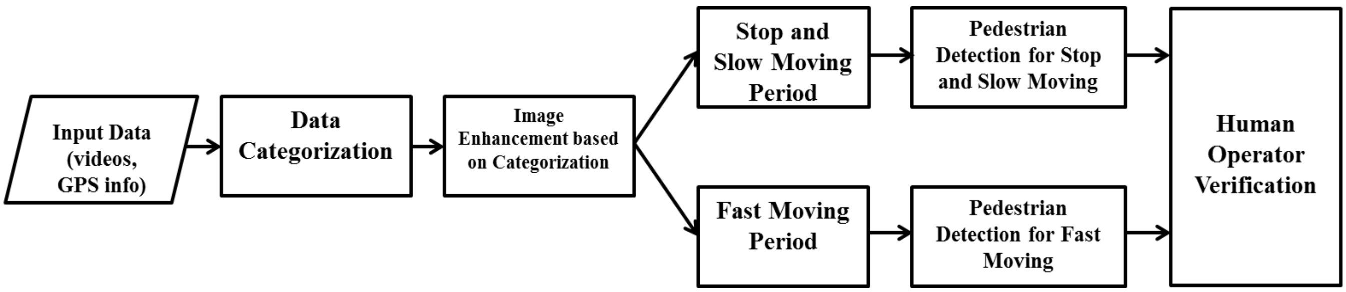


Figure 8 Overview of the categorization based pedestrian detection method

subject and data collection coordinators, data documentation specialists, technical support personnel, and researchers work together to streamline the collection process and develop various damage mitigation procedures.

Data Processing

The flowchart of the entire process of the pedestrian detection and behavior analysis is shown in Figure 7. The collected data, including the recorded videos, GPS information and G sensor data, are first categorized based on the driving scenarios. We designed the categorization based automatic pedestrian detection algorithms [3] to class each video into different categories based on their driving scenario, location, time, and weather. We designed the category-specific algorithms to process each segment of the data based on its category. The automatic pedestrian detection results are verified and processed by reductionists. The tasks of reductionists include verifying the correctly detected pedestrians and eliminating the falsely detected frames and repeatedly detected pedestrian using our frame reduction tool. The rationale behind our human-in-loop process is illustrated in [3]. No automatic pedestrian system can achieve 100% accuracy, but on the other hand, pure manual selection and labeling is extremely expensive and time consuming given the fact that we have huge number of data to process. Therefore, the proposed human-in-loop strategy is a practical and effective trade-off between the accuracy and cost. The automatic algorithm can efficiently generate possible pedestrian frames while eliminating most non-pedestrian frames with high accuracy. The measured reduction rate is 99.92%, which means most of the non-pedestrian frames are eliminated by the automatic algorithm. After frame reduction, only one frame for each pedestrian appearance event is kept. A five-second video is generated for each frame verified by reductionists. All the videos are preliminarily analyzed by our video analysts using our pedestrian behavior analysis tool. The potential conflict videos are selected and gone through quantitative analysis and modeling.

Automatic pedestrian detection process It is very challenging to design an algorithm that can work with all kinds of real-life driving scenarios. It would be reasonable to categorize the driving scenario first and apply a corresponding detection algorithm for different categories. The detailed flow chart of categorization based pedestrian detection is shown in Figure 8. The collected naturalistic driving data is first categorized into stop, slow moving, and fast moving periods based on the speed of the vehicles obtained from the GPS data. Categorization-specific algorithms will be applied to different categories of data respectively to achieve a well balance between accuracy and efficiency.

In the stop and slow moving periods, moving cars and pedestrians can be easily detected comparing to the relatively static background. We designed a simple background subtraction algorithm to generate possible binary foreground Regions of Interest (ROIs). By preprocessing the generated ROI, we can roughly get the following characteristics of the moving objects: object size, length-width radio and orientation of the detected object. It would be very time-consuming and unnecessary to perform pedestrian detections in each frame since a pedestrian would show up in consecutive multiple frames. Therefore we can process several frames per second . For highway or relatively low speed area, we use a bigger interval between frames and for local or higher speed area, we use smaller intervals. The potential pedestrians can be detected by matching the features we found.

For fast moving category, we designed a new pedestrian detection method based on multimodal histogram of gradient (HOG) and kernel based Extreme Learning Machine (ELM) [4-6] to improve the processing speed of the traditional HOG based method and at the same time it achieves a better detection rate. The pre-screening step can effectively reduce the number of the sliding windows and false positives. The lower body detector is additionally incorporated into the traditional whole body detector to effectively reduce the false positives. The naturalistic driving video is sampled and the generated video frame is first preprocessed and pre-screened to eliminate the non-pedestrian windows. Whole body and lower body HOG feature extractions are performed on the regions of interest using sliding window searching. The prescreening step dramatically reduced the number of slide windows. The kernel based ELM classification is then applied to each detection window. The classification results of the whole body and lower body are combined to generate the final decision.

Frame verification and reduction The goal of this step is to reduce the false alarm (the automatically detected frames that have no pedestrians) and reduce the same scenario frames. Our trained data reductionists look through each frame the computer filtered out to determine if there was a pedestrian. If there is a pedestrian in multiple frames, the data reductionist would only select one of the middle frames. Each data reductionist was specially trained by our data processing trainer and can only work after he/she passed our data reduction process test. To assist data reductionist, we developed a user friendly data reduction GUI to automatically log the results.

Preliminary pedestrian behavior analysis For each selected frame by the data reductionist, we generate a 5-second video to perform preliminary pedestrian behavior analysis. We have developed the preliminary pedestrian behavior video analysis tool (Figure 9). It has four main functions: mark potential confliction cases; mark the main pedestrian(s) of interests in the video; label the video based our video analyst's tag to provide searching index and categorizing statistics; and record the pedestrian step frequency.

Our video data analysts are trained specialists in providing preliminary analysis of pedestrian behavior. Each video data analysis can only work on this task after passing the video data analysis test.

Potential conflict scenarios analysis graphical user interface For each selected potential conflict scenario, a 15-second video will be segmented for further analysis. Figure 10 shows our GUI for the behavior analysis which is designed to analyze the selected potential conflict cases. In this step, the analyst will provide more detailed information about the scenario. We will count pedestrian step frequencies to further study pedestrian walking behavior; and calculate the time to collision (TTC) value when applicable.

RESULTS AND DISCUSSION

To date, we have collected 65TB driving data with about 1 million miles. And we have processed about 54% of data for data analysis. About 15,000 hours driving data has been processed by our pedestrian detection system with about 1.7 billion frames. After automatic pedestrian detection, about 2 million frames were detected with possible pedestrians. After verification and data reduction (remove the frames from same events), 9097 videos of interests were analyzed. From these videos, our video analysts detected about 773 potential conflict scenarios for our behavior analysts for further detailed behavior analysis. Here is the statistical information from our processed naturalistic driving data. We label 9097 videos as pedestrian videos which include both normal and potential conflict case. And calculate the potential conflict's rate by dividing the potential conflicts with the pedestrian videos.

Pedestrian behavior data statistics for potential conflict scenarios

Table 1 shows the statistical result of videos of potential conflict with all pedestrian videos (including both normal and potential conflict cases), and the potential conflict's rate. Of all pedestrian videos, we can see that within over 50% cases, only one adult pedestrian is present. Second most cases are two adults present (23.72%). Very few cases (0.76%) that only children were present.

Overall, for the potential conflict rate: when only children as pedestrians (no adult present), there is 23.19% potential conflict rate, which is 177% more likely than the cases with adult pedestrians present. This shows that there is elevated risk to let children walk alone. When only one adult is present, there are about 7.56 % cases that have potential conflict. When two adults are present, there are about 8.71% cases that have potential conflict. When three or more adults are present, there is about 10.26% chances to have potential conflict. This shows that it is more likely to have potential conflicts when more pedestrians are present. Moreover the case with only children as pedestrians has 175% more likelihood to have a potential conflict than the average of the other three cases, which is quite a relatively dangerous case.

Table 2 shows the statistical results of potential conflict rate at different driving environments. We can see that most of the potential conflicts happen in urban area (74.43%), and only 9.18% are encountered from rural area, the rest part (14.47%) are from other areas, such as parking lot, community, school area, etc. However, when comparing with the potential conflicts rate,

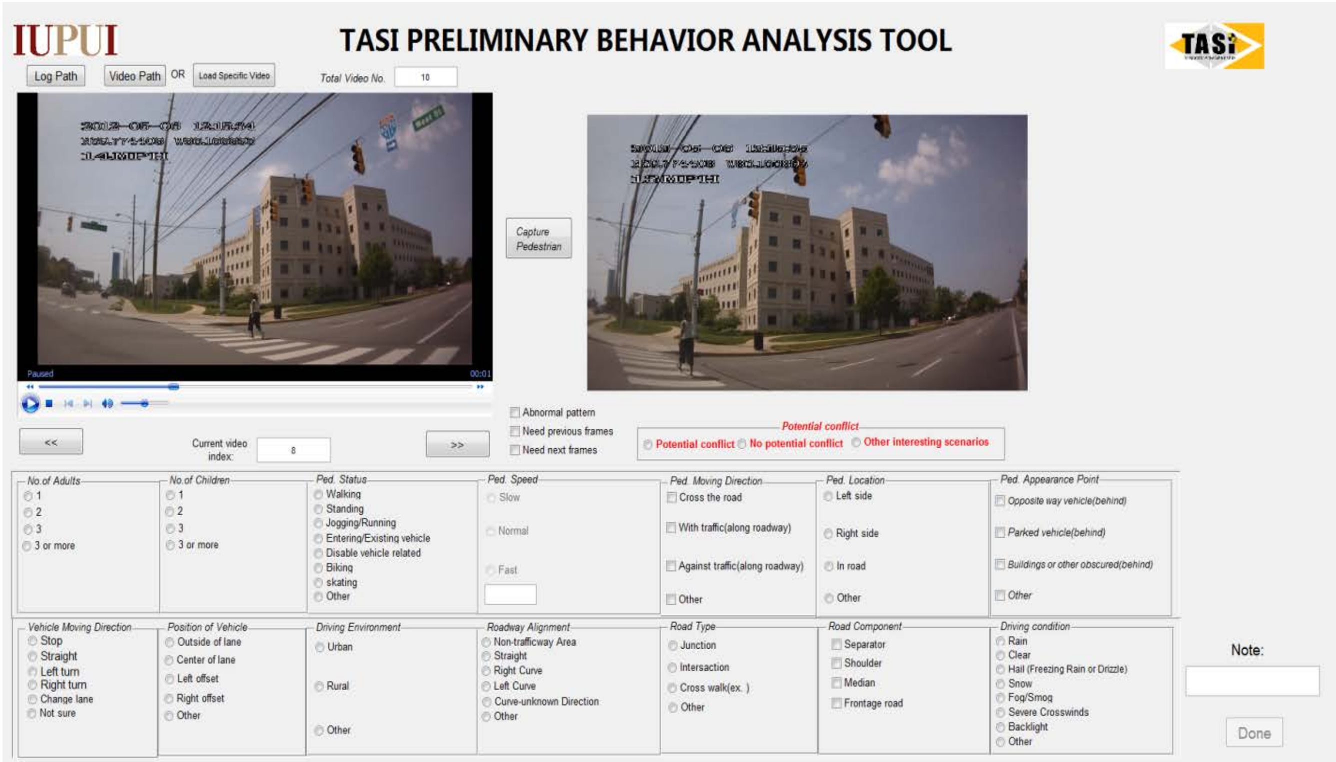


Figure 9 Pedestrian preliminary behavior analysis tool

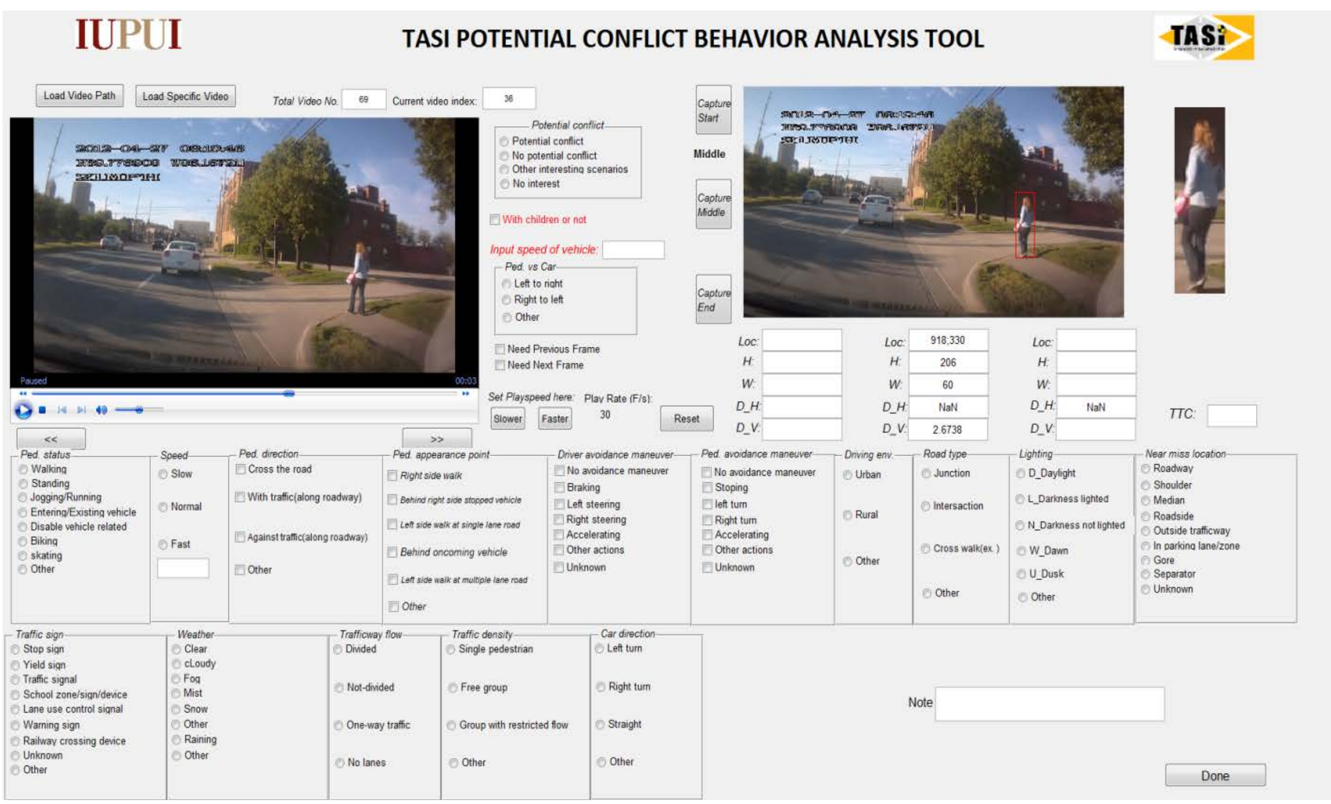


Figure 10 Potential conflict scenarios analysis

Table 1 Number of Adults Presented in the Scene

	Zero adult		One adult		Two adults		Three or more adults	
	No.	%	No.	%	No.	%	No.	%
Pedestrian videos	69	0.76%	5028	55.27%	2158	23.72%	1842	20.25%
Potential conflicts	16	2.07%	380	49.16%	188	24.32%	189	24.45%
Potential conflict rate	23.19%		7.56%		8.71%		10.26%	

Table 2 Potential Conflict Rate at Different Driving Environments

	Rural		Urban		Other	
	No.	%	No.	%	No.	%
Pedestrian videos	1158	12.73%	6771	74.43%	1168	12.84%
Potential conflicts	71	9.18%	533	68.95%	169	21.86%
Potential conflict rate	6.13%		7.87%		14.47%	

Table 3 Potential Conflict Rate at Different Pedestrian Moving Directions

	Against traffic		With traffic		Cross the road		Other	
	No.	%	No.	%	No.	%	No.	%
Pedestrian videos	1723	18.94%	1831	20.13%	2154	23.68%	3389	37.25%
Potential conflicts	50	6.47%	83	10.74%	423	54.72%	217	28.07%
Potential conflict rate	2.90%		4.53%		19.64%		6.40%	

Table 4 Potential Conflict Rate when Pedestrians Show up at Different Locations

	In road		Left side		Right side		Other	
	No.	%	No.	%	No.	%	No.	%
Pedestrian videos	1337	14.70%	2229	24.50%	4346	47.77%	1185	13.03%
Potential conflicts	270	34.93%	173	22.38%	233	30.14%	97	12.55%
Potential conflict rate	20.19%		7.76%		5.36%		8.19%	

Table 5 Potential Conflict Rate at Different Pedestrian Statuses

	Walking		Standing		Jogging		Entering/exiting vehicle		Skating		Other	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Pedestrian videos	6015	66.12%	1636	17.98%	226	2.48%	206	2.26%	8	0.09%	1006	11.06%
Potential conflicts	558	72.19%	47	6.08%	37	4.79%	23	2.98%	1	0.13%	107	13.84%
Potential conflict rate	9.28%		2.87%		16.37%		11.17%		12.50%		10.63%	

Table 6 Potential Conflict Rate when Different Road Types Presented

	Cross walk		Intersection		Junction		other	
	No.	%	No.	%	No.	%	No.	%
Pedestrian videos	177	1.95%	2612	28.71%	146	1.60%	6162	67.74
Potential conflicts	31	4.01%	193	78.14%	23	2.98%	526	68.05%
Potential conflict rate	17.51%		7.39%		15.75%		8.54%	

we can see that 14.47% cases from other driving environments are potential conflicts, which is almost 100% more likelihood than the other two cases.

Table 3 shows the statistical results of potential conflict rate categorized by different pedestrian moving directions. We collected almost evenly distributed pedestrian videos from four pedestrian moving directions: 18.94% are against traffic, 20.13% are with traffic, 23.68% are crossing the road and 37.25% from other moving scenarios. Over half of the potential conflicts (54.72%) are observed from pedestrian crossing the road, and the second most are from other moving directions (28.07%), 6.47% are from against traffic, 10.74% are from with traffic. The statistical results suggest that potential conflicts are more likely to happen in pedestrian crossing scenarios with 19.64% potential conflict rate, which is three times more likelihood than other cases. This shows that road crossing has an elevated risk when compared to other scenarios.

Table 4 shows the statistical results of the pedestrian appearance location. Nearly half (47.77%) of the pedestrians appears on the right side of the road in our pedestrian videos, which is reasonable considering that vehicles drive on right side in USA. Within all the pedestrian videos classified as potential conflicts videos, 34.93% are from pedestrians in road, 22.38% are from pedestrian on left side, 30.14% are from pedestrian on right side and 12.55% from other appearance locations. Pedestrian in road has the highest potential conflict rate (20.19%) and it is two times more likelihood than the average of other cases, which shows that there is an elevated risk for pedestrians to walk in road.

Table **5** shows the pedestrian statuses within all the pedestrian videos: walking (66.12%), standing (17.98%), jogging (2.48%), entering/exiting vehicle (2.26%), skating (0.09%) and other (11.06%). Most data collected are categorized into walking and standing. We observed that higher pedestrian speed may leads to higher rate of potential conflicts as can be seen from jogging (16.37%), and skating (12.50%). Note for skating case, we do not observe many cases to draw conclusion yet.

Table 6 shows the statistical results of potential conflicts with respect to different road types. Most of the collected data are from other category (67.74%) which consists of regular traffic way of non-traffic way. We focus more about the regions of interest such as cross walk (1.95%), intersection (28.71%) and junction (1.60%). We can see that potential conflicts rate is highest at cross walk (17.51%) and second highest is at the junction (15.75%), which are more than 100% likelihood than the other two cases. The potential conflict rate is much lower at intersection when compared to the above two cases. This could be because that intersection has clear traffic signals that pedestrians/drivers can easily follow.

Pedestrian Appearance Points and TTC for Potential Conflict Crossing Events

Figure 11 shows the pedestrian appearance points of all the potential conflict events. The pedestrian appearance point is defined as the first point that the full body of the pedestrian can be seen in the video. Different situations are included:

- “Pedestrian Crosses” situations refer to that the vehicle has given right-of-way to the pedestrians to allow them pass the potential conflict point first;
- “Vehicle Passes” situations refer that the pedestrian has given right-of-way to the vehicle to allow the vehicle pass the potential conflict point first;
- Potential conflict events happening in parking lots are separated from those happening in the traffic way.
- Vehicle movement is categorized into straight movement, left turn, and right turn when the events are happening in the traffic way.

The results show that the density of pedestrian appearance point is much higher in the range of 2 to 8 meters in lateral direction and 0 to 20 meters in longitudinal direction. Also the density of pedestrian appearance points gets lower when getting further away from the vehicle in both directions. For all the situations, the pedestrian appearance points are generally balanced without very obvious patterns in terms of both directions and sides towards the vehicle moving trajectory.

The distribution of time to collision (TTC) values is shown in Figure 12. Most potential conflict events have a TTC value ranging from 1 second to 6 seconds, with the range of 2 seconds to 4 seconds being associated with highest percentages of all the cases. The mean value of TTC is 3.84 seconds with standard deviation of 1.74. The maximum TTC value is 10.11 seconds, and the minimum is 0.7 seconds. Note that our observations are based on near-misses. Therefore the TTC for crash scenarios could be much shorter.

