Analysis of rescue operations of injured vehicle occupants by fire fighters

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ABSTRACT

One of the responsibilities of fire fighters is to rescue injured occupants from crushed vehicles. Such occupants are frequently trapped in vehicles whose structure has been damaged to a devastating extent. However, few studies about the relationship between the original vehicle structure and the rescue procedures have been undertaken. The main reason for this is a lack of details regarding rescue operations.

In this report, rescue cases in which fire fighters rescued injured occupants in a crash using rescue equipment were analyzed statistically. These cases were collected by some fire stations in the area.

Vehicle occupants are often rescued by fire fighters (rescue workers) within five minutes. The rescue time (time lapse from site arrival to rescue of the casualty from the vehicle) required by fire fighters was 20 minutes on average. However, when there were two or more persons to be rescued, the average rescue time exceeded 30 minutes. Rescues involving heavy truck frontal impacts took twice as long as rescues involving passenger car casualties. Moreover, rescue operations in which the colliding vehicle was a heavy truck required more rescue time than passenger car accidents.

Proper casualty rescue from vehicles should be divided into four phases (initial opening, treatment opening, rescue opening, and rescue of the casualty). In these phases, we focused on five tasks (removing windows, vehicle stabilization or pulling the vehicle, door opening using a bar/door opening using hydraulic tools, pillar cutting using hydraulic tools, and pushing away the front end using hydraulic tools). The most frequent task was door opening using hydraulic tools, and next was pushing away the front end using hydraulic tools. Cases involving two tasks required more rescue time. In particular, a frontal impact involving a cab-over vehicle took more time.

In addition, some typical accidents including heavy trucks were reproduced by full crash tests, and the problem of current rescue procedures were investigated by trying these rescue activities. The fire fighters could easily rescue the occupant dummies in a crash test of a car under-ride with a heavy truck rear end. However, a long rescue time occurred if lifting of the rear end of the truck was needed. The operation took over 30 minutes to rescue the truck occupant dummies in a frontal collision. The principal problems were rescue procedures of door-opening and pushing-away the front end using hydraulic tools.

From these results, we should study original rescue procedures of door-opening and pushing-away the front end, considering the structure of heavy trucks. This should be done in cooperation with fire departments. In Europe, some rescue manuals which specialize in heavy trucks are made, and such manuals would be valuable in Japan.

Because the rescue equipment in fire engines is different in Japan and Europe, an original Japanese rescue guide of heavy trucks is necessary based current rescue equipment available in Japan. We believe that the amount of time needed to rescue vehicle occupants injured in traffic accidents can be reduced by improving rescue procedures.

INTRODUCTION

The number of fatal traffic accidents in Japan has been continuously decreasing since 1993 (Figure 1). The number of traffic-related injuries has also exhibited a decreasing tendency since 2005. For this reason, the Japanese government applied pressure on manufacturers, etc., with the result that the targets initially planned for 2010 (a reduction of 1,200 fatalities by vehicle safety measures) were achieved by 2008, and new targets for further reductions were set [1].

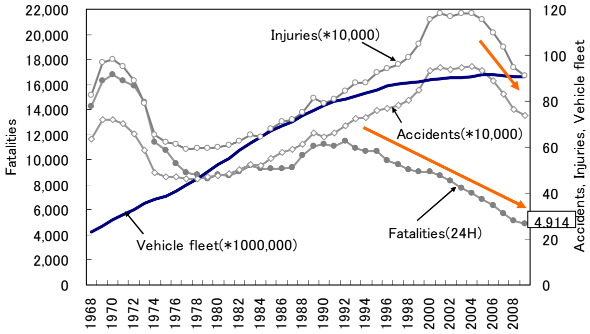


Figure 1. Traffic statistics in Japan

To achieve the new targets, vehicle manufacturers have to think about improving post-crash safety measures in addition to active and passive safety measures. Emergency call systems have been developed by some vehicle manufacturers with the objective of facilitating early assistance to injured occupants [2]. However, such occupants are sometimes trapped in vehicles where the structure has been damaged to a devastating extent. In these cases, the fire fighters have to safely remove the injured occupants from the vehicle. Improvements in crash safety have recently been achieved by increasing the complexity of vehicle structures, and the understanding of such changes has become an important issue for fire fighters in carrying out their operations efficiently. Therefore, it is necessary to study vehicles' structure and how it may affect rescue operations. Such information, provided to fire fighters through training programs, may become a valuable asset for improving rescue work in the future.

As a first step, in-depth data collected in Japan were used for this work. The types of vehicles involved and the types of accidents requiring rescue work were analyzed. In addition, some typical accidents were reproduced by full-scale crash tests to investigate the associated problems of current rescue methods.

In the following, these results are described. This research was executed in a JAMA project "research on improvement of vehicle rescue methods".

EMERGENCY WORK IN TRAFFIC ACCIDENTS

Accidents requiring emergency work

A series of 609 vehicle-to-vehicle accidents (involving 905 occupants) collected by the Institute for Traffic Accident Research and Data Analysis (ITARDA) from 1996 to 2006 was analyzed to evaluate the time lapse of the emergency work [3]. All of the selected cases involved an emergency call and the transportation of the injured occupant to a hospital by ambulance. However, it was not recorded whether rescue work was carried out or not.

Figure 2 shows the crashes in which emergency work was done, grouped by accident type. The most common type was the intersection type (348 cases). In these accidents, occupants transported to the hospital included 714 drivers, 133 front-seat passengers, and 58 rear-seat passengers.

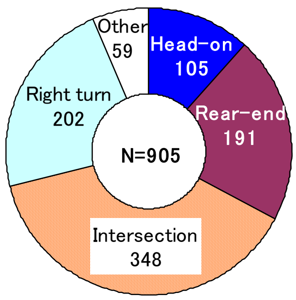


Figure 2. Accident type involving emergency work (ITARDA 1996-2006)

Time lapse required for emergency work

The time required in each case from the moment of the crash to the patient's arrival at the hospital was calculated based on five reported times from two different sources. The first reported time (called Crash) was taken from the police report. The other four recorded times (called Call, Arrival, Accommodation, and Hospital) were taken from fire station reports. Cases that presented incoherent reports were omitted from this study. Terms used to calculate the emergency time lapses are defined below.

Crash: Time at which the accident occurred.
Call: Time at which the emergency call was received at the fire station.
Arrival: Arrival time at the accident site.
Accommodation: Time at which the fire fighters (emergency medical technician) accommodated the injured occupant in the ambulance.
Hospital: The arrival time at the first hospital.

Figure 3 illustrates the average calculated time lapses between reported times from the crash to the arrival of the ambulance at the hospital for different injury levels. 672 (74%) of the transported occupants had minor injuries while fatal and serious injuries accounted for 22% (29+171) of the selected cases.

The average crash-call time lapse for minor/no injury was longer than for fatal/serious injury cases. This may be caused by the fact that people involved in accidents took time to decide whether or not to call an ambulance. No important differences were observed for the call-arrival time lapse. However, a difference of more than two minutes was found for the arrival-accommodation time lapse between the minor/no injury cases and the serious/fatal injury cases. This may be caused by the fact that preparation of the equipment needed for initial treatment takes more time in the case of serious injuries. The accommodation-hospital time lapse for fatal injuries was an average of three minutes longer than for the rest of the injury severity levels. One factor that could affect this delay is the necessity of choosing a hospital that can guarantee an appropriate first intervention when the occupant's life is seriously threatened.

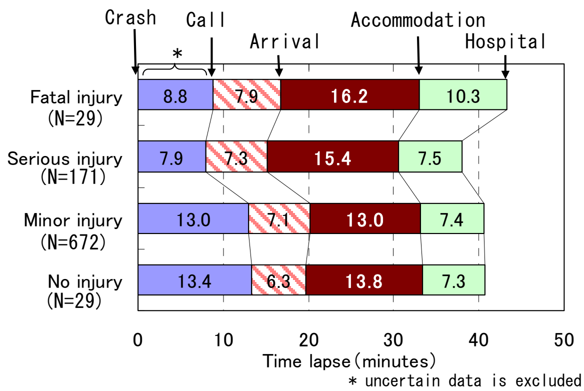


Figure 3. Average time lapse by injury severity (ITARDA 1996-2006)

Figure 4 illustrates the time lapses from the emergency call to the arrival at a hospital by injury severity. In this case, the results are grouped by crash type (frontal impact, side impact, and rear impact). For frontal impacts, the average arrival-accommodation time lapse tends to increase with the severity of injury.

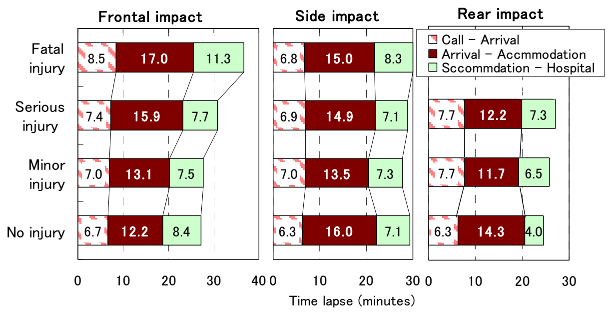


Figure 4. Average time lapse by injury level and crash type (ITARDA 1996-2006)

Figure 5 illustrates the injury severity ratios for the arrival–accommodation time lapse. The ratio of fatal/serious injuries tends to increase with time, and this tendency is seen especially in abdominal injuries. For elapsed time exceeding 26 minutes, the fatal/serious injury ratio rises to 50%. Based on these results, it can be said that when the occupant is severely injured, more time is required for the process from arrival at the crash site to accommodation of the casualty in the ambulance.

An estimated target of 30 minutes from the emergency call to arrival at an appropriate hospital has been reported in Japan as the critical time within which severely injured occupants should be transported [4].

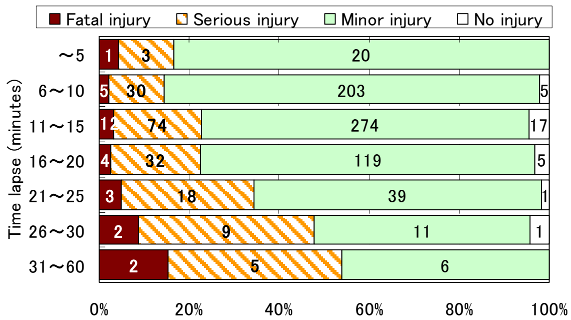


Figure 5. Injury severity ratio for arrival - accommodation time lapse (ITARDA 1996-2006)

To complement the Japanese data, other in-depth data sources such as data collected by the NASS CDS in the US were analyzed. Figure 6 plots the cumulative probability of the time to death by injury location. The cumulative probability of death due to chest injury within 1.5 hours after the accident (considered as instant death) is 68%, and it is 48% for head injuries. However, the cumulative probability of death due to abdominal injury within 1.5 hours is below 20%. This tendency for death due to abdominal injuries changes rapidly as the time to death increases, becoming as probable as head injuries at 7.5 hours.

This is not to say that only a shorter time lapse can increase the survival probability; rather, it is thought that rescuing injured occupants from damaged vehicles at an early stage and performing appropriate treatment early is effective in raising the survival probability. In particular, abdominal injuries are sensitive to this effect.

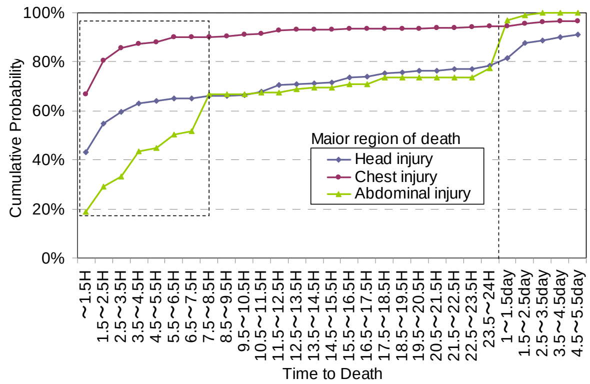


Figure 6. Cumulative probability at time to death by injury region (NASS CDS 2000-2004)

RESCUE WORK IN TRAFFIC ACCIDENTS

Accidents requiring rescue work

Fire fighters (rescue workers) have to rescue injured occupants trapped in devastated vehicle structures. Therefore, rescue work in which rescue equipment was used by fire fighters were collected with the cooperation of some fire stations in the area (see Figure 7). Accident types and rescue operations that required some time were analyzed. The collected data consisted of 78 cases involving 91 occupants trapped in damaged four-wheel vehicles.

Figure 7. Image of data collection

Figure 8 indicates the number of rescued occupants per case. In most of the cases (85%) only one occupant was rescued. In the rest of the cases, two or three occupants were rescued. By seating position, (see Table 1), 75 (82%) of the rescued occupants were rescued from the driver's seat while 16 individuals were in the passenger area. Rescue operations are often required in the case of rollover (20 cases).

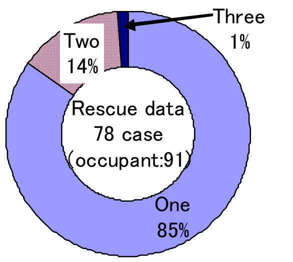


Figure 8. Number of rescued occupant / case (rescue case)

Table 1.
Accident type and seating position of the rescued occupant (rescue case)

Accident type	Rollover	Rescued case	Number of vehicles	Rescued occupant	
				Driver	Passenger
Vehicle to vehicle	w/o	42	43	40	8
	with	10	11	11	2
Single accident	w/o	16	16	16	1
	with	10	10	8	5
Total		78	80	75	16

Rescue time needed by fire fighters

Figure 9 graphs the rescue times for injured occupants. The rescue time is defined as the time lapse from the arrival of the rescue crew at the crash site to the extraction of the injured occupant from the vehicle. When two or more occupants need rescuing, the priority is usually judged on-site based on the injury level and the ease of the operation, among other factors.

Most of the work was finalized within five minutes, while the average rescue time was 20 minutes. However, the rescue of 14 occupants exceeded 31 minutes. If the data is divided by rescue order, the average for a subsequently rescued occupant is 36 minutes. Therefore, the average for the subsequently rescued occupant exceeds the target time lapse of less than 30 minutes for just the rescue work alone.

Figure 10 graphs the rescue times grouped by collision type (front, side, rear, and rollover). The rescue time for a frontal impact was 26 minutes on average, and longer for the other collision types. Most rescue times were less than 30 minutes for side impact and rear impact. Rescue times of less than 10 minutes occurred in 50% of the rollover cases. The reason is thought to be that the occupants could not escape by themselves, though the injury level may have been minor.

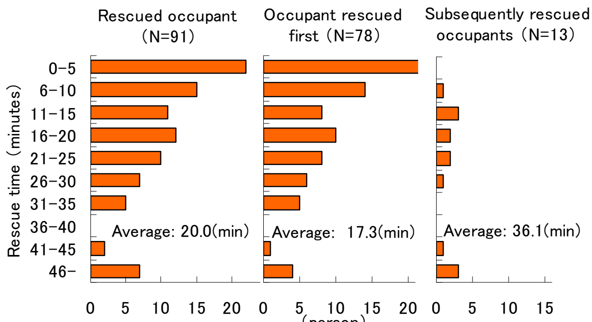


Figure 9. Rescue time divided by rescue order (rescue case)

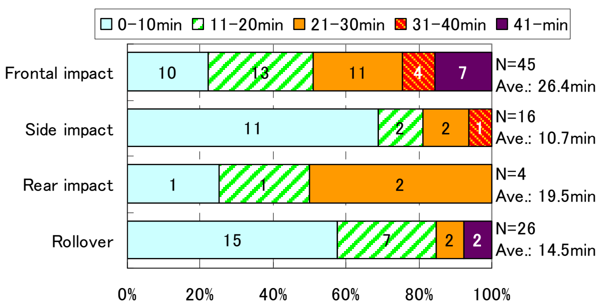


Figure 10. Rescue time divided by collision type (rescue case)

Figure 11 graphs the rescue times divided by vehicle type. For heavy trucks, all of the cases required over 10 minutes, and 3 out of 8 of the cases required over 41 minutes. The average rescue time was 50 minutes, two times longer than for other vehicle types. The rescue of truck occupants tends to take longer than passenger-car occupants. The reason is thought to be that most trucks in Japan are of the cab-over type, and the survival area is often crushed by a frontal impact. In addition, proper rescue from heavy trucks is generally much more complicated than in passenger-car accidents because the rescuers have to work at dangerous heights.

Figure 12 graphs the average rescue times divided by vehicle type and opponent vehicle type for frontal impact accidents. The average for a heavy truck/heavy truck accident is about 18 minutes longer than that for a heavy truck/car accident (**). When these two forms were compared, a significant probability difference was confirmed. The average rescue time for a car/heavy truck accident was longer than that of car/car accident (*). It can be said that rescue work needs additional time when the colliding vehicle is a heavy truck, even if the car occupant is rescued. A significant probability difference was not found in a comparison between car/car accidents and car/structure accidents.

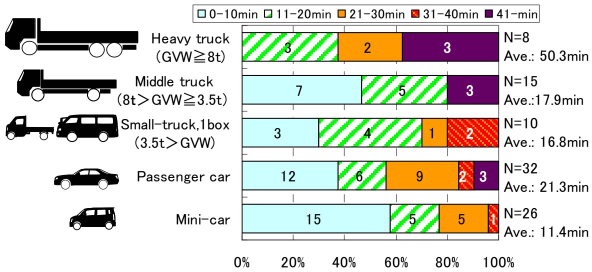


Figure 11. Rescue time divided by vehicle type (rescue case)

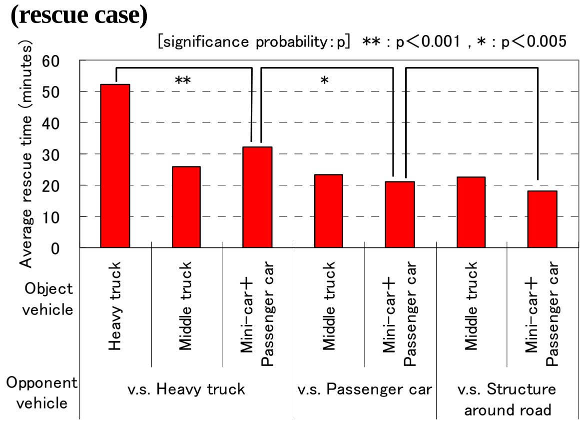


Figure 12. Average rescue time divided by vehicle type and opponent vehicle type in frontal impact (rescue case)

Figure 13 graphs the average rescue time divided by vehicle type and the occupant's injury level. The rescue time tends to be long relative to the injury level. After an investigation of conditions in which the average rescue time was over 30 minutes, the relevant conditions were found to be fatal/serious injury of heavy-truck and middle-truck occupants and mid-level injury of heavy-truck occupants. Because the injury region of heavy-truck occupants was predominantly the abdomen [5], improving the rescue work could be expected to lead to an increase in the survival probability.

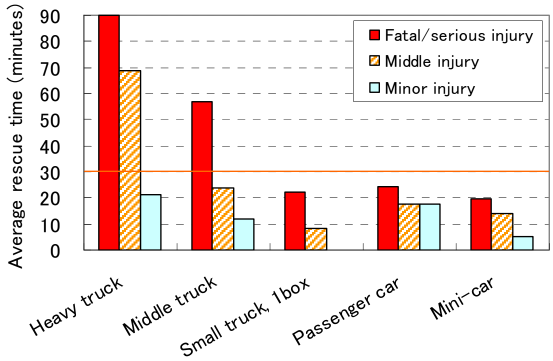


Figure 13. Average rescue time divided by vehicle type and occupant's injury level (rescue case)

Rescue methods used by fire fighters

The appropriate method for rescuing vehicle occupants is divided into four phases, according to the Guide for Rescue Service (for trucks, 2007) [6]. The rescue procedure is almost the same in Japan. This procedure dictates that the crew chief act based on his experience and knowledge.

1st phase, "initial opening": Removal of window glass for the first contact with an injured occupant.

2nd phase, "treatment opening": Initial treatment and safe securing of vehicle. (vehicle stabilization, pulling the vehicle)

3rd phase, "rescue opening": Door-opening, pillar-cutting, and pushing away the front door to clear a rescue route.

4th phase, "rescue of the casualty": The injured occupant is transported out of the vehicle.

In this analysis, attention is focused on five operations (removing windows, vehicle stabilization /pulling the vehicle, door-opening, pillar-cutting, and pushing away the front end) in rescue work. Figure 14 shows executed rescue operations divided by collision type.

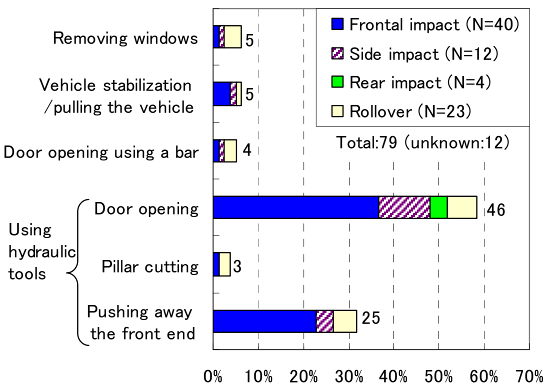


Figure 14. Executed rescue operations divided by collision type (rescue case)

In this graph, the numbers include all rescued occupants. Therefore, when two occupants were rescued in a single case, it was counted as two rescues. Moreover, the door-opening was divided into two operations based on the rescue equipment used (using a bar and using hydraulic tools).

The most frequent operation was door-opening using hydraulic tools, which was executed in 58% of the cases (representing 46 occupants). This is executed especially frequently in cases with a frontal impact and a side impact. The majority of the rescue teams (i.e. fire engines) at Japanese fire station are equipped with hydraulic tools such as a hydraulic cutter and a hydraulic spreader, though few are equipped with a rescue ram (Figure 15). The second most frequent operation was pushing away the front end using hydraulic tools. As mentioned above, rescue operations using hydraulic tools were frequently performed in vehicle accident rescues.

(a) Hydraulic cutter; It uses it to cut pillar and the door hinge, etc.(Weight:14kg)

(b) Hydraulic spreader; It uses it to expand the collapsing part locally or to break it open. (Weight: 20 kg)

(c) Rescue ram; It uses it to expand the door frame and the roof, etc.

Figure 15. Examples of hydraulic tools

The data was divided into four tasks as follows, and the rescue times were compared.

Task A: Door-opening using hydraulic tools.
Task B: Pushing-away front end using hydraulic tools
Task C: Opening the door and pushing away the front end using hydraulic tools.
Task D: Without using hydraulic tools.

Table 2 indicates how the rescue work was divided among the four tasks. Task A was performed frequently in the case of collision accidents (frontal, side, and rear impact). In contrast, Task D was performed frequently in rollover accidents.

Figure 16 graphs the average rescue time, divided into four tasks. For a side impact and a rear impact, the analysis is difficult because of the limited number of samples.

Task D did not require rescue time in front impact and rollover accidents. The average rescue time for Task A was almost equal to that for Task B, about 20 minutes. The average rescue time for Task C was over 30 minutes, and over 60 minutes was required for Task C when the crash involved frontal impact in a cab-over type truck. It is thought that cab-over occupants are frequently trapped in frontal collisions and that performance of Task C is required because this type of vehicle does not have a crushable zone in the front.

Table 2.
Rescue method divided four tasks

Rescue method		Task A	Task B	Task C	Task D	Total
Frontal impact	Bonnet type	11	7	4	1	23
	Cabover type	7	1	7	2	17
Side impact		7	1	2	2	12
Rear impact		4				4
Rollover		3	2	2	16	23
Total		32	11	15	21	79

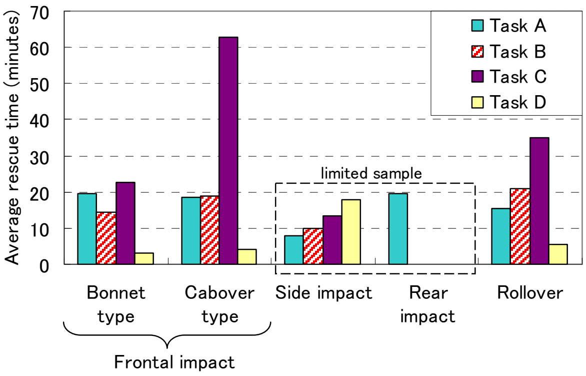


Figure 16. Average rescue time divided into four tasks (rescue case)

ACCIDENT REPRODUCTION AND RESCUE OPERATION OF OCCUPANT DUMMIES

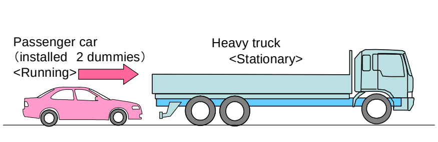
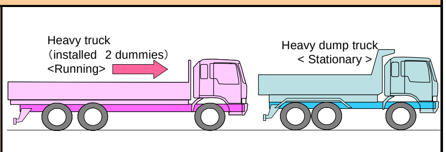
Reproduced accident form

To analyze rescue operations in detail, specific traffic accidents were reproduced by full-scale crash tests, and fire fighters were trained on how to rescue occupants represented by dummies. Two cases were executed. In each case, the vehicles were collided with 100% over-lapped in width.