CONCLUSIONS

This collected data provides a promising approach to study pre-crash scenarios for vehicle-to-pedestrian collisions in United States. We observed: 1) children alone as pedestrians have an elevated risk; 2) three or more adults may be more likely to result in potential conflicts with vehicles than one or two adults; 3) parking lots, communities, school areas, shopping malls, etc. could have more potential conflicts than regular urban/rural driving environments; 4) when pedestrian crossing road, there is much higher potential conflicts than pedestrian walking along/against traffic; 5) there is an elevated risk for pedestrians walking in road (where vehicles can drive by); 6) when pedestrians are jogging, it is much more likely to have potential conflict than walking or standing; and 7) it is more likely to have

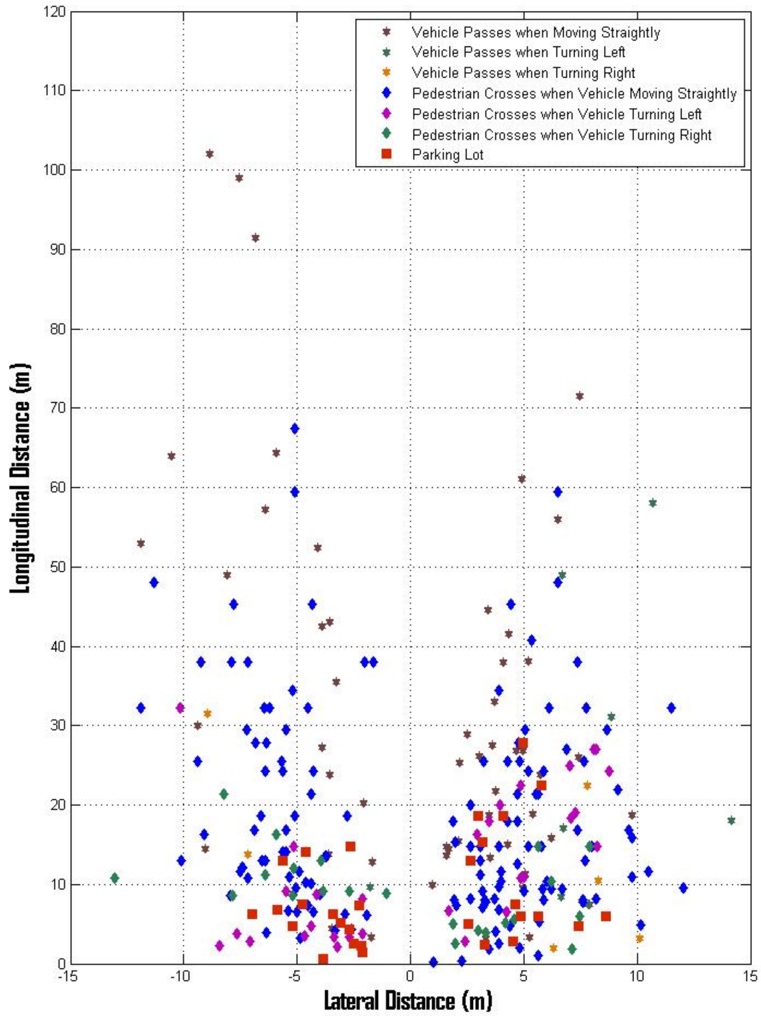


Figure 11 Map of Pedestrian Appearance Points of All the Potential Conflict Events

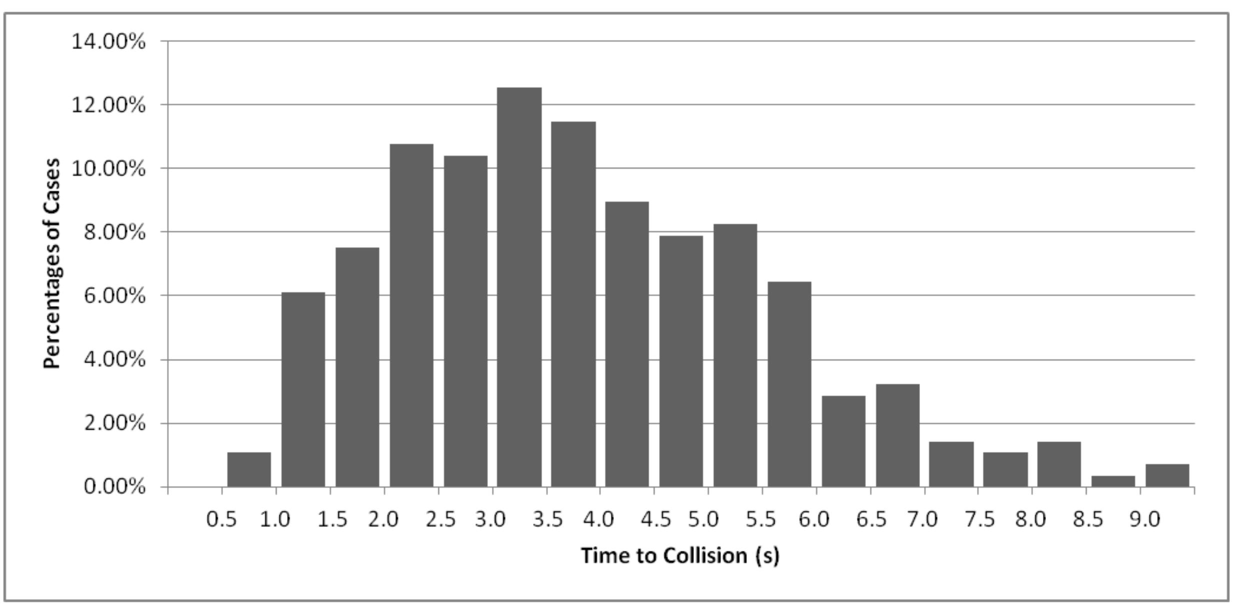


Figure 12 Distribution of Time to Collision Value

potential conflict at cross walk and junction than other road types.

Furthermore, we estimated the pedestrian appearance points of all potential conflict events and time to collision (TTC). Most potential conflict events have a TTC value ranging from 1 second to 6 seconds, with the range of 2 seconds to 4 seconds being associated with highest percentages of all the cases. The mean value of TTC is 3.84 seconds with standard deviation of 1.74. Note that our observations are based on near-misses. Therefore the TTC for crash scenarios could be much shorter.

A limitation of our research is that the collected data does not provide information about drivers' and occupants' behaviors during the conflicts. Therefore, this project is not designed to provide driver's behavior information.

ACKNOWLEDGEMENT

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THE USAGE OF SMARTPHONES FOR RECORDING ACCIDENTS AND INCIDENTS FROM THE CRITICAL SITUATION UP TO THE POST-CRASH PHASE

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ABSTRACT

Smartphones are becoming more and more popular not only for younger people. Contrary to traditional mobile phones they are mostly equipped with sensors for acceleration and yaw rates, GPS modules as well as cameras in high definition resolution. Additionally they have high-performance processors that enable the execution of CPU-intensive tools directly on the phone. The wide distribution of these smartphones enables researchers to get high numbers of users for such studies.

The paper shows and demonstrates a software app for smartphones that is able to record different driving situations up to crashes. Therefore all relevant parameters from the sensors, camera and GPS device are saved for a given duration if the event was triggered. The complete configuration is independently adjustable to the relevant driver and all events were sent automatically to the research institute for a further process. Direct after the event, interviews with the driver can be done and important data regarding the event itself are documented.

The presentation shows the methodology and gives a demonstration of the working progress as well as first results and examples of the current study. In the discussion the advantages of this method will be discussed and compared with the disadvantages.

INTRODUCTION

Changes of technologies from passive/secondary to active/primary safety become more and more important. Due to that, also the used data will change from conventional impact und injury data to all information prior to the collision. In figure 1 the real accident database GIDAS is compared to naturalistic driving data of VUFO.

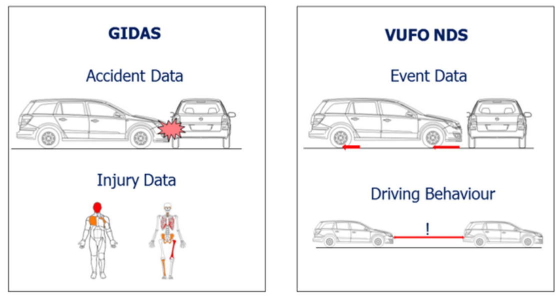

Figure 1. Comparison of accident and incident data.

If an accident occurs, the accident investigation team will be informed by the police or rescue services, so that they can investigate the real data on the spot immediately.

If an incident occurs, it will be much more difficult to get informed. A complete new method of investigation of this data is necessary to realize an interview with the participant as fast as possible. A normal event data recorder can detect crashes and strong near misses, but a video-based analysis of the situation is not applicable.

INVESTIGATION OF INCIDENTS

For that reasons VUFO began to develop a new tool for the investigation of incident data with the following boundary conditions.

- minimum installation effort at the vehicle
- (preferably) no influence to the driver
- Tool should record video-, speed-, acceleration-, gyro- and global position-data
- events should be triggered automatically

- triggering should be possible depending on position, by exceeding of physical thresholds or manually
- tool should be centrally configurable

To realize a high number of participants in a representative manner the tool should be easy to handle for consumers as well as the study operators. For an easier analysis of the data, the coding of the parameters should be analog to the GIDAS database. This also implements the simulation process analog to GIDAS with a Pre-Incident-Matrix (PIM). This allows the use of the same tools and simulation framework that already exist for real accident database like GIDAS.

In figure 2 the setup of this method is shown.

Figure 2. Setup for investigation of naturalistic driving data using smartphones.

Modern smartphones are equipped with

- camera
- acceleration sensor
- gyro-sensor
- GPS sensor
- transceiver
- CPU and memory

The described method based on an application for these smartphones which will record all the necessary parameters in a circular buffer.

For the central configuration of the application, especially for the individual triggering parameters, the method bases on a server environment as shown in figure 3.

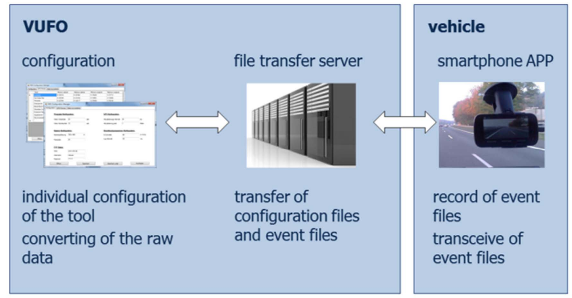

Figure 3. Server environment.

To realize a complete and independent investigation of all parameters, the tool can be configured via file transfer server. The complete data exchange is also managed via file transfer server. This guarantees that the triggered events will be as fast as possible available for the subsequent investigation of the other relevant data in relation to the event. The study participant can be interviewed concerning the event by our experts soon.

In figure 4 the basic functionality of the VUFO NDS-APP is shown.

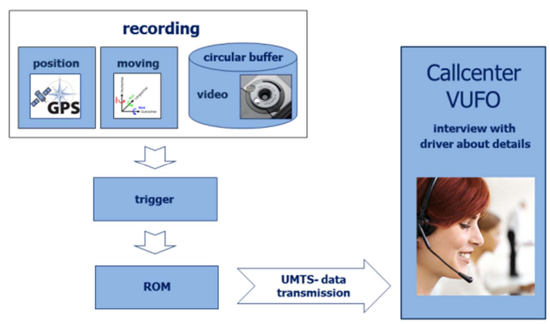

Figure 4. Basic functionality of VUFO NDS-APP.

The software records the GPS positions, all the moving parameters and the video stream in a circular buffer. If an event is triggered, a sequence of maximum 60 seconds backwards will be saved to the RAM of the smartphone. This event file will be sent via UMTS or WLAN connection to the file transfer server immediately.

In the next step VUFO will analyze this event and call back the participant to get further information, if the event is of interest for VUFO NDS.

In figure 5 the further tasks are shown.

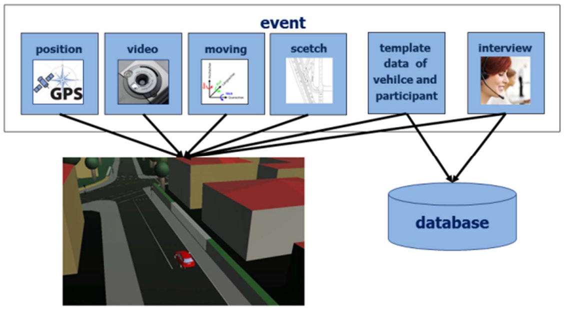

Figure 5. Further tasks for events in VUFO NDS.

The event data will be combined with a scaled sketch, all available template data of the vehicle and the participant and the interview data to a simulation of the event. This file is called Pre Incident Matrix (PIM). All parameters will be coded into the VUFO NDS database additionally.

DATA OF VUFO NDS

With the described process VUFO NDS is able to collect data in the following manner:

- driving behavior
- incidents
- accidents
- manually triggered records
- position-based records

Especially the driving behavior of the participants is important to know. VUFO NDS is using this data for an individual triggering threshold for incidents of this participant as well.

Driving Behavior

Figure 6 shows a recording of a participant with his individual comfort zone regarding longitudinal and lateral acceleration. This comfort zone is based on a record of all moving parameters for several days.

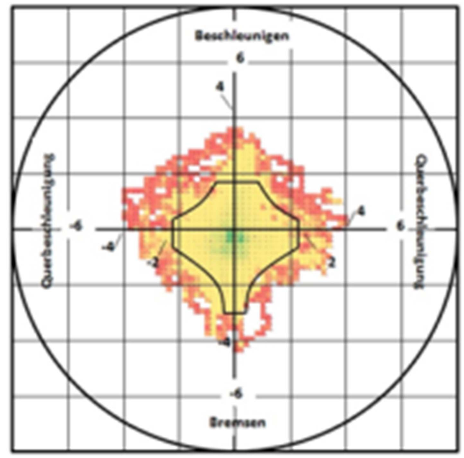

Figure 6. Recorded individual comfort zone for acceleration in x- and y-direction for the individual participant.

Incidents

Especially incidents and more or less critical situations are of interest in this project. As rare as they happen, they are very important to analyze the pre incident phase.

All warning strategies of ADAS are only appropriate when they are accepted. If acceptance could be assumed in high critical situations, it will become more and more difficult for less and uncritical situations.

Accidents

Accidents are very rare events. Only every 500.000 km an accident will occur. Nevertheless if an accident happens, the VUFO APP will record all the relevant parameters prior to the crash. These data could be used by experts to proof the innocence of the participant or at least provide data similar to an EDR.

Manually triggered records

Not all situations of interest can be triggered by exceeding of a moving parameter or by passing of GPS positions. In that case the participant can trigger an event manually.

Position based records

Especially for accident hotspots it will be of high interest to record individual sequences by passing the spot. These records can be analyzed via video and moving parameters. In figure 7 a special analysis regarding loss of control accidents on an accident hotspot is depicted.

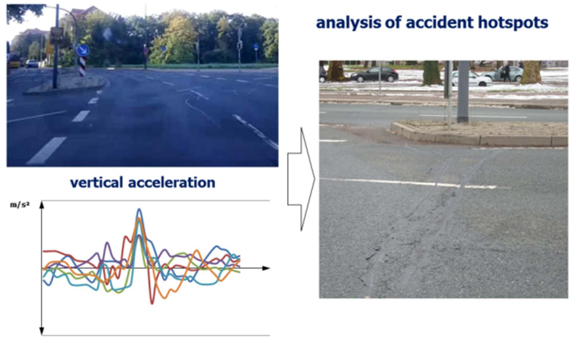

Figure 7. GPS position based accident hotspot recording.

VALIDATION OF VUFO NDS

To validate the measurement results of the VUFO NDS APP different test drives were initiated. Figure 8 shows the scenario on the test track.

Figure 8. Scenario of the test drive.

The test car was equipped with a KIENZLE event data recorder and the VUFO NDS APP. Both measuring devices recorded the longitudinal and lateral acceleration as well as the speed.

Figures 9 and 10 show the validation results of longitudinal and lateral acceleration.

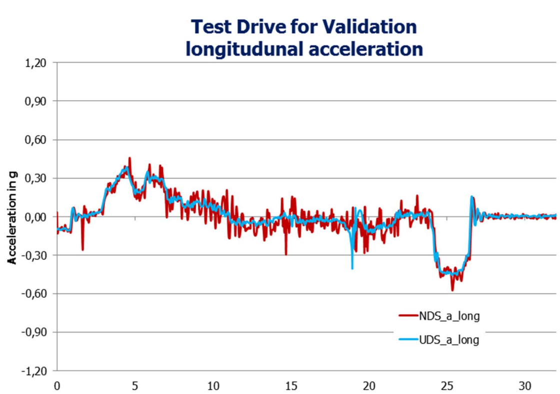

Figure 9. Validation of the longitudinal acceleration.

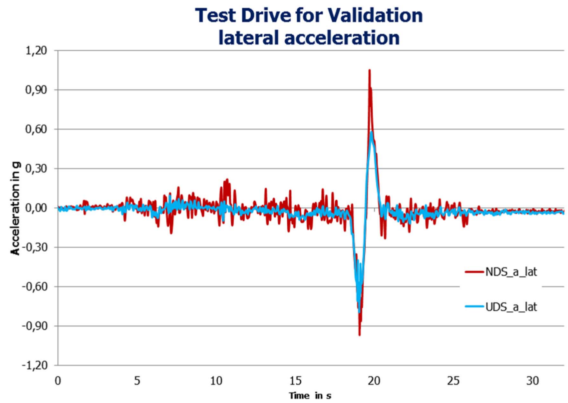

Figure 10. Validation of the lateral acceleration.

Both measurement results of VUFO NDS APP correlate with the accredited and calibrated results from the event data recorder.

CONSUMER BENEFIT OF VUFO NDS

Event Data Recorder

For the consumer and study participants of this project the VUFO NDS APP will work as a normal event data recorder with additional video information. (see figure 11) This data could be used by experts to proof the innocence of the participant.

Figure 11 VUFO APP as event data recorder

A normal upgraded event data recorder costs around 1000€ while the VUFO NDS APP is free of charge.

Hazard Warning

The VUFO NDS APP could also be used as a hazard warning due to different daily driven situations. Figure 12 shows show some of these possibilities.

Figure 12. Hazard warning functionality.

The warning threshold could be easily adjusted be using the driver behavior results as described before.

Economic Driving

Economic driving is becoming more and more important. VUFO NDS APP could help to drive as economically as possible by measuring the real situation and comparing it to the average or most effective one in the same situation. This will help to reduce unnecessary expense. Figure 13 shows the principle setup.

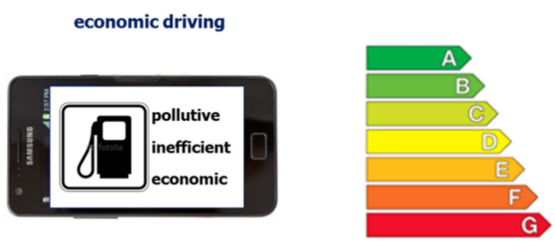

Figure 13. Economic driving functionality.

CONCLUSIONS

Detailed information about the pre-crash or pre-incidence phase needs to be investigated with new methods. The paper shows an application for smartphones which is able to detect critical scenarios as well as recording moving parameters of the participant.

At the Accident Research Unit VUFO, this app is used to build up a naturalistic driving database near to existing real world accident databases (e.g. GIDAS).

The comparability to this database guarantees the use of the same methods and simulation tools for all future users.

The VUFO NDS APP could also be used for the consumer in terms of event data recorder for crashes and warnings and information about hazard and economic driving.

ACCURACY OF FOLKSAM ELECTRONIC CRASH RECORDER (ECR) IN FRONTAL AND SIDE IMPACT CRASHES

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ABSTRACT

Estimation of crash severity from crash recorders is important in the evaluations of vehicle crashworthiness. The number of cars fitted with on-board crash recorders is increasing. The majority of these recorders are integrated with airbag sensors that usually have limitations regarding e.g. recording time and sampling rate. The aim with this study was to evaluate the accuracy of an Electronic Crash Recorder (ECR) compared to laboratory accelerometers.

The ECR records car body acceleration during a crash event. The ECR is part of a large accident data collection system where 10,000 units per year are installed in various car models in Sweden. The ECR has the possibility to record acceleration in longitudinal and lateral impacts and also in multiple events. The ECR also meet requirements like recording data 30 ms prior to pulse start (t_0) and recording time up to 500 ms with 1 kHz sampling rate.

The focus was to evaluate the accuracy in a wide range of impact speeds and with different pulse shapes. A series of 12 sled tests were conducted with delta-V between 12.3 and 73.5 km/h. In each test the sled was fitted with 10 ECRs as well as a laboratory accelerometer. Five ECRs were fitted in the longitudinal direction and five in the lateral. In total 120 ECR recordings were evaluated.

Acceleration data were filtered according to CFC60 as defined in SAE J211. Change of velocity, mean and peak accelerations were derived from the filtered acceleration.

No systematic error was found regarding delta-V. The systematic error of mean acceleration in the longitudinal direction was 0.4 g (3.5%).

For all tests the standard deviation for delta-V in the longitudinal direction was 0.8 km/h (1.9%). The corresponding value for the lateral direction was 1.4 km/h (3.9%). The standard deviation for mean acceleration was 0.2 g (1.7%) in the longitudinal direction and 0.4 g (3.0%) in the lateral direction. In general no major differences in standard deviation between low and high speed crash tests were found.

Overall the evaluation of the ECR showed that a low cost accelerometer device gives accuracy close to a laboratory accelerometer.

INTRODUCTION

Knowledge of crash severity is important in crash injury analyses. The link between injury outcome and crash severity is essential for both car manufacturers and road designers. Traditionally crash severity, often change of velocity, is calculated with energy based reconstruction software based on measurements of structural deformation of the car. Historically the most frequently used ones are CRASH3, SMASH and WinSmash, where WinSmash is the most recent one. The error of such reconstruction software has been shown to be large, with underestimations of delta-V up to 33% (Smith and Noga 1982; O'Neill et al. 1996; Lenard et al. 1998; Gabler et al. 2004; Niehoff and Gabler 2006) .

Using crash recorders may have a profound impact on vehicle crashworthiness by providing delta-V, mean and peak acceleration to be used in crash reconstruction and analyses. This helps car manufacturers to improve automotive safety more effectively, but also to evaluate benefits of new safety technology. The most used severity parameter in crashworthiness analysis is delta-V. Mean acceleration is also used and shown to have a good correlation to injury risk (Ydenius 2009). Peak acceleration is not commonly used in crash analysis partly caused by the absence of detailed acceleration data in most EDRs.

Folksam introduced a crash recorder in 1992 with a mechanical Crash Pulse Recorder (CPR) (Aldman et al. 1991). The CPR has been installed in Toyota, Saab, Opel, and Honda cars in Sweden. In total approximately 260,000 cars have been fitted with a CPR. The CPR has been replaced by a new electronic crash recorder (ECR) that the present study aims to evaluate. The installation of the successor ECR began in mid 2008 with an installation rate of 8,000-10,000 units per year. The installation of the ECR is continuously implemented in Toyota cars.

The ECR is an electronic accelerometer measuring acceleration in the longitudinal and lateral directions. It is not capable of measuring the variety of parameters such as seat belt use, applied brakes or driving speed, that many other accident data recorders are capable of, e.g. Event Data Recorders (EDRs) used in the USA. The National Highway Traffic Safety Administration (NHTSA) refers to them generically as Event Data Recorders. In this paper the term “crash recorder” is generally used to describe an on-board accelerometer device.

One important use of crash recorder data has been to evaluate the car occupant injury risk and injury tolerance levels. The quality of real world crash data has often been a limiting factor in establishing injury tolerance (Kullgren and Lie 1998; Funk et al. 2008). During the last 15 years, studies aimed at evaluating injury tolerance based on real world crashes with recorded crash severity have been presented (Kullgren et al. 2000; Krafft et al. 2002; Gabauer and Gabler 2008; Kullgren and Krafft 2008; Ydenius 2010). In these studies, injury risks for different injury types versus recorded impact severity have been established.

An additional advantage with crash recorder data is the ability to evaluate effectiveness of various safety technologies. One of the latest introduced safety system is autonomous emergency braking (AEB). Based on analysis of data from crash recorders, injury risk reduction for AEB can be estimated (Kullgren 2008). As more advanced safety technologies are introduced in cars, it is important to continuously evaluate effectiveness for these systems, preferably with help from crash recorder data.

The importance of using crash recorder data in car accident research has led to an increasing number of car fleets with crash recorders as standard equipment. Cars are often equipped with crash recorders making it possible to measure change of velocity time history or acceleration time history during the crash phase. In large car fleets, such as Toyota, GM (General Motors) and Ford in the U.S., EDRs with lower sampling frequency and limited recording time are used.