Case 1 is an accident in which a passenger car collides with the rear of a heavy truck. Adult human dummies (Hybrid-II) were installed in the driver's seat and the passenger's seat of the passenger car. The passenger car was made to collide at a speed assumed to cause it to under-ride the stopped truck. Fire fighters rescued the injured passenger car occupants (two dummies).

Case 2 is an accident in which a heavy truck collides with the back of a heavy dump truck. Two dummies were installed in the frontal-impact truck. The truck was made to collide with a stopped dump truck at a speed at which the occupants were assumed to receive serious injuries. The fire fighters rescued the injured truck occupants (two dummies).

Table 3.
Conditions of reproduced crash test

Case 1		
Accident form		
Vehicle	Object	Opponent
Type	Passenger car	Heavy truck
Rescue	Occupant dummies *2	−
Purpose	Rescue of under−ride accident	
Case 2		
Accident form		
Vehicle	Object	Opponent
Type	Heavy truck	Heavy dump truck
Rescue	Occupant dummies *2	−
Purpose	Rescue of heavy truck occupant at frontal impact	

Current rescue method

Referring to Case 1, the rear under-run protector (RUP) of the heavy truck was deformed in the high-speed collision, though the RUP slightly restrained car under-riding. These rescue operations were conducted by four fire fighters. The fire fighters were easily able to rescue the occupant dummies from the rear door because they could open all doors of the passenger car without pulling the vehicle apart (Figure 17). The rescue time was about six minutes.

Figure 17. Rescue situation of under-ride accident (Case 1)

Though it was unnecessary in this case, fire fighters sometimes perform a rescue after pulling the vehicles apart because the car occupant is trapped by the truck. In Case 1, it took about 24 minutes for the fire fighters to pull the vehicles apart after the occupant dummies had been rescued (Figure 18). The operation of lifting the truck rear end took most of the time.

Therefore, it is necessary to discuss prompt and efficient methods for lifting a truck rear end since it is predicted to take 30 minutes to rescue a trapped occupant.

Figure 18. Rescue situation of pulling apart the vehicles (Case 1)

In Case 2, the cabin of the frontal-impact truck was significantly deformed, and the occupant dummies were trapped in the cabin. Six fire fighters operated in the rescue, working on both sides of the cabin. Figure 19 presents the flow of the rescue operations.

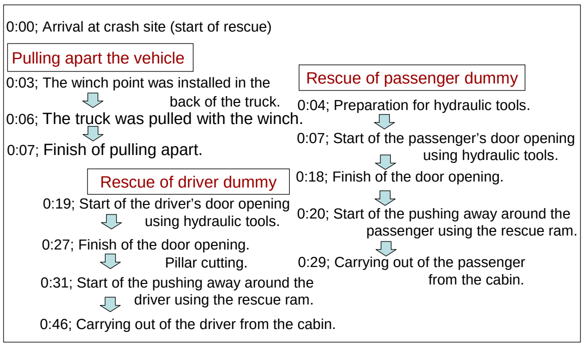


Figure 19. Flow of the rescue operations (case 2)

It took a total of 46 minutes to conduct these rescue operations. The principal problems were thought to be the door-opening and pushing-away operations. A ladder is needed to open the door of the heavy truck (Figure 20). The fire fighters must pay attention to their own movements and to the movement of the door when setting the height point. The process of opening the driver's door might be shortened by acquiring experience with the passenger door.

However, pushing-away operations around the driver took more time because the instrument panel around the driver was complex. Especially, it is important to do this work after looking around the ankles of the injured driver. Relief cutting of the front pillar is effective for pushing away the front end and expanding the space (Figure 21). When the fire fighters carried the occupant out, the supporting rescue ram interfered with the rescue, as the rescuers were inexperienced in using the ram (Figure 22). Because of the high cost, rescue teams (rescue engines) in Japan are rarely equipped with rescue rams, and if equipped, they have only one ram. It takes a long time to push an obstacle away if they have only one ram but it is difficult to equip each rescue team in Japan with two or more rams at once. Therefore, it is important to identify a better rescue method which uses the current rescue gear that rescue teams have.

Current problems and measures discussed of Case 2 are given in Table 4. It is thought that these discussions are necessary to rescue injured occupants from a destroyed cabin safely in the future.

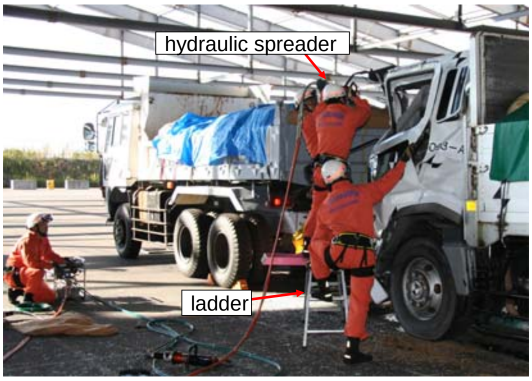


Figure 20. Door-opening operation (Case 2)

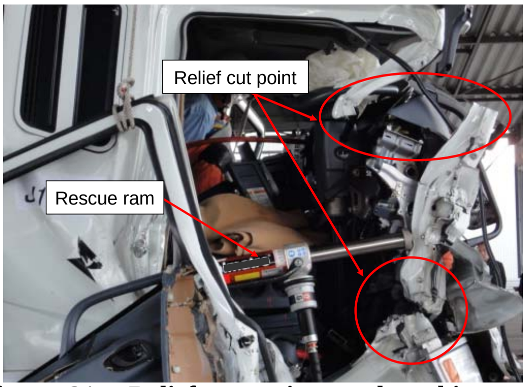


Figure 21. Relief cut points and pushing-away the front end (Case 2)

Figure 22 Rescue of the injured occupant (Case 2)

Table 4.
Current problems and discussed measures of Case 2

Problems	Measures discussed
Safety of rescue worker	Necessity of ladder Fixation of moving parts
Efficient way to remove door	Structural knowledge of door How to use of hydraulic tools (first opening point)
Efficient way to push away the front end	Necessity of relief cut. How to use of rescue ram (fixed point).
How to detach the rescue ram when a injured occupant is transported out of the vehicle	Necessity of splint Structural knowledge of cabin.

Some rescue manuals which specialize in heavy trucks are made in Europe [6] [7]. A working group concerned with truck rescue has been established in Germany, and a more efficient rescue method has been examined. It is also necessary to establish an original rescue method in traffic accidents involving heavy trucks in cooperation with the fire departments in Japan.

CONCLUSION

1) The ratio of fatal/serious injury tends to increase by the time lapse of arrival-accommodation length. The average time after receiving a fatal or serious injury is two minutes longer than that with a minor injury or no injury.
2) Vehicle occupants are often rescued by fire fighters (rescue workers) within five minutes. The average rescue time is about 20 minutes.
3) The rescue of heavy-truck occupants took twice as long as that of passenger-car occupants. Furthermore, frontal-impact accidents of a passenger car with a heavy truck result in a longer rescue time than passenger-car accidents.
4) The most frequent operation was door-opening using hydraulic tools, and the next most frequent was pushing away the front end using hydraulic tools.
5) Rescue operations that result in long rescue times occur when both door-opening and pushing away of the front end using hydraulic tools are needed. Rescuing occupants in accidents involving frontal impact of a cab-over truck requires a particularly long time.
6) The fire fighters could easily rescue occupant dummies in the rescue case of a car under-ride. However, a long rescue time occurred if lifting of the rear end of the truck was needed before the occupant could be removed.
7) The rescue operation took over 30 minutes in a case of truck occupants in a frontal collision. The principal problems were rescue methods of door-opening and pushing-away the front end using hydraulic tools.

We believe that the rescue time of vehicle occupants injured in traffic accidents can be reduced by improving rescue methods, and therefore save lives.

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CRASH PULSE DATA FROM EVENT DATA RECORDERS IN RIGID BARRIER TESTS

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Paper Number 11-0395

ABSTRACT

In recent years, major advances in field data collection and analysis have been achieved through the integration of real-world vehicle crash data captured by on-board, electronic, event data recorders (EDR's). For some time, data has been publicly available from EDR's in General Motors, Ford, and Chrysler vehicles. Recently, Toyota has provided a proprietary tool through which researchers can access EDR's installed in their vehicles. The current study looks at the crash data that are available and explores the accuracy of this information. The study uses a series of staged collisions with EDR-equipped vehicles and compares data downloaded from these devices to equivalent information captured by laboratory instrumentation. Full-frontal crash tests, conducted by Transport Canada, at 48 km/h into a rigid barrier are used. The results show generally good agreement between the two datasets, with some limitations in the EDR-reported data being noted. These comparisons of data obtained from on-board vehicle EDR's, with equivalent information collected using sophisticated laboratory instrumentation, provide a valuable measure of confidence in the use of similar data collected from real-world events.

INTRODUCTION

Event data recorders capture information about the status of various vehicle safety systems, such as seat belt use and air bag deployment; details of pre-crash driver actions such as inputs to the throttle and brake, and the nature of the crash pulse in the form of the vehicle's velocity change and/or acceleration time history. [1]

The objective collision data provided by EDR's have proven useful to a variety of interest groups, including automobile manufacturers, government regulators, safety researchers, law enforcement personnel, vehicle insurers, and the legal community. The data have allowed vehicle safety systems to be refined, vehicle regulations to be enhanced, safety-related defects to be identified and corrected, and have provided the basis for the resolution of court cases and insurance claims. [2]

General Motors Corporation (GM) pioneered the installation of EDR's in its vehicles, and was the first manufacturer to provide access to the data captured by these devices through a publicly-available crash data retrieval (CDR) tool. [3] In 2003, Ford Motor Company was the second manufacturer to adopt the CDR system for its EDR's. Subsequently, in 2008, Chrysler announced its use of the same tool for the EDR's in its vehicles.

Toyota started phasing EDR's into certain of its vehicles in 2001, and all vehicles from the 2007 model year forward are equipped with these devices. [4] While a publicly-available crash data retrieval tool is not yet available for use with Toyota EDR's, the company has provided prototype units to both Transport Canada and the National Highway Traffic Administration (NHTSA). It is one of the units provided to Transport Canada that has been used in the present work.

The study compares crash pulses recorded by EDR's installed in vehicles subject to crash testing to equivalent data captured by the test laboratory's instrumentation. For each test vehicle, the report from the data retrieval tool provides the change in vehicle’s velocity (delta-V) or its acceleration as a function of time. These data are provided in either 1 ms or 10 ms increments. For any given test, the laboratory data consist of the vehicle’s acceleration profile during the crash on a much finer time scale (0.1 ms). Consequently, in order to allow direct and consistent comparisons, the laboratory data have been integrated to provide an equivalent profile of the vehicle’s change in velocity to that produced by the EDR for each GM, Ford and Toyota vehicle. In the case of Chrysler, where only acceleration is recorded, integration of the acceleration data for both the EDR, and the laboratory data, were conducted in order to provide similar comparisons of delta-V.

An additional point of comparison is provided by some of the pre-crash data that are captured by the EDR’s. In particular, the units record the pre-impact vehicle speed. Depending on the manufacturer, and the specific type of EDR, these values are last taken between 0.1 s and 1 s prior to algorithm enable (AE) in the vehicle’s air bag control module. The initial speeds recorded by the EDR’s were compared to equivalent data measured by the laboratory instrumentation.

Similar research conducted on General Motors’ vehicles has been reported previously [5], while other prior work has included both GM and Toyota vehicles. [6,7].

CRASH TEST METHODOLOGY

Data were obtained from a series of staged collisions conducted by Transport Canada that involved vehicles equipped with event data recorders. In particular, full frontal rigid barrier (FFRB) crash tests were performed at a nominal impact speed of 48 km/h.

The instrumentation used for the staged collisions conducted at Transport Canada’s Motor Vehicle Test Centre included accelerometers with a sampling frequency of 10 kHz. The test vehicle was instrumented with several such accelerometers, the most relevant of which, for the present purposes, were units mounted on the floor at the base of the left and right B-pillars, and on the central tunnel, at the vehicle’s centre of gravity. These three accelerometers were in the closest proximity to the original-equipment event data recorders which form part of the air bag control module (ACM) located inside the passenger compartment.

A tape switch mounted on the vehicle’s front bumper was used to establish the time of first contact with the barrier structure. The impact speed of the vehicle was captured by means of an external speed trap.

All the data from the laboratory instrumentation were sampled over 400 ms, and subsequently filtered in accordance with SAE Recommended Practice J221-1. [8] For each test vehicle, the acceleration data were integrated to provide the vehicle’s change in velocity over the crash period.

Figure 1. Full frontal rigid barrier crash test.

Figure 2. Crash tested vehicle.

For General Motors, Ford and Chrysler vehicles, the change in velocity or the acceleration profile recorded by the on-board EDR were retrieved using a Bosch Diagnostics’ Crash Data Retrieval tool. [9].

In the case of Toyota vehicles, the changes in velocity recorded by the on-board EDR's were retrieved using Toyota's Read Out Tool (ROT).

DATA PROCESSING

In processing the data from the EDR's the following manufacturer-specific procedures should be noted:

General Motors

For General Motors' vehicles, the vehicle delta-V is reported at 10 ms intervals. For deployment events, the EDR will record data up to 70 ms before the deployment criteria are met, and up to 220 ms after these criteria are met. Prior to impact, zero values of delta-V are recorded by the EDR. The equivalent laboratory data are synchronized to the actual time of initial impact through a tape switch mounted on the vehicle's front bumper. Consequently, in order to better match the timing sequences between the two datasets, any leading zeros in the delta-V data from the EDR's were discarded. The first non-zero value of delta-V was assigned to t = 10 ms.

Ford

Some Ford EDR's are unique in providing both delta-V and acceleration values at 1 ms intervals from a point approximately 100 ms prior to a nominal time-zero, and subsequently for a further 100 ms. While the downloaded delta-V values were plotted directly on the charts, the acceleration data were used to identify an appropriate time-zero.

Examination of the following figures illustrates the procedure adopted. Figure 3 shows the acceleration pulse recorded by the EDR. The acceleration (black line) initially remains close to zero, after which the onset of the crash pulse is quite apparent. In particular, after remaining between 0 and -1 g for almost 95 ms, the acceleration abruptly goes to -4.00 g at an implied time of t = -6 ms, and subsequently to -9.60 g at t = -5 ms. These specific values were obtained from the tabular EDR data as shown in Figure 4. Consequently, in this instance, a time shift of 7 ms was introduced to process the EDR data.

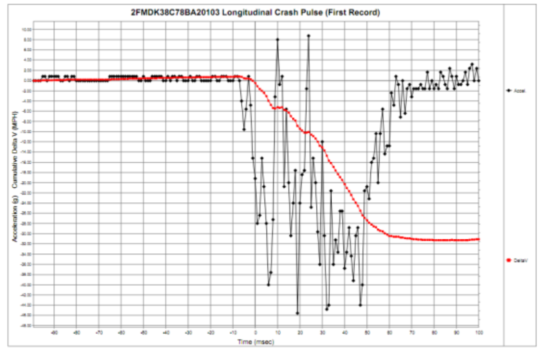

Figure 3. Crash pulse for 2008 Ford Edge (TC08-120).

Time (msec)	Recorded Vehicle Longitudinal Acceleration (g)
-10	0.00
-9	0.80
-8	0.80
-7	0.00
-6	-4.00
-5	-9.60
-4	-5.60
-3	0.80
-2	-4.80
-1	-15.20
0	-19.20
1	-28.00
2	-26.40
3	-15.20
4	-20.80
5	-28.00
6	-40.00
7	-37.60
8	-27.20
9	-3.20
10	8.00

Figure 4. Extract from the acceleration data for Test No. TC08-120.

Toyota

As for General Motors' vehicles, Toyota EDR's also report delta-V in 10 ms increments; however, no leading zeros were observed in any of the EDR readouts from these vehicles. The downloaded Toyota delta-V values were therefore used directly as obtained from the readout tool.

Chrysler

As noted earlier, Chrysler EDR's do not give direct readouts of delta-V, and provide only acceleration data. Two types of modules are employed, one manufactured by TRW Automotive and the other by Continental Corporation [10]. The Continental modules report acceleration over a period of 250 ms following AE. The TRW modules provide vehicle acceleration from approximately 100 ms before a nominal time-zero, and subsequently for a further 150 ms. Consequently, in order to refine time-zero, a similar procedure to that adopted for the Ford EDR's was applied to the TRW modules

RESULTS

In all of the charts that follow, the vehicle's delta-V computed from the accelerometer installed at the vehicle's centre of gravity is annotated in the form TC08_119_CG_DV, where TC08_119 refers to the number assigned to a specific crash test.

Similarly, the delta-V computed from the accelerometer mounted at the left-side B-pillar is designated as TC08_119_LS_DV, and that from the accelerometer mounted at the right-side B-pillar as TC08_119_RS_DV.

The delta-V values obtained from the vehicle's EDR are plotted in the graph annotated in the form TC08_119_EDR_DV.

A similar annotation convention has been adopted for the test results for all of the other vehicle manufacturers.

General Motors Vehicles

Four different General Motors models, namely the 2008 Chevrolet Malibu, the 2009 Pontiac G8 and Wave, and the 2008 Saturn Vue, were crash tested as shown in Table 1.

Table 1. Test Matrix for GM Vehicles

Test No.	Test Vehicle	Test Speed (km/h)
TC08-119	2008 Chevrolet Malibu	47.77
TC09-142	2009 Pontiac G8	47.55
TC09-140	2009 Pontiac Wave	47.70
TC09-213	2009 Pontiac Wave	47.93
TC08-126	2008 Saturn Vue	47.79

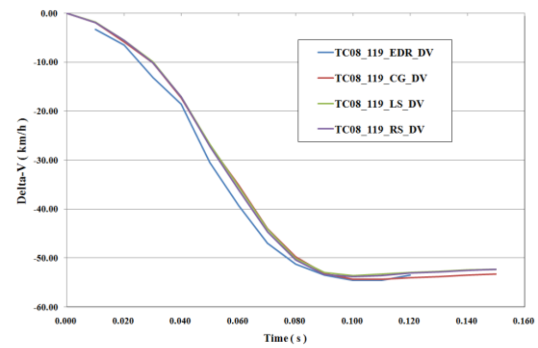

Figure 5. 2008 Chevrolet Malibu (TC08-119).

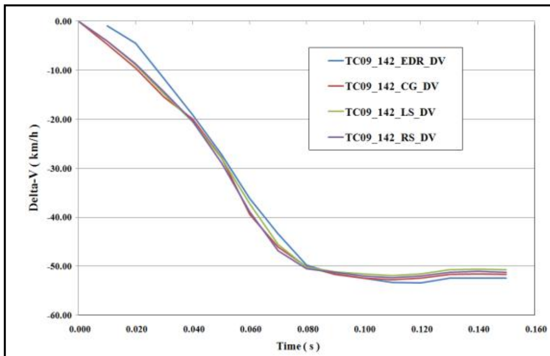

Figure 6. 2009 Pontiac G8 (TC09-142).

Figure 7. 2009 Pontiac G8 (TC09-142).

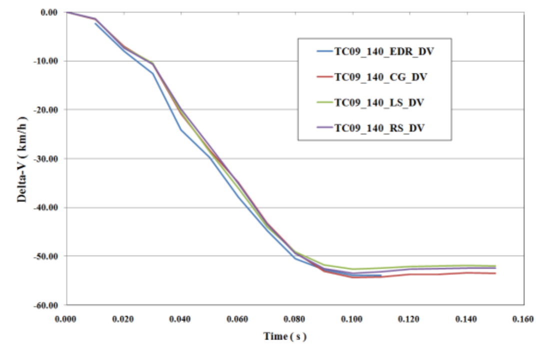

Figure 8. 2009 Pontiac Wave (TC09-140).

Figure 9. 2009 Pontiac Wave (TC09-140).

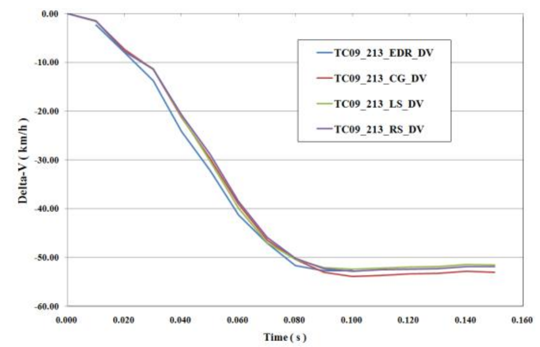

Figure 10. 2009 Pontiac Wave (TC09-213).

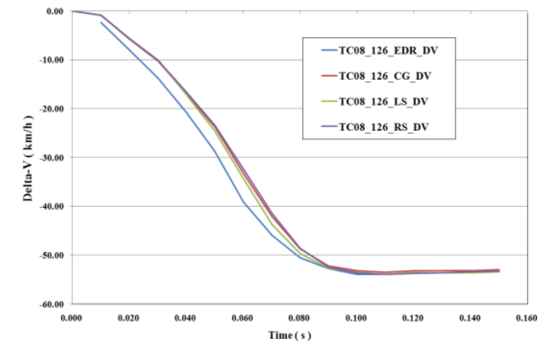

Figure 11. 2008 Saturn Vue (TC08-126).

Ford Vehicles

Three different Ford models were crash tested as shown in Table 2.

Table 2. Test Matrix for Ford Vehicles

Test No.	Test Vehicle	Test Speed (km/h)
TC08-120	2008 Ford Edge	47.88
TC08-121	2008 Ford Focus	47.66
TC09-128	2009 Ford F150	47.84

The resulting delta-V plots are shown in the following figures.

As noted earlier, the delta-V values obtained directly from the vehicle's EDR are annotated in the form TC08_120_EDR_DV.

For the 2008 Ford Edge and Ford Focus, pre-impact acceleration data allowed time-zero to be refined using the procedure noted earlier. In these cases, graphs with annotations similar to TC08_120_ EDR_DV_S have had a time shift introduced into the delta-V data stream.

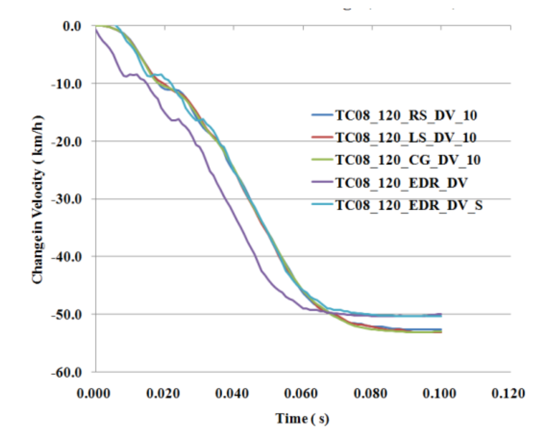

Figure 12. 2008 Ford Edge (TC08-120).

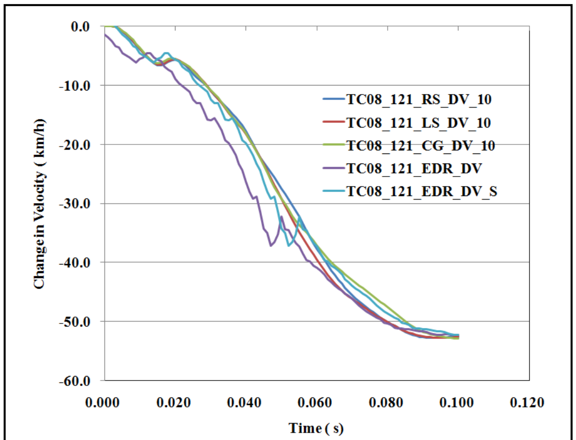

Figure 13. 2008 Ford Focus (TC08-121).

Figure 14. 2008 Ford Focus (TC08-121).

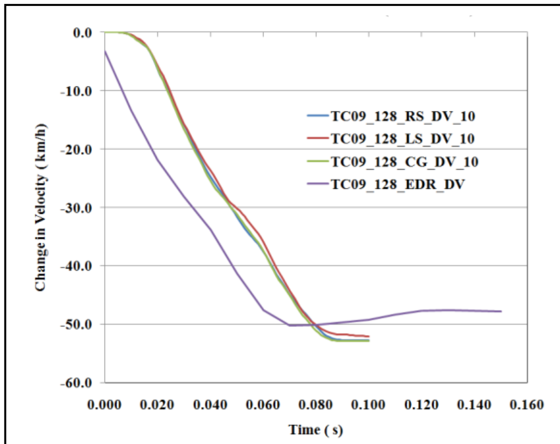

Figure 15. 2009 Ford F-150 (TC09-128).

Toyota Vehicles

Four different Toyota models were crash tested as shown in Table 3.

Table 3. Test Matrix for Toyota Vehicles

Test No.	Test Vehicle	Test Speed (km/h)
TC05-119	2005 Toyota Camry	47.93
TC09-244	2009 Toyota Corolla	47.85
TC10-149	2010 Toyota Corolla	47.97
TC09-145	2009 Toyota Matrix	47.70
TC09-219	2009 Toyota Matrix	48.01
TC09-262	2009 Toyota Matrix XRS	47.91
TC09-146	2009 Toyota Venza	47.96

The resulting delta-V plots are shown in the following figures:

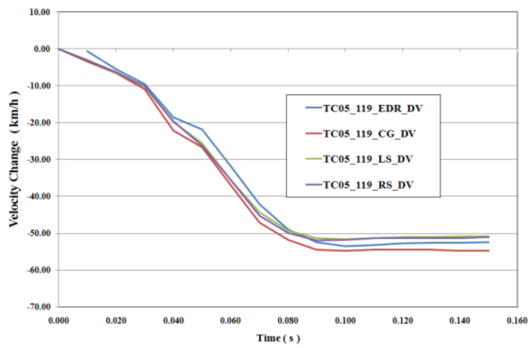

Figure 16 2005 Toyota Camry (TC05-119).

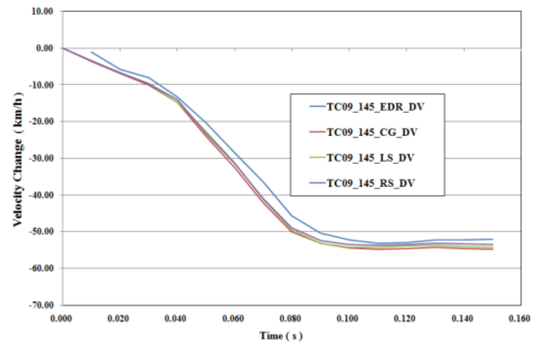

Figure 19. 2009 Toyota Matrix (TC09-145).

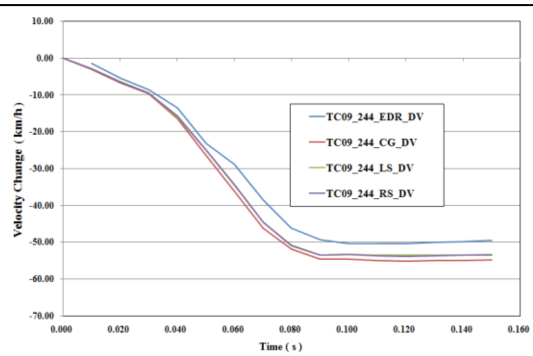

Figure 17. 2009 Toyota Corolla (TC09-244).

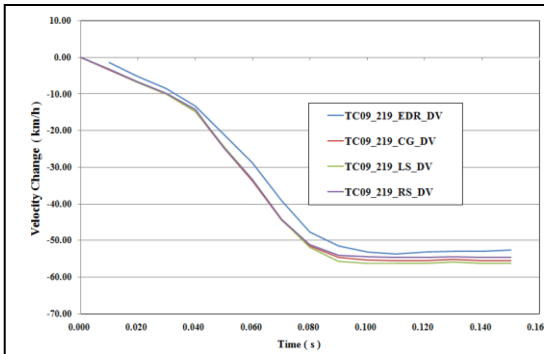

Figure 20. 2009 Toyota Matrix (TC09-219).

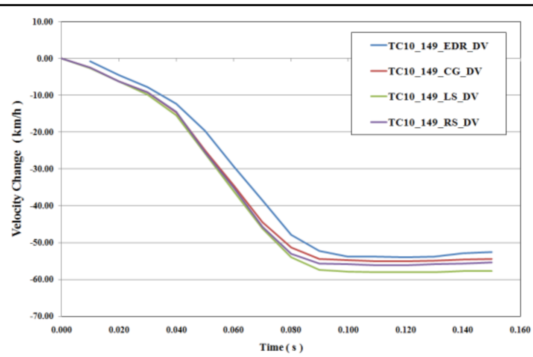

Figure 18. 2010 Toyota Corolla (TC10-149).

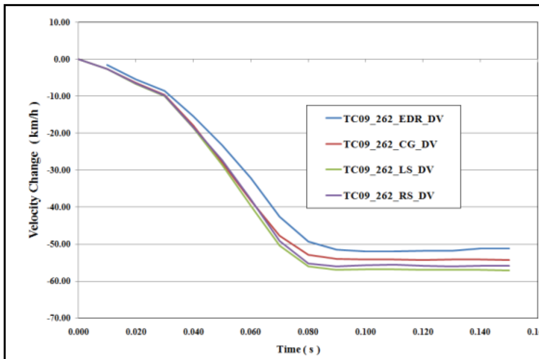

Figure 21. 2009 Toyota Matrix XRS (TC09-262).

Figure 22. 2009 Toyota Venza (TC09-146).

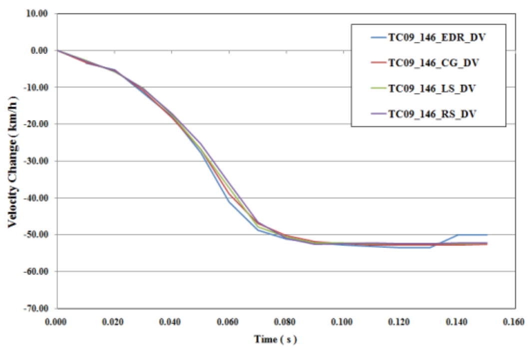

Figure 23. 2009 Toyota Venza (TC09-146).

Chrysler Vehicles

Five different Chrysler models were crash tested as shown in Table 4.

Table 4. Test Matrix for Chrysler Vehicles

Test No.	Test Vehicle	Test Speed (km/h
TC09-126	2009 Dodge Journey	47.90
TC07-218	2007 Jeep Compass	47.84
TC08-131	2008 Dodge Avenger	47.80
TC09-125	2009 Chrysler Aspen	47.69
TC09-127	2009 Dodge Ram	47.66

For the Chrysler vehicles, time shifts were introduced into the delta-V plots in cases where the modules provided pre-impact acceleration data. In the following charts, graphs with annotations such as TC07_218_EDR_DV relate to non-time shifted delta-V data, while TC07_218_EDR_DV _S indicates that a time shift was introduced into the delta-V data stream.

It should be noted that values of delta-V for these vehicles were calculated through integration of the acceleration data stored in the EDR's. The use of a value for time-zero different from that nominally identified by the EDR introduces a number of additional acceleration values into the calculation. The result of adopting such a procedure is, therefore, not only to time shift the curve, but also to change the shape of the curve itself.

The resulting delta-V plots are shown in the following figures.

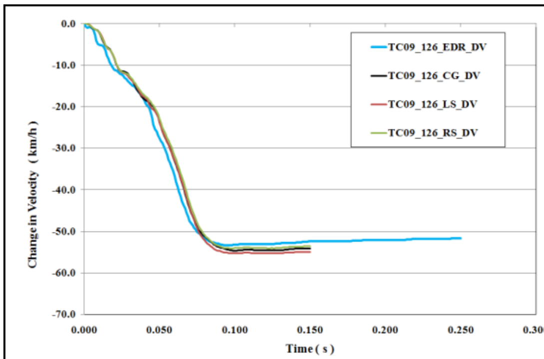

Figure 24. 2009 Dodge Journey (TC09-126).

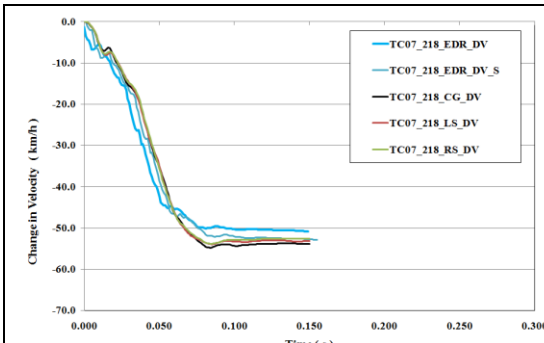

Figure 25. 2007 Jeep Compass (TC07-218).

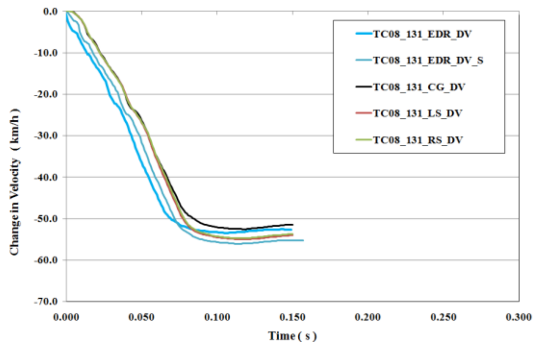

Figure 26. 2008 Dodge Avenger (TC08-131).

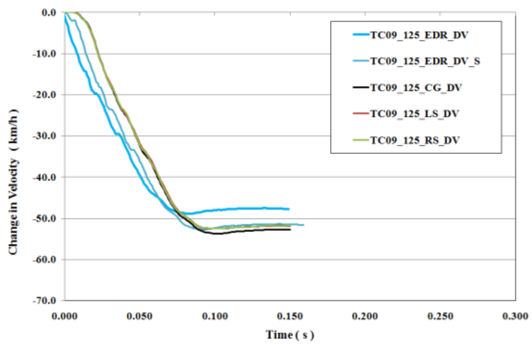

Figure 27. 2009 Chrysler Aspen (TC09-125).

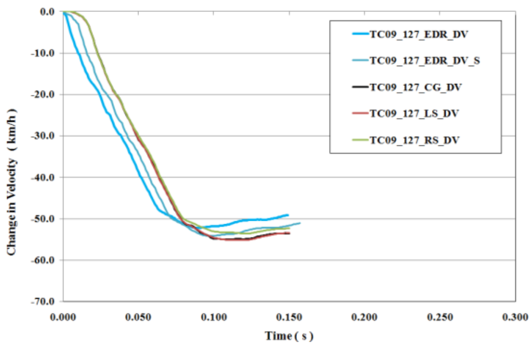

Figure 28. 2009 Dodge Ram (TC09-127).

Figure 29. 2009 Dodge Ram (TC09-127).

DISCUSSION

Comparisons of both the initial vehicle speed and the change in velocity (delta-V) between the values recorded by the EDR's and those measured by laboratory instrumentation are shown for each vehicle tested in Figure 30.

The initial speeds of the test vehicles as obtained from the pre-crash data recorded by the EDR's were generally within 2 km/h (4%) of the values measured by the crash test laboratory's instrumentation.

Delta-V values reported by the EDR's in General Motors' vehicles also closely matched the data captured by the test instrumentation. The graphs of the delta-V profiles obtained from the EDR's and those from all three laboratory accelerometers (Figures 5-6, 8 and 10-11) are all closely aligned. The tabular data shows that the differences in the maximum delta-V's ranged from 0.47 km/h (0.88%) to -1.13 km/h (-2.09%)

For the Ford vehicles tested, the delta-V curves for the EDR data generally matched those developed from the laboratory data (Figures 12, 13 and 15). For Test No. TC08-120 and TC08-121, pre-acceleration data allowed time-zero to be refined. In these cases,

Test No.	Test Vehicle	Test Speed (km/h	Initial Speed			Delta-V			
			EDR (km/h)	Difference (km/h	Difference (%)	Laboratory (km/h)	EDR (km/h)	Difference (km/h	Difference (%)
TC08-119	2008 Chevrolet Malibu	47.77	46.67	-1.10	-2.35	-54.42	-54.52	0.10	0.18
TC09-142	2009 Pontiac G8	47.55	46.67	-0.88	-1.88	-52.90	-53.37	0.47	0.88
TC09-140	2009 Pontiac Wave	47.70	46.67	-1.03	-2.20	-54.44	-53.91	-0.52	-0.96
TC09-213	2009 Pontiac Wave	47.93	46.67	-1.26	-2.70	-53.88	-52.75	-1.13	-2.09
TC08-126	2008 Saturn Vue	47.79	46.67	-1.12	-2.40	-53.55	-53.91	0.37	0.69
			Average	-1.08	-2.31		Average	-0.14	-0.26
TC08-120	2008 Ford Edge	47.88	47.15	-0.73	-1.54	-53.11	-50.37	-2.74	-5.16
TC08-121	2008 Ford Focus	47.66	46.83	-0.83	-1.77	-53.26	-52.29	-0.97	-1.83
TC09-128	2009 Ford F150	47.84	46.03	-1.81	-3.94	-53.09	-50.22	-2.87	-5.41
			Average	-1.11	-2.39		Average	-1.68	-3.16
TC05-119	2005 Toyota Camry	47.93				-55.17	-53.43	-1.74	-3.16
TC09-244	2009 Toyota Corolla	47.85	46	-1.85	-3.87	-55.13	-50.37	-4.75	-8.62
TC10-149	2010 Toyota Corolla	47.97	46	-1.97	-4.11	-55.16	-53.91	-1.24	-2.26
TC09-145	2009 Toyota Matrix	47.70	46	-1.70	-3.56	-54.80	-53.11	-1.69	-3.09
TC09-219	2009 Toyota Matrix	48.01	46	-2.01	-4.19	-55.50	-53.75	-1.75	-3.16
TC09-262	2009 Toyota Matrix XRS	47.91	46	-1.91	-3.99	-54.29	-51.98	-2.31	-4.26
TC09-146	2009 Toyota Venza	47.96	46	-1.96	-4.09	-52.96	-53.43	0.47	0.89
			Average	-1.90	-3.97		Average	-1.86	-3.38
TC09-126	2009 Dodge Journey	47.90	46	-1.90	-3.97	-54.60	-53.34	-1.27	-2.32
TC07-218	2007 Jeep Compass	47.84	47	-0.84	-1.76	-54.73	-52.85	-1.87	-3.42
TC08-131	2008 Dodge Avenger	47.80	48	0.20	0.42	-52.51	-56.11	3.59	6.85
TC09-125	2009 Chrysler Aspen	47.69	47	-0.69	-1.45	-53.71	-52.71	-1.00	-1.86
TC09-127	2009 Dodge Ram	47.66	47	-0.66	-1.38	-55.03	-54.17	-0.87	-1.57
			Average	-0.78	-1.63		Average	-0.28	-0.47

Figure 30. Comparisons of initial speed and delta-V from vehicle EDR's and laboratory instrumentation.

the time-shifted delta-V plots were more closely aligned with those produced from the test centre's accelerometers. No similar accommodation was possible for Test No. TC09-128 since this EDR only provided cumulative delta-V. The maximum values of delta-V from the Ford EDR's that are shown in Figure 30 were extracted directly from the tabular data provided in the data retrieval reports. The differences in these delta-V's and those calculated from the laboratory data ranged between -0.97 km/h (-1.83%) and -2.87 km/h (-5.41 km/h). On average the difference was -1.68 km/h (-3.16%)

The shape and range of the delta-V curves obtained from the EDR's in Toyota vehicles (Figures 16-21 and Figure 23) are in good agreement with the laboratory data. The differences in delta-V for the Toyota vehicles tested ranged from 0.47 km/h (0.89%) to -4.75 km/h (-8.62%). On average the difference was -1.86 km/h (-3.38%).

For the Chrysler vehicles tested, the delta-V curves for the EDR data generally matched those developed from the laboratory data (Figures 24-28). As noted above for Ford vehicles, where pre-acceleration data allowed time-zero to be refined, the time-shifted delta-V plots for the Chrysler vehicles were more closely aligned with those produced from the test centre's accelerometers. As noted earlier, the shapes of the time-shifted delta-V curves for the Chrysler vehicles were also modified as a result of the calculations on a greater number of acceleration values. The values of the maximum delta-V's for the Chrysler vehicles shown in Figure 30 are for the time shifted calculations, i.e. those based on a time-zero identified by examination of the acceleration data captured by the EDR's. The differences in these delta-V's ranged between 3.59 km/h (6.85%) and -1.87 km/h (-3.42%). On average the difference was -0.28 km/h (-0.47%)

CONCLUSIONS

The initial speeds of the test vehicles obtained from the pre-crash data recorded by the EDR's were generally within 2 km/h (4%) of the values measured by the crash test laboratory's instrumentation.

The delta-V curves produced based on the EDR data generally matched those calculated from acceleration data captured by the laboratory instrumentation. In most instances only small differences were noted between the plots developed from the three accelerometers used by the crash test centre.

Some degree of time shifting of the EDR curves was evident in all cases. Where pre-impact acceleration data were available for certain Ford and Chrysler models, the procedure developed to refine time-zero, and to introduce a time shift into the curves, showed a beneficial effect in matching the curves.

For Chrysler vehicles, where it was possible to select a value for time-zero different from that reported by the EDR, a specific set of acceleration values could be identified as being related to the impact. The use of such time-shifted values introduces a number of non-zero acceleration values into the delta-V calculations that would otherwise be excluded. The calculated delta-V's then more closely match the values computed from the laboratory acceleration data than had the non-time shifted data (i.e. based on the EDR's reported t=0) been used. Consequently, it is recommended that end users of EDR data from Chrysler vehicles should examine the acceleration data stream in order to identify the most appropriate value of time-zero, and integrate the vehicle acceleration from this point onwards.

The differences in the maximum delta-V's recorded by the EDR's from all manufacturers were generally under-reported by approximately 2 km/h (3.5%) of those developed from the laboratory data. The maximum observed difference between the delta-V values was 4.75 km/h (8.62%).

Overall, the results from the series of crash tests undertaken in this study, for a number of different vehicle models, indicate that end users of the output from vehicle EDR's involved in real-world crashes can have some confidence in the accuracy of these data. However, since the current study is restricted to full-frontal crashes at a single speed, and noting that bi-axial accelerometers are employed in many vehicles, the specific accuracies noted here may not be generally applicable to all crash modes and speeds.

Past experience has shown that data captured by vehicle EDR's add considerably to the knowledge gained from real-world collisions where the information obtained from these devices through programmes of in-depth investigations is integrated into the analysis and reporting systems.

Comparison of data obtained from on-board vehicle EDR's in tightly-controlled crash test situations, with equivalent information collected using sophisticated laboratory instrumentation, provides a valuable measure of confidence in the use of similar data collected from real-world events.

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The opinions, findings and conclusions expressed in this paper are solely those of the authors and do not necessarily represent the views and/or policies of Transport Canada.

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DROWNING DEATHS IN MOTOR VEHICLE TRAFFIC ACCIDENTS

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ABSTRACT

Very little is known about drowning deaths that occur as the result of motor vehicle traffic accidents. The two research questions addressed in this paper are how frequently do drowning deaths as a result of motor vehicle traffic accidents occur and what are the circumstances surrounding these deaths. The choice of the word "accident" instead of "crash" in this paper is intentional to avoid confusion related to the various source documents that define traffic and transport accidents.

The primary data source for this analysis is the linked Fatality Analysis Reporting System (FARS) – Multiple Cause of Death (MCoD) file that is produced by the National Highway Traffic Safety Administration's (NHTSA) National Center for Statistics and Analysis (NCSA) in collaboration with the Centers for Disease Control (CDC). The years used for the analysis start with 2004 and end with 2007.

From 2004 through 2007, there was an annual average of 384 traffic fatalities in FARS where accidental drowning was listed as one of the causes of death. Note, however, that this number may be slightly lower than the national total because of missing MCoD data from two States (Hawaii and Wisconsin). Also a few fatalities from December 2007 crashes may not have matching mortality data because the death occurred in January 2008.

Drowning fatalities are more common in some States than in others. The top five States, which are all large coastal States, accounted for slightly more than half of the total drowning deaths in the 48 States and D.C. The occupants' motor vehicles included a wide range of body types from passenger cars and pickups to motorcycles. However, the passenger vehicle category, which accounted for 94 percent of the drowning fatalities from 2004 through 2007, is the focus of this paper.

Overall 63 percent of the passenger vehicle drowning fatalities involved a rollover, and 12 percent involved a collision with another motor vehicle. The most common passenger vehicle crash scenario was a single-vehicle rollover accounting for 59 percent of the fatalities. These crashes frequently involved running off the road and colliding with a fixed object prior to the rollover and immersion. In cases with known restraint use, the victim was not using any form of restraint system 52 percent of the time.

Two types of motor vehicle related drowning deaths are not included in FARS based upon the American National Standards Institute's (ANSI) definition of a motor vehicle traffic accident. The first type is a drowning that occurs as the result of a nontraffic accident, which occurs off of public roads. While NHTSA collects information about nontraffic crashes, it does not have the multiple cause of death information to enable a similar analysis. The second type is a drowning as the result of a cataclysm, such as flooding, that is not a motor vehicle accident fatality per ANSI definitions. Including nontraffic and cataclysm cases would lead to a larger number of motor vehicle related drowning fatalities.

INTRODUCTION

Very little is known about drowning deaths in the United States that occur as the result of motor vehicle traffic accidents. While NHTSA's FARS database contains a census of all motor vehicle traffic fatalities, it does not contain the information needed to identify fatalities that resulted from drowning. Therefore not only are the circumstances surrounding these drowning deaths uncertain, the frequency of such deaths is also unknown. The purpose of this paper is to provide answers to both of these research questions by using a powerful dataset containing fatalities in FARS linked to mortality data from the CDC via death certificates.

This paper intentionally uses the term "accident" even though FARS now refers to all accidents as "crashes." One reason is the mortality coding, and the public health field in general, still use the term accident rather than crash. The second reason is that the choice of what to include in FARS, which is discussed in a later section, is based upon the ANSI definition of a "motor vehicle traffic accident." While the choice of accident is meant to avoid confusion related to these source documents, the term accident and crash are synonymous.

DATA AND METHODOLOGY

This paper uses underlying cause of mortality data from the CDC's National Center for Health Statistics (NCHS) that have been linked to the NHTSA's FARS database. The NCHS MCoD data set includes data on all recorded deaths that occur in the United States. Each record includes information from the decedent's death certificate about the underlying cause of death and multiple conditions that contributed to the death. The underlying cause of death may be internal morbid bodily conditions (natural causes) or external conditions such as injury, poisoning, and other adverse effects coded using the World Health Organization's (WHO) International Classification of Diseases, Tenth Revision (ICD-10).

Two sets of codes on conditions considered contributing causes of death are included for each data record in the MCoD files. The original death certificate coding is preserved in one set of codes. A second set of codes, known as record-axis codes, have been edited by NCHS to eliminate contradictions and to define the condition most precisely within the limitations of ICD-10 coding and the available medical information on the death certificate. This paper uses the record-axis coding as well as the ICD-10 underlying cause of death to identify drowning fatalities that resulted from a motor vehicle traffic accident.

Per ICD-10 coding instructions, a drowning death in a motor vehicle traffic accident would have an external cause or mechanism of "transport accident" rather than "accidental drowning and submersion." Drowning would be noted as a consequence of the external cause in one of the record-axes. Thus the external cause and the consequence code used together indicate drowning as the result or consequence of a transport accident. For example, the underlying cause of death may be "car occupant injured in noncollision traffic accident" (V48) or "unspecified motor vehicle traffic accident" (V892). The listed consequence of the accident would be "drowning as the effect of other external causes" (T751) in one of the 15 record-axes.

In some cases, drowning is the only recorded consequence of the motor vehicle traffic accident. In other cases, injuries from the crash are also listed as conditions contributing to the death. For example, a case may list drowning as well as other injuries. Common examples of the other injuries include "unspecified injury of head" (S099), "injury of unspecified body region" (T149), and "unspecified multiple injuries" (T07). This paper counts both situations as motor vehicle traffic drowning deaths.

Finally, in some cases it is not possible to determine whether drowning was involved. These cases include recorded deaths with an external cause but without any listed consequences, such as a motor vehicle traffic accident without any coded injuries, and FARS fatalities that could not be matched to a record in the MCoD file.

The years selected for this paper include linked FARS and MCoD data from 2004 through 2007. The beginning year of 2004 corresponds to the first year that FARS recorded the sequence of crash events for each vehicle that is used later in this paper. The end year of 2007 corresponds to the most currently available linked MCoD file. The analysis focuses only on occupants of motor vehicles and thus excludes nonoccupants such as pedestrians or bicyclists.

RESULTS

Drowning deaths based upon ICD-10 codes

Table 1 contains the annual average deaths in the linked FARS-MCoD 2004 through 2007 files by external cause and whether drowning was recorded as a contributing condition. The results indicate an annual average of 384 motor vehicle occupant traffic fatalities involved drowning, which is the sum of the three lines in Table 1 indicating a drowning. This average is 1 percent of all motor vehicle occupant fatalities where it was known whether drowning was involved, which is calculated by dividing the 384 cases of drowning by the sum of all cases with drowning involvement known as either yes or no (35,242).

Most of the fatalities indicate the expected coding of a transport accident with drowning as one of the consequences. The cases with drowning as the external cause also had an external cause of transport accident listed in the conditions contributing to the death. The cases without an external cause indicate that the underlying cause of death was an internal morbid bodily condition such as a disease of the nervous or circulatory system. However, since the drowning was listed as a contributing condition, this situation is included here for completeness.

Table 1.
Motor vehicle traffic fatalities
by external cause and resulting injuries

External Cause	Drowning?	Annual Average
Transport	Yes	381
Transport	No	34,585
Transport	Unknown	106
Drowning	Yes	<1
Other	No	23
None	Yes	2
None	No	251
None	Unknown	71
Unknown	Unknown	1,527
TOTAL		36,946

Note: Drowning fatalities shaded in table.