To ensure quality of crash recorder data in the U.S., the road safety authority (*NHTSA 49 CFR Part 563 Event Data Recorders*) has decided a standardization rule for collecting EDR data. The final rule requires an accuracy of delta-V and acceleration of ±10%. Transport Canada and GM found the delta-V error of the GM EDRs to be within ±10% (Comeau et al. (2004). Niehoff et al.(2005) evaluated the performance of EDRs from GM, Ford and Toyota in crash tests. They found that the average error in frontal crashes was just below six percent. One observation done by several authors is that crash recorders generally underestimate delta-V in relation to laboratory accelerometers (Chidester et al. 1999; Lawrence et al. 2003; Comeau et al. 2004; Niehoff 2005).

Smaller car fleets give more freedom to use high performance crash recorders with larger capacity, such as AXA Winterthur (2011) and Folksam (Kullgren and Krafft 2008). The crash recorder used by AXA Winterthur has similar specifications as the one used by Folksam. The AXA crash recorder has an accuracy of ±10% on acceleration measurement. The previous crash recorder CPR from Folksam had a systematic error of 8.8% on delta-V measurement (Kullgren et al. 1995).

The aim with this study was to evaluate the accuracy of the Folksam Electronic Crash Recorder (ECR) compared to a laboratory accelerometer.

METHODS

ECR description

The ECR has a 2-axial accelerometer (see Figure 1). The evaluation of the ECR was done in longitudinal (x) and lateral (y) direction separately. The ECR had an external 12 V power supply. The recording time is 500 ms per event and up to four subsequent events can be recorded. The sampling frequency is 1 kHz. The trigger level of the accelerometer is 1.5 g over a 5 ms time period. Data 32 ms prior to trigger level is recorded. The longitudinal range is ± 72 g and the lateral ± 36 g.

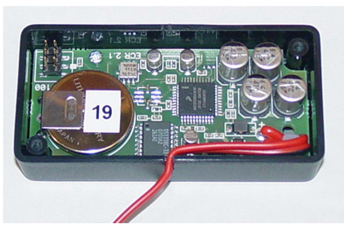

Figure 1. Electronic Crash Recorder (ECR)

Crash tests

Twelve sled tests were performed to evaluate the accuracy of the ECR. In each test 10 ECRs were attached to the sled, five with longitudinal orientation and five with lateral (see Figure 2). As reference accelerometer a laboratory accelerometer (Endevco 7267A) was used with a sampling frequency of 20 kHz. In total 12 crash tests were conducted with impact speed between 10-67 km/h (see Table 1). The test pulses were based on three predefined pulses, Euro NCAP at 64 km/h, US-NCAP at 56 km/h and a "non fire" airbag pulse at 15 km/h. In order to get a variation in crash severity and pulse shape, the impact speed varied and ride down acceleration were adjusted by varying the brake force of the sled.

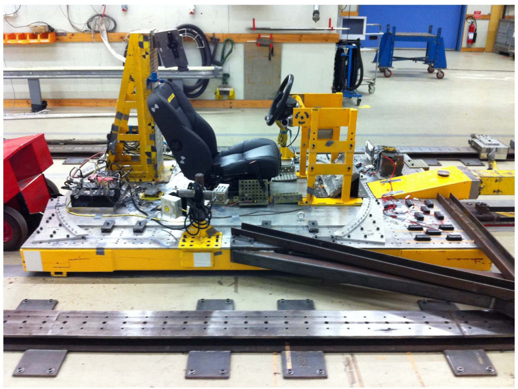

Figure 2. Sled test set up with the ECRs on the sled to the right.

Table 1. Crash test severity level

Test	Delta-V km/h (lab)	Impact speed (km/h)	Severity level
T-0711	12.2	10	Low
T-0712	17.7	15 "Non fire" airb	Low
T-0713	22.6	20	Low
T-0714	28.1	25	Medium
T-0707	28.2	25	Medium
T-0703	28.2	25	Medium
T-0708	32.8	30	Medium
T-0704	33.3	30	Medium
T-0705	62.8	56 US-NCAP	High
T-0709	69.9	64 EuroNCAP	High
T-0706	70.3	63	High
T-0710	73.5	67	High

Computations

Delta-V was derived from the acceleration pulse between t_0 and t_{end} and mean acceleration was calculated. To determine t_0 and t_{end} one of the methods, *Method C*, described in ISO 12353-3 (SIS 2013) was used for both the laboratory and the ECR recordings. The ECR and laboratory recordings were filtered according to CFC60 as defined by SAE J211.

Evaluation of the random and systematic error of the ECR was done in longitudinal and lateral direction separately. The evaluation was done for delta-V, mean and peak acceleration.

The crash tests were divided in three severity levels. Low severity had delta-V below 25km/h. Medium severity were between 25 km/h to 50 km/h and high severity were tests with delta-V above 50 km/h.

Systematic error

Systematic errors were calculated according to Equation (1), showing the average difference between the ECR and the laboratory accelerometer.

$$Systematic\ error = \frac{\sum_{i=1}^{n}(x_i - x_{lab})}{n} \qquad (1)$$

Random error

Standard deviation was calculated according to Equation (2). Standard deviation was calculated for each test and for each orientation of the ECRs. The standard deviation for all 12 tests was computed as the mean value of the standard deviation for all 12 tests as well as for the three severity levels.

$$Std\ Dev = \sqrt{Var\ x} = \sqrt{\sum_{i=1}^{5}\frac{(x_i - \bar{x})^2}{(n-1)}} \qquad (2)$$

RESULTS

Pulses from laboratory accelerometers in the 12 crash tests are presented in Appendix A.

Systematic error

No evidence of systematic error for delta-V (ΔV) either in the longitudinal or in the lateral direction was found (see Table 2). In lateral direction there was an underestimation of delta-V less than one km/h for low/medium severity. In high severity tests there was an overestimation of 1.8 km/h (2.8%).

The systematic errors for both longitudinal and lateral mean acceleration (ā) were found to be 0.5 g or less (3.5% and 3.9 % respectively). Longitudinal mean acceleration showed a decreasing error between low severity tests and medium/high severity, from 5.5% to 3.4%.

In both directions there was a larger systematic error for peak acceleration ($\hat{a}$) than for the other parameters. The error for peak acceleration was an underestimation of 8.7% and 5.1% in longitudinal and lateral directions respectively.

Table 2. Systematic error of longitudinal and lateral delta-V, mean and peak acceleration - divided in severity levels

		Error		%
Total	ΔV_x	0.2	km/h	0.4
0-75 km/h	ΔV_y	0.0	km/h	0.0
n_x=60	$\bar{a}_x$	0.4	g	3.5
n_y=53	$\bar{a}_y$	0.5	g	3.9
	$\hat{a}_x$	-1.8	g	-8.7
	$\hat{a}_y$	-1.0	g	-5.1
Low ΔV	ΔV_x	0.0	km/h	0.3
0-25 km/h	ΔV_y	-0.5	km/h	-3.0
n_x=15	$\bar{a}_x$	0.3	g	5.5
n_y=14	$\bar{a}_y$	0.2	g	3.0
	$\hat{a}_x$	-0.5	g	-5.2
	$\hat{a}_y$	-0.9	g	-8.4
Medium ΔV	ΔV_x	-0.2	km/h	-0.5
25-50 km/h	ΔV_y	-0.8	km/h	-2.6
n_x=25	$\bar{a}_x$	0.3	g	3.4
n_y=24	$\bar{a}_y$	0.2	g	2.2
	$\hat{a}_x$	-2.3	g	-12.6
	$\hat{a}_y$	-1.3	g	-7.5
High ΔV	ΔV_x	0.6	km/h	0.9
50-75 km/h	ΔV_y	1.8	km/h	2.8
n_x=20	$\bar{a}_x$	0.7	g	3.4
n_y=15	$\bar{a}_y$	1.3	g	6.3
	$\hat{a}_x$	-2.1	g	-5.7
	$\hat{a}_y$	-0.9	g	-2.5

Random error

In general no major differences in standard deviation between low, medium and high speed crash tests were found (see Table 3). For all tests the standard deviation for delta-V in the longitudinal direction was 0.8 km/h (1.9%). The corresponding value for the lateral direction was 1.4 km/h (3.9%).

The standard deviation for mean acceleration was 0.2 g (1.7 %) in the longitudinal direction and 0.4 g (3.0 %) in the lateral direction. The standard deviation for peak acceleration was larger than for the other parameters (see Table 3).

Table 3. Random error of longitudinal and lateral delta-V, mean and peak acceleration - divided in severity levels

		Error		%
Total	ΔV_x	0.8	km/h	1.9
0-75 km/h	ΔV_y	1.4	km/h	3.9
n_x=60	$\bar{a}_x$	0.2	g	1.7
n_y=53	$\bar{a}_y$	0.4	g	3.0
	$\hat{a}_x$	1.0	g	4.6
	$\hat{a}_y$	0.7	g	3.6
Low ΔV	ΔV_x	0.3	km/h	1.6
0-25 km/h	ΔV_y	0.2	km/h	1.1
n_x=15	$\bar{a}_x$	0.1	g	1.5
n_y=14	$\bar{a}_y$	0.1	g	1.2
	$\hat{a}_x$	0.4	g	3.7
	$\hat{a}_y$	0.6	g	5.8
Medium ΔV	ΔV_x	0.9	km/h	3.0
25-50 km/h	ΔV_y	0.3	km/h	0.8
n_x=25	$\bar{a}_x$	0.3	g	2.6
n_y=24	$\bar{a}_y$	0.1	g	1.1
	$\hat{a}_x$	0.8	g	4.4
	$\hat{a}_y$	0.7	g	3.8
High ΔV	ΔV_x	0.9	km/h	1.3
50-75 km/h	ΔV_y	2.8	km/h	4.2
n_x=20	$\bar{a}_x$	0.2	g	1.1
n_y=15	$\bar{a}_y$	0.7	g	3.3
	$\hat{a}_x$	1.5	g	4.1
	$\hat{a}_y$	0.9	g	2.8

Two outliers were identified among the longitudinally mounted ECRs in the medium severity group; one with a delta-V 2.0 km/h below and another with a delta-V 3.6 km/h above the laboratory value. The standard deviation for delta-V in the group with the two outliers was 3.0% compared to 1.9% for all delta-V_x values.

In one of the high severity tests there were three outliers among the laterally mounted ECRs. The standard deviation for delta-V_y in that test was 4.2% compared to 3.9% for all delta-V_y values.

All individual data from the 120 ECR recordings as well as the figures of standard deviation are presented in Appendix B.

DISCUSSION

NHTSA has published a standardization rule for EDRs that requires an accuracy of measured delta-V and acceleration within ±10%. The present study shows that the Folksam ECR has no systematic error and a longitudinal random error of 1.9% of measured delta-V. Compared to other crash recorders (AXA Winterthur 2011; Comeau et al. 2004; Niehoff et al. 2005), the Folksam ECR appears to measure more accurately. The Folksam ECR is one of the most highly specified large fleet crash recorders on the market regarding acceleration recordings.

Although crash recorders have been introduced in accident research, crash severity estimations are still performed with computer software that estimates delta-V based on post-crash measurements of car structural deformation. The accuracy analysis of such reconstruction software has been shown to be large, with underestimations of delta-V between 10%-33% and with large random errors (Smith and Noga 1982; O'Neill et al. 1996; Lenard et al. 1998; Gabler et al. 2004; Niehoff and Gabler 2006) . The influence of large measurement errors on injury risk curves will be extensive (Kullgren and Lie 1998; Funk et al. 2008). In order to conduct an appropriate injury tolerance analysis it is essential to have crash severity data with low measurement errors, especially concerning random errors. Using crash recorders gives a possibility to obtain this.

Studies of the accuracy of reconstruction program are in some publications done in comparison with EDR data, not laboratory data (Gabler et al. 2004; Niehoff and Gabler 2006). Although there is a variation in accuracy of different types of crash recorders, the error output from reconstruction programs are greater and in addition more sensitive to crash modes than crash recorders. Furthermore, this comparison favors reconstruction programs since studies show that errors of EDRs usually are underestimations as well as errors from reconstruction programs (Chidester et al. 1999; Lawrence et al. 2003; Comeau et al. 2004; Niehoff 2005).

The accuracy of a crash recorder is not only dependent of the accelerometer specifications but also recording capacity. Problems with truncated pulses are an important source of error. Absence of sufficient recording time may lead to larger systematic errors than minor measurement errors. Although there are methods to make estimations of the missing parts of truncated pulses under certain circumstances (SIS 2013), it results in an underestimation of delta-V when the whole pulse is not captured. In many crashes the crash recorder does not cover the whole event (Gabler et al. 2005; Niehoff 2005; Ydenius 2010). To ensure a 95% coverage of the whole pulse in frontal crashes, at least 250 ms recording duration is needed (Niehoff 2005) and in car to roadside events, at least 300 ms (Gabler et al. 2005; Stigson et al. 2009; Ydenius 2010). To capture the majority of long crash pulses the authors suggest ensuring at least 300 ms recording time.

The systematic error for peak acceleration was larger than for the other parameters. Both the laboratory accelerometer and the ECR recordings were filtered according to CFC60. Despite that an explanation could be the large difference in sampling rate between the ECR and the laboratory accelerometer (1 kHz compared to 20 kHz).

Five outliers were found in two tests influencing the standard deviation. These were included in the evaluations. A possible explanation to these outliers could be the attachments to the sled that may have caused small movements during the deceleration. Two outliers were found among the longitudinally mounted ECRs in test T-0703 and three among the laterally mounted ECRs in test T-0709. The random error in T-0703 was for delta-V_x 3.0% compared to 1.9% for all delta-V_x. Changing the random errors of these outliers to zero would have changed the standard deviation of delta-V_x from 1.9% to 1.4%. And in test T-0709 the random error for delta-V_y was 4.2 % compared to 3.9% for all for delta-V_x. Changing the random errors of the outliers to zero would have changed the standard deviation of delta-V_y from 3.9% to 1.7%.

An accelerometer with laboratory specifications is still an expensive component if no compromises regarding sampling frequency, recording time or ability of multiple event recording are made. It is reasonable to assume that a car manufacturer will use the most cost effective crash recorder solutions in the future. However, the present study shows that the Folksam ECR is almost as accurate as a laboratory accelerometer. It is encouraging to find that it is possible to achieve this for a relatively low cost.

Limitations

It was decided to conduct twelve crash tests at different crash severity levels. From a statistical point of view it would have been more favorable to run a larger number of ECRs in each crash test in order to better evaluate the random error of the ECR. However, since the ECR is used in real-world crashes, the intention was to evaluate if any differences could be found between high and low speed crashes. The number of possible tests to run was limited, so 10 ECRs in each test (5 lateral and 5 longitudinal) was a good compromise.

In each of the 12 crash tests one single laboratory accelerometer was used as a golden standard. Although laboratory accelerometers could be assumed to have high accuracy, these accelerometers are also associated with random errors themselves. Therefore, it would have been better to use for example three laboratory accelerometers and use the average of their measurements in the comparisons with the ECR.

CONCLUSIONS

Regarding systematic and random measurement errors of the Folksam ECR the following were found based on 12 crash tests with 120 ECR recordings in three severity levels:

- No systematic error was found regarding delta-V.
- The systematic error of mean acceleration in the longitudinal direction was 0.4 g (3.5%) and 0.5 g (3.9%) in lateral direction.
- In general no major differences in standard deviation between low and high speed crash tests were found.
- For all tests the standard deviation for delta-V in the longitudinal direction was 0.8 km/h (1.9%). The corresponding value for the lateral direction was 1.4 km/h (3.9%).
- The standard deviation for mean acceleration was 0.2 g (1.7%) in the longitudinal direction and 0.4 g (3.0%) in the lateral direction.

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APPENDIX A

Crash pulses from laboratory accelerometers in the twelve sled tests are presented below.

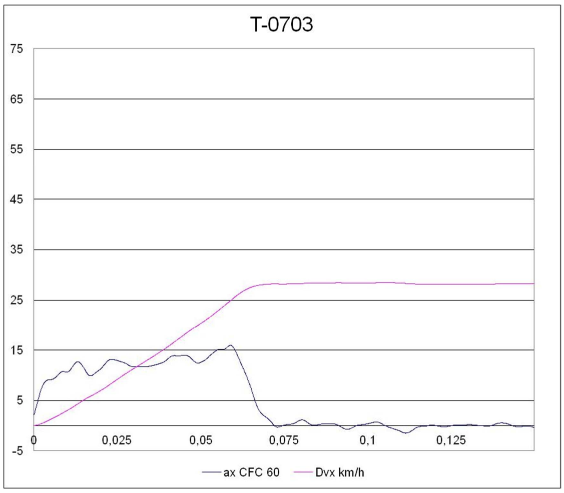

Figure A1. T-0703 (modified US-NCAP)

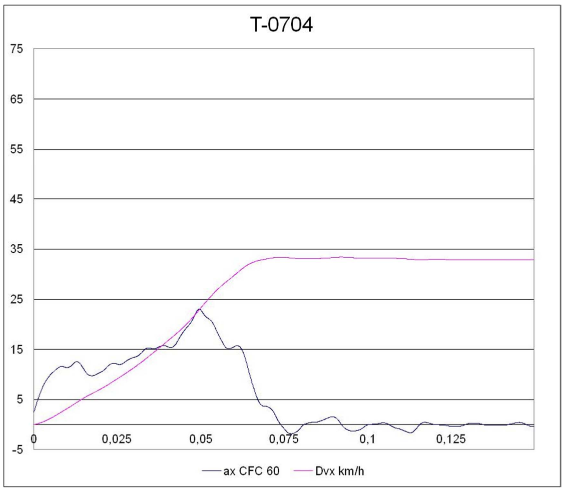

Figure A2. T-0704 (modified US-NCAP)

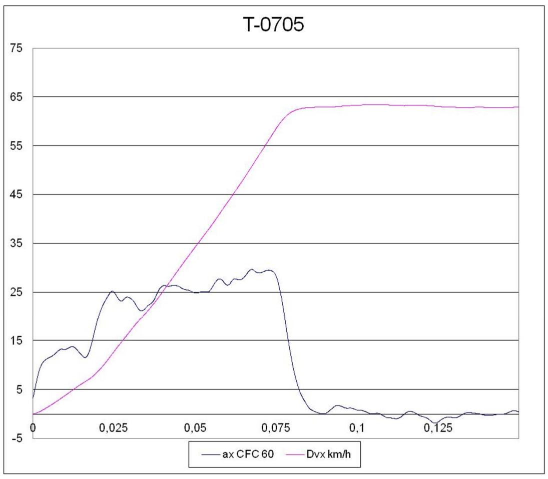

Figure A3. T-0705 US-NCAP (56 km/h)

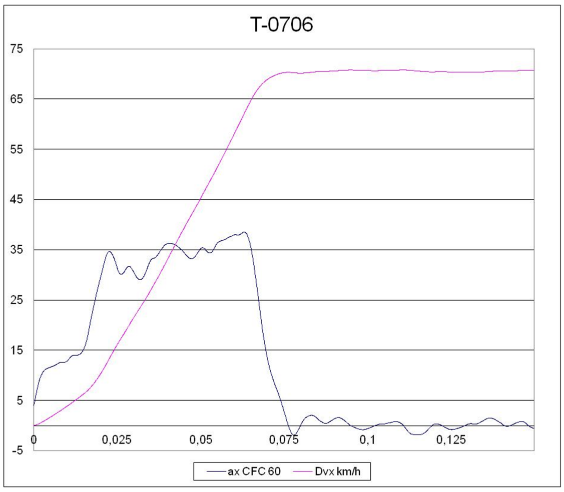

Figure A4. T-0706 (modified US-NCAP)

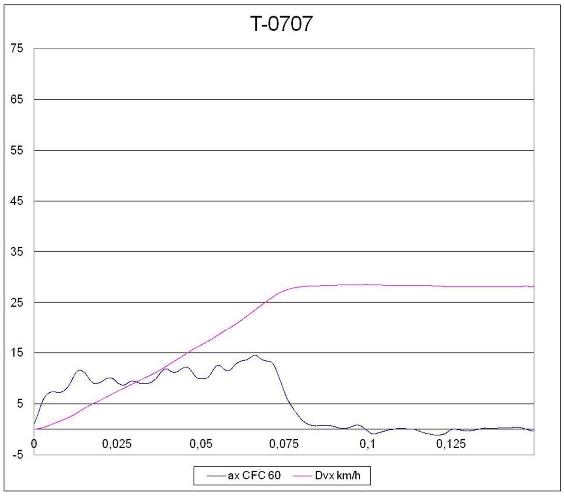

Figure A5. T-0707 (modified EuroNCAP)

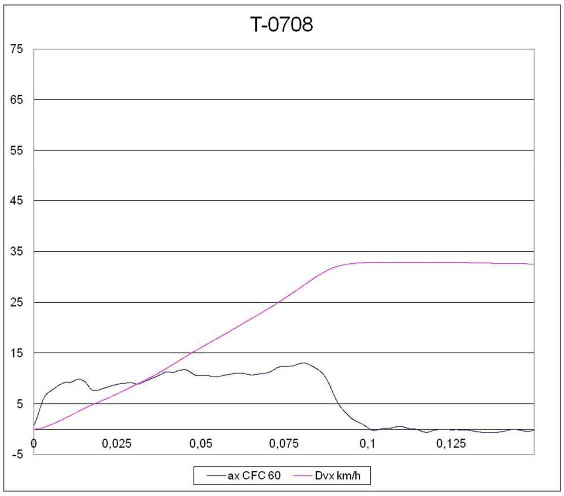

Figure A6. T-0708 (modified EuroNCAP)

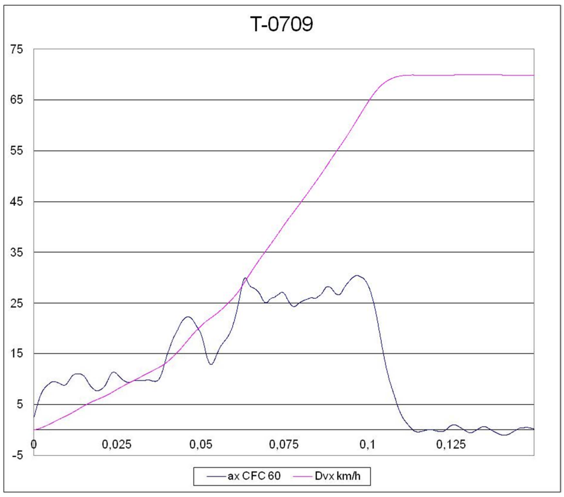

Figure A7. T-0709 EuroNCAP (64km/h)