Table 1 also shows that for about 5 percent of the fatalities it is not possible to determine whether the person drowned. In some cases the mortality data does not contain any injuries related to an external cause. More frequently, however, there is no mortality data linked to the FARS fatality. The linked FARS-MCoD file does not contain any mortality data from Hawaii or Wisconsin, and it lacks mortality data from New Jersey for 2007. It is also the case that some fatalities associated with crashes in December 2007 may not have mortality data because the death occurred in January 2008. The percent of FARS occupant fatalities for which drowning could not be determined ranged from 3 percent in 2006 to 8 percent in 2004. Therefore, all of the counts in this report represent most of the deaths from 48 States and the District of Columbia. National totals, however, would likely be larger by about 5 percent.

Comparing drowning deaths to FARS immersions

FARS does not have a code to indicate drowning, which is why drowning deaths were identified using the linked FARS-MCoD file. However, since 2004 FARS has included a set of variables that capture the events in the crash related to each vehicle. The FARS analysts are instructed to include both collision and non-collision events regardless of injury or property damage for each vehicle in the order that the events occurred. One of the possible events is "immersion," meaning immersed in a body of water.

The maximum number of events that can be listed for each vehicle is six. If immersion is one of the six listed events, then the vehicle is categorized as an "immersion" for this paper. If there are five or less events and immersion is not one of the events, then the vehicle is not an immersion case. Finally, if there are six events and immersion is not one of them, then immersion status is unknown because it could have occurred as a seventh or later event. This special case, which affects less than 100 fatalities per year, is treated as unknown even though it is possible that there were exactly six events and none of them were drowning.

Note also that immersion is a vehicle-level variable meant to provide information about the vehicle. It does not directly tell us about drowning deaths because some or all of the occupants of the immersed vehicle may have survived and fatally injured occupants could have died of crash injuries rather than drowning. However, there is interest in knowing whether fatally injured occupants in immersed vehicles are all or mostly drowning deaths. If there is close correspondence between fatally injured occupants of immersed vehicles and drowning deaths, then immersion could be considered a proxy for drowning deaths.

Table 2 shows the correspondence between whether immersion was included in the sequence of vehicle events and whether a drowning death occurred within the vehicle. The 384 drowning fatalities from Table 1 occurred in 339 vehicles. Overall Table 2 demonstrates that immersion is not a good predictor of whether the occupant fatalities involved drowning. Of the 332 vehicles with an immersion status of "yes" or "no" and a drowning death in the vehicle, immersion was included in the sequence of events only 61 percent (203/332) of the time. Among the 384 vehicles where immersion was recorded in the sequence of events including both vehicles with and without a drowning death, only 53 percent (203/384) had a known drowning fatality.

Table 2.
Immersed vehicles by whether an occupant
of the vehicle drowned

Immersion in Sequence of Events?	Annual Average with Drowning Death	Annual Average without Drowning Death	TOTAL
Yes	203	181	384
No	129	31,555	31,684
Unknown	7	1,524	1,531
TOTAL	339	33,260	33,599

Immersed vehicles without a drowning death could be situations where the occupants died of injuries other than drowning. Drowning deaths where the sequence of events did not include immersion are more difficult to explain. One possibility is that the police accident report did not indicate immersion, which is why the FARS analyst did not record immersion, but an exploration of source documents is needed to provide a more definitive explanation for the difference.

Drowning fatalities by crash and vehicle characteristics

As expected, drowning fatalities are more common in some States than in others. In fact, the top five States accounted for slightly more than half of the total drowning deaths in 48 States and D.C. Table 3 contains the five States with the most recorded motor vehicle traffic deaths involving drowning.

Table 3.
States with the largest number of motor vehicle occupant traffic drowning fatalities

State	Fatalities
Florida	57
California	49
Texas	31
Louisiana	19
North Carolina	15

Note: No data for Hawaii and Wisconsin.

Generally Table 3 contains large coastal States. Given that these States are large and have many traffic accidents, another way to rank the States is by the percent of the traffic fatalities in the State that involve drowning. The results for the top five States by percent of fatalities involving drowning are included in Table 4.

Table 4.
States with the highest percent of motor vehicle occupant traffic fatalities involving drowning

State	Percent of Fatalities Involving Drowning
Idaho	3.5%
Vermont	2.9%
Alaska	2.8%
Louisiana	2.2%
Florida	2.1%

Note: No data for Hawaii and Wisconsin. Percent is based on fatalities with mortality data.

By the measure used in Table 4, Florida and Louisiana remain in the top five, but three different States also join the list. The top three States all have a relatively small number of total traffic fatalities, and their inclusion at the top of the list could be due to the percent being more sensitive to random variation in the number of drowning fatalities.

Table 5 indicates that the body types of the occupants' motor vehicles included a wide range of vehicles from passenger cars and pickups to motorcycles. However, the passenger vehicle category, which includes cars, utility vehicles, and most vans and pickups, accounted for 94 percent of the drowning fatalities and 94 percent of the vehicles involved in drowning. Given that drowning fatalities in non-passenger vehicles were relatively rare compared to passenger vehicles and because the crash dynamics and injury mechanisms are likely to be very different for non-passenger vehicles, the remainder of this paper focuses on the annual average of 361 drowning fatalities in passenger vehicle traffic crashes.

Table 5.
Motor vehicles where an occupant of the vehicle drowned

Vehicle Type	Annual Average Vehicles	Annual Average Drowning Fatalities
Passenger Vehicles		
Passenger car	181	206
Utility vehicle	51	65
Van	13	15
Pickup truck	72	75
Other Vehicles		
Bus	1	1
Large truck	7	7
Motorcycle	9	9
Other (ATV, etc.)	4	4
Unknown	2	2
TOTAL	339	384

Table 6 contains the passenger vehicle drowning fatalities categorized in terms of the number of vehicles involved in the crash and rollover occurrence. Table 7 contains information about the first harmful event for the single-vehicle crashes. Overall, 71 percent of the fatalities involved either a rollover or a collision with another motor vehicle: 59 percent in single-vehicle rollovers, 8 percent in a collision with another motor vehicle without a rollover, and another 4 percent in a collision with another motor vehicle and a rollover.

Table 6.
Passenger vehicle drowning fatalities by number of vehicles in crash and rollover

Number of Vehicles	Rollover?	Annual Average Drowning Fatalities	Percent of Total
1	No	106	29%
1	Yes	214	59%
>1	No	29	8%
>1	Yes	12	4%
TOTAL		361	100%

Table 7.
Passenger vehicle drowning fatalities in single vehicle crashes by rollover and first harmful event

Rollover?	First Harmful Event	Annual Average Drowning Fatalities	Percent of Subtotal
Yes	Rollover	73	34%
Yes	Fixed Object	132	62%
Yes	Other	9	4%
Subtotal		214	100%
No	Immersion	26	24%
No	Fixed Object	73	69%
No	Other	7	7%
Subtotal		106	100%

Single-vehicle rollovers that result in drowning deaths began the crash sequence by running off the road or crossing the median or centerline 90 percent of the time. As indicated in Table 7, the first harmful event was a collision with a fixed object for 62 percent of the fatalities, most commonly a bridge rail, a guard rail, or a tree. In another 34 percent of the fatalities, the rollover was recorded as the first harmful event. Immersion was recorded as the most harmful event for 47 percent of the fatalities, and the rollover was recorded as the most harmful event in another 43 percent. Most of the remaining fatalities recorded a fixed object collision, most commonly a tree or bridge rail, as the most harmful event.

The second most common scenario in Table 6, accounting for 29 percent of the fatalities, was a single-vehicle crash without a rollover. Similar to the single-vehicle rollover, the first event in most of these fatalities (76%) was running off the road or crossing the median or center line. As indicated in Table 7, the first harmful event was a fixed object collision in 69 percent of the fatalities, most commonly with a tree, a guard rail or a curb. Immersion was recorded as the first harmful event in only 24 percent of the fatalities. The most harmful event was recorded as immersion in 69 percent of the fatalities, and the remaining fatalities were mostly in fixed object collisions, with trees alone accounting for 9 percent of the deaths.

The remaining 12 percent of the drowning fatalities occurred in more complicated situations involving more than one more vehicle. The first event in 67 percent of these fatalities was a collision with a vehicle in transport and another 25 percent involving crossing the median or centerline. In 90 percent of the fatalities, the collision with another motor vehicle in transport was the first harmful event, and the collision was the most harmful event in 69 percent of the deaths. The remaining most harmful events associated with the fatality were mostly immersion (19%) and rollover (7%).

While the previous tables addressed the circumstances surrounding drowning fatalities, they did not provide any information about the other occupants. Situations where the vehicle contained one occupant and the occupant drowned do not provide any information regarding other occupants. However, situations with more than one occupant provide variation for analysis because some occupants may have survived and some may have died of injuries other than drowning. Among vehicles with more than one occupant and at least one drowning death, about half (58%) of the vehicles had exactly two occupants. The maximum number of occupants in any one vehicle was 17. Table 8 gives counts of the total number of occupants, the total number of fatalities, and the total number of drowning fatalities for all passenger vehicles with at least one drowning fatality and at least two occupants.

Table 8.
Fatality outcome for occupants of passenger vehicles with at least one drowning fatality and at least two occupants

Number of Vehicles	Roll-over?	All Occu-pants	All Fatalities	Drowning Fatalities
1	No	149	101	44
1	Yes	376	221	101
>1	No	68	49	15
>1	Yes	26	16	7
TOTAL		619	387	167

Overall 37 percent of the occupants in passenger vehicles with at least one drowning fatality and at least two occupants survived the crash, which is calculated as the number of surviving occupants (619 minus 387 or 232) divided by the total number of occupants (619). The percent of surviving occupants ranged from 28 percent in multi-vehicle non-rollover crashes to 41 percent for single-vehicle rollovers. Table 8 also indicates that more than half of the fatalities (57%) in these vehicles were not drowning fatalities, which is calculated as the number of non-drowning fatalities (387 minus 167 or 220) divided by the total number of fatalities (387). The percent of fatalities that were not drowning fatalities ranged from 54 percent in single-vehicle rollovers to 69 percent for multi-vehicle non-rollover crashes.

Characteristics of drowning victims

While the preceding results concentrated on the crash and vehicle characteristics, this last section describes the characteristics of the annual average of 361 passenger vehicle drowning victims. In describing these traits, percentages are presented among those with known values. The characteristics of victim age, gender, seating position and ejection status were known for 96 percent or more of the cases. Police-reported restraint system use and alcohol involvement had smaller percentages of known values at 84 percent and 48 percent respectively.

Overall, 6 percent of the drowning victims were children 14 and younger, and 2.5 percent were children three and younger. Another 5 percent of the drowning victims were 75 years old or older. Males accounted for 65 percent of the victims. When seating position was known, 90 percent were in the front row. Among those with known ejection status, 14 percent were ejected: 10 percent totally and 4 percent partially ejected.

Table 9.
Key Characteristics of Drowning Victims among Fatalities with Known Values

Characteristic	Statistic
Age	6% Children 14 & under
Age	5% Adults 75 & over
Gender	65% Male
Seating Position	90% Front row
Ejection Status	10% Totally ejected
Police-reported restraint use	52% Not Using Any Restraint System
Police-reported alcohol use	44% Police-Reported Alcohol Use

Police-reported restraint system use was known for 84 percent of the drowning victims, and 52 percent of those with known restraint use were not using any restraint system. More than half the time, police-reported alcohol involvement for the occupant was either unknown or not stated on the police report. However, for the cases with known values, the police reported that alcohol was involved in 44 percent of the fatalities. Note that police-reported alcohol use only indicates the police officer's judgment as to whether alcohol was involved in the accident, and it is not based upon an alcohol test. It is only meant to provide an indication of the involvement of alcohol, and a more accurate estimate of alcohol involvement could be produced using model-based multiple imputation.

LIMITATIONS

As discussed previously, the linked FARS-MCoD file does not contain mortality data from two States (Hawaii and Wisconsin) and is missing one year of data from New Jersey. This missing mortality data means that the results represent 48 States and the District of Columbia rather than the entire United States. Also there is a small proportion of fatalities in each State (usually less than 5 percent) that do not link to the mortality data and thus drowning status is unknown.

In addition to missing data, there are two types of motor-vehicle related drowning deaths that are not considered in this paper. FARS contains only motor vehicle traffic accident fatalities as defined by the American National Standards Institute's "Manual on Classification of Motor Vehicle Traffic Accidents, Seventh Edition" (ANSI D16.1-2007). The two situations under which motor vehicle occupant drowning deaths may occur that would not be included in FARS are nontraffic accidents and cataclysms.

Nontraffic accidents occur off of public roads in locations such as private roads, driveways, parking lots and undeveloped areas. One example of a nontraffic fatality involving drowning could occur at a private boat ramp where the vehicle accidently backs into the water and the occupant drowns. NHTSA recently started tracking nontraffic fatalities as part of its Not-in-Traffic Surveillance (NiTS). The NiTS 2007 system provided information about an estimated 545 occupant fatalities that occurred in nontraffic crashes such as single-vehicle crashes on private roads and two-vehicle crashes in parking facilities. Unfortunately, the system does not have any linked mortality data, which prevents a similar analysis to the one for traffic fatalities using FARS. Furthermore, while the file contains a most harmful event of immersion, the results previously presented in this paper indicate that this variable does not provide a good proxy for counting drowning deaths.

The second type not included in FARS is a drowning as the result of a cataclysm, such as flooding, that is not a motor vehicle accident fatality per ANSI definitions. For example, a motor vehicle swept away while a bridge it was crossing is washed out during a hurricane or flood would not qualify for FARS because the accident directly resulted from a cataclysm. Therefore cases of people who drowned in their vehicles during a flood or a hurricane would not be included in the statistics in this paper. However, accidents related to a cataclysm, but occurring after the cataclysm has ended, can be traffic accidents and could qualify for FARS. For example, a motor vehicle driven into water after a hurricane or flood because a bridge was washed out occur after the cataclysm has ended, and associated occupant drowning fatalities could qualify for FARS.

CONCLUSIONS

In spite of the limitations presented above, this paper provides answers to the two original research questions regarding how many drowning fatalities occur in motor vehicle traffic accidents and under what circumstances. Overall, drowning is associated with an annual average of 381 occupant fatalities in motor vehicle traffic accidents from 2004 through 2007 or about 1 percent of all occupant traffic fatalities during this period.

Focusing on the 361 passenger vehicle occupant drowning fatalities indicated that the most common crash scenario was a single-vehicle rollover. In fact, most (63%) drowning fatalities occurred in a vehicle that overturned when counting both single and multi-vehicle crashes. This statistic is important because rollovers are more dangerous crash scenarios than non-rollovers regardless of immersion status. Based upon passenger vehicle fatalities in the 2009 FARS and estimated passenger vehicle occupants from the National Automotive Sampling System-General Estimates System (NASS-GES), the estimated odds ratio of a fatality in a rollover versus a non-rollover is 29. Also, many drowning fatalities involved fixed object collisions or even collisions with another motor vehicle before entering the water. Therefore, most vehicles experienced some form of damage, and the occupants may have suffered injuries, before the immersion. Even when the drowning death involved a single vehicle that did not overturn, most fatalities (76%) occurred in vehicles that experienced a harmful event prior to immersion.

Overall, the victim was not using any form of restraint system 52 percent of the time. This statistic is important because restraint use is highly effective in preventing fatalities. In 2009, the use of seat belts in passenger vehicles saved an estimated 12,713 lives. Seat belts have saved over 72,000 lives during the 5-year period from 2005 through 2009. Given the effectiveness of seat belts in preventing fatalities in passenger vehicle crashes, the lack of restraint use greatly increases the odds of a fatality in a crash compared to using a seat belt. It is also likely that an unrestrained occupant in a rollover or collision with another motor vehicle would suffer injuries before the immersion.

While the paper provides information to address the original research questions, it leads to an additional query. It is not clear why many of the drowning deaths identified in the mortality data did not have immersion in the FARS sequence of events. Answering this question would require a special study of the FARS source documents to better understand how immersion is captured (or not captured) on police accident reports, and NCSA is currently exploring the feasibility of obtaining the police reports through FARS. The answer to this question, as well as drowning deaths in general, are important and deserving of further study.

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Introduction and Initial Analysis of New Side Impact Variables Captured in NHTSA Crash Databases

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ABSTRACT

Long-term data systems typically need to evolve to keep pace with changing elements in the data environment. The crash data systems developed and maintained by the National Highway Traffic Safety Administration (NHTSA) are not immune to such demands. Changes in the system may be driven by known fleet changes such as the need to expand air bag definitions when additional side and knee air bags were introduced into the fleet several years ago. Changes in the data capture may also arise from issues discovered during research. Prior to the 2008 data year NHTSA crash data systems lacked coding that would identify possible compatibility issues related to side impact configurations.

Beginning in 2008, NHTSA adopted new investigation protocols and data elements to improve the documentation of the aspects of a crash that aid in identifying compatibility issues and bear on the resolution of injury causation scenarios that occur in multivehicle crashes involving the interaction of the frontal-plane of one collision partner with the side-plane of the passenger compartment of the other. The new variables include damage measurements that are designed to enhance the research with respect to door intrusions, by documenting external damage to structures indicating the extent of override/underride in crashes where vehicle compatibility maybe an issue. This paper will review the case data that has been amassed in the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and the Crash Investigation Research and Engineering Network (CIREN) programs for side impact cases where the new techniques and data have been captured. Utilizing the data sets from NASS 2008 in conjunction with CIREN data (2008-10) 524 cases were extracted that indicated capture of the new variables.

This paper will explore the development of a correlation between the new side impact variables collected in NASS-CDS and CIREN and crash severity. The new side impact variables are expected to perform as desired by indicating crash severity and potential for injury causation. The new variables cover a wide array of issues related to side impact crashes. Issues related to compatibility between struck and striking vehicles can be better assessed. The role of door intrusion relevant to pillar and rocker involvement can be pursued as well as using the variables as another metric for crash severity. Do the new side impact variables captured in the NASS-CDS and CIREN aid in the identification of compatibility issues and severity of side impact crashes?

This study was limited to the first year of NASS data and two years of CIREN data collection on the new variables. This paper describes new variables available to research crashes involving the frontal plane of one vehicle and the side plane of the struck vehicle.

INTRODUCTION

The subject of vehicle compatibility related to crashes is not a new research subject. However, a majority of the work to date has focused on frontal impacts. When larger, heavier vehicles impact smaller vehicles in the side plane, the higher front bumper frequently overrides the sill of smaller cars [IIHS, 2005]. The Insurance Institute for Highway Safety (IIHS) has established a side impact vehicle test that attempts to recreate the compatibility issues of mass and geometry. The IIHS side-impact test utilizes a moveable deformable barrier (MDB) that is designed to be taller and heavier than a typical passenger car. The MDB is designed to mimic the size and shape of a larger and heavier sport utility vehicle (SUV) [IIHS, 2008]. This type of rigorous testing keeps automotive manufacturers endeavoring to find new ways to improve the performance of their products and protect occupants. There is a statistically significant higher risk of a serious injury for the driver of a passenger car when struck on the nearside by a larger utility vehicle. The risk is 50% higher when the larger vehicle is a minivan and three times higher when the larger vehicle is a standard pick-up truck [Austin, 2005].

The laboratory continues to be a good venue for exploring the performance of vehicles in crashes, but performance in the real-world must also be examined. Not only must real-world crash performance be studied, it must be measured in a robust manner that returns valid and applicable data in order to support successful research. The data captured from real-world crashes must be continuously screened to ensure it is properly classifying and adequately describing the crash event(s). The entire crash, including the environment, vehicle(s), impact(s), and injury outcome, must be captured and recorded appropriately.

NHTSA developed new variables and protocols to better measure and describe impact damage severity when the frontal plane of one vehicle interacts with the side plane of another vehicle. The design of the new variables needed to be both appropriate for applicable research and feasible from a crash investigation point-of-view.

METHODS

The purpose of this paper is to introduce the new variables collected by NHTSA and also to conduct some initial analysis utilizing the new variables. This process will require a review of the definitions and methods for the new variables, which will be based on the NASS-CDS Coding Manual [NHTSA, 2009]. The analytical portion of this paper will be based on data extracted from the NASS-CDS and CIREN data repositories.

The NASS-CDS Coding Manual is a complete and thorough data manual on all the variables collected in the NASS-CDS system. The same manual applies to the Special Crash Investigation program (SCI) and the crash investigations performed by CIREN. The 2010 manual is over 1,200 pages in length, and contains a section for each variable captured, its attributes, technique for capture, SAS and ORACLE field name and also the name of the data table where the variable is stored. The process, procedure and definitions for the new side impact variables will be presented in summarized form, and the reader is asked to refer to the NASS-CDS manual for more information.

The extracted data was queried from both the NASS-CDS and CIREN repositories as of December 2010. The NASS-CDS data was queried for the initial year of new side impact variable availability, calendar year 2008. The CIREN data query covered all applicable cases up to the current year (2010) if the case had undergone multidisciplinary review and initial quality control. The exact inclusion and exclusion criteria will be discussed as part of the new variable review.

SIDE IMPACT DEFINITION

Since the new variables were designed for a certain type of side impact crash, it was necessary to properly define such crashes within the context of the current NASS-CDS investigation process and data architecture. At the highest level of the definition, the requirement for inclusion is that the crash must involve the case vehicle being struck in the right or left side plane by the frontal plane of another vehicle. The additional crash variables are collected only on the vehicle with side-plane damage. The next step of the inclusion requires use of the Collision Deformation Classification (CDC) [SAE, 1980]. The CDC is a uniform method used to document external sheet metal damage to a light passenger vehicle (see Figure 1). This classification is a fundamental variable in the NASS-CDS and CIREN crash investigation process. The next step in the definition utilizes the CDC to narrow the crash types down to only those impacts with direct damage to the occupant compartment by the striking vehicle. The direct damage in the side plane of the case vehicle must be in a zone classified by the CDC to include the passenger area or "P-zone" (see Figure 1). The zones included in the definition are D, P, Y and Z. Collection of the new variables in NASS-CDS, CIREN and SCI will only be conducted for vehicles meeting this definition.

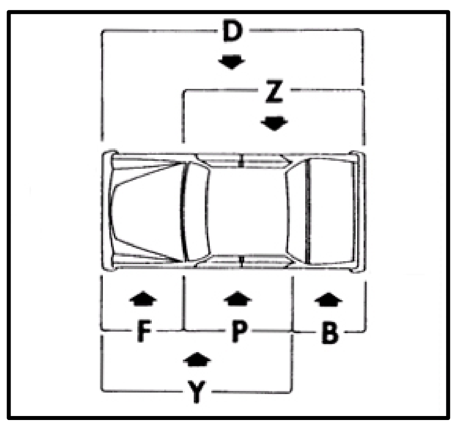

Figure 1: CDC zones for side impact crashes

NEW SIDE-IMPACT VARIABLES

To keep the task of collecting the new information manageable from a field investigation stand point, only four new variables were created. The new variables are Sill Height, Direct Damage to Pillars, Height of Max Door Crush and Door Sill Differential (DSD).

Sill Height: Sill height is a vertical measurement from the ground to the seam at the bottom edge of the door skin. This measurement should be taken at the B-pillar or as close as possible. Case vehicle inspection is the preferred source for this measurement. An exemplar vehicle or manufacturer specifications may be used if case vehicle inspection is not possible. Vehicles that have post-manufacturer modifications that affect the sill height, such as oversized tires, should not be measured and exemplar vehicles or manufacturer specifications are not substituted [NHTSA, 2009]. This variable aids in determining the structural geometry of the case vehicle. Figure 2 shows an example of sill height measurement.

Figure 2: Sill height measurement

Direct Damage to Pillar(s): This variable records the vehicle side pillar(s) that sustained direct damage from the impact of the striking vehicle. The variable is assessed visually by the crash investigator at the time of vehicle inspection [NHTSA, 2009]. This variable is intended to convey the extent of engagement the stiff vertical side structures of the case vehicle experienced.

Height of Max Door Crush: This is a vertical measurement from the ground to the area of maximum crush sustained in the "P-zone" [NHTSA, 2009]. This variable was designed to give researchers an indication of the frontal plane geometry of the impacting vehicle relative to the side plane geometry of the struck vehicle. The variable also allows researchers to analyze door structure damage (see Figure 3).

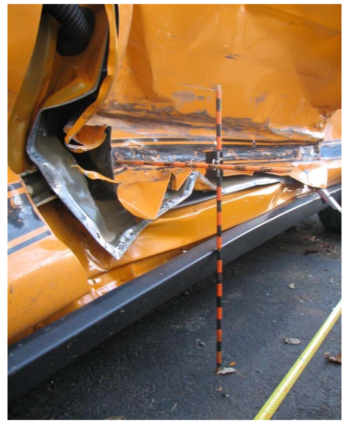

Figure 3: Height of Max Door Crush

Door Sill Differential (DSD): This variable is a post-crash lateral measurement of the difference between the sill or rocker panel level and the maximum crush in the "P-zone" [NHTSA, 2009]. This variable was designed to indicate the uniformity of crush in the side plane in the vertical direction of the case vehicle. A positive measurement indicates that the door has been crushed inboard beyond the outside edge of the sill or rocker panel. The DSD also serves as an indicator of override of the striking vehicle into the passenger compartment of the case vehicle (see Figures 4-6).

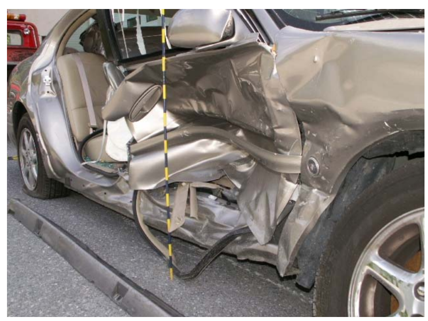

Figure 4: Door Sill Differential measurement

Figure 5: Uniform crush with a zero value for DSD

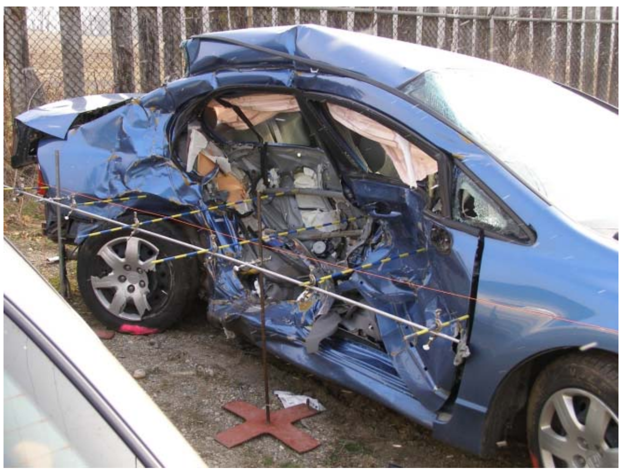

Figure 6: Vehicle exhibiting a large DSD

All of the new variables were designed to be easily integrated into the current NASS-CDS field investigation process.

RESULTS

The initial data extract captured 524 vehicles that were suitable for the analysis of the new side impact variables. The total occupant count for these vehicles was 702. After initial review of the data, seven vehicles were identified that needed to be removed from the dataset. One vehicle had the new side impact variables completed, but had been involved in a lateral crash with a tree. Another vehicle was removed due to being measured with oversized tires in place. The remaining five vehicles were removed due to recorded DSD appearing grossly in error when compared to images of the vehicle. The final data extract captured 517 case vehicles and 695 occupants. The model year breakdown of the case vehicles indicated in Figure 7, shows over seventy-five percent of the captured group were 1998 or newer.

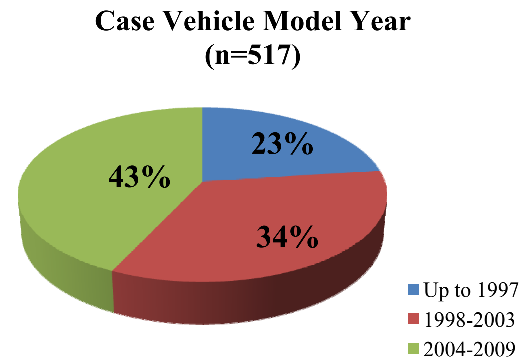

Figure 7: Case vehicle model year breakdown

For the purposes of this paper, the twelve different vehicle class categories utilized by NASS-CDS in this dataset were merged into three simpler categories. The revised classifications are passenger vehicles (PC), compact utility vehicles (CLTV) and large utility vehicles (LLTV). The details of the vehicle class merging are displayed in Table 1.

Table 1 – Revised Vehicle Class

NASS-CDS Vehicle Class	Revised Vehicle Class*
Subcompact/mini (wheelbase < 254 cm)	PC
Compact (wheelbase >=254 but < 265 cm)	PC
Intermediate (wheelbase >=265 but < 278 cm)	PC
Full size (wheelbase >=278 but < 291 cm)	PC
Largest (wheelbase >=291 cm)	PC
Minivan (<=4,536 kgs GVWR)	CLTV
Compact utility vehicle	CLTV
Compact pickup truck (<=4,536 kgs GVWR)	CLTV
Large van (<=4,536 kgs GVWR)	LLTV
Large utility vehicle (<=4,536 kgs GVWR)	LLTV
Large pickup truck (<=4,536 kgs GVWR)	LLTV
Utility station wagon (<=4,536 kgs GVWR)	LLTV
***-PC-Passenger Vehicle, CLTV-Compact Utility Vehicle, LLTV-Large Utility Vehicle**	

Table 2 displays an overview of the crash configurations for the entire dataset using the revised vehicle class. There were nine vehicles that were outside the scope of the revised vehicle class, such as a semi tractor-trailer, and were labeled as unknown. Seventy-one percent of the applicable crashes involved a PC as the struck vehicle. The majority of those were struck by either a CLTV or LLTV. The 367 crashes where the case vehicle (struck vehicle) was a PC will be the primary focus for the remainder of this paper.

Table 2: Crash configurations (all cases)

Case Vehicle Class	Striking Vehicle Class	N=517	%
PC	PC	179	35
PC	CLTV	105	20
PC	LLTV	83	16
CLTV	PC	58	11
CLTV	CLTV	31	6
CLTV	LLTV	23	4
LLTV	PC	16	3
LLTV	CLTV	9	2
LLTV	LLTV	4	1
Unknown		9	2

It should be noted that the model year breakdown for the dataset of crashes where the PC was struck in the side plane mimicked the larger group as depicted in Figure 7. Twenty four percent were model year 1997 or older, thirty two percent were model year 1998 to 2003 and forty four percent were model year 2004 to 2009.

The mass ratio (striking vehicle curb weight/case vehicle curb weight) between the crash partners was explored to establish if the majority of the CLTV and LLTV striking vehicles were indeed heavier than the case vehicle (PC). As indicated in Figure 8, the CLTV crashes indicated greater than 1:1 mass ratio in more than eighty percent of the cases. Large LTV crashes indicated a ratio greater than 1:1 more than ninety-five percent of the time.

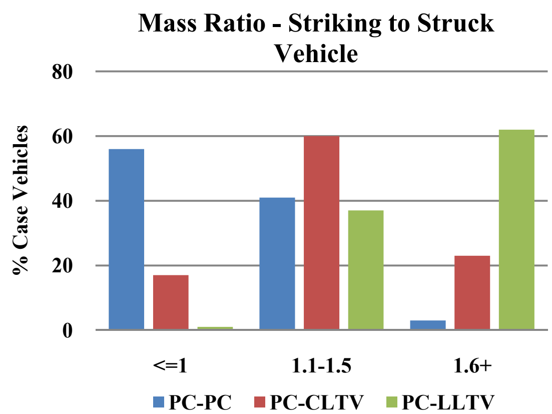

Figure 8: Mass ratio for PC cases

Since geometry is also a key component for compatibility, we wanted to evaluate the bumper height of the striking vehicle for the three different crash configurations. The results of the average bumper height comparison are indicated in Figure 9. Although there is an increase in bumper height as vehicle class goes from PC to LLTV, the difference is minor. The striking vehicle bumper height data is surprising, since the difference in mean height between a striking PC and LLTV is only 1.5 cm. However, it should be noted that the missing data rate for this variable was as high as 33% (in the LLTV group), which could result in inaccurate mean measurements for a vehicle class.

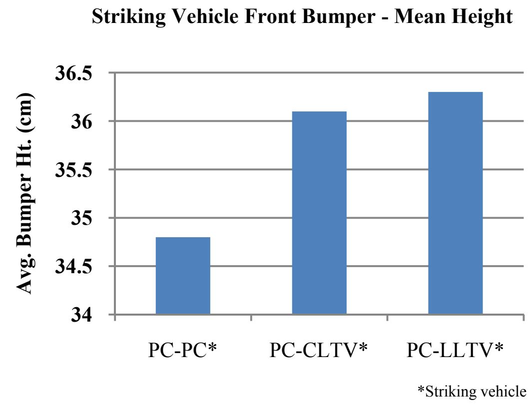

Figure 9: Striking vehicle bumper height

The principal direction of force (PDOF) was evaluated to determine the angle of impact for all crashes. The percent of crashes are plotted by the PDOF of the case vehicle in Figure 10. Using 90° +/- 10° for right side impact impacts and 270° +/- 10° for left side impacts, we discovered that less than thirty percent of the crashes in any combination were at or near a perpendicular impact. The majority of the study case vehicles experienced a PDOF with some amount of obliquity.

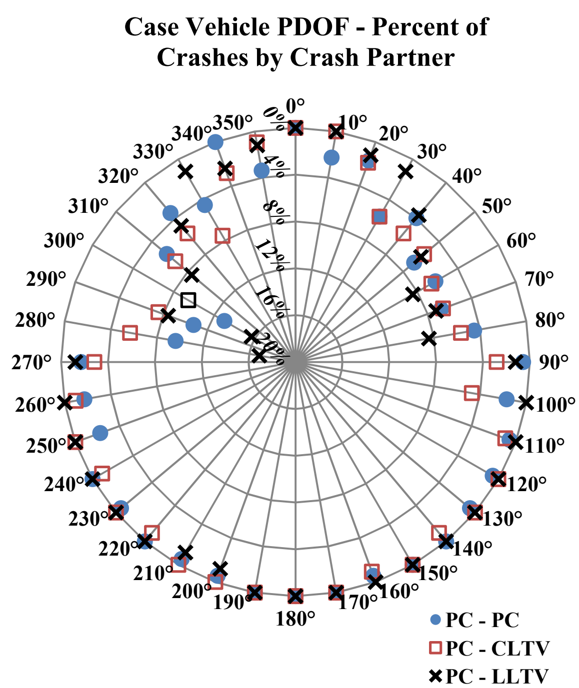

Figure 10: Case vehicle PDOF

Table 4 shows a summary of the new variables from the captured dataset where the vehicle being laterally impacted was a PC. The table also includes the delta-V data for the population as calculated by the Winsmash algorithm. Delta-V has long been a standard metric for crash severity. The mean delta-V in this dataset increases in magnitude as the mass, and possibly even stiffness, of the striking vehicle increases with the categories of CLTV and LLTV. There is a 9 kph difference between the mean delta-V in the PC/PC crash and the PC/LLTV crash. The mean sill height for the struck vehicle (PC) in the different crash partner configurations varies less than 1 cm, which lends additional confidence to the measurement techniques developed and utilized in the field. The mean height of maximum door crush increases as the striking vehicle transitions from PC to CLTV to LLTV, with the LLTV mean value being over 4 cm higher than that of a PC. The mean DSD in each group follows a similar trend, with PC/LLTV crashes having a mean DSD that is 8.2 cm larger than that for the PC/PC impacts. This data review also indicates a more than satisfactory capture rate for the new variables by researchers in the field. The worst missing rate for capture in the field of the new variables is only 4% (sill height of PC vehicles in CLTV crashes).

Figure 11 shows the relationship of the mean DSD and the mean height of maximum door crush for each crash configuration. This relationship indicates increasing override into the door, and increasing height of damage, as the class of striking vehicle grows. This is another indicator that the new variables are doing a good job of identifying cases where side sill override is occurring and generating encroachment on the passenger compartment of the struck vehicle.

Table 4 – Summary data on new side-impact variables

Crash Type	PC/ PC (n=179)		PC/CLTV (n=105)		PC/LLTV (n=83)	
Sill Height (cm)	Missing n=5		Missing n=4		Missing n=0	
	Min	7	Min	10	Min	15
	Max	37	Max	37	Max	38
	Mean	25.5	Mean	25.8	Mean	26.2
Height of Max Door Crush (cm)	Missing n=4		Missing n=2		Missing n=2	
	Min	19	Min	17	Min	14
	Max	81	Max	89	Max	84
	Mean	48.3	Mean	50.1	Mean	52.6
DSD (cm)	Missing n=0		Missing n=0		Missing n=0	
	Min	0	Min	0	Min	0
	Max	60	Max	55	Max	101
	Mean	13.1	Mean	18.6	Mean	21.3
Delta-V * (kph)	Missing n=14		Missing n=7		Missing n=7	
	Min	5	Min	6	Min	6
	Max	65	Max	72	Max	83
	Mean	26.6	Mean	32.3	Mean	35.6

*- Winsmash derived

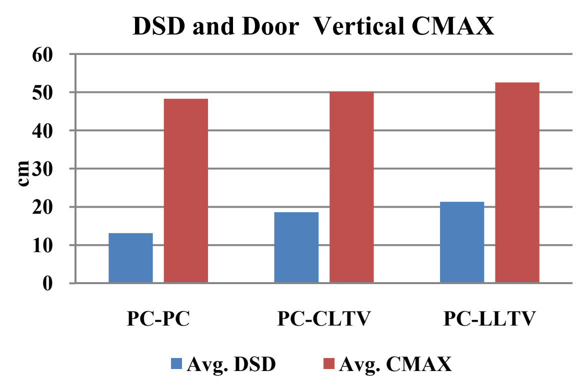

Figure 11: DSD and Height of Max Door Crush

The last variable of the new set we reviewed was the Direct Damage to Pillars variable. The initial expectation of this variable was to be a good inverse-correlate for DSD. We made the assumption that increasing the direct damage associated with the vertical structures would increase the effective stiffness for the side plane and potentially result in a decrease in the DSD and crush values. However, the data did not support our initial theory. Figure 12 indicates that as the number of pillars that are directly contacted by the striking vehicle increases, the DSD, on average increases, as well.

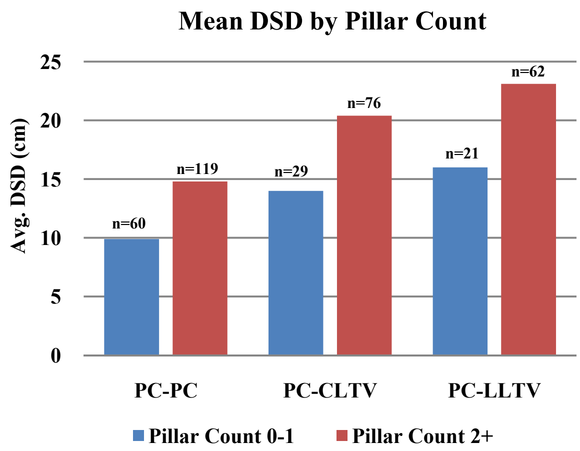

Figure 12: Direct pillar contact and mean DSD

Since the pillar count to DSD correlation finding was in contrast with the expected outcome, we reviewed the crash severity for each of the pillar count groups. The average delta-v for all of the crash partner groupings, where it was known, was higher for all pillar damage counts of two and greater as displayed in Figure 13. Therefore, it can be ascertained that the higher DSD results in the two plus pillar group are likely related to the crash severity.

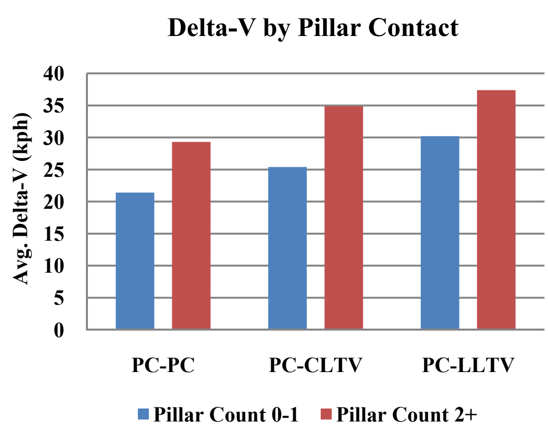

Figure 13: Direct pillar contact and delta v

Finally, we wanted to see how delta-V, a standard metric for crash severity, compared to DSD. The simple assumption was made that as delta-V increased, DSD would increase as well. We have already established increased mass and bumper height with both the CLTV and LLTV as striking vehicles when compared to the struck PC. This would also suggest that LLTV, and to some extent CLTV, would result in larger DSD as well. The scatter-plot in Figure 14 shows the delta-V and DSD relationship for each crash configuration where both delta-V and DSD were available. In general, the plot exhibited a correlation of DSD to delta-V as the crash partner gained mass and height from PC to LLTV. The plot did indicate a few puzzling points. There are approximately 13 struck PC vehicles that have DSD measures of zero yet have delta-V measures of 20 kph and higher. One crash involving a LLTV has a delta-V of greater than 60 kph and a DSD of zero. These cases were reviewed closer to check for potential data errors. It turns out that the issue is actually with the shortcomings of the CDC and when minimal "P-zone" is involved. If any part of the "P-zone" is directly involved with the impact, the new measurement variables must be recorded. But, as can be seen in Figure 15, there are occasions where the "P-zone" experiences a minimal direct contact, while other parts of the side plane that are in direct contact experience more significant crush.

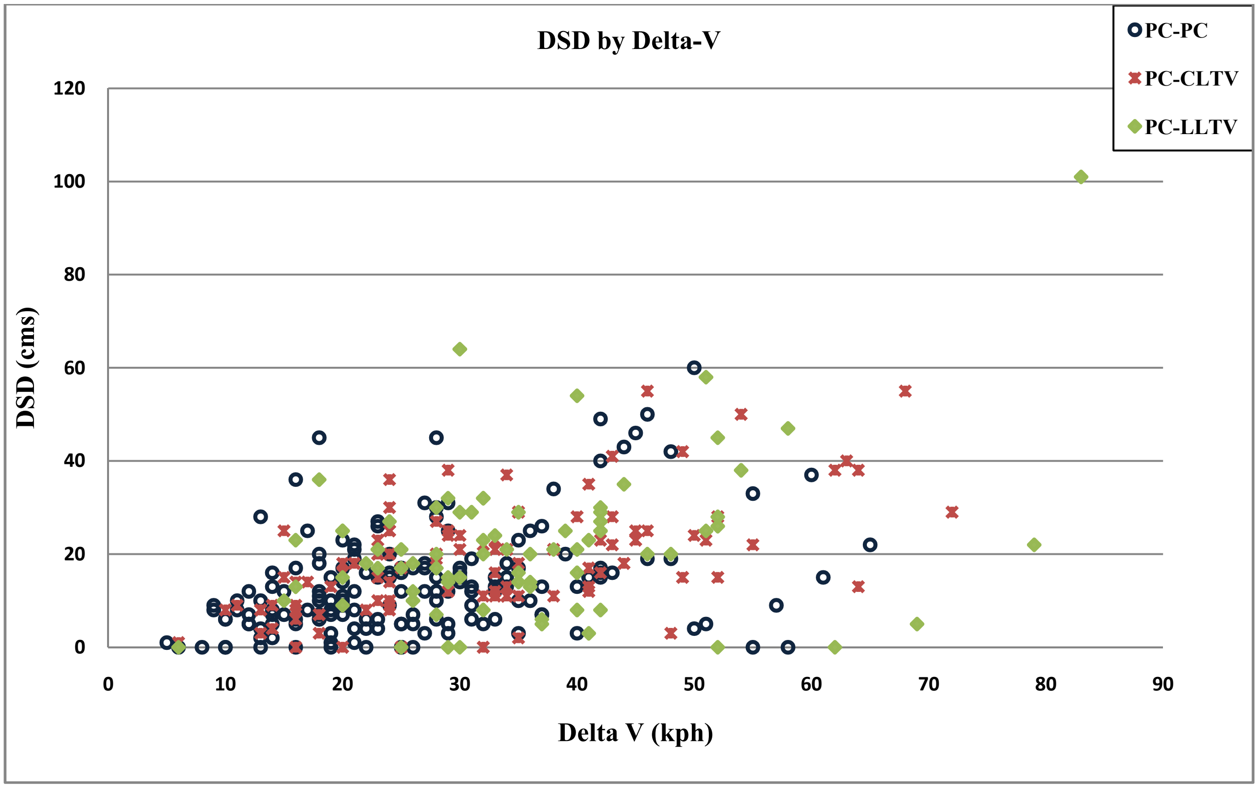

Figure 14: Plot of DSD vs. delta v for PC case vehicles

Figure 15: Example high delta v with low DSD (PC-LLTV)

CONCLUSION

In 2008, NHTSA began collecting newly developed variables as part of its field crash investigation programs. The variables were designed to help identify override and compatability issues related to side impact crashes. This paper discusses an initial review of the new variables to assess if they are achieving the goal for which they were designed.

Although over 500 cases have been coded, we concentrated this review on the cases where the vehicle impacted in the side plane was a passenger car (n=367). This enabled us to focus on the population most vulnerable to side impact compatibility issues.

Sill Height is a new variable that is a simple measurement in the field, but can be compromised due to vehicle damage. The data indicate that the measurements vary little in different crash configurations and are missing less than four percent of the time from the study population. Direct Damage to Pillars is a field observation determined by the crash investigator. The variable assesses the direct damage contact of the striking vehicle on the vertical side pillars of the struck vehicle. Review of this variable yielded unexpected results. More significant override, or DSD increase, was expected to be seen in cases with fewer pillars contacted and larger crash partner involvement. The data actually indicated the opposite, with more pillar involvement in cases with greater override. Additional analysis indicated the cases with the greater pillar involvement also had much higher delta-v results on average. Height of Maximum Door Crush was developed to determine the extent of crush and how high over the sill structure a vehicle was being struck on the side of the passenger compartment. Initial review of this variable indicates good field collection and accurate assessment of the role the frontal geometry of the impacting vehicle is having on passenger compartment deformation of the struck vehicle. The final new variable in the assessment is the DSD, or Door Sill Differential. This variable was designed to give insight into the amount of deformation a vehicle door experiences as compared to the sill or rocker panel. Large positive DSD measurements should indicate side plane override. The analysis of DSD shows it does a good job of identifying override and potential compatibiltiy issues. DSD and delta-V correlate reasonably well throughout this dataset in predicting crash severity. The DSD to delta-V correlation did indictate that DSD is only a good metric for side-impact crash severity where a significant portion of the passenger compartment is involved. Otherwise, delta-V becomes the more efficient indicator. The results of this review indicate the new variables to be of good quality and the majority are yielding the type of results that were anticipated.

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MEASUREMENTS OF THE GRIP LEVEL AND THE WATER FILM DEPTH FOR REAL ACCIDENTS OF THE GERMAN IN-DEPTH ACCIDENT STUDY (GIDAS).

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Paper Number 11-0314

ABSTRACT

The grip between the road surface and vehicle tires is the physical basis for the moving of all vehicles in road traffic. In case of an accident the available grip level is one of the most relevant influence factors, influencing the causation and the procedure of the accident. However, the estimation of the grip level is not easy and therefore, is commonly not done on the accident scene. This is especially true for the measurement of the water depth. Until now, real accident databases provide no measurement data about the grip level and the water film depth and thus, the estimation of its influence is not possible yet.

From the tyre manufacturers point of view, it is important to know about the road conditions (namely grip level, macro-texture, water depth, temperature) at the accident scene, as well as the operating conditions of the vehicles (braking, loss of control, speed, etc). These data is necessary to define relevant tyre traction tests for the end-user and for regulations.

For this reason VUFO and Michelin developed a consistent method for the measurements of grip level and water depth for the accidents of the GIDAS database. The accident research team of Dresden, which documents about 1000 accidents with at least one injured person every year, is measuring the micro-roughness and the macro-roughness directly on the spot.

For the measurement of the micro-roughness a Skid Resistance Tester (British Pendulum) is used. The Mean Texture Depth (describing the macro-roughness) is measured by the Sand Depth Method. Since June 2009, measurements for more than 700 accidents including 1200 participants have been carried out. In case of wet or damp road conditions during the accident, the water depth is measured additionally. Therefore VUFO and Michelin developed a special measurement device, which allows measurements with an accuracy of 1/10 millimetre. The measurement point at the accident scene is clearly defined and thus, the results are comparable for all different accidents and participants.

The use of the GIDAS database and the accident sampling plan allows representative statements for the German accident scenario. With this data it is possible for the first time to have an accurate view of the road conditions at the accident scene. One possibility is a more detailed estimation of hydroplaning accidents using the actually measured water depths. The development of new testing methods and new tires can be based on the real situation of the road infrastructure. Furthermore, the combination of the technical GIDAS data and the measured road surface properties can also be used for the estimation of effectiveness of several safety systems like the brake assist and/or emergency braking systems. The calculation of a reduced collision speed due to the use of a brake assist is only one example for the application of real measured grip level data.

INTRODUCTION

GIDAS is a joint project of the German Association for Research in Automobile Technology (FAT) and the Federal Highway Research Institute (BASt) of Germany. It started in 1999 with two research areas around Dresden and Hanover.

Figure 1. Research areas of Dresden and Hanover

The research area of Dresden covers about 3.000 km² with about 1 million people living there. The research area of Hanover comprises 2.289 km² and about 1.2 million inhabitants.

Facts about accident investigation

Each accident is encoded in the GIDAS database with about 3.000 variables. The database contains detailed information about:

- environment (meteorological influences, street conditions, traffic control),
- vehicles (deformations, technical characteristics, safety measures),
- persons (first aid measures, therapy, rehabilitation) and
- injuries (severity, description, causation).