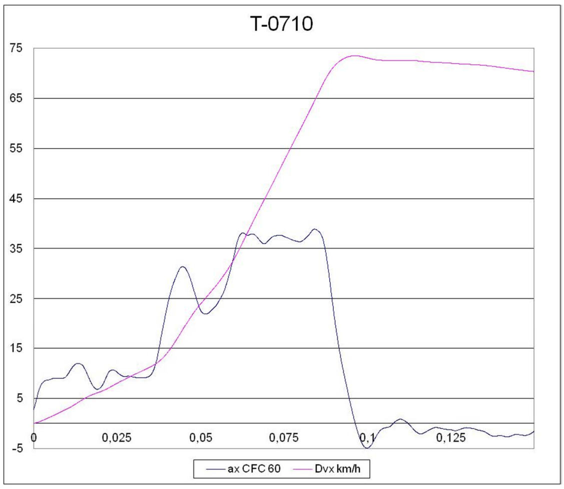

Figure A8. T-0710 (modified EuroNCAP)

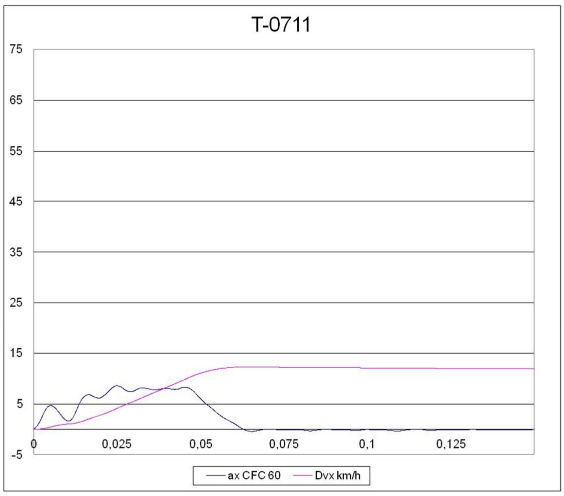

Figure A9. T-0711

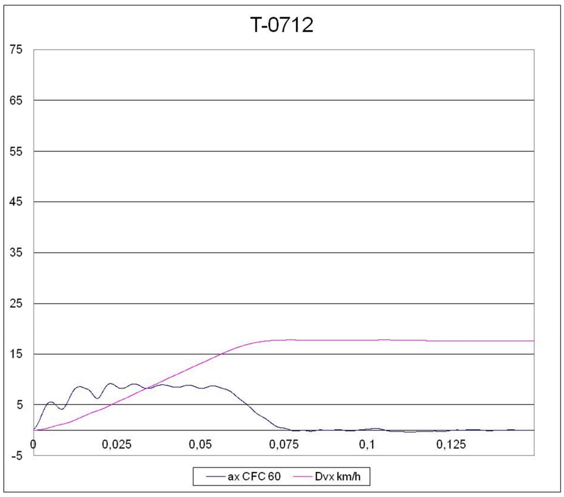

Figure A10. T-0712

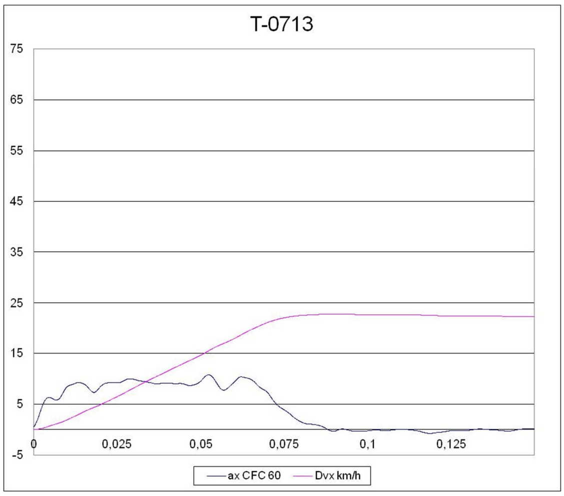

Figure A11. T-0713

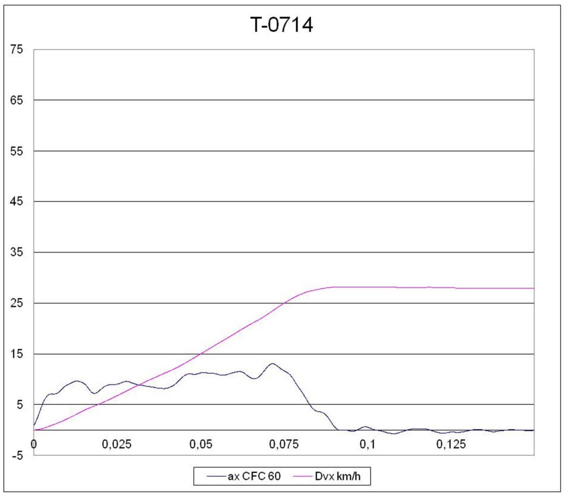

Figure A12. T-0714

APPENDIX B

Random errors for each tested ECR device.

Table B1. Random error delta-V- longitudinal

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	28.2	33.3	28.2	32.8	28.1	12.3	17.7	22.7	62.8	70.3	69.9	73.5
ECR1	28.2	33.4	28.0	33.1	28.6	12.5	17.5	23.3	62.6	70.2	69.3	72.8
ECR2	27.9	33.2	28.3	33.5	27.7	12.1	17.3	22.2	60.7	69.9	67.7	73.9
ECR3	28.3	33.2	28.8	33.3	28.7	12.4	17.3	22.7	61.4	70.6	67.5	72.4
ECR4	28.9	33.9	28.4	32.8	27.5	12.0	17.7	23.0	60.5	70.1	68.6	74.0
ECR5	28.2	34.1	27.1	32.6	28.1	12.2	17.5	22.6	63.8	70.6	69.9	73.5
Mean	28.3	33.5	28.1	33.0	28.1	12.2	17.5	22.7	61.8	70.3	68.6	73.3
Var	0,1	0,2	0,4	0,1	0,3	0,0	0,0	0,2	1,9	0,1	1,0	0,5
Std Dev	0,3	0,4	0,6	0,3	0,5	0,2	0,2	0,4	1,4	0,3	1,0	0,7
Std Dev(%)	1.2	1.3	2.3	1.1	1.8	1.8	0.9	1.9	2.2	0.5	1.5	0.9

Table B2. Random error delta-V - lateral

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	28.2	33.3	28.2	32.8	28.1	12.3	17.7	22.7	62.8	70.3	69.9	73.5
ECR1	29.2	34.3	28.7	34.5	29.0	12.7	17.6	23.2	60.2	71.1	64.3	-
ECR2	28.4	34.5	28.7	33.7	29.1	12.7	18.0	23.6	63.5	70.9	70.0	-
ECR3	29.1	-	28.9	34.0	28.8	13.0	17.7	23.6	64.4	70.8	67.9	-
ECR4	28.5	34.3	28.7	33.4	28.8	12.8	18.2	23.7	61.7	70.0	62.4	-
ECR5	28.7	34.6	28.7	33.7	28.8	12.7	-	23.4	63.5	68.9	57.8	-
Mean	28.8	34.4	28.7	33.8	28.9	12.8	17.9	23.5	62.7	70.4	64.5	
Var	0.1	0.0	0.0	0.2	0.0	0.0	0.1	0.0	2.9	0.8	22.7	
Std Dev	0.4	0.1	0.1	0.4	0.1	0.1	0.2	0.2	1.7	0.9	4.8	
Std Dev(%)	1.3	0.4	0.4	1.2	0.4	1.2	1.3	0.9	2.7	1.3	7.4	

Table B3. Random error mean acceleration - longitudinal

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	11.1	13.1	9.6	9.5	8.8	5.7	6.8	7.7	20.7	26.3	17.7	21.6
ECR1	10.5	12.8	9.6	9.4	8.7	5.5	6.4	7.1	19.9	25.5	17.1	21.2
ECR2	9.8	12.9	9.0	9.4	8.6	5.4	6.5	7.3	19.2	25.4	17.1	21.3
ECR3	10.7	12.9	9.6	9.4	8.7	5.4	6.3	7.4	19.7	25.7	17.0	21.2
ECR4	10.5	13.0	9.0	9.3	8.4	5.3	6.5	7.5	19.2	25.5	17.0	21.6
ECR5	9.9	13.2	8.7	9.1	8.8	5.3	6.4	7.5	20.1	25.3	17.4	21.4
Mean	10.3	13.0	9.2	9.3	8.6	5.4	6.4	7.4	19.6	25.5	17.1	21.3
Var	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Std Dev	0.4	0.2	0.4	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.2	0.2
Std Dev(%)	4.2	1.3	4.3	1.6	1.6	1.5	1.3	2.0	2.1	0.5	1.0	0.7

Table B4. Random error mean acceleration - lateral

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	11.1	13.1	9.6	9.5	8.8	5.7	6.8	7.7	20.7	26.3	17.7	
ECR1	10.7	13.1	9.2	9.6	8.5	5.5	6.4	7.5	18.7	25.4	15.6	
ECR2	10.6	13.2	9.3	9.3	8.7	5.4	6.4	7.6	19.9	25.7	17.2	
ECR3	10.7	-	9.4	9.5	8.8	5.6	6.4	7.6	20.2	25.7	16.6	
ECR4	10.9	13.0	9.1	9.3	8.7	5.5	6.7	7.6	19.6	25.1	15.4	
ECR5	10.5	13.1	9.2	9.4	8.7	5.4	-	7.6	19.7	25.0	14.5	
Mean	10.7	13.1	9.3	9.4	8.7	5.5	6.5	7.6	19.6	25.4	15.8	
Var	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	1.2	
Std Dev	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.6	0.3	1.1	
Std Dev(%)	1.2	0.7	1.2	1.5	1.1	1.3	1.8	0.6	3.0	1.4	6.8	

Table B5. Random error peak acceleration - longitudinal

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	15.9	23.1	14.5	13.0	13.1	8.6	9.1	10.7	29.7	38.5	30.5	38.9
ECR1	19.5	27.1	17.4	15.2	15.0	8.9	9.3	12.7	33.8	41.3	32.3	39.9
ECR2	16.2	27.6	15.8	15.2	14.9	8.4	9.3	11.4	31.3	39.4	33.0	40.4
ECR3	18.2	27.2	18.3	14.7	14.5	8.3	9.0	11.9	30.2	39.4	33.7	39.7
ECR4	17.5	26.8	15.2	15.0	14.6	8.4	9.1	12.7	30.4	40.3	32.8	42.1
ECR5	16.8	27.5	15.1	15.0	15.4	9.1	9.4	12.3	36.9	38.1	33.1	41.0
Mean	17.6	27.3	16.4	15.0	14.8	8.6	9.2	12.2	32.5	39.7	33.0	40.6
Var	1.7	0.1	2.0	0.0	0.1	0.1	0.0	0.3	8.2	1.4	0.3	0.9
Std Dev	1.3	0.3	1.4	0.2	0.3	0.4	0.1	0.6	2.9	1.2	0.5	1.0
Lab	7.3	1.2	8.6	1.5	2.3	4.4	1.5	4.7	8.8	3.0	1.5	2.4

Table B6. Random error peak acceleration - lateral

	T-0703	T-0704	T-0707	T-0708	T-0714	T-0711	T-0712	T-0713	T-0705	T-0706	T-0709	T-0710
Lab	15.9	23.1	14.5	13.0	13.1	8.6	9.1	10.7	29.7	38.5	30.5	
ECR1	17.7	26.5	15.2	14.5	13.5	8.8	9.3	12.2	29.7	38.9	31.2	-
ECR2	16.4	26.4	15.2	14.2	13.9	8.8	9.4	12.3	31.7	39.0	29.7	-
ECR3	17.7	-	15.1	14.4	14.3	9.5	10.6	11.7	31.9	38.9	32.7	-
ECR4	17.3	23.9	14.7	14.4	14.7	8.7	11.4	12.2	29.7	38.8	31.4	-
ECR5	16.4	25.1	16.0	13.6	14.4	8.9	-	11.7	30.3	40.8	31.6	-
Mean	17.1	25.5	15.2	14.2	14.1	8.9	10.2	12.0	30.6	39.3	31.3	
Var	0.4	1.6	0.2	0.1	0.2	0.1	1.0	0.1	1.1	0.7	1.2	
Std Dev	0.6	1.2	0.4	0.3	0.5	0.3	1.0	0.3	1.1	0.8	1.1	
Std Dev(%)	3.8	4.9	2.9	2.4	3.2	3.5	9.8	2.4	3.5	2.2	3.4	

Analysis of Pedestrian Accidents Based on In-vehicle Real Accident Videos

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ABSTRACT

For last several years, the number of pedestrian fatalities due to traffic accident is over 2,000 in Korea. The portion of pedestrian fatalities in total traffic fatalities reached about 40%. In this reason, it is important to introduce effective and aggressive policies which can reduce pedestrian traffic accidents. To do this, it is necessary to understand of actual situation and characteristics of pedestrian accidents. In this study, it is assessed that potential of in-vehicle real accident videos which can be used to analysis of pedestrian accidents. In-vehicle real accident videos used in this study contain real situation about collision.

In this study, we used the in-vehicle real accident videos recorded by car black-box in taxis. In-vehicle blackboxes (dashboard cameras) which recorded accident situation were installed in taxis in Incheon city. Therefore, analyzed accident videos are about car-pedestrian traffic accidents between taxis and pedestrians. Total 252 car-pedestrian accidents or car-bicycle accidents videos in 2010 were used. All videos contain the situation of accidents about between taxis and pedestrian or bicycle. 25 accidents videos are about children, 202 videos are about adults, and 25 videos are about elderly people.

In-vehicle real accident videos have a potential to explain several characteristics of accident such as violations of driver or pedestrian, car speed, causes of poor visibility of a car driver, and so on. Furthermore, the eye direction of pedestrians could be checked using accident videos. As a result of analysis, the ratio of pedestrians who looked taxi before collision is only 29%. It has decreased with higher car speed, bad weather conditions, car violation speed limit. Average duration between sudden appearance of pedestrian and collision is only 2.6 seconds. We thought that this duration is not enough time to dodge collision when considering drivers PIEV time. Duration has been decreased when taxi have darkness, high car speed, poor visibility.

Car-pedestrian accidents are very dangerous because collided pedestrian could be serious injury or fatality. However, it is not easy to understand the exact situation when car-pedestrian collision was occurred. In this study, in-vehicle real accident videos which recorded situation of collision are used. Accident videos have important information about collision time of accident.

Through this study, we can find that In-vehicle real accident videos have potential to analyze of pedestrian accidents. Using accident videos, many characteristics of traffic accident can be explained. Nevertheless, it should be pointed that accident videos are not enough to analysis various cases of accident. Since in-vehicle dashboard cameras installed in vehicles are increasing, more accident videos will be archived in the future.

INTRODUCTION

Background

The severity of road traffic safety concerns has been escalating in recent years in South Korea. While the number of fatalities from traffic accidents has steadily decreased globally, in South Korea, some 5,000 people still die on the road and 340,000 people are injured in traffic accidents yearly. The total cost of road traffic accidents in the country amounted to 17.7 trillion won in 2010, about 1.51 percent of its gross domestic product and significantly higher than that of Japan (1.33 percent) and the United Kingdom (1.02 percent). Among road traffic accidents, car-pedestrian accidents are especially acute, accounting for 39 percent of the total number of deaths from traffic accidents in the country as of 2011. The elderly accounted for nearly 43 percent of the total number of deaths from car-pedestrian accidents in 2011. Ensuring road traffic safety is one of the top priorities of the government in its fulfillment of its obligation to protect the lives and property of its citizens. Both the central and municipal governments are taking various policy initiatives to promote public awareness of traffic safety. Ensuring road traffic safety requires satisfying diverse prerequisites, chief of which are the collection and construction of accurate data to identify the cause and characteristics of traffic accidents for the promotion of road traffic safety.

The most recently collected traffic accident data are mostly on the posterior handling of accidents, which limits investigators' capability to accurately understand the situation at the time of each accident. In this study, the characteristics of car-pedestrian accidents were investigated by examining video files recorded by in-vehicle black boxes (dashboard cameras) in an attempt to prevent car-pedestrian accidents. Video files recorded by in-vehicle dashboard cameras are valuable because they allow investigators to have a closer look at the series of events that lead up to an accident. As of 2011, an estimated 1.5 million vehicles in South Korea had an in-vehicle camera installed on their dashboard. Spurred by the potential to accurately identify the cause of each accident and the generous insurance discounts offered by insurers for insured cars with an in-vehicle dashboard camera, the number of vehicles with a dashboard camera installed is projected to significantly rise. This study was conducted to analyze the characteristics of car-pedestrian accidents by examining the recorded video files stored in in-vehicle dashboard cameras so as to identify the possibility of applying the findings to the prevention of car-pedestrian accidents.

Research Scope

The current data on traffic accidents in South Korea were first examined. Victims of car-pedestrian accidents were singled out from the data set before they were divided again by age into children, grown-ups and the elderly. Next, the concept of the in-vehicle dashboard camera was examined along with its expected outcomes, installation method and current adoption rate. The characteristics of car-pedestrian accidents were analyzed by examining the video files stored in the sample dashboard cameras. The victims also included those of car-bicycle accidents, because bicyclers, like pedestrians, tend to ride along byways and side streets at much slower speeds than automobiles.

With regard to the characteristics of car-pedestrian accidents, some general factors of car-pedestrian accidents were analyzed, including the time of the accident, the behavioral attributes of each pedestrian, and the violation of relevant laws, along with other specific elements available only in recorded video files like the time leading up to the accident and the direction of the pedestrian's eyes.

The video files that were used in this study were sampled from those stored in the in-vehicle dashboard cameras installed in taxis operating in Incheon City. The city government ordered the installation of the device in the city taxis to identify the prime causes of accidents in the area. The video file samples were provided by the Incheon City Taxi Operators Mutual Benefits Association.

Literature Review

Han In-hwan et al. (2007) conducted a study on the development of a risk-detection algorithm by relying on the data recorded in in-vehicle dashboard camera cameras. Dangerous driving patterns were categorized and analyzed by collecting related data. Toward this end, the critical threshold was set. Kim Sook-hee et al. (2005) proposed a method of analyzing the traffic accident data and identifying only those factors that would raise the likelihood of an accident. In the study on the "Efficient

Operation of the Automatic Traffic Accident Recording System" commissioned by the Korea Transportation Safety Authority (2005), the effectiveness of the automatic traffic accident recording system was analyzed in a pilot test and ways to run the system more effectively were investigated.

Past studies on ways to reduce traffic accidents focused on the posterior development of improvement methods, or systems that alert the driver to oncoming dangers in real time. Such studies had limitations like their inability to consider the relationship between the driving status of the operating vehicle and that of other cars on the road at the same time, which spawned their limited ability to foretell and prevent accidents. Thus, this study is significant because it analyzes the causes of traffic accidents from actual car-pedestrian accidents recorded in in-vehicle dashboard cameras and suggests potential ways to prevent them.

CAR-PEDESTRIAN ACCIDENTS IN SOUTH KOREA

In 2011, there were 220,000 traffic accidents in South Korea, 16,363 of which involved children; 178,865, grown-ups; and the remaining 26,483, the elderly. Compared to 2005, the fatality rate in 2011 dipped by 3.2 percent, but the total number of accidents and of the injured either rose or remained the same.

A closer look at the numbers shows that the percentage of accidents that involved the elderly over 65 is higher, whereas the percentage of accidents that involved children decreased by 3.7 percent and that of accidents that involved grown-ups increased slightly by 0.4 percent. The same pattern is seen in the total number of deaths from traffic accidents: the fatality rate of traffic accidents generally decreased by 3.2 percent but increased among the elderly. The number of casualties from traffic accidents again shows a similar trend. As a result, the percentage of the elderly who were killed in traffic accidents increased to 33 percent in 2011 and has kept rising. The elderly accounted for nearly one-third of the total number of deaths from traffic accidents, whereas their share in the total population was 11.2 percent as of 2011. Thus, there were 30.1 elderly car-pedestrian accident victims per hundred thousand people in 2011, about 23.4 times higher than the number of child victims and 3.3 times higher than that of grown-up victims.

Table 1. Yearly traffic accidents in South Korea

Criteria		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Annual Growth Rate (%)**
Total no. of traffic acci-dents	Children	20,495	19,223	18,416	17,874	18,092	17,174	16,363	-3.7
	Grown-ups	174,610	174,965	172,112	174,936	187,915	183,894	178,865	0.4
	Elderly	19,066	19,557	21,134	23,012	25,983	25,810	26,483	5.6
	Total	214,171	213,745	211,662	215,822	231,990	226,878	221,711	0.6
No. of deaths from traffic acci-dents	Children	284	276	202	161	154	160	101	-15.8
	Grown-ups	4,386	4,317	4,177	3,970	3,857	3,592	3,404	-4.1
	Elderly	1,700	1,731	1,786	1,735	1,826	1,752	1,724	0.2
	Total	6,370	6,324	6,165	5,866	5,837	5,504	5,229	-3.2
No. of the injured in traffic acci-dents	Children	25,314	23,880	22,806	22,364	22,257	21,066	20,086	-3.8
	Grown-ups	297,087	296,131	291,087	292,430	312,209	303,998	293,306	-0.2
	Elderly	19,832	20,218	22,013	24,168	27,409	27,394	27,999	5.9
	Total	342,233	340,229	335,906	338,962	361,875	352,458	341,391	0.0

Note: Children are under 14 and the elderly are over 65.

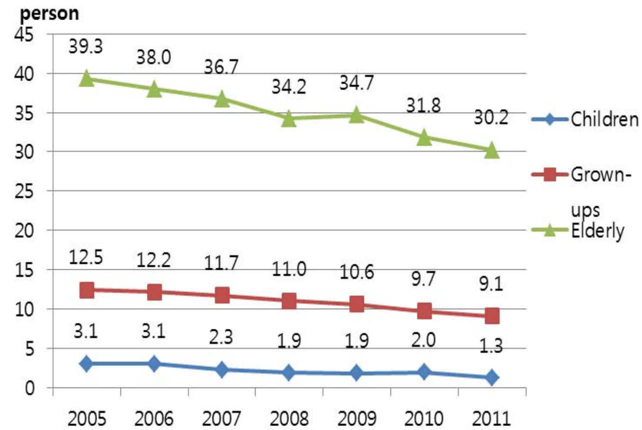

Figure 1. Number of deaths from traffic accidents per 100,000 people

The number of deaths from car-pedestrian accidents has consistently decreased in recent years but still hovers at 2,000 each year. The share of the deaths from car-pedestrian accidents in the total deaths from traffic accidents was about 38 percent, which is another evidence that traffic safety for pedestrians is critical in improving the overall traffic safety standards. Among the total number of pedestrians killed in traffic accidents, elderly victims exceeded 40 percent, which underscores the importance of devising ways to improve traffic safety that are tailor-made for each age group.