About 100 photos are taken to document the accident scene, injuries, safety devices, traces and deformations of the vehicles. For each case the investigation team also draws a detailed sketch of the accident scene. This full-scale sketch shows the final positions of involved vehicles or persons and the positions of participants at the time of collision. Furthermore, view obstacles between the participants are measured and drawn into the sketch as well.

Reconstruction

On the basis of the full-scale sketch of the accident scenario and the vehicle deformations, every accident is reconstructed. The aim is to get information about the acceleration, deceleration, braking distance, collision speed, and initial speed for each participant and each single collision. To get this information for every involved vehicle it is necessary to reconstruct the pre-collision sequence, the impact and the post collision sequence for each participant. This can be achieved by using a reconstruction program called PC-Crash. After the reconstruction of the accident all information is coded into the GIDAS database as well.

Applications of GIDAS data

GIDAS offers important information regarding the optimization of vehicle safety for the automobile industry and their suppliers and is furthermore the basis for future ideas and concepts in research and development.
Using real accident data comparisons of the accident situation in reality and crash tests can be drawn and injury causing structures of vehicles can be identified very early. Analyses for legislators offer a close observation of the accident situation to discover negative developments immediately. The extensive documentation of the accident situation gives the possibility to work out legislative proposals and to analyse existing laws regarding their benefit for traffic safety.

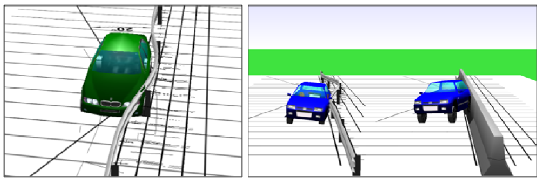

Figure 2. Simulation of steel- and concrete barriers

In the field of road traffic technology the GIDAS database allows the estimation of infrastructures and traffic control systems.

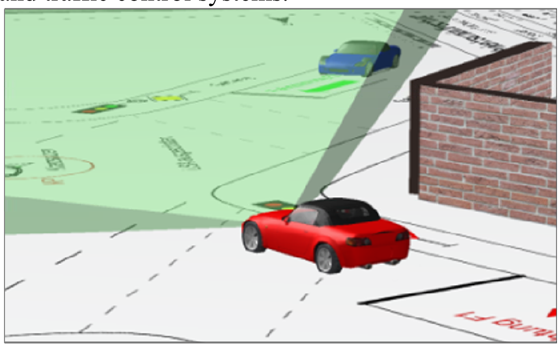

Figure 3. 3-D real accident simulation considering sensor-based safety system

The 3-dimensional simulation of the accident initiation phase is getting more and more important for the estimation of primary safety systems and thus, detailed information about the road surface is essential for precise results.

METHODOLOGY OF THE SKID RESISTANCE MEASUREMENTS

Aim of the cooperation between Michelin and VUFO was the development of a consistent method for the measurements of the grip level and the water depth directly on the accident scene. Therefore the definition of the measurement values, the measurement devices and the place of the measurement was necessary. The chronological implementation during the accident investigation and the education of the accident research team was one more important point in this process. For the measurements of the water depth it was additionally necessary to develop a new measurement device.

Measurement directly at the accident scene

The measurements of the grip level and the water depth are done directly at the accident scene during the accident documentation of the research team and the police.

Figure 4. Measurements at the accident scene

The by the police blocked and secured accident scene allows secure and precise measurements of high frequently used roads, in urban as well as rural areas also. Normally the research team reaches the accident scene 20 minutes after the notification by the police.
In case of rain, damp or wet road conditions the research team measures the water depth at first after arriving at the scene, so the variances can be reduced between the time of the measurement and time of the accident.
By the reason that the measurement of the sand depth method is only possible on dry road surfaces, a re-work is necessary for wet and damp accident scenes. Furthermore a rework is needful in cases of high frequently used accident scenes where the closure is not possible by the VUFO. These accident scenes are measured another time, mostly by night. By the help of the previously marked measurement point, the re-work measurements are possible during low traffic times.
Generally the measurements are done for each motorized vehicle that is involved in the accident. Measurements for bicycles, pedestrians, parking cars and trams are excluded.

Definition of the measurement points

To get comparable measurement values for all different kind of accidents a clear definition of the measurement points at the accident scene is absolutely essential. Therefore VUFO and Michelin define the following measurement points, which are explained by an example in the following figures.

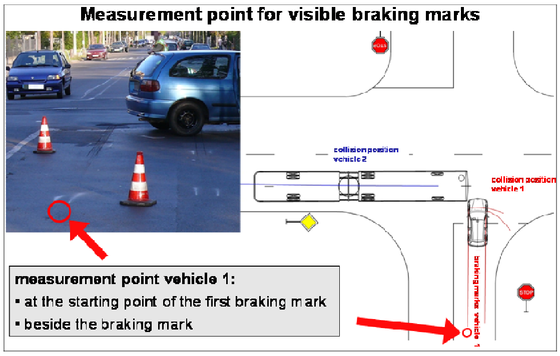

Figure 5. Measurement point for visible braking marks

In accidents where the braking mark of the participant is visible the micro- / macro-roughness and water depth are measured at the beginning of the first braking mark.

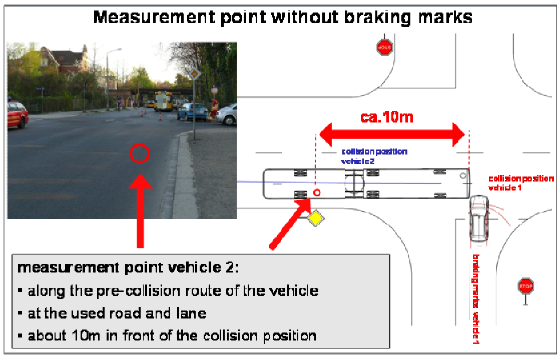

Figure 6. Measurement point without braking marks

If there are no braking marks at the accident scene, the measurements are done about 10 meters in front of the collision point in the right or left wheel track of the participant. The right or left wheel track means the track where normally the tires of the vehicles are rolling. For motorbikes the measurements takes place in the middle of the used lane.

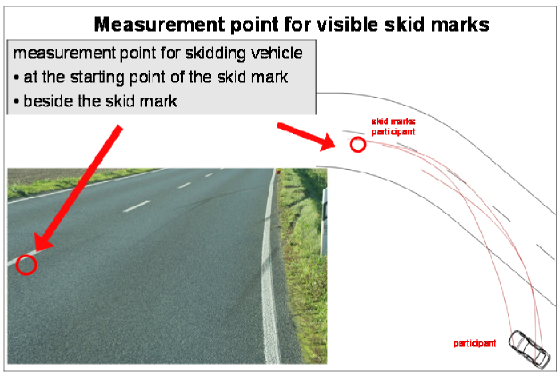

Figure 7. Measurement point for visible skid marks

In case of a skidding vehicle the measurements are done at the beginning of the first skid mark.
In general all the measurements are done on every kind of asphalt and concrete.
For roads with gobbles stones or a graveled surface the measurements are not possible with the used measurement devices. Apart from the measurement point the accident research team documents some more information at the accidents scene which is relevant for the analysis of the grip situation.

The most important information is the condition of the road surface. Here it is distinguished into dry, damp, wet, snow or icy condition. The distinction into damp or wet is done with the help of the water depth measurement device. If the device cannot measure a water depth value by the reason of too less water, the road surface condition is damp. Otherwise the condition is coded wet.

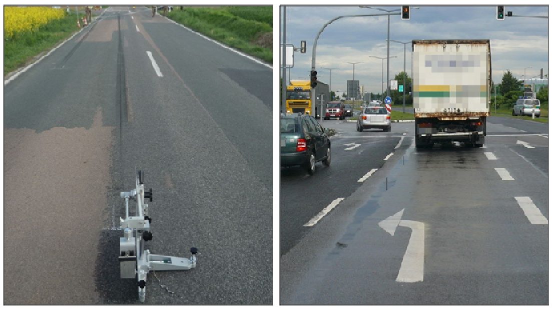

Figure 8. Changing material of road surface and influence of ruts

Furthermore changing materials of the road surface, the time of measurements, the influence of puddles or the influence of ruts at the accident scene are coded in the database. Here is also coded, if the measurement point is located in wheel track of the participant.

The Database includes the following information about the measurement point:

- position of measurement point
- condition of road surface
- time of the measurements
- changing material of road surface
- influence of puddles
- influence of ruts

Measurement values and measurement devices

For the definition of the useful measurement values is was important that the used devices are manageable by one person and the measurement time is less than maximum five minutes per participant. For this reason the following values were chosen.

Micro-roughness The micro-roughness is measured by the skid resistance tester (british pendulum).

Figure 9. Skid resistance tester

The functional principle of this device is quite simple, the pendulum is released from the horizontal position by a quick release button, it swings down with uniform force each time, and the rubber slider at the bottom of the pendulum contacts the road surface for a defined length. The degree to which the pendulum will rise up the calibration on the left-hand side of the image depends on the friction (resistance) of the rubber slider and the road surface. The more friction the less the pendulum will rise and the higher is the Skid Resistance Tester Value (SRT Value) of the road surface. For a better accuracy the measurements are done on wet road conditions only and dry road surfaces are watered.

At the accident scene five measurements are done for each participant and afterwards the mean value is calculated. The additional measuring of the road and the rubber temperature allows the correction of the temperature influence.

The Database includes the following measurement values for micro-roughness:

- five single SRT value
- mean SRT value
- rubber slider temperature
- road surface temperature
- temperature corrected mean SRT value

Macro-roughness For the measurement of the macro-roughness the sand depth method is used. The advantages of this method are the minor measurement time and the simple methodology.

Figure 10. Sand depth method

The necessary steps are: Spreading circularly a known volume of sand on dry road surface, measuring the area covered, subsequently calculation of the average depth between the bottom of the surface voids and the tops of surface aggregate particles. The result is the Mean Texture Depth which reflects the macro-roughness of the road surface.

The Database includes the following measurement values for macro-roughness:

- two diameters of sand covered area
- mean diameter of sand covered area
- calculated Mean Texture Depth (MTD)

<u>**Water depth**</u> For the measurements of the water depth a measurement device was developed which allows a measurement accuracy of one-tenth of millimetre.

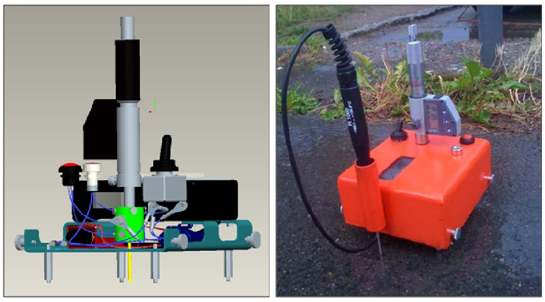

Figure 11. Water measurement device

The measurements are done at the same point where the micro- and macro- roughness is measured.
The principle of the measurement is very simple, easy to handle and very precise. The measurement prod of the device is coupled with the measurement screw. If the measurement prod has contact with the water film of the road an electric circuit is closed and an LED sign is shining. The digital display shows the measured water depth. The contact patch of the device is the zero level of the road surface and the measurement prod is calibrated of this surface level of the road.

Depending of the volume of water positive and negative measurement values are possible. The following figure illustrates the correlation.

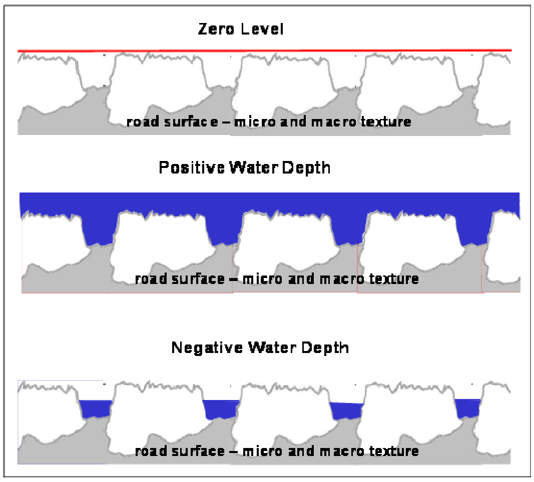

Figure 12. Explanation of positive and negative water depth

If the macro texture is completely covered with water, the water measurement device measures a positive water depth. In cases where the water only stands inside the macro texture the measurement value is negative.
At the accident scene the water depth is measured at the same point like the micro- and macro-roughness.

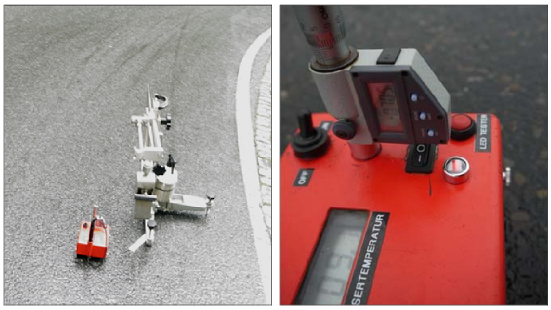

Figure 13. Water depth measurement at the accident scene

Therefore three separate measurements are done at this point and afterwards the mean water depth is calculated. Furthermore the temperature of the water on the road surface is measured and coded in the GIDAS database.
In case of ruts at the accident scene the water measurement will be extended by the following method.

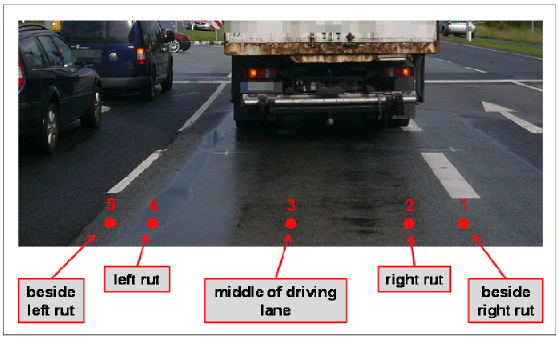

Figure 14. Additional measurements in case of ruts at the accident scene

For each of these five points one measurement value is measured and coded in the database. Therefore the analysis of the different water depths across the lane is possible and the influence of water filled ruts can be assessed.

The Database includes the following measurement values for water depth:

- three values for regular measurement point
- mean value for regular measurement point
- water temperature
- five measurement points for ruts across the lane

RESULTS

Since April 2009 the measurement team of the accident research unit in Dresden was at the scene of 639 accidents. In all 1002 participants (motorized vehicles) were involved in these accidents. Motorized participants means passenger cars, trucks, busses and motorbikes.

Analysis of representativity

The following diagrams show the comparison of accidents with measurement team and all accidents of the GIDAS database. At first the accident location is compared.

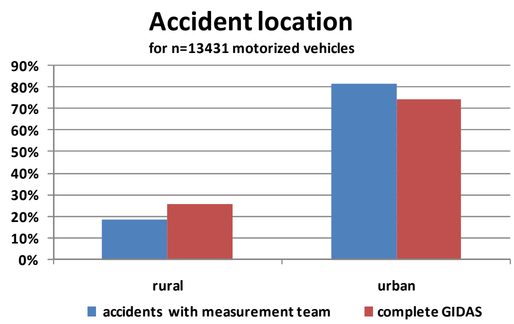

Figure 15. Distribution of accident location.

There are only small differences in the distribution of the accident location between the accidents with a measurement team and the whole GIDAS data-base of Dresden. The portion of accidents in rural areas amounts for the accident with a measurement team 19% and for the complete GIDAS database about 25%.

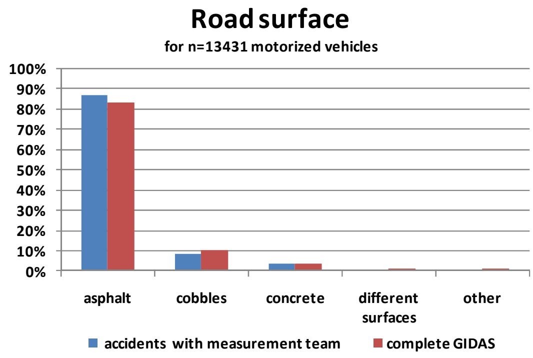

Figure 16. Distribution of road surface

The diagram of the road surfaces shows a similar distribution for both accident groups. Asphalt is the major road surface with a portion of approximately 85% in both groups. The portion of concrete surfaces is only 4% and is typical by used on highways. The coding different surfaces includes all accidents where the surface changes between the measurement point and the collision point.

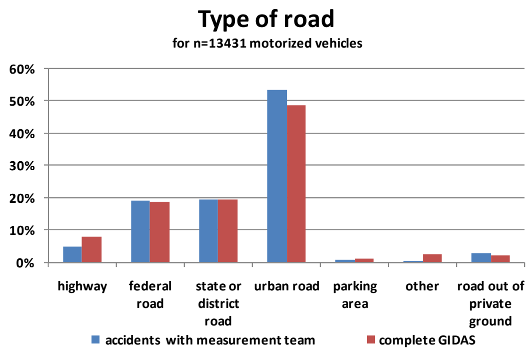

Figure 17. Distribution of type of road

The distribution of the road type shows a very good compliance between of the accidents with a measurement team and all motorized vehicles in GIDAS.

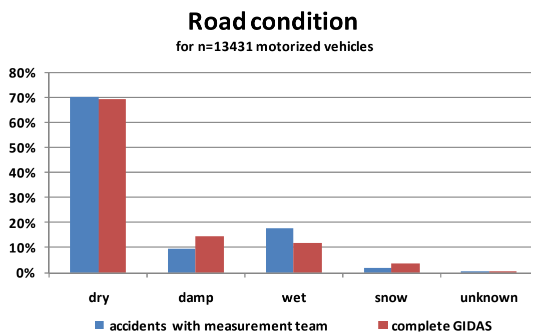

Figure 18. Distribution of condition of road surface

There are only small differences for damp and wet road conditions. The reason is the difficult distinction between wet and damp condition. The distinction criterion for the accidents with a measurement team is the functionality of the water depth measurement device. If the device is not able to detect a value by the reason of less water, the road surface is coded as damp. This possibility of distinction did not exist for the accidents before this measurement project.
In sum the previous comparisons show that the accidents with a measurement team are a comparable and representative selection of the GIDAS database. Therefore the results of the skid resistance measurement are representative for the German accident scenario.

Results of Micro-roughness measurements

The measurement of the micro-roughness for 864 motorized vehicles by using a Skid Resistance Tester shows the following results.

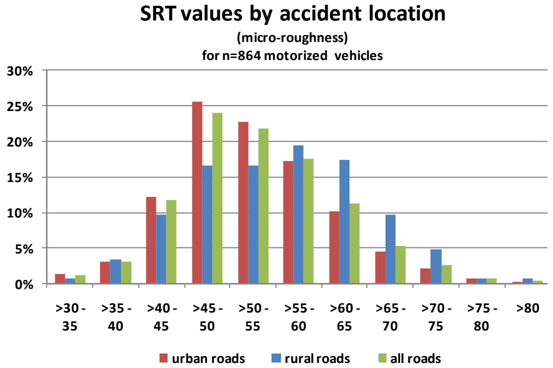

Figure 19. Distribution of SRT values

The distribution of the measured SRT values in wet conditions shows clear differences between the accident locations. In accidents in rural areas the measured SRT values (micro-roughness) are clearly higher than on urban roads.

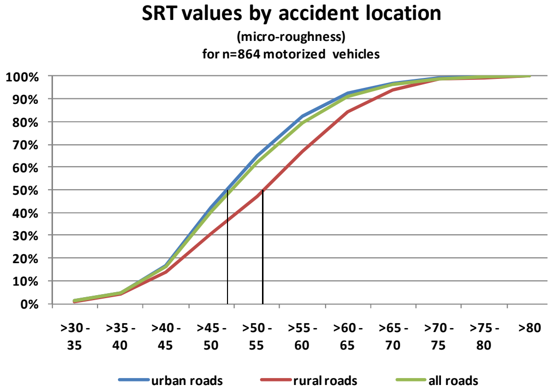

Figure 20. Cumulative distribution of SRT values

In about 50% of all accidents in urban areas the SRT values are less than 50 points. Compared to that, the SRT values of the half of all rural accidents is about 5 points higher on average. Only for 10% of all accidents (urban and rural) the SRT values are less than 40 points in wet conditions. It is assumed that the lower SRT value on the urban area can be explained by the impact of the higher traffic on the road wear which leads to lower micro-texture and therefore lower SRT values. In contrast, the evolution of the macro-texture due to the traffic is very small. This is consistent with the results shown on figure 21 and figure 22.

Results of Macro-roughness measurements

The macro-roughness of the road is important for the removal of the water for higher driving speeds. A high macro-roughness of the road surface allows a better displacement of the water by the tire.

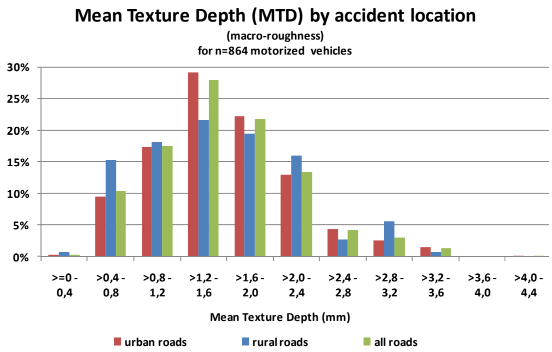

Figure 21. Distribution of Mean Texture Depth

In contrast to the SRT values, no clear differences between urban and rural accident locations can be noticed for the macro-roughness.

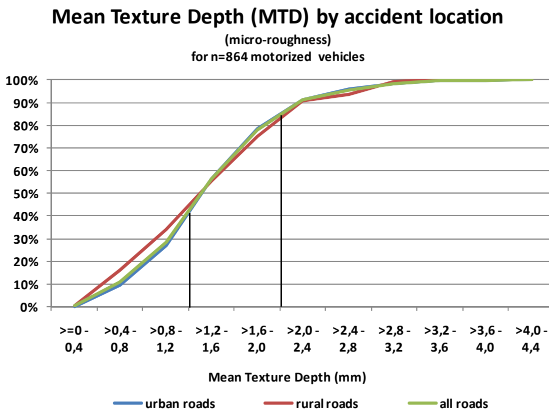

Figure 22. Cumulative distribution of Mean Texture Depth

For about 40% of all measured roads the Mean Texture Depth is lower or equal than 1,2mm and only in 25% the value is higher than 2,0mm. As mentioned the cumulative chart shows also the more consistent distribution of the rural accidents.

Result of water depth measurements

The water depth measurements take place directly after the arrival of the research team at the accident scene. Therefore minor changes of the water depth are possible from the time of accident to the time of measurement. The road of 67 motorized vehicles was only damp and thus a water depth measurement was not possible because of too less water. Altogether for 83 motorized vehicles a measurement of the water depth was possible.
For seven (about 8%) of these vehicles the road surfaces were covered with ruts.
In 76 accidents the road was without ruts. The following figure shows the distribution of the water measurements at the regular measurement point.

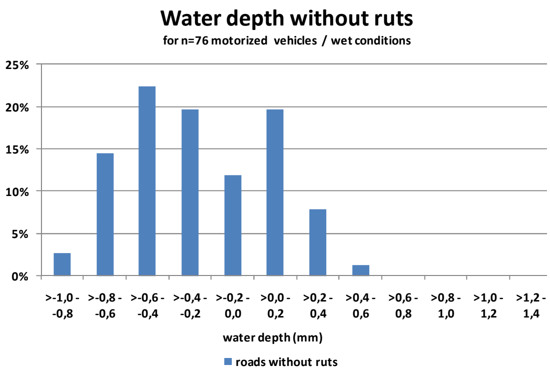

Figure 23. Distribution of water depth without ruts

The distribution of the water depth shows that for about 70% of all measured roads without ruts the water stands below the surface in the macro-texture. The water depth is never higher than 0,6mm.

The following figure shows the mean and maximum water depth for roads with ruts.

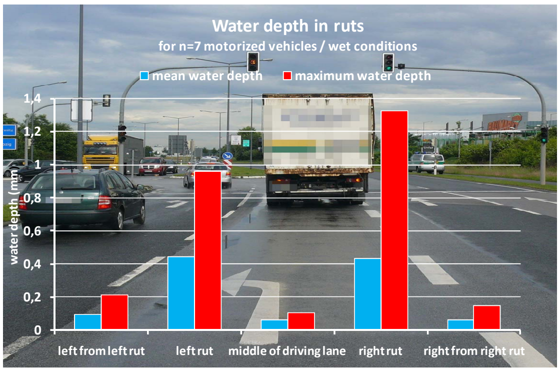

Figure 24. Distribution of water depth in ruts

The maximum water depth was measured with about 1,3mm, inside the right rut. In average the water depth is lower than 0,5mm for all measured accidents with ruts.