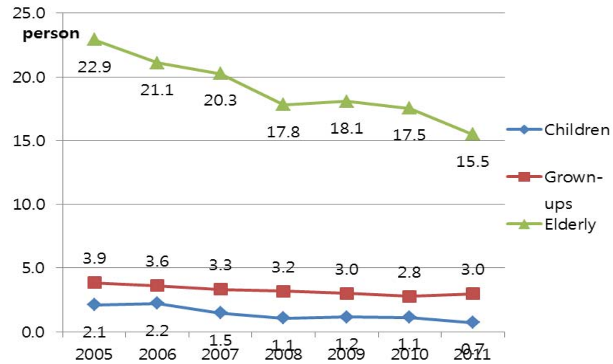

Figure 2. Number of deaths from car-pedestrian accidents per 100,000 people

MARKET PENETRATION AND CHARACTERISTICS OF THE IN-VEHICLE DASHBOARD CAMERA

Market Penetration of the In-vehicle Dashboard camera

The in-vehicle dashboard camera is a device that, installed on the dashboard or rear-view mirror of a vehicle, automatically records such varied driving data as videos before and after a traffic accident, the accident site, the vehicle speed and velocity, and the driver's voice (optional). Its key features include video recording of an accident (10-14 seconds before the accident and 6-10 seconds after the accident), continuous video recording (12-24 hours), and video recording when the vehicle is parked. Its working concept is as follows.

Table 2. Yearly number of deaths from car-pedestrian accidents

Year	2005	2006	2007	2008	2009	2010	2011	Annual Growth Rate (%)
Children	194	199	128	90	96	91	56	-18.7
Grown-ups	1,358	1,279	1,190	1,140	1,088	1,025	1,105	-3.4
Elderly	991	961	985	903	952	966	883	-1.9
Average	2,543	2,439	2,303	2,133	2,136	2,082	2,044	-3.6

Table 3. Yearly number of the injured in car-pedestrian accidents

Year	2005	2006	2007	2008	2009	2010	2011	Annual Growth Rate (%)
Children	10,697	9,914	9,318	8,798	8,616	8,174	7,713	-5.3
Grown-ups	30,808	30,594	30,506	32,709	34,933	34,801	35,443	2.4
Elderly	6,321	6,169	6,541	7,181	7,832	7,924	8,131	4.3
Average	47,826	46,677	46,365	48,688	51,381	50,899	51,287	1.2

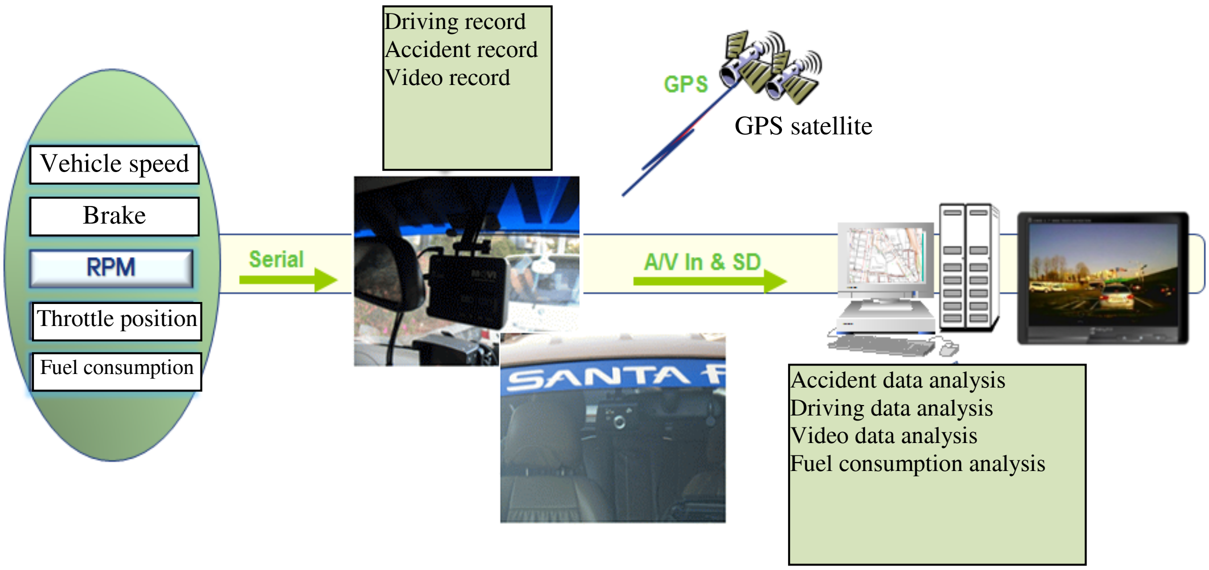

Figure 3. System concept of the in-vehicle dashboard camera - 1

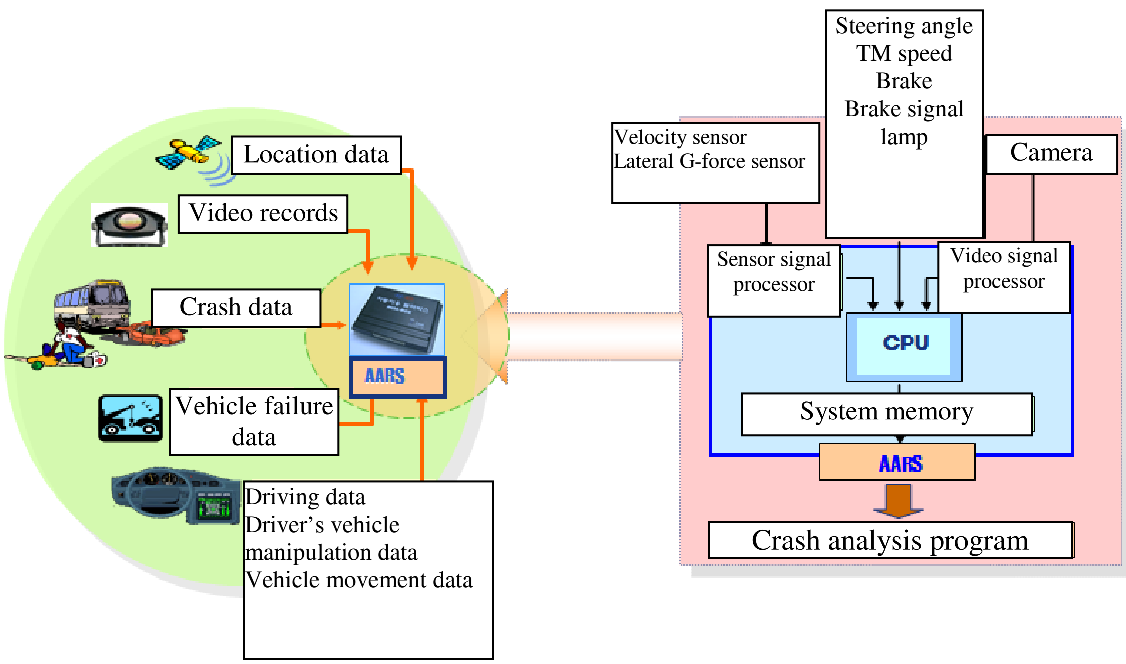

Figure 4. System concept of the in-vehicle dashboard camera – 2

There are different models available in the market. An example of the traffic accident analysis screen captured in the in-vehicle dashboard camera follows.

Figure 5. Traffic accident analysis screen of an in-vehicle dashboard camera

In 2008, about 5,300 taxis in Incheon City had an in-vehicle dashboard camera. In 2009, about 34,000 taxis in Gyonggi-do followed suit. The device has since been adopted fast in other provinces: in Seoul City (by 22,700 taxis run by taxi companies and 23,300 privately-owned taxis) and Jeollanam-do (3,200 taxis run by taxi companies and 3,900 privately-owned taxis) in 2010, and in Busan City (11,000 taxis run by taxi companies and 14,000 privately-owned taxis), the Jeju Special Self-governing Province (1,500 taxis run by taxi companies and 1,000 privately owned taxis) and Jeollanam-do (9,500 taxis) in 2011. Thus, roughly 1.5 million vehicles are thought to be running in South Korea with the device installed on their dashboard. They account for approximately 7 percent of all the vehicles registered in the country. In 2011 alone, 250,000 vehicles were estimated to have had the device installed, followed by 500,000 additional vehicles in 2012 – about twice the number of total installations in 2010.

Effect of In-vehicle Dashboard Cameras

Installing in-vehicle dashboard cameras on corporate taxis is expected lower the direct and indirect costs.
Reduction in direct cost includes reduction in repair cost due to reduction in crash frequency, Reduction in insurance fees due to reduction in crash frequency, and increase of operating mileage per liter due to safe/cautious driving. Indirect cost includes are Reduction in accident negotiation and management costs, Improving the social valuation of corporate image as a safety-oriented institution, and Avoiding disadvantaging the driver in the course of crash investigation.
In an effort to estimate the crash reduction effects, key crash statistics have been investigated on a taxi company in Busan Metropolitan City (Daedo Taxi Company) by comparing the figures before and after installation of in-vehicle dashboard cameras on 178 taxis. Person damage rate after installation was reduced from 44.88% to 25.51%. Property damage rate was reduced from 53.37% to 33.74%. These are the average figures for one year before and after installation and the reduction in damage compensation during these two periods was 500,000,000KRW (438,000USD). Similar comparisons were made on 3 other taxi companies (companies with approximately 80 taxi vehicles) and the rate of crash reduction showed similar average figures in all criteria of personal and property damages.

RESULT OF ANALYSIS OF THE CAR-PEDESTRIAN ACCIDENTS VIDEOS

Methods and Data Sources

In this study, we used the in-vehicle real accident videos recorded by car black-box in taxis. In-vehicle dashboard cameras which recorded accident situation were installed in taxis in Incheon city. Therefore, analyzed accident videos are about car-pedestrian traffic accidents between taxis and pedestrians. Total 252 car-pedestrian accidents or car-bicycle accidents videos in 2010 were used. All videos contain the situation of accidents about between taxis and pedestrian or bicycle. 25 accidents videos are about children, 202 videos are about adults, and 25 videos are about elderly people.

Analysis of the General Characteristics of Car-Pedestrian Accidents

With regard to the time of the accidents of the surveyed vehicles, accidents that involved children and the elderly happened more frequently in the day, whereas those that involved grown-ups happened more frequently at night. The hourly distribution of those accidents is as follows: the accidents that involved child and elderly pedestrians happened more frequently in the afternoon, whereas those that involved grown-ups happened more frequently from midnight to 3 a.m. These figures suggest that more grown-ups tend to go out at night than children and the elderly.

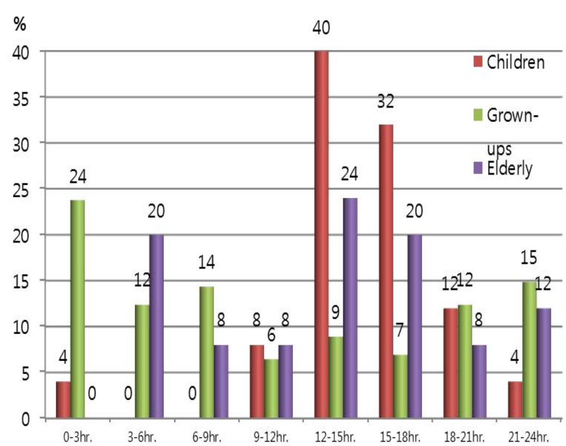

Figure 6. Hourly distribution of car-pedestrian accidents

With regard to season, car-pedestrian accidents that involved children happened more frequently in summer and those that involved the elderly happened more frequently in autumn. Those that involved grown-ups happened almost uniformly across different seasons.

In terms of the pedestrian’s behavior at the time of an accident, about half of the grown-up victims were walking, about 88 percent of the child victims were running, and 44 percent of the elderly victims were riding a bicycle. There were even accidents that involved victims who were standing still. With regard to the types of violations of traffic laws and regulations by pedestrians, jaywalking accounted for more than 40 percent, but nearly half of the victims were simply walking normally, which suggests that accidents are happening even if the pedestrians involved did not violate traffic laws. Thus, some pre-emptive policy moves must be made to prevent those accidents.

With regard to the total hospitalization period of each victim, about 10 percent of them did not require prolonged hospitalization, whereas more than half of them had to be hospitalized from one to four weeks. However, the elderly victims were frequently required to be hospitalized for more than nine weeks, during which they often underwent emergency treatment or eventually died.

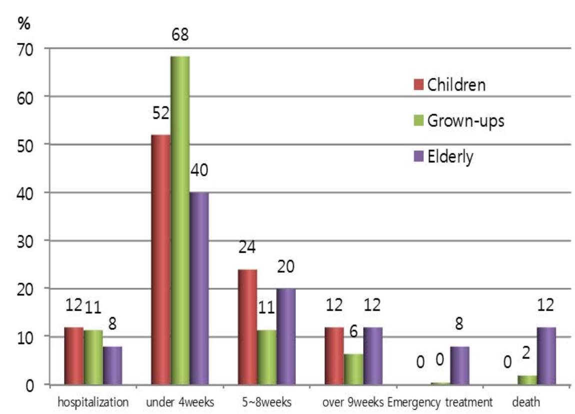

Figure 7. Distribution of the post-accident hospitalization periods by age

Analysis of the Moment of Car-Pedestrian Accidents

The unique characteristics of the moments of car-pedestrian accidents recorded in in-vehicle dashboard cameras were analyzed. The analysis

Figure 8. Various causes of a poor field of vision and visual obstruction

of the directions of the victims' eyes showed that they were looking somewhere else than at the rushing vehicle -- which means that many pedestrian victims simply did not see the vehicle involved in an accident in the first place, or were unable to foretell or prevent the accident.

In the case of the elderly victims, 76 percent of those surveyed did not see the rushing vehicle. Their percentage is about three times higher than that of the elderly who saw the rushing vehicle. This is because the elderly victims tended to show various types of deterioration in their physical strength. They have been known to experience about 30-percent deterioration in their aural capability, unlike the grown-ups (Han Sang-bok et al., 2005). The main causes of a poor field of vision are obstruction by other vehicles, nighttime walking and poor weather conditions.

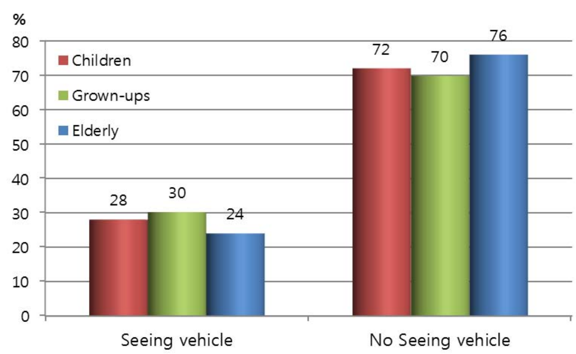

Figure 9. Directions of the pedestrian victims' eyes by age at the moment of an accident

It was also proven that blind spots are the main causes of accidents. The key causes of the poor field of vision of drivers include nighttime driving, blind spots, and visual obstruction by vehicles parked along byways. As a poor field of vision can endanger both drivers and pedestrians, immediate actions are needed to address it.

It was proven that the field of vision deteriorated notably when the pedestrian looked somewhere else other than at the vehicle that was rushing toward him or her. The fatal accidents (seven in all) happened only when the victim looked somewhere else other than at the rushing vehicle. In the case of the elderly victims, they were injured more seriously when they failed to spot the rushing vehicle.

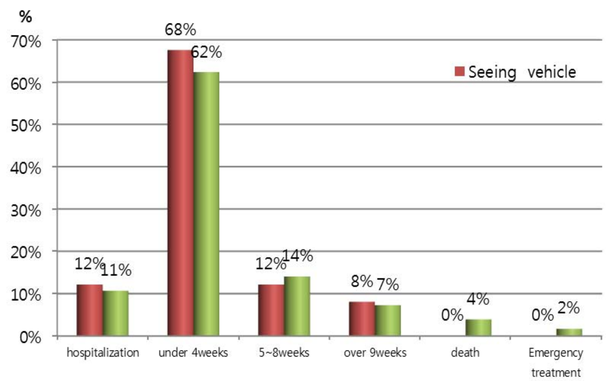

Figure 10. Direction of the pedestrians' eyes and their post-accident hospitalization periods

As for the speed **of** the vehicle at the moment of an accident, accidents happened even at low speeds but also at speeds higher than 60 kph. About 42 percent of the accidents happened at speeds higher than 30 kph, and it is known that the fatality rate among pedestrians rises rapidly at speeds higher than 30 kph (Takada, 2012).

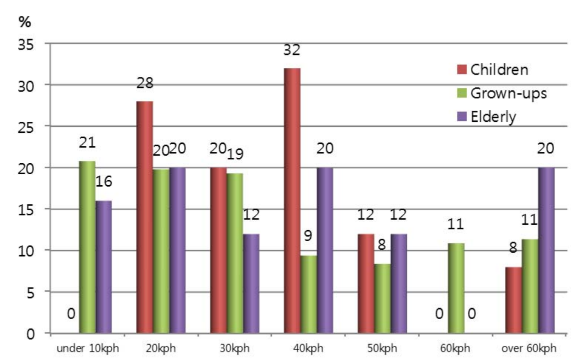

Figure 11. Instantaneous velocity by age at the moment of an accident

The vehicles' cruising mode in the accidents showed that most of the accidents happened when the vehicle was driving straight along the motorway, and that 80 percent of such accidents involved children and 68 percent, the elderly. With regard to the violation of traffic laws by drivers, the number of accidents caused by the driver's negligence (XX percent) was higher than those of the accidents caused by traffic signal violations (XX percent) and speeding (XX percent). Among them, 73 percent of those that involved children, 39 percent of those that involved grown-ups, and 44 percent of those that involved the elderly still happened despite the driver's non-violation of traffic laws. The videos recorded in the dashboard camera confirmed that accidents are still happening even without violations of traffic laws.

With regard to the correlation between a vehicle's instantaneous velocity and the direction of the pedestrian's eyes, the faster the instantaneous velocity of the vehicle was, the higher the probability of the pedestrian looking somewhere else other than at the oncoming vehicle was. In the case of the elderly pedestrians with aural and visual capabilities that were inferior to those of the grown-ups, only 13 percent of them were able to recognize the oncoming vehicle cruising at a speed higher than 60 kph, whereas the rest (87 percent) did not see the oncoming vehicle at all. With regard to the direction of the pedestrian's eyes depending on the weather condition, the pedestrians tended to look somewhere else other than at the oncoming vehicle on rainy (76 percent) and snowy (100 percent) days than on fine-weather days (69 percent).

Moreover, the pedestrians failed to spot the oncoming vehicle more frequently when the driver violated traffic laws than otherwise, which provides powerful evidence of the danger of traffic violations.

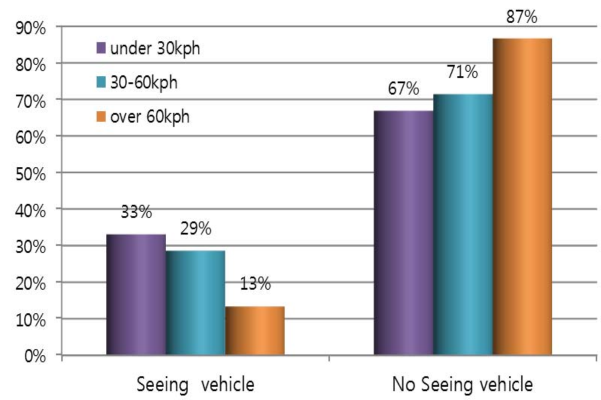

Figure 12. Direction of pedestrians' eyes by the instantaneous velocity of a vehicle at the moment of an accident

In addition, the time from the moment when the pedestrian appeared in the recorded video all the way to the moment of the accident was measured. The time from the appearance of the pedestrian to the accident was defined by the time from the video frame right before the appearance of the pedestrian to the video frame in which it is clear that the accident indeed happened. The single video frame that was used in this study lasted 0.2 second. However, the elapsed time was measured only in about 81 video files in which it was possible to clearly confirm the appearance of the pedestrian and the occurrence of the accident. The surveyed video files were categorized according to the age of the filmed victims, as follows: one file with a child victim; 73 with grown-ups; and seven with elderly victims.

The calculated elapsed time from the appearance of the pedestrian in the video frame to the moment of the accident averaged 2.6 seconds. Considering that it was the time it took for the driver to recognize the pedestrian and start decelerating the vehicle, the accident happened within a very short time span. The elapsed time from the appearance of the pedestrian to the accident was further reduced when another vehicle obstructed the driver's field of vision: by 2.13 seconds at night, which is much shorter than in the day (3.66 seconds). The faster the vehicle rushed on, the shorter the elapsed time was for the driver. Most of the accidents that involved the elderly pedestrians were caused by the driver's poor field of vision, which underscores the importance of ensuring a clear field of vision for drivers.

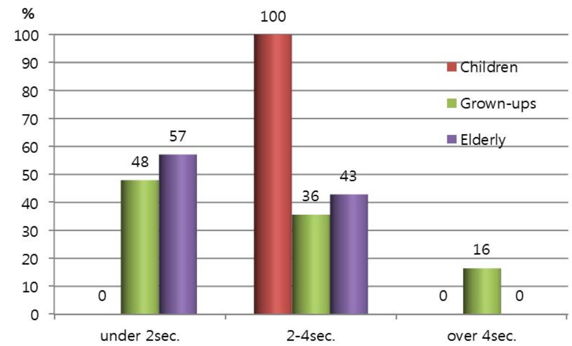

Figure 13. Elapsed time from the appearance of the pedestrian to the moment of the accident (sec)

Moreover, the elapsed time from the appearance of the pedestrian to the accident decreased notably in cases of jaywalking and signal violation by the pedestrian compared to the cases when the pedestrian walked normally straight. In the case of the elderly pedestrians, the accident happened within 4 seconds after the appearance of the victim in the video frame.

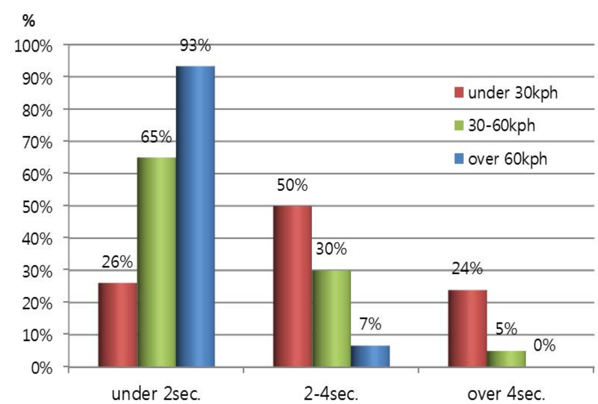

Figure 14. Time elapsed from the appearance of the pedestrian to the accident depending on the instantaneous velocity of the vehicle at the time of the accident

STUDY IMPLICATIONS

The video files stored in the in-vehicle dashboard camera installed on vehicle dashboards record the changing conditions in front of the vehicle while it is running. With the recent increase in the number of vehicles with a dashboard camera installed, it has become possible to understand what had been previously impossible to figure out with respect to accidents. In the case of traffic accidents, it is critical to comprehend the situation right at the moment of the accident. The arrival of the in-vehicle dashboard camera is significant in this respect because the device allows investigators to accurately comprehend specific details related to the accident -- which means that it is now possible to pinpoint the driver who triggered the accident, while accurate understanding of the cause of an accident opens up new possibilities for the prevention of traffic accidents.

The video records of traffic accidents that were used in this study gave detailed accounts of accidents like the location and eye direction of the pedestrian, the causes of the obstruction of the driver's field of vision, and the time that elapsed from the appearance of the pedestrian to the moment of the accident. Additional information on whether the driver exceeded the speed limit or obeyed traffic laws allows investigators to nail down the cause of an accident, which makes it possible to come up with measures to prevent accidents according to their causes. Furthermore, the dashboard camera data that were used in this study enabled discernment of the differences among the accidents that involved children and those that involved adults and the elderly, which again provided a useful platform for the establishment of policies to ensure road traffic safety for different age groups.

To reduce the number of car-pedestrian traffic accidents, the following policy initiatives are required. Currently, transportation facilities are being built and managed around automobiles. The automobile-centric transportation environment can cause inconveniences and anxieties among pedestrians. The simple act of restraining speeding is the fastest way to prevent traffic accidents, because it gives pedestrians time to recognize an oncoming vehicle and drivers to recognize pedestrians. Toward this end, methods of calming traffic flow and gently nudging automobile drivers to slow down, as well as installing roadside speed cameras, are needed.

It is also important to eliminate blind spots in places where car-pedestrian accidents happen frequently. There are many causes of drivers' poor field of vision. Such causes must be identified from the perspective of drivers and fixed immediately. Moreover, motorway visibility must be improved to prevent pedestrian jaywalking while the causes of poor driver visibility must be eliminated. The implementation of such policy initiatives should be accompanied by related education and publicity activities to boost their effectiveness. To ensure traffic safety, pedestrians and drivers should simultaneously be made more aware of it. Policymakers must provide legal and regulatory support to promote the emergence of an environment conducive to traffic safety and public awareness of it.

CONCLUSION

Car-pedestrian accidents are very dangerous because collided pedestrian could be serious injury or fatality. However, it is not easy to understand the exact situation when car-pedestrian collision was occurred. In this study, in-vehicle real accident videos which recorded situation of collision are used. Accident videos have important information about collision time of accident.

Through this study, we can find that In-vehicle real accident videos have potential to analyze of pedestrian accidents. Using accident videos, many characteristics of traffic accident can be explained. Since in-vehicle dashboard cameras installed in vehicles are increasing, more accident videos will be archived in the future. Nevertheless, it should be pointed that accident videos are not enough to analysis various cases of accident.

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Effectiveness study of Crash Avoidance technologies by using Clustering and Self Organizing Map

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ABSTRACT

Implementation of appropriate safety measures, either from the viewpoint of a vehicle, individual or the infra-structure, it is an important issue to clearly understand the multi-dimension complicated real world accident scenarios. This study proposes a new method to easily capture and to extract the essence of such complicated multi-dimension mutual relationship by visualizing the results of accidents clustering by SOM (Self Organizing Map).

The FARS data from 2010 is used to generate a dataset comprised of 16,180 fatal passenger car drivers and 48 variables. The 16,180 fatal drivers were clustered using hierarchy cluster analysis method and mapped into a two-dimensional square with one dot representing one fatal driver using SOM. From the SOM assessment of the 16,180 fatal drivers, five clusters were created, and they are characterized as follows: Cluster 1 (Interstate highway accidents), Cluster 2 (Drunk speeding), Cluster 3 (Non speeding lane departure), Cluster 4 (Vehicle to vehicle) and Cluster 5 (Intersection).

Three accident scenarios are created to study potential areas of fatal accidents reduction in the SOM map, and the accident scenarios are: [A] Skidding Straight, [B] Lane Departure N.H. (National Highway) and [C] Rear-end. The three accident scenarios mutually had coverage of totally 31% of all the fatal drivers, and the three accident scenarios had high coverage of Cluster 1 (Interstate highway accidents) and some coverage over Clusters 2, 3 & 4. ESC (Electronic Stability Control), LDW (Lane Departure Warning) and FCW (Forward Collision Warning) may be relevant to help reduce the number of fatal accidents in these three accident scenarios.

The remaining areas that the three accident scenarios [A], [B] and [C] did not completely cover were the following accidents:
(1) Young drunk speeding at curves
(2) Speeding on low speed limit roads
(3) Speeding with previous speeding convictions
(4) Drunk driving that are not speeding
(5) Distraction
(6) Elderly
(7) Intersection

1. INTRODUCTION

Today there are many methods and many published values that explain the effectiveness of Crash Avoidance technologies, where the effectiveness is estimated as a value from accident simulations, field data or combination of accident data.
But through these current methods it is difficult to understand a global view to reduce accidents and fatalities in a strategic way and make the priority decision of implementing safety features or social measures.
This study focuses to visually understand the effectiveness of Crash Avoidance technologies in a global view, possible to perceive coverage of the technologies and overlap of the accident factors, which enables intuitive insight in priority decision of measures and remaining areas to be developed and implemented.
The present study focuses on a generalized method, by utilizing SOM to visualize the multi-dimension accident scenario. A Self Organizing map (SOM) is a type of artificial neural network that is trained using unsupervised learning to map mutual relationship into a two-dimensional representation. This can prevent the analyst's arbitrary perspective.
Further, SOM is useful for low-dimensional visualization of high-dimensional input data, by using a neighborhood function to preserve the topological properties of the input space. This can preserve all characteristics of a large dataset (48 variables x 16,180 cases) used in this study and one can visually percept all 48 variables and their mutual relationships across the clusters at a glance.

2. METHODOLOGY

Data Set

This study uses the FARS 2010 data base maintained by NHTSA and UMTRI. Each traffic accident in FARS includes at least one fatality that occurred on a traffic way. Data key of FARS 2010 Occupant (FARS10OC) consists of driving scenarios including road environment, vehicle / driver relating information and occupant characteristics. As the objective of this study is to understand accident scenarios of general cars, the data set conditions are filtered as fatal passenger car and light truck drivers shown in Table 1. From the total 69,124 fatal accident occupants in the FARC10OC data base, 16,180 passenger car fatal drivers can be extracted.

Table 1: Data set used in this study

2010 FARS Occupant cases (**FARS10OC**)	69,124
AUX: VEHICLE BODY TYPE = Passenger Car (1) + Light truck (2-5)	
OCCUPANT TYPE = Driver (1)	
OCCUPANT INJURY SEVERITY = fatal (4)	
Selected cases	16,180

Selection of variables

The first step is to narrow down the whole set of 566 variables to a subset of fewer meaningful variables. Without any loss of information, the fewer variables it will help to perceive the multi-dimension accident scenario more accurately. The 566 variables are narrowed down in the following rule by excluding, those semantically lower order variables, the variables having low frequency and similar variables.

(1) Exclude low-semantic variables in describing the accident. e.g. CASE NUMBER, COUNTY ID, VIN, ACCIDENT DATE-YEAR, etc.

(2) Exclude variables which attribute values having low-frequency occurrence of under 5%. e.g. CRASH RELATED FACTOR has 99.9% of value “0: none”

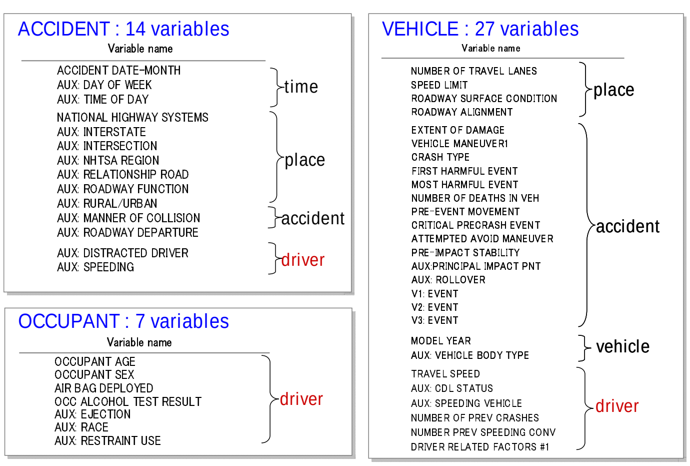
(3) Variables that have similar values with high coherence are grouped, to avoid over represented contribution. e.g. BODY TYPE, VIN BODY TYPE, VIN VEHICLE TYPE, etc. They are grouped by using only one representative variable.

Parameter selection

Based on the above rule, excluding similar variables and unimportant variables, finally a set of 48 variables were selected as shown in Table 2.

Table 2: The selected FARS variables

Total number of FARS10OC variables	566
(1) Low-semantic variables	346
(2) Low-frequency variables	59
(3) Similar variables	113
Selected variables	48



3. SELF ORGANIZING MAP

A Self Organizing map (SOM) is a type of artificial neural network that is trained using unsupervised learning to map mutual relationship into a two-dimensional representation. This can prevent the analyst’s arbitrary perspective.

Further, SOM is useful for low-dimensional visualization of high-dimensional input data, by using a neighborhood function to preserve the topological properties of the input space. This can preserve all characteristics of a large dataset (48 variables x 16,180 cases) used in this study and one can visually percept all 48 variables and their mutual relationships across the clusters at a glance.

Vector Quantization

Vector quantization is a classical quantization technique [1], [2]. Thus, this paper will only briefly explain the statistical outline to understand the results.

Vector quantization is to find the discrete approximate of the input vector *x* of the vector space *Rn*, by using infinite codebook vector *mi* ∈ *Rn*, *i=1,2,3,,,k*. The approximate of *x*, is to find the most nearest codevector *mc* to *x* with Euclidean distance as in equation (1). If the most appropriate value *mi* is chosen, the square quantization error will be the minimum, as in equation (2).

$$\| x - m_c \| = \min_i \{\| x - m_i \|\} \qquad (1)$$

$$E = \int \| x - m_c \|^2 \; p(x)dx \qquad (2)$$

Each, codevector is related with a nearest codevector, placed in a nearest neighbor region called a Voronoi region [3]. Voronoi is a space where the codebook vectors are fitted in the two-dimensional space side by side, like a mosaic, and the space is separated into a multiple domain, and each area is divided by a hyper-plane. Each separated area has a vector which has the most nearest vector to the surrounding vectors in the area.

Application

To calculate VQ’s for the FARS accident data, this would mean to calculate one VQ for each of all the 16,180 cases. The VQ is calculated by using the normalized 48 variables having a value in between 0 to 1. Similar accidents will have similar VQ values, meaning that the variable values of the 48 variables have a similar distribution.
More details of the method for applying FARS data to SOM can be available in the author’s previous study “Method development of multi-dimensional accident analysis using Self Organizing Map” [4].

Mapping

To map the items into a two-dimensional space, a square map of the size of all samples is prepared. From the calculated VQ values using equation (1) and (2) for each item, the items are plotted in the map by plotting each item with the closest VQ value. The mapping steps are shown below.

Step1. Calculate VQ value for each of all of the cases
Step2. Randomly plot one case in the middle of the map
Step3. Randomly select another case and plot beside the first case

Step4. Randomly select another case and plot beside the case with the nearest VQ value
Step5. Repeat Step4, repeat until there are no cases left.

Creating of SOM

As each VQ and accident number have a one-to-one correspondence, for each variable, the accident number is replaced by the variable value with color gradation, from the smallest value as blue to the largest value as red, as shown in Figure 1.

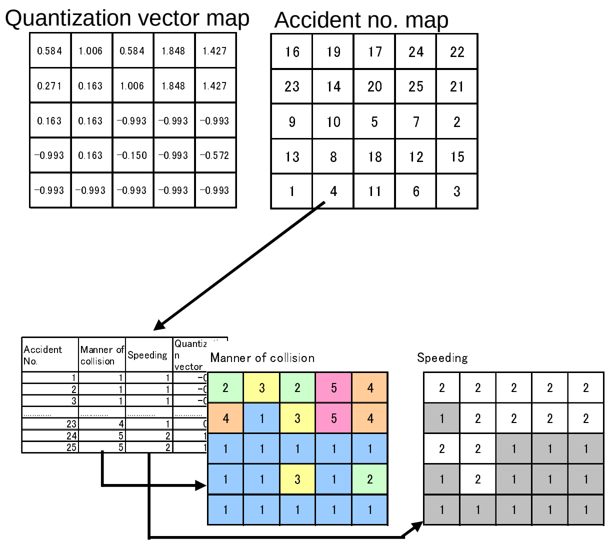


Figure 1: Creating SOM maps for each variable

For each variable, one SOM map was created, resulting in 48 SOM maps.
If there is an unknown value, the value is imputed by calculating the average value of the surrounding cells.

Clustering

Using the hierarchy clustering results, the SOM maps can be divided into clusters, as shown in Figure 2. .

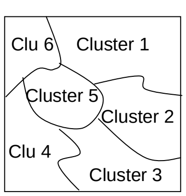


Figure 2: Clustering applied to SOM

The number of clusters can be chosen depending on the level of hierarchy, chosen by the analyst.

3. RESULTS

Clustering

Using hierarchy clustering analysis, FARS 16,180 drivers are clustered into 5 clusters, shown in Figure 3 and Table 3.

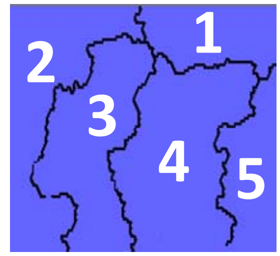


Figure 3: Clustering / SOM results of FARS2010

Table 3: Proportion of each cluster

	Drivers	(%)
Cluster 1	1,931	11.9%
Cluster 2	3,773	23.3%
Cluster 3	3,618	22.4%
Cluster 4	4,773	29.5%
Cluster 5	2,085	12.9%
Total	16,180	100.0%

Self Organizing Map

Each SOM is a representation of 16,180 fatal drivers, with one dot as one fatal driver, and each dot has a color representing the variables value. For example, Figure 4 shows the results of the variable "AUX: MANNER OF COLLISION", and has the following five attribute values.

1. Single (Not collision with motor vehicle): dark blue
2. Rear-end: bright blue
3. Head-on: bright green
4. Angle: bright yellow
5. Other (Sideswipe, Other): orange

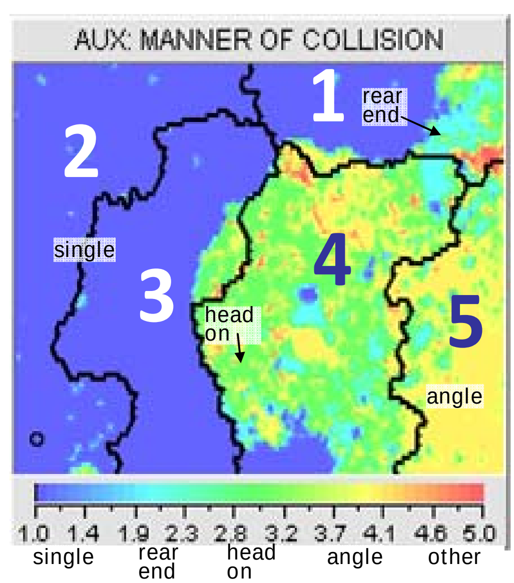


Figure 4: Clustering / SOM results of FARS variable AUX: MANNER OF COLLISION

For example, Cluster 1 has a mix of dark blue “1.Single” accidents and some bright blue “2.Rear-end” accidents. Cluster 2 and 3 are mostly covered with dark blue “1.Single” accident. Cluster 4 has a mix of all types, and Cluster 5 is mainly covered with bright yellow “4.Angle” accidents.
The SOM has a key on the bottom, showing the value and coordinating color. The values for each variable are shown in the FARS codebook in reference [5].
Regarding unknown attribute values, the SOM algorithm imputes a value by calculating the average value of the cells surrounding the unknown value and generates a color which is in between the surrounding cells. For example, for the above AUX: MANNER OF COLLISION, Cluster 2 is almost fully covered in dark blue “1.Single” accidents, thus, if there is an unknown value in this cluster, the value would be most likely imputed as a dark blue “1.Single” accident.

Viewing all 48 SOM maps

For each of the 48 variables, 48 SOM maps are created as shown in Figure 5. In each SOM map, the position of each dot representing a fatal driver is consistent and unique. Thus each SOM map corresponding to each individual variable can be compared. In each of the SOM maps, the cluster boundaries are indicated to clearly identify the characteristics of clusters by viewing several variable SOM maps at a glance.

4. CHARACTERISITICS OF CLUSTERS

This chapter explains the characteristics of each cluster by viewing the major contributing variables. A representative name is given to each of those clusters as shown in Table 4.

Table 4: Representative name of clusters

Cluster 1	Interstate highway accidents	12%
Cluster 2	Drunk speeding	23%
Cluster 3	Non speeding lane departure	22%
Cluster 4	Vehicle to vehicle	30%
Cluster 5	Intersection	13%

Cluster1. Interstate highway accidents

Figure 6 shows the key variables and corresponding SOM maps for Cluster 1. AUX: INTERSTATE, shows that accidents in this cluster occur on interstate highways. Also from AUX: MANNER OF COLLISION and V1: EVENT it can be seen that 62% are single accidents, 13% head-on, 12% rear-end. AUX: SPEEDING VEHICLE shows that half of them are due to Speeding. In this way, the characteristics of each cluster can be understood by viewing the SOM maps and can be quantified as shown in Table 5.

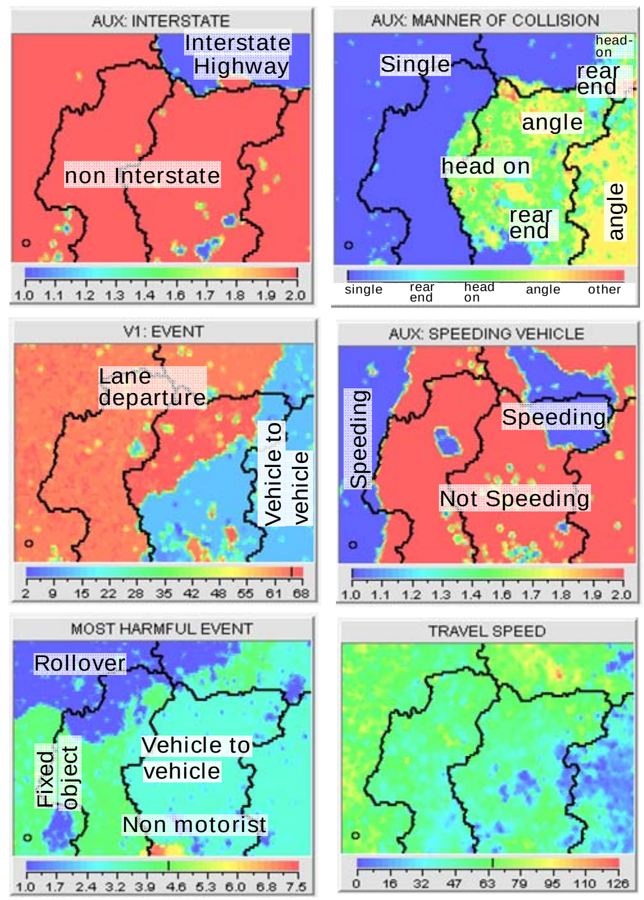


Figure 6: Key variables and corresponding SOM maps for Cluster 1

Table 5: Quantification of variables for each cluster

Variable name	Value	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
V18: NATIONAL HIGHWAY SYSTEMS	This section is on the NHS	100%	11%	14%	28%	25%
V77: AUX: INTERSTATE	Interstate	91%	1%	0%	2%	0%
V78: AUX: INTERSECTION	Intersection	1%	4%	7%	12%	87%
V92: AUX: RURAL/URBAN	Rural	45%	78%	65%	66%	39%
V393: ROADWAY ALIGNMENT	Curve	26%	52%	36%	27%	4%
V26: AUX: MANNER OF COLLISION	Single	62%	98%	91%	6%	0%
	rear end	12%	1%	2%	9%	4%
	head on	13%	0%	5%	47%	15%
	angle	10%	0%	2%	35%	81%
V461: V1 EVENT	Lane departure	62%	95%	93%	38%	0%
V93: AUX: SPEEDING	Speeding	44%	69%	6%	25%	11%
V623: OCC ALCOHOL TEST RESULT	0.08-0.16	13%	24%	11%	7%	4%
	0.16 +	10%	30%	16%	6%	2%
V667: AUX: RESTRAINT USE	unbelted	42%	77%	60%	36%	27%

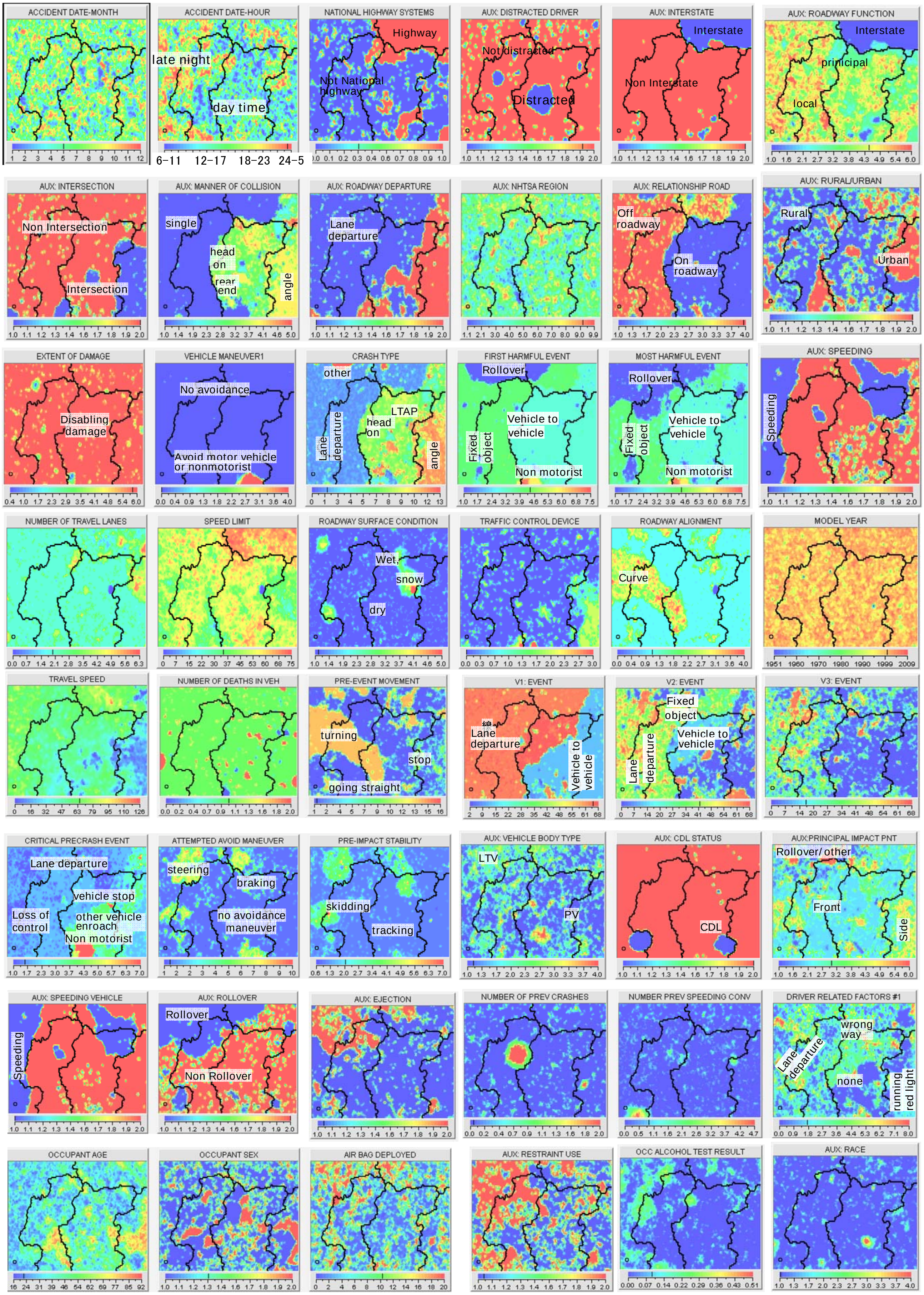


Figure 5: 48 Self Organization Maps

5. MAPPING THREE ACCIDENT SCENARIOS

Three accident scenarios are created to study potential areas of fatal accidents reduction in the SOM map. The three accident scenarios are;

[A] Skidding Straight
[B] Lane Departure N.H. (National Highway)
[C] Rear-end

By mapping these accident scenarios into the SOM map, it is possible to simulate each accident scenario as a virtual CA (Crash Avoidance) technology that can prevent the accidents in that accident scenario. By this simulation, it is possible to understand the coverage areas of these virtual CA technologies, and also clarify uncovered accident scenarios, to study a global approach for reducing traffic accident fatalities.
The definition of the accident scenarios are set by a single or combination of the FARS variables, and are described below.