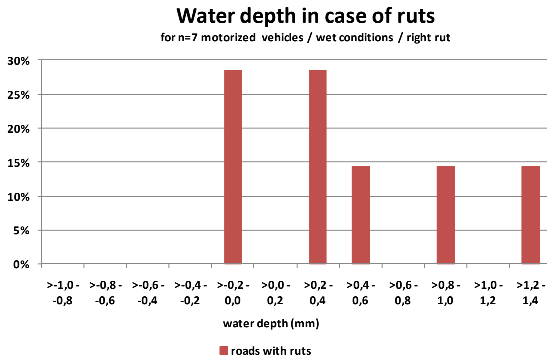

Figure 25. Distribution of water depth in ruts

The distribution shows the measurement values of the right rut. The diagram shows that for about 30% of all measured roads with ruts the water depth is higher than 0,50mm. It is important to remember that the existence of water filled ruts is very seldom in the accident scenario. Only in about 0,8% of all measured roads water filled ruts could be found and only in a thousandth of all roads the water depth inside the ruts is higher than 1,00mm.
The following figure shows the comparison of the water depth between roads with and without ruts.

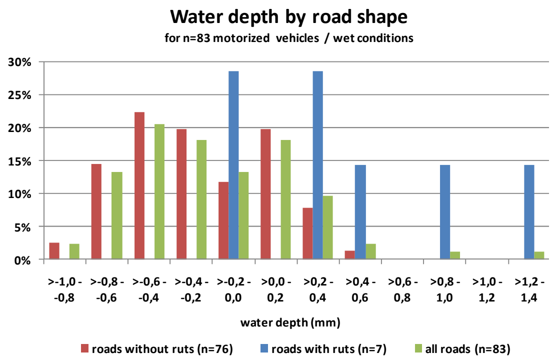

Figure 26. Distribution of water depth by road shape

The figure shows clear differences between roads with and without ruts. In general the water depth is clearly higher for roads with ruts compared to roads without ruts. For roads without ruts the maximum water depth was 0,60mm.

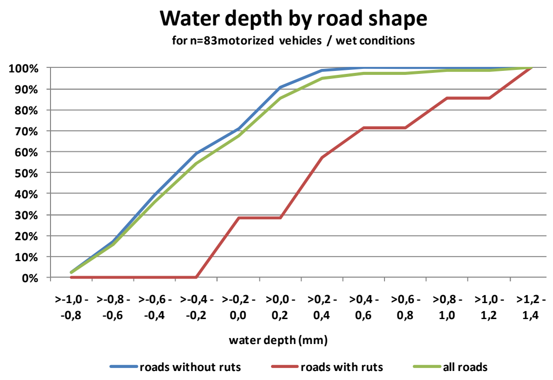

Figure 27. Cumulative distribution of water depth by road shape

For 80% of the roads without ruts the water stands below the surface inside the macro-texture. (resulting in a negative water depth) In case of ruts for 30% of the roads the water height is also below the road surface. On roads without ruts the water depth is never higher than 0,60mm.

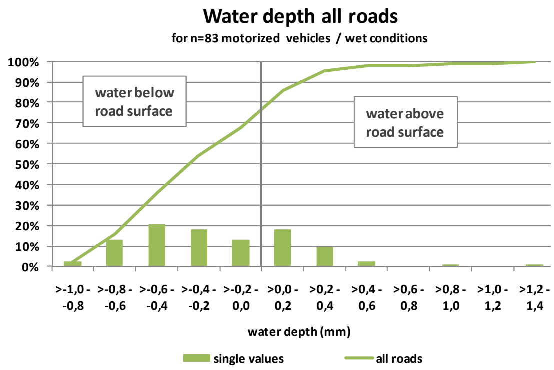

Figure 28. Distribution water depth of all roads

The water depth is lower than 0,00mm for about 80% of all motorized vehicles. In 80% of all measured accidents with wet conditions the water stands below the road surface only in the macro-texture. The following diagram is the result of the comparison of the water depth distinguished by the accident location for all roads (with and without ruts).

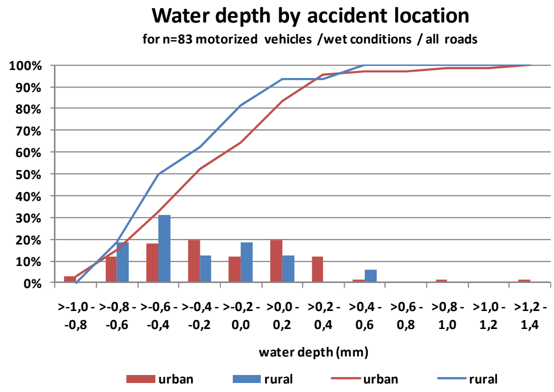

Figure 29. Distribution of water depth by accident location

In general the water depth in urban accident areas is slightly higher than in rural areas. In 50% of all measured roads in rural areas the water depth is lower than -0,50mm, contrary to the water depth in urban areas, where the 50% border amounts about -0,30mm. The reason for this difference is the distribution of ruts. However, the driven speed in urban areas (speed limit 50km/h) is clearly lower than in rural areas. The influence of the water depth on the tire road grip is not significant at a speed below 50km/h. Therefore the higher water depth in urban areas is noncritical for the tire road friction.

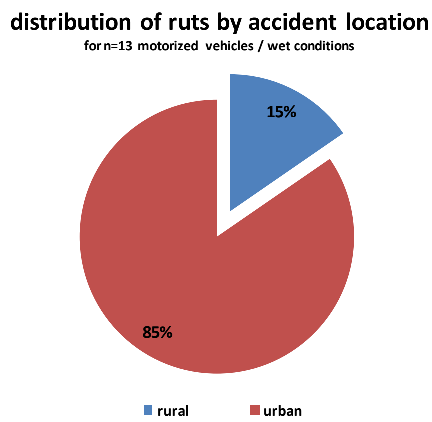

Figure 30. Distribution of ruts by accident location

Furthermore 11 of the 13 cases with ruts on the roads could be found in urban areas. Due to lower driving speeds of the vehicles in urban areas the influence of the higher water depth is also uncritical. In rural accidents where the driving speed is clearly higher the water depth is in 90% of all participants negative and thereby the water stands below the road surface inside the macro-texture.

SUMMARY AND CONCLUSION

The implementation of the consistent methodology for the measurement of the grip level and the water depth in real accidents scenarios is possible. The measurement of 639 accidents including 1002 motorized vehicles supplies revealing results.
The micro-roughness amounts more than 50 SRT points for 50% of all roads (urban and rural). Roads in rural areas have slightly higher SRT values than urban roads. In average the SRT value is three points higher for rural roads than for urban roads. Contrary to this there are no differences between rural and urban roads for the macro-roughness. Only for 30% of roads the Mean Texture Depth (macro-texture) is less than one millimetre.
The analysis of the water depth measurements shows clear differences between roads with and without ruts. For every road without ruts the water depth is lower than 0,5mm but for 30% of the roads with ruts the water depth amounts more than 0,5mm. Nevertheless the relevance of water filled ruts is very low in the real accident scenario, only 0,7% of all measured participants had to deal with water filled ruts. In general the most frequent water depths in real accidents in wet and damp conditions are lower than 0mm. The following table shows a summary of water depth in different situations.

Table 1.
Summary of water depth measurements

condition of road surface	dry	damp	wet	snowy	icy
% of all roads	69,8%	14,7%	12,0%	1,9%	1,7%

water depth	< 0,0mm	0,0 - 0,5mm	>0,5 - 1,0mm	> 1,0mm
% of roads in wet and damp conditions	82,00%	16,70%	0,65%	0,65%

In wet and damp conditions the water depth is lower than 0,0mm for 82% of all participants. Only in 1,2% the water depth is higher than 0,5mm. The consideration of the whole accident scenario (dry, damp, wet) shows only for 0,15% of the participants a water depth of more than 0,5mm. For 96,8% of all participants the road was dry or the water stands below the road surface in the macro-texture.

PERSPECTIVES

The measurements of the grip level and the water depth are still going on and so the number of measured accidents and participants increases every day. At the same time the already existing accidents will be completely coded and reconstructed by the accident research unit of Dresden. After finishing this process it is possible to analyse the influence of the vehicle speed, the vehicle tire and the road curvature. Especially the analysis of the influence of the tire parameters like the tire width and the tread depth in wet accidents will be very helpful to detect critical situations on wet road surfaces. Furthermore, in combination with the driving speed the identification of hydroplaning accidents will be possible. In addition, it is planned to develop a methodology for the correction of water depth measurements based on the rainfall intensity and elapsed time between accident and water measurement.

SURVIVAL ANALYSIS OF REAL-WORLD TIRE AGING DATA

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United States
Paper No. 11-0231

ABSTRACT

This paper focuses on tire aging and tire failures due to increased chronological tire age, miles driven, and harsher environmental conditions. Fundamental material failure mechanism is presented first to illustrate why tires are aging faster under higher loads or temperatures. Then Kaplan-Meier curves and Log-rank tests are used to compare various risk factors that may lead to tire aging. Similarly, Weibull analysis is used to predict the tire failure probability against tire age or mileage. Finally, Cox proportional hazard model is utilized to explore the tire aging relative risk with statistical significances. It is found that greater chronological tire age, higher mileage, initial tire loads, and manufacturing characteristics or tire types all contribute to tire aging or failures.

INTRODUCTION

While crash data such as the National Motor Vehicle Crash Causation Study (NMVCCS) and Fatality Analysis Reporting System (FARS) indicate that tire failures contribute to vehicle crashes and to approximately 400 fatalities per year (around 1% of total motor vehicle fatalities in US), relatively little is known about the risk of tire aging/tire failure due to increased chronological tire age, miles driven, and harsher environmental conditions (tire aging). This paper investigates the various reasons or risks, numerically and graphically, that lead to tire failures over certain time or mileages, using survival analysis or reliability engineering techniques.

The research data used in this paper comes from National Highway Traffic Safety Administration (NHTSA) Vehicle Research and Test Center (VRTC). VRTC has been collecting and analyzing in-service tires from the southwest area of US. The research background and motivations were earlier introduced by MacIsaac and Feve. [1, 2] Phoenix, Arizona was selected for the tire collection site due to its high average ambient temperatures and large population. It is believed, from earlier tests [1, 2, 3], that thermo-oxidative degradation within the tires is the main risk factor that leads to tire aging, and that this thermo-oxidative degradation rate is proportional to the temperature.

Earlier work at VRTC provided rich data for this current research. [3] There are four phases of this ongoing tire aging program at VRTC [2, 3]: Phase one of the project consisted of the engineering analysis of six different tire models collected from on-vehicle service in Phoenix during March to April 2003. From the point of view of reliability and test validation, 250 collected tires of six different tire models were studied to provide details about their material properties and degradations. The results were then compared against 82 new, unused, same versions of the tire models to quantify the amount of degradation in each measured property. The results of phase one provided some insight of service-related tire degradation, and can be served as the real-world 'baseline' reference for the future laboratory-based tire test.

One typical reliability method, so called step stress test, or accelerated test, was performed for each tire at VRTC. Fundamental fatigue theory of materials is used as the guideline, and the test loads, or speeds were gradually increased, step-by-step, which were then associated with increased mechanical stress and higher temperatures within the tires under test. Accelerated tests are normally done by means of dynamic or vibration test, and by thermal chamber or oven test. Figure 1 shows one of such road-wheel dynamic test setup used in the VRTC research [2]. The experimental data patterns are compared to verify the effects of some possible tire relative risk factors, especially, greater tire chronological age, high mileage, initial tire load, and tire types or manufacturing characteristics.

Figure 1: Tire Aging Roadwheel Test Used by VRTC [2]

For phase two testing carried out by VRTC researchers, a thermal oven (Figure 2) was utilized, and this thermal test can realistically simulate the tire aging process, with the oven internal temperature varying from low to high, for instance, 55-70^{o}C degrees for a period of 3-12 weeks [2]. It is observed, from repeated experiments, that only the oven thermal test during Phase two could replicate the tire material properties of the six Phoenix retrieved tire models [2].

Phase three and Phase four testing, proposed by VRTC, further validated the oven test results and model parameters derived from Phase two test based on the accelerated test theory. This paper will not address the details of Phase three and Phase four testing, but the theoretical analysis of this paper can be a useful hint.

More detailed statistical analyses are done in this paper compared with earlier Phase one work, two main experimental data sets derived from Phase one test at VRTC are used for the survival analysis in this study: the first dataset, 'Step Load', contains data from the stepped-up load road-wheel durability test performed on 127 unique tires (with no repeated tests). The second main dataset, 'Step Speed', contains data from the stepped-up speed road-wheel durability test performed on 95 unique tires (no repeated tests). Both step stress tests, either step load or step speed, were done to tire failures with associated higher stress, from each step of either higher load or faster speed. The main outcome variables of the above two data sets are time to failure (hours), mileage at failure (kilometers), and millions of cycles at failure. Some continuous data, such as tire age or mileage, are also categorized if needed in the modeling for the purpose of group comparison.

Figure 2: Oven Thermal Test to Simulate Tire Aging Used by VRTC [2]

The objectives of this research are listed as follows:

- Simply asking why tires fail, especially why tires fail much faster in hotter regions like Phoenix. Fundamental failure mechanisms, related to temperature and dynamic loads, are introduced first.
- Comparing the tire survival or failure probabilities of various factors leading to tire aging or failures, these factors are tire age, tire mileage, tire types and others, that are examined by paired comparison using Kaplan-Meier curves and Log-rank test.
- Predicting tire aging and failure probability using Weibull failure probability plots.
- Comparing the relative risks or hazard ratios of various factors and their statistical significances with p-values using Cox Proportional Hazard model.
- Providing some hints for future tire accelerated tests based on real-world data, failure theory of thermal and dynamic loads, and survival analysis.

EXPLORE TIRE AGING FROM A PERSPECTIVE OF AN ACCELERATED TEST

Tires fail because of high stress from a point of view of mechanical and reliability engineering. Stress-Cycle relationship or 'S-N curve' is used here to explain the tire failures, the tire failure happens when the following condition, Eq.(1), is met [6] –

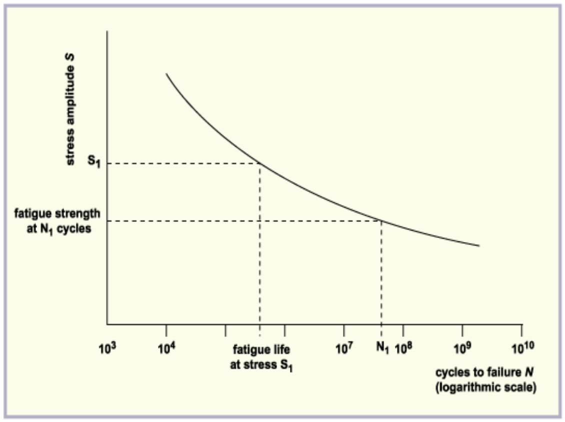


Figure 3: Stress-Life Curve (S-N Curve)

$$\sum_{i=1}^{K} \frac{n_i}{N_i} = 1 \qquad (1)$$

Where n_i is the test cycles performed at stress S_i while N_i is the maximum cycles before failure at stress S_i. Mechanical stresses in tires are mainly from two sources: stress caused by dynamic loads (for example, driving at high speeds), and stress caused by high temperature (for instance, driving in Phoenix during the summer or tire testing in a hot oven, Figure 2).

The tire aging can be much accelerated if used at a higher temperature than at a lower one. Accelerated temperature stress is described by an accelerated factor, or, AF $_{thermal}$, as following [6] (page 472-474) –

$$AF_{thermal} = \exp(E_a * TDF) \qquad (2)$$

Where

$$TDF = \frac{11605}{temp._{low}\,{}^{o}K} - \frac{11605}{temp._{high}\,{}^{o}K} \qquad (3)$$

In Eqs. (2-3), temp.^{o}K (absolute temperature) = (temp.^{o}C + 273.15), and 'E_a' is the activation energy in electron volts (eV). 'TDF' is defined as 'Temperature Differential Factor' from the Arrhenius Time-Acceleration Model. [6]

One example using Eqs. (2-3) is presented here - if a tire is exposed at a higher oven temperature of 65^{o}C (or temp.^{o}K $_{high}$ = 65 + 273.15 =338.15), compared to being tested at a lower 50^{o}C (or temp.^{o}K $_{low}$= 50 + 273.15 = 323.15), TDF=1.59 from above Eq.(3), if 'E_a' is related to material and assumed to be 1.2eV (the proper 'E_a' value can be obtained only after careful study of tire material), then AF $_{thermal}$ = exp(1.2x1.59)=6.76 from Eq. (2). The interpretation of this numerical example is that exposure of a tire to a higher temperature of 65^{o}C for one hour is equivalent to almost 6.76 hours at a lower temperature of 50^{o}C in the thermal oven, assuming other test conditions remain the same.

Like oven thermal accelerated test, the tire aging can also be much accelerated if used under higher dynamic loads than the lower one, such as step speed test. Dynamic accelerated factor can be obtained by the following formula, similarly [6, 7] -

$$\frac{T_{low}}{T_{high}} = \left(\frac{G_{high}}{G_{low}}\right)^m \qquad (4)$$

$$AF_{dynamic} = \frac{T_{low}}{T_{high}} \qquad (5)$$

Where G_{high} is the higher dynamic load that results in shorter test time, T_{high}, and G_{low} is a lower dynamic load that leads to longer test time, T_{low} (see S-N curve of Figure 3) [6]. G_{low} or G_{high} is dynamic or vibration power spectral density (PSD) related to driving speed with a unit of g^2/hz, while 'm' is a constant relate to tire materials and S-N curve (normally between 2.5 to 6). [6] However, this short paper will not address detailed effects of dynamic loads, tire materials and tire structures on the tire aging.

One example using Eqs. (4-5) is shown here - if G_{low} =0.04 g^2/hz, and G_{high} =0.06 g^2/hz, assuming 'm'=4, then AF $_{dynamic}$ = $(0.06/0.04)^4$ = 5.06 (times). This example implies that a tire tested at a 50% higher dynamic level of 0.06g^2/hz for one hour is equivalent to almost 5 hours if tested at a lower level of 0.04 g^2/hz.

If both thermal and dynamic accelerated factors are considered, then the total accelerated test factor is [6] –

$$AF_{total} = AF_{thermal} \times AF_{dynamic} \qquad (6)$$

Eq (6) indicates that tires used under both higher temperature and higher dynamic loads, as two examples above, will have a total accelerated factor of AF $_{total}$ = AF $_{thermal}$ x AF $_{dynamic}$ = 6.76 x 5.06 = 34.2 (times). We can interpret this approximately - one day *fast* driving (assuming dynamic loads 50% higher) in *hot* Phoenix (assuming more than 15°C degrees hotter) is 'almost equivalent to' one month *normal speed* driving in *cool* Seattle. Again, the different assumptions of material related constants of 'E_a' and 'm' in Eq.(2) and Eq.(4) can lead to different acceleration factors. The actual AF $_{total}$ might be much smaller than the value in this illustrative example.

COMPARING TIRE RELATIVE RISKS USING KAPLAN-MEIER CURVES

One important variable used for survival analysis is time, for instance, the test time until failure of a tire in the laboratory, or years of tires being used in the field, or the treatment time of a patient enrolled into a clinical trial [8]. In this paper, tire age is represented by the variable "DOT Age", which was determined by subtracting the build date in the DOT code from the date the tire was collected from service. This was considered a more accurate measure of tire age [3, 9]. Further, DOT Age (Year) is defined as (collection date - DOT Middle week Date) *(1/365.25).

The estimated mileage of the tire is represented by the variable "DOT Estimated Mileage". The value of this variable is zero miles for new tires, actual vehicle odometer mileage for original equipment manufacturer (OEM) tires. For replacement tires, DOT Estimated Mileage is defined as (Vehicle Mileage/Vehicle Age)*Tire Age.

It is of great interest to observe the tire failure, or survival probability varying over a test time. One of the most useful tools to compare the survival probability over time is a method proposed by Kaplan and Meier [4]. The Kaplan-Meier survival curve is described by the following formula:

$$\hat{S}(t) = \prod_{t_i <= t} \left(1 - \frac{d_i}{n_i}\right) = \prod_{t_i <= t} \left(\frac{s_i}{n_i}\right) \qquad (7)$$

Where 'd_i ' is 'deceased' subject, or failure tires, and 'S_i ' is the 'survivor' subject or tires still under testing, and 'n_i ' is total subject number (total tires) in the study at the study moment.

The Log-Rank test, used to compare the Kaplan-Meir curves and statistical significance with p-value, is shown as follows [4, 8]

$$T_L^2 = \frac{\sum_{i=1}^{I} (O_i - E_i)^2}{\sum_{i=1}^{I} V_i} \qquad (8)$$

Where 'O_i' is the 'observed' while 'E_i' is the 'expected' values, and V_i is the variance. The Log-Rank test is similar to Chi-Square test. The survival analysis is done using SAS Procedure of 'LifeTest' [11] and the Kaplan-Meier plots (or K-M Curves) are done using open source package R library of 'Survival' (www.r-project.org).

There are several research questions related to tire aging to be asked, some are listed as follows –

- Are greater chronological age tires prone to fail more easily?
- Will tires with higher mileages fail sooner? (Or alternatively, what is the combined effect of the tire age and mileage on aging if using a 'Service Factor' that correlates with tire age and mileage, see details on page 7)
- Do different tire types have different risks?
- Are tires located at front or rear associated with different Risks?

The following results, in the format of graphics, are several typical hypothesis questions that are studied using Kaplan-Meier curves, one by one.

CASE STUDIES

- <u>Hypothesis Question One</u>: Do Older Tires Have the Same Failure Rates as Newer Tires?

The engineering tests and experimental data suggest that tires with greater chronological age may be failing earlier than the new ones. Kaplan-Meier test and Log rank test were performed on 'step load' data set, and the following Figure 4 compares the survival rate over time between the older and newer tires.

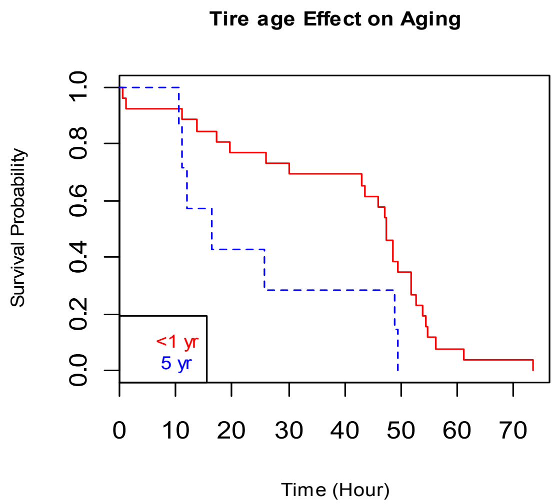


Figure 4 Survival Plot Comparing Older (dotted-line: >=5 years) and New Tires

The vertical axis of the above Figure 4 is the survival probability (0 to 1.0, or, 0-100%) and the horizontal axis is tire test time (0 to failure time, hours).

The results from Figure 4 indicate that there is a statistically significant difference (p-value=0.03 from Log rank test) between newer tires and older tires (>=5 years old) that failed much sooner from 'step load' data.

The same Kaplan-Meier test is also applied to 'step speed' data, and Figure 5 below indicates the same trend with 'step speed' data as Figure 4..

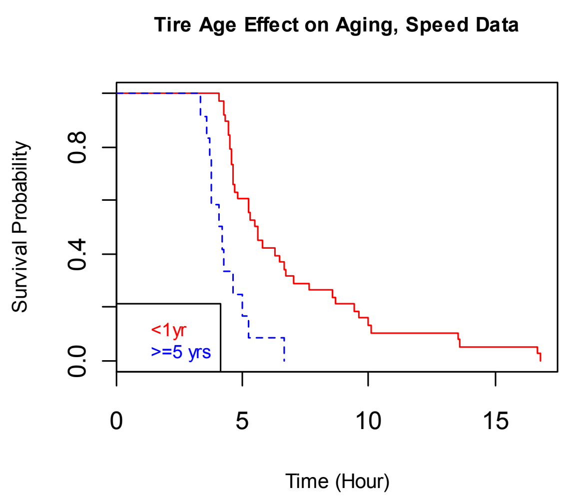


Figure 5 Survival Plots Comparing New and Old Tires (dotted-line)

- Hypothesis Question Two: Will High Mileage Tires Fail the Same as Lower Mileage Tires?

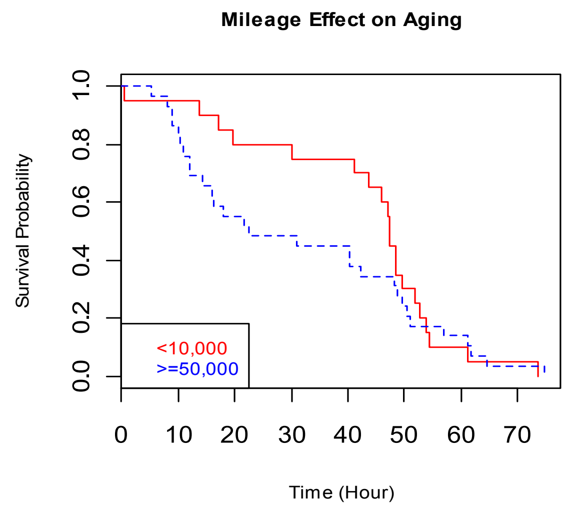


Figure 6 Survival Plots Comparing Low and High Mileage Tires (dotted-line: mileage<10,000)

The results from the above Figure 6 (using 'Step Load' data) indicate that there is a statistically significant difference between lower mileage tires (red curve) and higher mileage tires (p-value <5%).