[A] Skidding Straight

This accident scenario assumes a virtual CA technology to theoretically avoid skidding accidents on straight roads. The accident scenario is defined as PRE-IMPACT STABILITY = "Skidding" and ROADWAY ALIGNMENT = "Straight".
With current available CA technologies, ESC (Electronic Stability Control) may be effective to help reduce the number of fatal accidents in this accident scenario.

Figure 7 shows the areas of PRE-IMPACT STABILITY = "Skidding" and ROADWAY ALIGNMENT = "Straight". The left SOM of Figure 8 shows the SOM of AUX: MANNER OF COLLISION and the black dots represents the mutual assembly of [PRE-IMPACT STABILITY = "Skidding"] AND [ROADWAY ALIGNMENT = "Straight"]. The right SOM of Figure 8 encircles the high density black dots area, to define an easily recognizable area of [A] Skidding Straight.

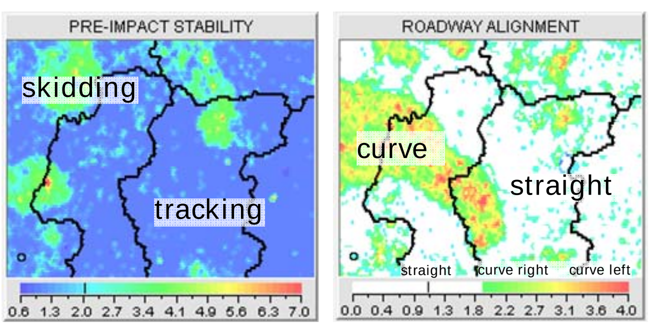


Figure 7: Stability and Road Alignment SOM maps

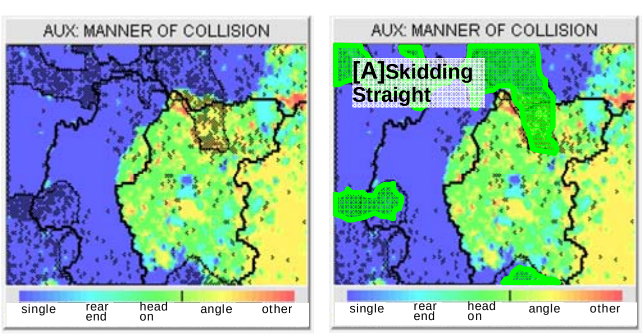


Figure 8: [A] Skidding Straight coverage areas

This [A] Skidding Straight covers 14% of all areas, 27% of Cluster 1(Interstate highway accidents), 25% of Cluster 2(Drunk speeding) and 11% of Cluster 3(Non speeding lane departure).

[B] Lane Departure N.H. (National Highway)

This accident scenario assumes a virtual CA technology to theoretically avoid un-intentional lane departure accidents on national highways. The accident scenario is defined as NATIONAL HIGHWAY SYSTEMS = "National highway", V1: EVENT = "Lane departure (Ran off road, cross median)" and VEHICLE MANUEVER = "No avoidance".
With current CA technologies, LDW (Lane Departure Warning) may be effective to help reduce the number of fatal accidents in this accident scenario.

Figure 9 shows the relevant SOM maps and Figure 10 shows the SOM of AUX: MANNER OF COLLISION with the mutual assembly of NATIONAL HIGHWAY SYSTEMS = "National highway", V1:EVENT = "Lane departure" AND VEHICLE MANUEVER = "No avoidance" with black spots and the [B] Lane Departure N.H. area encircled for simplification.

Figure 9: V1: Event, National Highway Systems and Vehicle Maneuver SOM maps

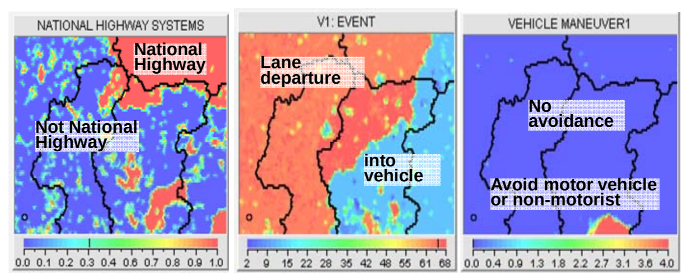
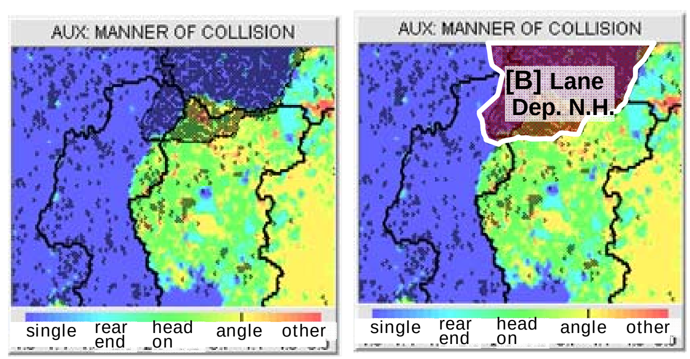


Figure 10: [B] Lane Departure N.H. coverage areas



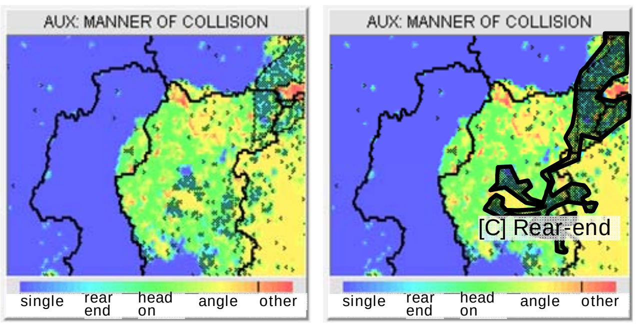
This [B] Lane Departure N.H. covers 16% of all areas, 62% of Cluster 1(Interstate highway accidents), 14% of Cluster 2(Drunk speeding) and 11% of Cluster 3 (Non speeding lane departure) and Cluster 4 (Vehicle to vehicle).

[C] Rear-end

This accident scenario assumes a virtual CA technology to theoretically avoid rear-end accidents, and is defined as AUX: MANNER OF COLLISION = "Rear end". With current CA technologies, FCW (Forward Collision Warning) may be effective to help reduce the number of fatal accidents in this accident scenario.

Figure 11 shows the SOM of AUX: MANNER OF COLLISION with "Rear end" with black spots and the [C] Rear-end Prevention area encircled for simplification.

Figure 11: [C] Rear-end coverage areas



This [C] Rear-end accident scenario covers 5% of all areas, 12% of Cluster 1(Interstate highway accidents) and 9% of Cluster 4 (Vehicle to vehicle).

Mutual coverage areas of [A], [B] and [C]

Figure 12 and Table 6 show the mutual coverage of [A] Skidding Straight, [B] Lane Departure N.H. and [C] Rear-end. The three accident scenarios have high coverage of Cluster 1 (Interstate highway accidents) and some coverage over Clusters 2, 3 & 4.

Figure12: Coverage areas of [A], [B] and [C]

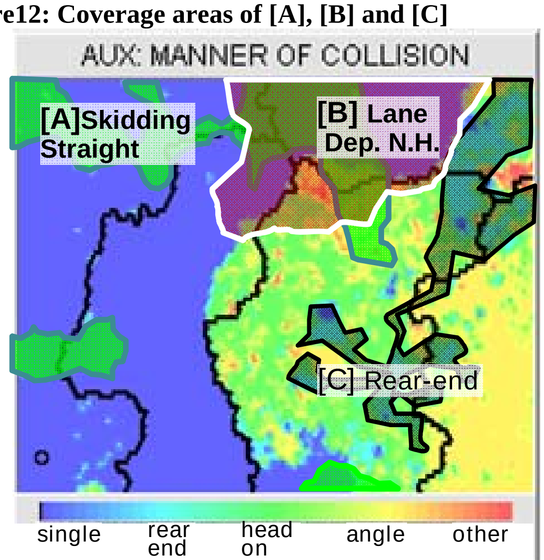


Table 6: Potential coverage of the three accident scenarios

Cluster		[A] Skid	[B] Lane	[C] Rear	Mutual [A][B][C]
1	Interstate highway accidents	27%	62%	12%	**77%**
2	Drunk speeding	25%	11%	1%	**32%**
3	Non speeding lane departure	11%	14%	2%	**23%**
4	Vehicle to vehicle	9%	11%	9%	**27%**
5	Intersection	2%	0%	4%	**5%**
	All areas	14%	16%	5%	**31%**

Characteristics of other areas

Focusing on other areas in the SOM map, the characteristics of the uncovered areas of the three accident scenarios can be understood. Examples of the perception of the remaining areas are shown in Figure 13. The characteristics of the remaining areas can be derived by viewing the relevant major SOM maps in Figure 14.

The summary of the remaining areas are described below, and the implementation of appropriate safety measures, could be either from the viewpoint of a vehicle, individual or the society.

(1) Young drunk speeding at curves
(2) Speeding on low speed limit roads
(3) Speeding with previous speeding convictions
(4) Drunk driving that are not speeding
(5) Distraction
(6) Elderly
(7) Intersection

Figure13: Characteristics of remaining areas

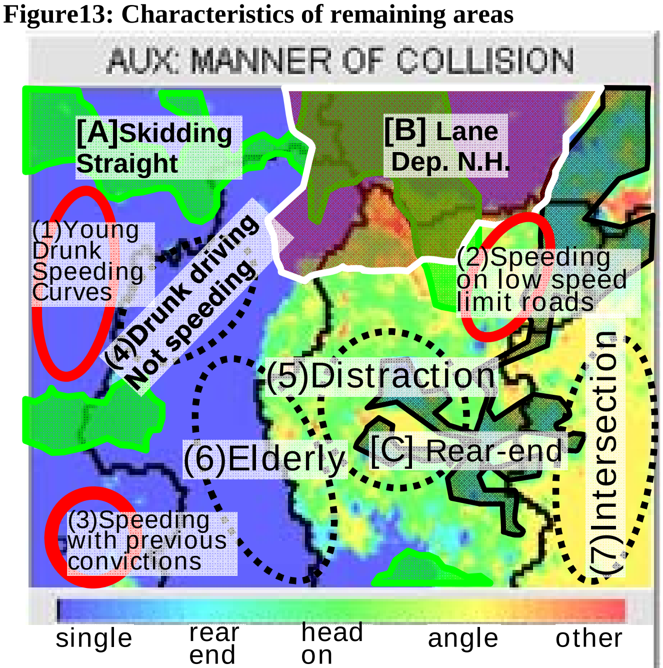
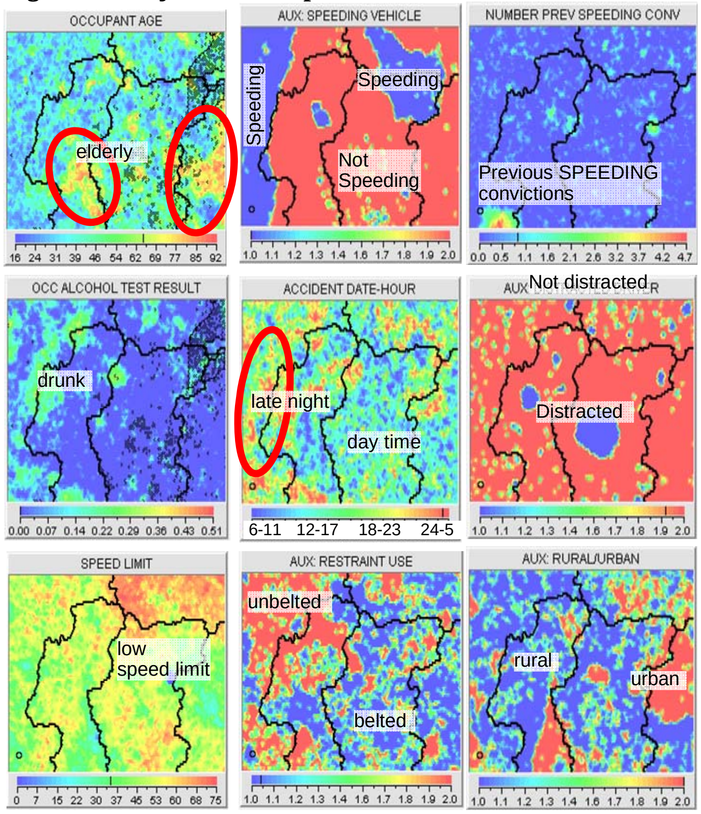


Figure14: Major SOM maps to understand characteristics



4. CONCLUSION

This present paper shows that clustering & SOM analysis can be used to classify FARS accidents into a number of clusters using all necessary factors, without setting any specific evaluation criteria.
Five clusters can be successfully generated from 16,180 fatal drivers from FARS2010 database. They are Cluster 1 (Interstate highway accidents), Cluster 2 (Drunk speeding), Cluster 3 (Non speeding lane departure), Cluster 4 (Vehicle to vehicle) and Cluster 5 (Intersection).

Three accident scenarios are created to study potential areas of fatal accidents reduction in the SOM map, and the accident scenarios are: [A] Skidding Straight, [B] Lane Departure N.H. (National Highway) and [C] Rear-end. The three accident scenarios mutually had coverage of totally 31% of all the fatal drivers, and the three accident scenarios had high coverage of Cluster 1 (Interstate highway accidents) and some coverage over Clusters 2, 3 & 4.
By focusing on the areas that the three accident scenarios did not cover, the characteristics of the uncovered accident scenarios were clarified.

When focusing on the effective areas of CA technologies and other areas which overlap across the adjacent clusters, all important factors such as driver age, drunk driving, seatbelt usage, etc. can be visualized. Thus, by analyzing the characteristics of the clusters using SOM to consider new counter-measures, it may be possible to explore new strategic solutions to reduce US fatalities.

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ELECTRONIC STABILITY CONTROL AND SIDE IMPACT CRASHES: 100% CURE OR A CASE OF REALIGNING SAFETY PRIORITIES

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ABSTRACT

Side impact crashes remain a key road safety priority. Electronic stability control (ESC) has been shown to be a life-saving technology and was heavily promoted as having significant benefits in reducing rollover crashes and run-off-road crashes in particular. Similarly, side impact airbags (SAB) offer considerable promise in reducing the number of people killed and seriously injured in side impact crashes.

The paper has two aims: 1 to estimate the likely crash reduction benefits and financial savings in terms of ESC in reducing pole side impact crashes in Victoria, and 2, to assess the need for, and type of, road safety countermeasures required to address the persisting side impact crash problem. In doing so, the role of side airbags was assessed, and a case for the pole side impact Global Technical Regulation (GTR) examined.

Using historical crash data from Victoria, vehicle ownership rates, actuarial determinations of crash risk and future population projections, future crash rates were determined. It was projected that in the period 2016 to 2045, a total of 1088 passenger car and SUV occupants were predicted to be killed and 8661 seriously injured due to pole side impact crashes. Given a range of evidence on the effectiveness of ESC, side impact airbags and the proposed new Pole Side Impact global Technical Regulation, the combined crash reduction benefit was established.

Given stated implementation scenarios and associated assumptions, the combined benefit of ESC, SAB and the proposed PSI GTR was a 50% reduction in the number of occupants killed and seriously injured in narrow object side impact crashes. Conversely, half of all projected fatalities and serious injuries still occur, translating to the likely deaths of 547 occupants and serious injuries sustained by 4145 occupants.

It is clear then that ESC and side airbags are highly effective however other crash prevention and injury mitigation countermeasures are required to address the remaining crash problem. Adoption of a broader view of side impact safety countermeasures, including improved infrastructure and safer road user behavior, is essential.

INTRODUCTION

Side impact crashes represent a significant proportion of the number of people killed and seriously injured. Fatalities due to narrow object side impact crashes range from 5.7% (USA) to 17.1% (Germany) of all occupants of 4-wheeled vehicles killed. Moreover, high numbers of people are seriously injured and admitted to hospital due to side impact crashes [1]. Narrow object impacts, such as trees and poles, carry an especially high risk of fatality; however they are generally fewer in number than vehicle-to-vehicle side impact crashes when fatality and injury crashes are considered together.[1] In Victoria, Australia, side impact crashes remain a key road safety priority, accounting for 35% of fatalities and costing the community an estimated $AUD 1.5 bn. per annum.

The injury risk associated with side impact crashes is well understood. [1-15] At particular risk in side impact crashes are the head and thorax body regions.

The search for improved side impact protection countermeasures has been the subject of considerable research over the past two decades. Recognizing the risk associated with side impact crashes, governments and manufacturers have adopted a range of countermeasure strategies and performance-based requirements, such as US FMVSS 214 and the UN ECE 95.[16, 17] To meet these requirements manufacturers have used a range of strategies, including for example, door padding, side intrusion bars, refinements to seat belts and seat technology, structural changes including stiffness and new materials, as well as side impact airbags. (SAB)[1, 10, 17, 18]

The safety improvements described above relate to ‘passive safety’, however with improvements in technology, ‘active safety’ systems offer scope for the crash to be either avoided entirely or injuries mitigated through reduced impact speeds or a more optimal crash geometry / trajectory. In particular, ESC – built off ABS, has been demonstrated to be highly efficacious in reducing run-off-road crashes, with some estimates pointing to a 65% reduction for SUV / light commercial vehicles, although the benefits to passenger cars is uniformly lower at up to 40%.[1, 19-22]

The focus on passive and active safety technology in the prevention and mitigation of side impact crashes has an important global context. 'Safer vehicles' falls directly under the ambit of the United Nations (UN) *Decade of Action for Road Safety 2011-2020* [23-25] and is one of the five key pillars of the *Decade 'Action Plan'*.[26] The *Action Plan* [26] for the Decade of Action specifically notes the role of passive and active safety technologies, such that it seeks to promote the...

> ...Global deployment of improved vehicle safety technologies for both passive and active safety through a combination of harmonization of relevant global standards, consumer information schemes and incentives to accelerate the uptake of new technologies...

This call for activity has been recognized by the UN ECE in the 154th Session WP.29 session (21-24 June 2011, agenda item 8.9.),[27] whereby activities under Pillar 3 that fall under the responsibility of WP.29 were to be defined. This culminated in the development of the UN ECE Decade of Action for Road Safety – UN ECE Plan 2011–2020 which outlines a number of innovations in the arena of active and passive safety systems.[28]

Further refinements and expansion of the ESC mandate, the proposal for the development of a Pole Side Impact Global Technical Regulation (PSI GTR) in order to overcome deficiencies in the current barrier test (see unece.org), and the promotion of technologies such as lane departure warning, fatigue monitoring and vehicle-to-infrastructure systems are indicative of the motivation to reduce the frequency and severity of side impact crashes.

That improved side impact protection has been a priority is also evidenced by New Car Assessment Program (NCAP) encouraging the fitment of side curtain airbags and rewarding vehicles that do so. The moves by NCAP in adding ESC and other safety assist technologies to the 'road map' is a further important step in improving vehicle safety.[29, 30]

The crash reduction and injury mitigation benefits of ESC and side impact airbags, respectively, are now well understood. Together both offer considerable promise in realizing significant road safety benefits, particularly in relation to run-off-road side impact crashes. The question is whether these two countermeasures represent 100% 'cure' for this highly injurious crash type, and if not, what more can be done?

Hence this paper has two aims: 1 to estimate the likely crash reduction benefits in terms of ESC SAB and the PSI in reducing the number and severity of run-off-road pole side impact crashes, using Victoria (Australia) as an exemplar jurisdiction, and 2, to assess the need for, and type of, road safety countermeasures required to address the persisting side impact crash problem.

METHOD AND RESULTS

The Method used to derive crash and injury reduction benefits were described in detail previously[31] and can also be found in a full report on the *Assessment of the need for, and the likely benefits of, enhanced pole side impact global technical regulation.*[1] The reader is referred to these complementary publications; however a broad overview of the analysis method is presented below.

The analysis refers only to passenger vehicles, these being defined as passenger cars and sports utility vehicles (SUVs); these are known as category M1 vehicles within the UN ECE framework.

The principal question of this paper is:

> What is the crash reduction and injury mitigation benefit of ESC, SAB, and the proposed PSI GTR?

In answering this question, the balance between the projected number of crashes per annum and the associated savings is the number requiring alternative safety countermeasures.

To address this question, a number of accurate data sources are required in order for the necessary inputs derived. The key steps in the analysis are as follows:

1. Project the future number of crashes given the population estimates:
    - this relies on the historical relationship between crashes (by type) and the number of registered vehicles, and population projections modeled by the Australian Bureau of Statistics[32];
    - the historical vehicle ownership ratio, expressed as the number of registered vehicles[33, 34] per persons aged 15 years and older in the population, and
    - using the above two inputs, the number of registered vehicles can be derived for each year, 2016 – 2045 is derived. The next step is to determine the number of

expected fatalities and injuries for each year in the future. To do so, we use the historical vehicle involvement rate in side impact fatalities to establish the 'fatalities per registered vehicle' and 'serious injuries per registered vehicle; note that this assumes no other changes in the injury rate into the future as the 'base' crash year.

The inputs here are the:

a. Number of registered vehicles for each year of available crash data [33, 34], and

b. Number of persons killed and injured [35-37]

The end result is the estimation of the number of fatalities and persons injured for every future year. The key parameter to estimate is the number of future crashes amenable to ESC and SAB systems.

2. Determine the likely benefit of ESC in reducing side impact crashes;

3. Account for the rate of penetration of side impact airbags though the fleet and their effectiveness in mitigating fatalities and injuries;

4. Determine the benefits afforded by the proposed PSI GTR, by injury severity;

5. Determine the total benefits of ESC and SAB, and derive the outstanding balance of fatalities and serious injury crashes.

With knowledge of the future population and the vehicle: person ratio, the number of registered vehicles into the future can be projected. Using the 'base-year' number of fatalities and injuries sustained in side impact crashes, the future number of side impact fatalities and injuries can also be determined. This is done so on the basis of the number of known fatalities and serious injuries per registered vehicle in the 'base year', this being the 2010 Victorian Police Reported Casualty data. Within this database, fatalities are defined as death within 30 days of the crash and a 'serious injury' was an individual who had been admitted to hospital for at least 24 hours.

Using the crash data, we determine the number of occupants involved in single vehicle run-off-road side impact crashes (Table 1). These fatalities and serious injuries are in the *field of influence of ESC and SAB systems.* Using the number of registered vehicles for 2010, the ratio of fatalities and serious injuries is derived. Similarly, using the population estimate for 2010, a passenger vehicle per person ratio is determined. These inputs form the basis of future fatality and serious injury estimations using projected population estimates as the key input.

Table 1. Estimation of current driver fatality and serious injury rates per registered passenger vehicles

Parameter	**Value**
Fatalities: number	27 (53% drivers killed involved in side impact crashes)
Serious injury: number	189 (17.8% drivers involved in collisions / rollovers and seriously injured)
Number of registered passenger vehicle[33]	3,280,682
Fatalities per registered passenger vehicle	0.00000823
Serious injuries per registered passenger vehicle	0.00006554
Population ≥ 15 years	4,467,428
Passenger vehicle per person ratio	0.734

Table 2 presents a snapshot of the projected narrow object impact crash projections, for the period 2016 / 2017 to 2045, as well as the total number across the 30 year period. These values are derived as per the process described above.

Table 2. Estimated number of run-off-road narrow object side impact fatalities and serious injuries, 2016 to 2045

Year	Future pop. estimate	Est. num. passenger vehicles†	Fatalities ‡	Serious injury‡
2016	4,857,898	3,567,426	29	234
2017	4,927,693	3,618,680	29	237
...	....	....	....	....
2044	7,138,348	5,242,088	43	344
2045	7,233,288	5,311,808	44	348
TOTAL			**1088**	**8661**

† Predicted number of passenger vehicles = future ABS population* passenger vehicles per person ratio (0.734)
‡Estimates number future passenger vehicles*fatality rate (per registered passenger vehicles) (& *serious injury rate per registered passenger vehicle)

Based on current fatality and serious injury rates, and given population growth and vehicle ownership, over the 30 year period 2016 to 2045, 1088 occupants are projected to be killed and 8661 seriously injured.

ESC fitment rates and the effectiveness of ESC in preventing crashes – The crash reduction benefits of ESC is well documented. For the purposes of obtaining the crash reduction benefit of ESC for run-off-road crashes, a 20.74% crash reduction value was adopted. This crash reduction value is specific to the Australian context and relates to passenger cars and SUVs, with consideration given to the differential effectiveness of ESC in passenger cars (18.6% reduction, 94.3% occupants) and SUV crashes (56% reduction, 5.6% of occupants), as well as vehicle ownership. These values were derived by the Monash University Accident Research Centre in an evaluation on ESC using police-reported crash data from five Australian states and NZ as part of the Used Car Safety Ratings program; the research examined the crash involvement of 175 1998 Model Year and newer vehicles with (n = 27, 252 vehicles) and without ESC fitted (n = 439,543).[38, 39]

The fitment rate of ESC into new vehicles is a critical consideration in its impact in reducing crashes. Figure 1 presents the percent of new car sales with ESC fitted as standard equipment in Victoria for the period 2006 to 2012.

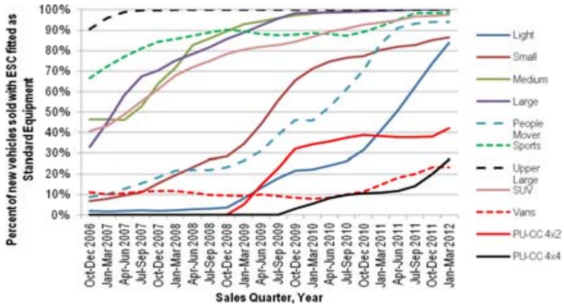

Figure 1. ESC fitment as standard equipment into passenger vehicles (M1) and light commercial vehicles (N1)

The rapid acceleration in the fitment of ESC (Figure 1) is in response to a number of factors, principally that from 1 November 2011 under Australian Design Rules all new model M1 vehicles will require ESC to be fitted, and in addition, from 1 November 2013 ESC must be fitted to all new vehicles sold. Consequently, 100% of all new vehicles purchased and entering the fleet will be fitted with ESC prior to the application of a pole side impact standard in Australia. Fitment rates in Victoria were likely also influenced by measures undertaken by the Victorian Government that required all newly registered vehicles by fitted with ESC from 1 January 2011.[40] Finally, fitment of ESC to vehicles would have been influenced by GTR 8 (UN R13H) as well as NCAP 5-star rating requirements.

A series of computational steps are required to account for the fitment rate of ESC, and hence the penetration through the fleet. Using a series of multiplier values that account for vehicle age, scrapage and turnover, an estimate of the number of vehicles fitted with ESC in each forward year can be derived (this process is described elsewhere in detail[1]). To this, we overlay the crash reduction benefit of ESC of 20.74%.

Table 3. Estimated number of run-off-road narrow object side impact fatalities saved due to ESC 2016 to 2045

Year	Fatals (Pred)	Prop fleet with ESC	ESC effectiveness multiplier (*20.7%)	ESC benefit per annum (PSI lives saved)
2016	29	0.7637	0.158	5
2017	30	0.8047	0.167	5
...				
2044	43	1.0000	0.207	9
2045	44	1.0000	0.207	9
TOTAL	**1088**			**218**

Table 3 shows a clear benefit of ESC, with 218 fatalities avoided over the 30 year period. Importantly, once saturation of the fleet is achieved (2043), the benefit of ESC is fully realized.

Table 4 uses the same method to derive savings in serious injuries due to ESC.

The results presented in Table 3 and Table 4 highlight the value of ESC in preventing run-off-road side impact fatalities and serious injuries. It can also be observed that over the 30 year period, ESC alone will reduce fatalities and serious injuries by 20%, leaving 80% requiring another form of safety countermeasure; this translates to 869 fatalities and 6922 persons seriously injured.

Table 4. Estimated number of run-off-road narrow object side impact serious injuries saved due to ESC 2016 to 2045

Year	Fatals (Pred)	Prop fleet with ESC	ESC effectiveness multiplier (*20.7%)	ESC benefit per annum (PSI lives saved)
2016	234	63.53%	0.13176	37
2017	237	70.53%	0.1463	40
...				
2044	344	100%	0.207	71
2045	348	100%	0.207	72
TOTAL	**8661**	**-**	**-**	**1739**

What benefits will side impact airbags deliver?
The analysis above indicates that ESC will reduce fatalities and serious injuries by 20%; hence, 80% of run-off-road side impact fatalities and serious injuries would still occur, given the 'base fitment rate' and crash risk of the 2010 crash year. Expressed in an alternative manner, side impact airbags (and other countermeasures) can play a role in the reduction of the 869 fatalities and 6922 persons seriously injured, after the effect of ESC is considered; these remaining crashes represent the field of crashes that SAB can influence.

Following regulatory intervention and increased consumer pressure – via NCAP and associated promotional advertising, the fitment of side airbag systems as standard equipment on new vehicles (in Australia) has increased (Figure 2).

As with ESC, the safety benefits associated with SAB depend on fitment and the penetration rate into the vehicle fleet.

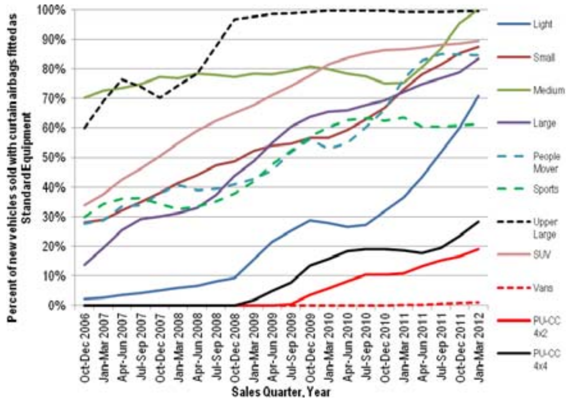

Figure 2. Side airbag fitment as standard equipment into passenger vehicles (M1) and light commercial vehicles (N1)

It was assumed that by the end of 2015, the percent of vehicles fitted with side impact curtain airbags and thorax airbags as standard equipment is as per Table 5. The forward projections are based on an on average 5.9% increase in the new car sales fitted with curtain side airbags as standard equipment per quarter since 2006 (Figure 2), however it is recognized that some segments will fail to reach 100% standard fitment. This is despite the requirement by NCAP for head protecting side impact airbags to be fitted for vehicles to achieve a 5-star ANCAP rating in 2012 for the front row and in 2014 for the rear seats. The ANCAP Road Map specifies fitment of head protecting side impact airbags at other star-rating levels in the period 2012-2017.

Table 5. Projected fitment rates of head protecting side airbags at the end of 2015

M1 vehicle sales class	Percent of M1 new vehicle sales	Side airbag fitment rate at end 2015 in vehicle class
Light	14.6%	90%
Small	28.1%	95%
Medium	11.7%	100%
Large	16.6%	100%
People mover	1.6%	95%
Sports	2.4%	85%
Upper large	0.8%	100%
SUV	24.2%	100%
Total	100%	

Using the historical and projected SAB fitment rates based on current vehicle sales and fitment rates, a penetration factor can be determined; this is the *SAB crash relevance factor*. The SAB relevance factor peaks at 96% in 2022 (Table 6); in the absence of a mandate is expected to remain at that level; this is described fully in Fitzharris and Stephan[1]. More precisely, the portion of the 869 fatalities and 6922 persons seriously injured is what SAB can reduce multiplied by the SAB fleet penetration rate (Table 6, column G), which is reflected in Table 6 – Column H and I. Based on this, in the period 2016 – 2045, 803 of the 869 and 6393 of the 6922 fatalities and persons seriously injured can be influenced by the protective benefits of SAB. Ultimately, the reductions in the fatalities and serious injuries are a product of the efficacy of the SAB itself.

Real-world effectiveness of SAB – A comprehensive review of SAB effectiveness was undertaken and reported as part of the *Assessment for the PSI GTR*. [1] On the basis of the fatality studies examined, and specifically the strength of the research conducted by Braver and Kyrychenko [41] and McCartt and Kyrychenko [42], we use a 32% reduction in fatalities due to the presence of a curtain plus thorax side airbag system. This value represents a lower bound, as their estimates are as high as a 45% reduction in fatality risk.

Similarly, we use the point estimate from the UAB CIREN Center as the basis of benefit ascribed to curtain plus thorax side airbag systems.[43] Specifically, we adopt a value of 34% as our basis of reduction in injuries.

Table 6. Fatalities and injuries possibly influenced under a business-as-usual side airbag implementation scenario

	Side impact fatalities and injuries post-ESC benefit (amenable to SAB)		**% fleet with side airbags**	**Open to influence from SAB / exposed given SAB fitment**	
	F_f	**F_i**	**G**	**H**	**I**
Year	Fatal	Serious injury	SAB penetration multiplier	Fatal	Serious injury
2016	25	197	0.582	14	115
2017	25	198	0.650	16	128
...					
2044	34	272	0.96	33	261
2045	35	276	0.96	33	265
Total	**869**	**6922**		**803**	**6393**

Using the observed real-world effectiveness values of SAB, we then reduce the number of occupants killed and seriously injured by this factor; this is presented in Table 7. The sum total savings associated with SAB is then 257 fatalities avoided and 2174 serious injuries.

Table 7. Fatalities and injuries avoided under a business-as-usual side airbag implementation scenario, after ESC

	Open to influence from SAB / exposed given SAB fitment		**BAU SAB reduction benefit**	
	H	**I**	**J**	**K**
Year	Fatalities	Injuries	Fatalities avoided @ 32% SAB	Injuries avoided @ 34% SAB benefit
2016	14	115	4.6	38.9
2017	16	128	5.2	43.6
...				
2044	33	261	10.50	89
2045	33	265	10.64	90
Total	**803**	**6393**	**257**	**2174**

Effect of a PSI GTR on run-off-road narrow object side impact crashes

The proposal to adopt a new performance-based Global Technical Regulation on Pole Side Impact Crashes, led by the Australian Government, was in recognition of the persistently high risk of death and serious injury, in spite of the present regulatory regime. The reader is referred to the draft proposal: ECE/TRANS/WP.29/GRSP/2013/7 - (Australia) Proposal for a global technical regulation on Pole Side Impact; this can be found at the WP29 site: (http://www.unece.org/trans/main/wp29/wp29wgs/wp29grsp/grsp2013.html).[44]

The effect of the GTR would be two-fold: 1) side curtain airbags fitment to all new vehicles would be assured, and 2) the protective value of side airbags would offer an incrementally higher level of protection. This would be the consequence of the increased safety demands of the oblique test and associated performance criteria. It is assumed that the GTR requirements would results in an incremental benefit of 30% over and above current side impact systems, which in effect is an added benefit of 9.6% and 10.2% for fatalities and serious injuries, however the enhanced SAB would also take time to completely penetrate the fleet (+ 30 years).

The practical effect of the fitment of side airbags to all vehicles would be a very small acceleration in the fleet penetration, but it would importantly guarantee that fitment reaches 100%. Following the same method described above, the number of fatalities and serious injuries avoided can be determined.

Table 8. Fatalities and injuries avoided due to the proposed PSI GTR.

	GTR benefit – 100% fitment and enhanced efficacy	
Year	**Fatalities avoided**	**Injuries avoided**
2016	0.08	0.64
2017	0.22	1.83
...		
2044	3.7	31.2
2045	3.7	31.7
Total	**66**	**563**

Hence, the proposed PSI GTR would result in an additional saving of 66 lives and prevent 563 serious injuries.

Summary of ESC, SAB and PSI GTR benefits: a 100% cure?

This paper set out to determine the likely benefits of ESC, SAB and the proposed PSI GTR. Of particular interest was the degree to which these three safety interventions would reduce the number of occupants killed and seriously injured in run-off-road narrow object pole side impact crashes.

To recap, over the period 2016 to 2045, 1088 fatalities and 8661 occupants were projected to be seriously injured. ESC alone reduced this by 20% (218 fewer fatalities; 1779 fewer seriously injured). Added to this is the safety effect of SAB, which results in an added saving of 257 lives and prevents 2174 occupants from being seriously injured. Added to this is the benefit afforded by the proposed PSI GTR. This is summarized in Table 9 below, which shows that the three interventions result in a halving of the number of occupants killed and seriously injured in run-off-road narrow object side impact crashes. The corollary of this is that half of the fatalities and serious injuries in this crash type are not amenable to reduction by these three advances in active and passive safety.

Table 9. Narrow object side impact fatalities and injuries occurring and avoided due to the ESC, SAB and the proposed PSI GTR.

	Killed		**Seriously injured**	
	Num	%	Num	%
Projected, 2016-2045	1088		8661	
ESC benefit	218↓	20.0	1779↓	20.5↓
Open to SAB influence	*803*		*6393*	
SAB reduction (BAU)	257↓	23.6	2174↓	25.1↓
PSI GTR benefit	66↓	6.1↓	563↓	6.5↓
SAB + PSI GTR	*323↓*	*29.7↓*	*2737↓*	*31.6↓*
Savings due to ESC, SAB, GTR	**541↓**	**49.7↓**	**4516↓**	**52.1↓**
Remaining	547	50.3	4145	47.9

DISCUSSION

Using a range of assumptions, in the period 2016 to 2045 a total of 1088 persons were predicted to be killed due to narrow object (pole / tree) side impact crashes. Given the current ESC fitment rate, the expected fatality reduction benefit associated with ESC was 218 fewer occupants killed. Consequently, 803 fatalities would still occur. Side impact airbags provide further significant benefits, and this is improved even further by the adoption of the proposed UN ECE pole side impact GTR. The triple antigen of ESC, SAB and the PSI GTR offer significant reduction benefits for serious injury crashes also.

The combined benefit of ESC, SAB and the proposed PSI GTR is a 50% reduction in the number of occupants killed and seriously injured in narrow object side impact crashes. Hence, half still occur, translating to the likely deaths of 547 occupants and serious injuries sustained by 4145 occupants.

A broader search for side impact safety – a realignment of priorities and a continued search for vehicle safety options

From the analysis presented above, and given stated limitations, it is clear that ESC and SAB systems – including the added benefit of the proposed pole side impact GTR will deliver considerable safety benefits. Two things are evident: 1. due to the pace of introduction of ESC and SAB and vehicle turnover rates, the full benefit of these safety technologies will not be realized for a considerable period of time, and 2. a large number of run-off-road side impact crashes not amenable to ESC or the safety benefits of side airbags will continued to occur. This future scenario clearly points to the need to take a holistic view of the run-off-road side impact crash problem.

As outlined in the discussion, safer vehicles represent one of the five action pillars for the Decade of Action, along with road safety management structures; road user behavior; road infrastructure; and 5. post-crash care [26]. The Action Plan is built on the safe systems model of road safety, whereby safe speeds, safe roads and roadsides, as well as safer vehicles act in concert to both prevent crashes that result in serious injury (Figure 3). The safe system model places the human in the centre of the road transport system, recognizing that humans make errors and are vulnerable to injury. By recognizing the ethical imperative that no road death is acceptable [45-48], policy action across the entirety of the system is demanded. Inspired to the work of Haddon [49] the safe systems approach posits that to central to achieving optimal reductions in road trauma is recognition that multiple risk factors need to be addressed, ideally simultaneously. [45-48, 50]

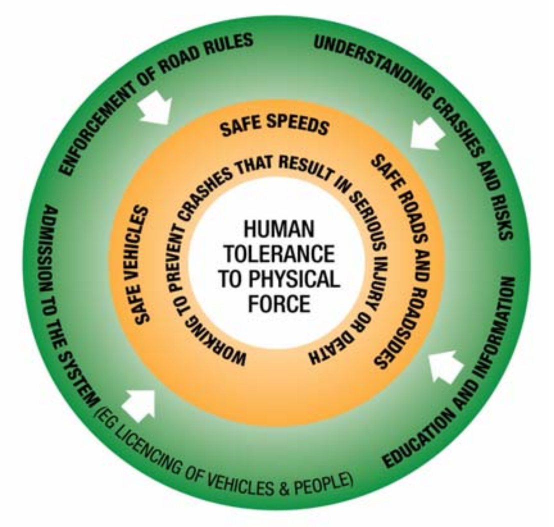

Figure 3. The Safe Systems Approach to Road Safety (Source: WHO, 2009)[51]

Within the vehicle safety domains, a range of new technologies, including lane departure warning, centre mounted airbags (Figure 4), improved seat design, and optimized seat restraints offer considerable promise in further reducing fatalities and injuries associated with side impact crashes.[52-56]

Figure 4. Front-centre mounted airbag (Source: Sikora[57])

Other factors such as pedestrian safety requirements and environmental concerns will likely lead to changes in vehicle design with respect to vehicle mass and vehicle geometry; these changes may have significant implications for side impact crashes with respect to run-off-road crashes, but will also influence injury outcomes from vehicle-to-vehicle side impact crashes to a greater extent.

An important premise of the safe systems approach and Vision Zero is that humans are error prone and the system needs to be designed in such a way to tolerate these errors. Fatigue, intoxication and inattention – which include distraction, remain significant issues that need to be addressed. In a study of 340 crashes examined as part of the Australian National Crash In-depth study, 11.8% of drivers stated they fell asleep, 10.9% stated they were fatigued, 13.5% were intoxicated (an BAC > 0.05), and 16% stated they were distracted; passenger distractions were the most common form of distraction (8.8%) immediately leading up to the crash.[58, 59] The mitigation of these behaviors sits within the ambit of safer road users and hinge on education and enforcement strategies.

In addition to improved vehicle safety, safer infrastructure can continue to play a critical role in mitigation both the occurrence and severity of run-off road crashes. For instance, Candappa et al demonstrated the value of flexible barrier systems, reporting an on average 44% reduction in serious injury crashes where flexible wire rope barrier systems were implemented; the benefits of WRB systems in some locations was as high as 86% reduction.[60] Further, extensive research has demonstrated the benefits of other infrastructure treatments such as rumble strips, shoulder treatments and clear zones.[60-63] It has also been shown that road design factors play an integral role in speed choice, and can be used as an effective speed control mechanism.[64]

As is evident, run-off-road crashes into fixed objects resulting in side impact crashes carry a high risk of serious injury. While further refinements to passive and active safety systems are likely, there is a need to continue to look to infrastructure improvements and addressing aspects of road user behavior in mitigating this serious crash problem. This approach is an explicit statement of the importance of adopting the safe systems approach to road safety.

Limitations

In the formulation of crash estimates, a number of assumptions were made and these are clearly stated. The present paper reports the findings from a single effectiveness value of ESC, side airbag systems and the effect of the PSI GTR. Ideally a sensitivity analysis would be conducted, however the point here is to demonstrate the principle that a broad range of interventions are required to address the run-off-road narrow object side impact problem. The effectiveness values used were drawn from the published literature, including from studies published using Australian and Victorian crash data. This provides confidence in the analysis reported here. Assumptions were required concerning the projected fitment and penetration rates for ESC and side airbags, although historical data forms the basis of these. This paper does not present the cost-effectiveness estimates of the three interventions, and an estimate of the cost-effectiveness of ESC remains to be determined; suffice to say the significant savings and the low cost of ESC fitment point to a strong benefit-cost ratio. Finally, the paper does not address the injury severity category shifting; that is, there is no consideration of occupants previously classified as being killed into the serious injury category and so on into the minor and involved but uninjured category. Finally, safety improvements to the road network and changes in driver behavior – hence crash risk, are not modeled here.

CONCLUSIONS

The analysis demonstrates the significant impact of ESC and side airbags in reducing death and serious injury stemming from run-off-road pole side impact crashes. Further benefits are observed from the proposed PSI GTR. Due to the pace of introduction of the new technologies as standard equipment, and the age of the vehicle fleet, the full benefits are not realized until at least 25 years. The combined benefit of ESC, SAB and the proposed PSI GTR is a 50% reduction in the number of occupants killed and seriously injured in narrow object side impact crashes. Hence, half still occur (given no other safety improvements), translating to the likely deaths of 547 occupants and serious injuries sustained by 4145 occupants. Following this, innovative passive and active safety solutions need to be found. Perhaps in time vehicle-to-infrastructure intelligent transport technologies will prove to be the silver bullet in preventing run-off-road crashes altogether. In the meantime, a continued focus on mitigating road user error, aberrant behaviors and the provision of appropriate infrastructure is required.

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