- Hypothesis Question Three: Do Different Type Tires Have Same Failure Risks?

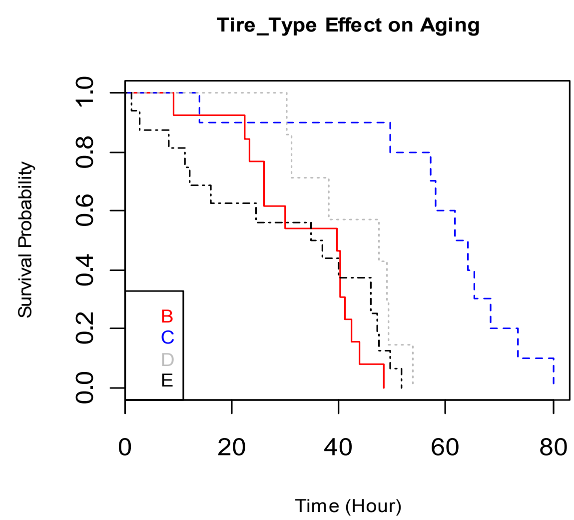


Figure 7 Survival Plots Comparing Various Tire Types

Figure 7 indicates (using 'Step Load' data) that there are significant differences among various tire types, especially between best survival one (Type C, blue) vs. worst survival one (Type E, black).

- Hypothesis Question Four: Do Tires with Different Positions Have Similar Failure Risks?

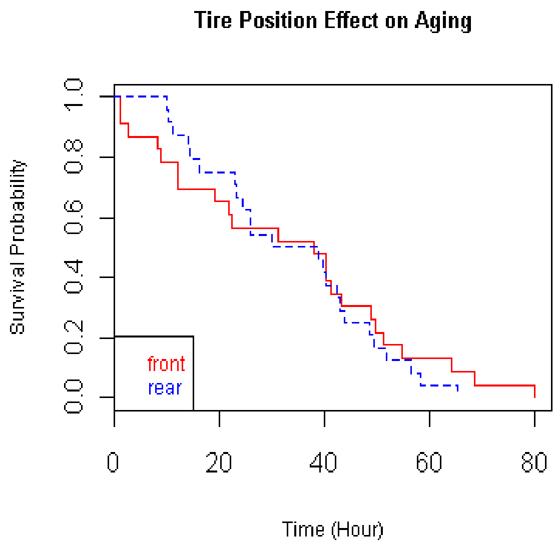


Figure 8 Survival Plots Comparing Positions (front/rear)

Figure 8 (from step load data) indicates a non-significant difference between the tires with different positions, 'front' vs. 'rear' position (p-value >10% from log-rank test).

More similar K-M curves also verify the significant effect of initial load although sample size is small. The effect of 'speed at failure' is also explored, and the results are not so statistically significant enough (p-value >0.05) if the speed is divided into two groups only (under, or above 170 km/hour), however, the speed can be divided into 3 or 4 groups later with a larger sample size, which may result in the greater aging differences between a very high speed group (with a higher relative risk) and a very low speed group. Some other parameters of tires, related to tire statuses, materials and structure, can also be explored in the similar procedure as above.

DISPLAY TIRE FAILURE PROBABILITY USING WEIBULL PLOT

The tire failure probability over test time, F(t), can be expressed by the following Eq. (9) in Weibull model:

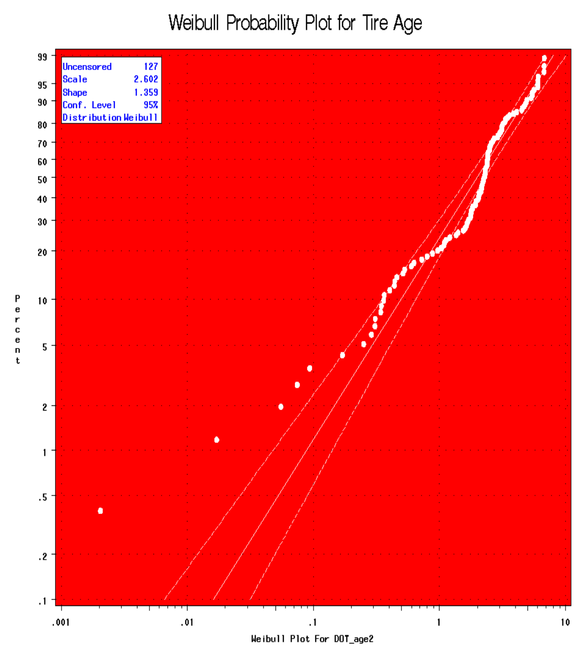
$$F(t) = 1 - e^{-(t/\alpha)^{\beta}} \qquad (9)$$

Or, equivalently it can be visualized by the following 'linear' transformation, as Eq. (10): [6, 8]

$$\log(-\log(S(t)) = \beta \log(t) - \beta \log(\alpha) \qquad (10)$$

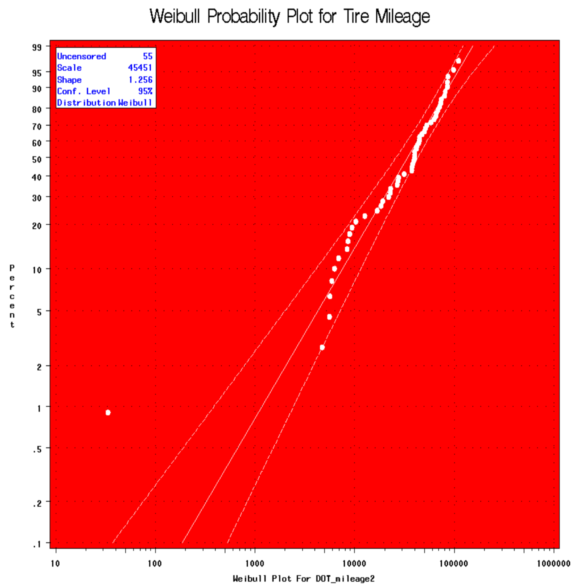
In the above Eq.(10), S(t) is survival function, which can be estimated from the Kaplan-Meier curve discussed earlier. Note S(t) = 1-F(t), and F(t) of Eq. (9) is the accumulation of failure probability as time increases. Weibull failure probability plot from Eq. (10) can be visualized as a 'linear' plot described by 'Y=βX+Constant', where vertical 'Y'=log(-log(S(t)), 'X'=log(t), and 'Constant'=-βlog(α). 'β' is regarded as the 'Slope' of the linear plot, or 'Shape' parameter, and 'α' is a 'Scale' parameter and is related to the intercept of the linear plot.

The following Figure 9 indicates that accumulation of tire failure probability increases with tire ages (step load data).



β =2.6 ('shape'), α =1.36 ('scale')
Figure 9 Failure Probability vs. Tire Age

The similar plot against mileage (Fig. 10 as below, using step speed data) indicates that accumulation failure probability also increases with tire mileages.



β =1.26 (‘shape’), α =45451 (‘scale’)

Figure 10 Failure Probability vs. Tire Mileage

The following Tables 1-2 provide more results of slope (β) and scale (α) parameters, from additional Weibull modeling using different data sets. SAS Procedure of ‘LifeReg’ is used for Weibull analysis [11].

Table 1: Weibull Slope and Scale Parameters (Step Load data)

parameter	Failure vs Tire age	Failure vs Mileage
β (slope/shape)	2.6	1.37
α (scale)	1.36	41667
99% failure	@6.5 yrs	@110,000km

Table 2: Weibull Slope and Scale Parameters (Step Speed Data)

parameter	Failure vs Tire age	Failure vs Mileage
β (slope/shape)	1.17	1.26
α (scale)	2.46	45451
99% failure	@7 yrs	@105,000km

RELATIVE RISKS OF TIRE AGING BY COX PROPORTIONAL HAZARD MODEL

It is of interest to analyze the relative effect of aging, for example, older tires vs. the newer tires. Cox Proportional Hazard model has been very popular in modeling censor data and analyzing the relative risk. The mathematical form is simply as follows, [5]

$$h(t \mid X_1, X_2, X_3, ..X_n) = h_o \exp(\beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... + \beta_n X_n) \qquad (11)$$

Where ‘h_o‘ is the hazard at base time while ‘h(t)’ is the hazard at any given time, X_1, X_2, X_3, …, X_i are the possible risk factors of tire aging, such as tire age, mileage, tire types, tire status (Original, Replacement, or New, ORN) , tire position,…etc., β1, β2, …βi are regression parameter associated with the possible risk factors, and especially ‘exp(β_i)’ can be regarded as the relative hazard ratio associated to the risk factor of X_i when X_i is modeled as categorical data. In Eq. (11), the combined risk factor that correlates with tire age and mileage, ‘Service Factor’ [3], can also be considered, if tire age and mileage are not used simultaneously while assuming the possible correlation, or collinearity between the tire age and mileage, although the interpretation of ‘Service Factor’ is more indirect while ‘tire age’ and ‘mileage’ tend to be direct.

The following tables are obtained with SAS Procedure of ‘PHReg’.[11] Table 3 comes from a modeling of ‘step-load’ data, and Table 4 comes from modeling ‘step speed’ data. Relatively small sample size makes it difficult to include multiple variables in Cox model.

Table 3: Cox Modeling of Hazard Ratios

Factor	p-value	Hazard ratio
Tire Age	0.03	0.78
Mileage	0.02	1.46
position	0.24	1.20

Table 4: Cox Modeling of Hazard Ratios

Factor	p-value	Hazard ratio
Tire Age	0.42	1.12
Status- ORN	0.04	0.66
Initial Loads	0.34	0.71
Mileage	0.20	1.32

One simple interpretation about ‘Mileage’ factor of Table 3: tires in a higher mileage group (20000 km vs. 10000 km group, for instance) have the aging risk 1.46 times (or 46% higher) compared with lower mileage group tires, with a significant p-value of 2%. Relatively small samples make it more difficult for Cox model with multiple risk factors.

Conditional probability of each risk predictor, X_i (such as tire age, mileage), or weight of each predictor can be obtained from regression parameters and is as follows [5, 8] –

$$W_i = \frac{\exp(\beta_i X_i)}{\sum_{j=1}^{n} \exp(\beta_j X_j)} \qquad (12)$$

The 'partial likelihood function', ℓ, is expressed as the product of all 'Conditional Probability of (X_i)'as the following formula that is similar to "Matched Case-Control" studies [5, 8] –

$$\ell = \prod_{i=1}^{m} \frac{\exp(\beta_i X_i)}{\sum_{j=1}^{n} \exp(\beta_j X_j)} \qquad (13)$$

$$= p_{age}\, p_{mileage}\, p_{load}\, p_{pos}\, p_{type}\, p_{temp}$$

The tires are aging or failing faster if the above partial likelihood function ,ℓ, reached the maximum value, or conditional probability of each risk conditional probability, p_{age}, $p_{mileage}$, .., reaches a maximum value, *simultaneously*.

Three analytical methods used in this paper: Kaplan-Meier survival probability S(t) plots, Weibull failure probability F(t) Plots, and Cox Proportional Hazard, h(t), have the internal links to each other (as shown by Figure 11), and three approaches provide similar results of tire aging trends, and each model gives a point of view from different perspective. Some researchers are more interested in product failure rates from Weibull model, F(t), and the others may pay more attentions to survival rates over time from Kaplan-Meier curve, S(t), and relative hazard ratios, $h_1(t)/h_2(t)$, of various risk factors. Cox model studies the relative risks clearly as logistic model, and is a popular tool modeling reliability time data. [8]

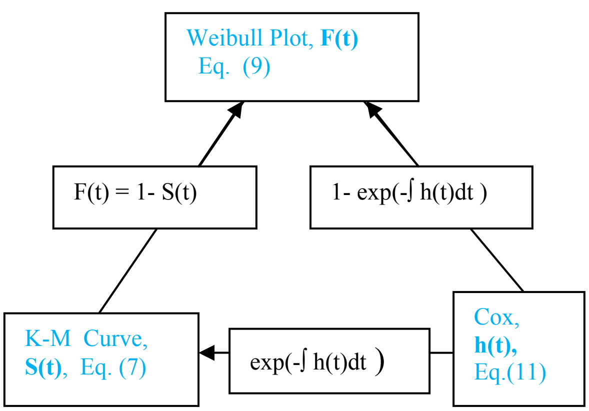


Figure 11 Linking Three Survival Models

CONCLUSIONS

- Greater chronological age tires are aging or failing faster than new tires, especially when tires older than five years are compared with new tires.

- Tires with higher mileages have higher aging risks.

- Different tire types or manufacturing characteristics lead to different aging risks. Also, tires with higher initial loads are prone to fail earlier.

- However, tires located at either front or rear vehicle positions have similar failure rates.

- Three analytical models discussed here, Kaplan-Meier survival curves, Weibull failure probability plots, and Cox Proportional Hazard Model, have the internal links to each other, and provide similar results.

- The statistical modeling of two data sets, step load and step speed, may provide different trends or statistical significances for certain parameters, and larger sample sizes may help multiple variable modeling. Furthermore, the tires studied are from the warmer Arizona area, and may have different characteristics from the tires of other areas.

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THE “AIS-0” CONUNDRUM: THE COMPLEXITIES OF IDENTIFYING THE UNINJURED IN NASS-CDS

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ABSTRACT

"Uninjured" occupants are part of many NASS-CDS safety analyses. However, the issue of precisely identifying "uninjured" persons in NASS-CDS is complex. There is no such severity code as "AIS-0". Neither the AIS-90 or NASS-93 manuals contain codes for persons whose medical records are examined and who have been found to have no codeable injuries. As a consequence, there is no such thing as "MAIS 0" defined by the AIS and as a result there is no way to query the NASS-CDS data on the NHTSA website for MAIS=0 injuries. The more appropriate statement about persons without AIS coding would be that the person either sustained no codeable NASS/AIS injuries, or was not coded at all. However, there is no data "flag" to identify which one is which.

This paper examines the approximately 90,000 vehicles in CDS from 1997 through 2007 and their occupants to illustrate the issues with identifying uninjured persons. More than 1/3 of these vehicles do not qualify under CDS rules for occupant coding. Therefore, AIS severity or MAIS codes cannot be used for the occupants of these vehicles, even if the codes appear in the data base as "blank" or "0".

In addition, for the approximately 90,000 occupants who do qualify for AIS/NASS coding (1997 through 2007) 35% (32,000) occupants have no AIS/NASS codes. A data run that relies on the MAIS code in the occupant file, (not the injury file), (which may be blank or zero) may assume these 32,000 occupants are "uninjured" rather than having “no codeable injury. This may result in a substantial overestimate of actual occupants without injury. This can seriously impact evaluation of safety interventions.

This paper identifies 5 occupant groups and several methods that can be used to help identify which of the 35% of occupants qualifying for AIS coding but without AIS codes are most likely to be uninjured. Issues created by using both the police KABCOU and AIS/NASS scales in mixed analyses to identify uninjured persons are also discussed. This paper is intended to be a general resource for researchers conducting safety analyses in NASS CDS that include uninjured persons.

INTRODUCTION

There is no “AIS=0" severity code defined in either the AIS-90/98 injury coding books used for trauma registry coding or in the NHTSA NASS-CDS 1993/2000 injury coding books used for coding injuries in NASS-CDS.(1,2) AIS severity levels of 1 through 6 and 9 for AIS and 1 through 7 for NASS-93 are defined. There is no injury code in either system to identify a person whose injury records have been reviewed and who was found to not have any codeable AIS / NASS injury. The AIS/NASS injury coding manuals alone do not identify occupants with no codeable injuries.

NASS-93/2000 Only In this paper we focus on the NHTSA NASS-CDS version of the AIS; as there are significant differences between AIS-90/98 and NHTSA’s NASS-CDS injury coding systems we will not address the AIS-90/98 system further.(3,4,5) In addition, because there are significant differences between the NASS-CDS 1988 injury coding system (used 1988-1992) and the NASS-CDS 1993/2000 system, we will address only the NASS-CDS 1993/2000 system used for NASS-CDS data between 1993 and 2010.(6,7,8)

No NASS Injury The terms “uninjured” and AIS/NASS=0 are not equivalent. An individual whose injury information has been examined by a NASS coder and found to have no AIS/NASS injury is exactly that - there is no codeable AIS/NASS injury. That does not mean they are uninjured. A number of conditions and injuries that the lay public would consider quite serious fall into this category including electrocution, hypothermia and drowning. The AIS/NASS is not an outcome scale; therefore a person can have no codeable AIS/NASS injury and be deceased.(1)

The NASS-CDS injury coding manual states that “NASS does not code unsubstantiated injuries”. However, it does allow persons to be coded as “uninjured” who may not be. On page 15 of the NASS Injury Coding manual it states “Presumption of No Injury” - that if the Police Accident Report (PAR) is blank for KABCO injury severity and the person was at the scene, the AIS/NASS coder should code “no injury”. To complicate issues further, it also states that if the PAR codes an individual with “complaint of pain” it is not necessary to do any AIS/NASS injury coding for the occupant.(2) As we show later, this likely causes many low severity AIS/NASS injuries to be missed.

Source of Injury Information

NASS CDS injury coding is not carried out to treat persons or evaluate medical care. Its purpose is to locate injuries and identify their type and severity. Consequently the rules for what source of injury information can be used are relaxed compared to AIS-90/98. As the NASS-CDS Coding Manual indicates, NASS-CDS coders may rely solely on injuries described by “unofficial” sources such as an interviewee (not necessarily the occupant), a lay corner (often a police officer), as well as EMS personnel or the police.(9) (page OI05) Verification by X-Ray, CT or MRI does not appear to be required for unofficial sources. This is different from the AIS system where verification of injuries is emphasized.(1)

Persons reviewed for AIS/NASS Coding

There is no flag in NASS-CDS that identifies persons whose injury information was reviewed by the NASS-CDS injury coders but who were found to have no codeable AIS/NASS injuries. However, the individuals whose records were reviewed can be partially determined by using NASS-CDS “missing record” rules. These rules are enumerated in the NASS-CDS Analytic User’s Manual associated with each year’s data. The following section discusses methods to identify occupants with no codeable AIS/NASS injuries in NASS-CDS.

MAIN BODY

Methodology

We used crash data from eleven years (CY 1997-2007) of the National Highway Traffic Safety Administration’s (NHTSA), National Automotive Sampling System (NASS), Crashworthiness Data System (CDS). NASS-CDS is “a probability sample of all police reported crashes in the U.S.”(10) Each year contains approximately 4,000 crashes in which a late model year (+1 / -2 model years around sampling calendar year starting in 1996) light passenger vehicle sustained sufficient damage to require towing from the scene. We used the SAS version of the files. There are several file types available that handle variable values differently.

The CDS sampling frame employs information from Police Accident Reports (PARS) to determine whether the crash is included in CDS or not. (No investigation has been done at the time the crash is selected). If persons are marked "uninjured" by the police and no later AIS coding is conducted, the occupants will remain marked in the police injury scale (KABCO) code as "uninjured". Note that the ANSI standard for KABCO (from which NHTSA derives the version they use) does not include any “uninjured” category, instead choosing to call those crashes “property damage only”.(11)

Rules for Injury Coding Not all crashes selected for inclusion in the sample are subject to injury coding. “Missing record” rules identify which occupants are subject to complete injury coding. The following conditions must be met.(12)

1. The vehicle must be “applicable” (meaning a late model light vehicle with a type code of 1 to 49)
2. The vehicle must be towed from the scene due to damage
3. The Occupant Assessment (OA) file must show that the number of injuries recorded by the AIS/NASS coders is greater than zero. Since there is no zero injury code, this means that a person with zero codeable injuries has no number of injury codes, and therefore would not have an Occupant Injury (OI) file. This might be considered a “catch 22".

The above missing data rules are not adequate to identify which persons had no codeable AIS/NASS injuries. This situation is compounded by analysis programs that might change blanks or character variables into numeric “zeros” that could be interpreted as zero number of injuries.

Air Bag Deployment

During the introduction of frontal airbags, NASS-CDS altered the missing record rules so that more data was collected for vehicles with airbag deployment whether the vehicle was “applicable” or not. Starting with 2003, these additional airbag cases no longer qualified for additional coding. As a result, the number of vehicles being inspected dropped. However, the rules for occupant injury missing records were not altered during these changes.

Inspected Vehicles

The data used in this paper is based on the above rules, but included the additional NASS-CDS rule that the vehicle be inspected. Inspected vehicles are the only vehicles guaranteed under CDS rules to have complete record information in the following CDS component files - Accident, Event, General Vehicle, Exterior Vehicle, Interior Vehicle, and Occupant Assessment.(12) All occupants in applicable, towed, inspected vehicles qualify for injury coding (but may or may not receive it). As stated in the NASS-CDS Analytic User's Guide "at least one of each record type will be required for a crash which includes a towed, inspected, CDS applicable vehicle involved in a CDC (Collision Deformation Classification) applicable event (or CDC is blank) with an occupant having a recorded injury".(12)

Occupant Compartment Intrusion
Any analysis that requires occupant compartment intrusions by necessity must use only inspected vehicles. CDS measures intrusions only above a certain magnitude (generally 3cm). Intrusions less than that magnitude are not recorded. Therefore, to compare vehicles with and without intrusions, it is necessary to identify all the inspected vehicles, then subtract the subset with measured intrusions to determine the subset of inspected vehicles that did not have intrusion in the location of interest. Otherwise there will be no correct accounting for vehicles without any intrusion.
We compiled all NASS-CDS occupants for years 1997-2007 from applicable, towed, inspected vehicles. The data presented is based on this group.

NHTSA CDS Query Portal The operation of the NASS-CDS online query portal is consistent with the above sections. Requesting results for MAIS=0 produces the warning "The value should be a number 1-7". Likewise, requesting results for injuries with AIS/NASS code=0 produces the result "Cases Found: 0".(13) However, researchers running their own copies of the datafiles using database programs may obtain erroneous results, depending on how they have set up their databases.

Results

Identifying Occupants Qualifying for AIS/NASS Coding There are 89,996 vehicles in CDS from 1997 through 2007. Of these vehicles 58,026 (64%) qualify as applicable, towed, inspected vehicles, whose occupants qualify for (but may or may not receive) injury coding. The 89,996 number is an unweighted (actual vehicle count) the "weighted" national estimate equivalent is 49,501,785. The issue we are exploring in this paper is related to the actual unweighted cases that are sampled, not the national estimate, and therefore we report only numbers based on the unweighted values from this point forward.
The result of the above is that AIS/NASS injury data does not exist for the other 36% of the vehicles. These vehicles did not qualify for occupant AIS/NASS coding. We confirmed this with a data run - none of the occupants in the 36% of vehicles had Occupant Assessment (OA) records or Occupant Injury (OI) records.
The above 58,026 qualifying, inspected and towed vehicles contain 90,556 occupants who qualify for AIS/NASS coding. However 78 vehicles have no occupants with Occupant Assessment files, and therefore per CDS rules, none of those occupants will receive AIS/NASS coding, leaving 57,948 vehicles with occupants that qualify for coding.
Sixty-five percent of the occupants (n=58,757) in these 57,948 vehicles have at least one AIS/NASS injury code (the maximum number of injury codes for any one occupant was 59).

Occupants without AIS/NASS codes The remaining 35% of occupants (n=31,799) in qualifying vehicles have no AIS/NASS codes. The breakdown of these occupants are as follows:

a. 1,193 Unknown if Injured
b. 4,663 Injured but unknown severity
c. 25,943 Number of Injuries (InjNum) = zero

We confirmed that all these occupants, in accordance with CDS's missing records rules, do not have an OI file or any AIS/NASS injury codes recorded. Occupant types "a" and "b" types cannot be said to be "uninjured". This leaves the 25,943 occupants with InjNum=0. The question is whether these occupants are actually uninjured or not.

MAIS
CDS provides a pre-computed one-per-occupant Maximum AIS/NASS code. The computation for this is listed in the Analytic Users Guide. It is correctly computed so that levels 1-6 take precedence over levels 7 (injured, but unknown severity) and 9 (unknown if injured). The Analytic User's Manual states that an InjNum value of "00" indicates that the person was "uninjured" and will be allocated a MAIS=0. However, this statement is not supported anywhere in the injury coding manual or NASS-CDS Coding Manual. Note that the value zero-zero "00" is not possible numerically; and in fact the SAS files are supplied with InjNum as a "character" variable, in which case "00" is a possible character value (InjNum in the SAS dataset also includes values of 1-59, 97 and U). Note that changing the properties of this variable to numeric would eradicate the "U"

values (some database software will convert character values to “blanks”, other database programs will convert blanks to “zeros”) - and that the code “00" would be converted to a plain numeric “0". This makes it indistinguishable from values that were converted from “U” or blanks. Occupants coded with “blank”, U or 97 values are not uninjured. Compounding this confusing situation, the SAS dataset, even in character format does not contain the stated “00" values; only “0". This brings into question whether it is reliable to use MAIS to detect persons with only a “0" indicating no codeable AIS/NASS injuries. It is possible that a number of the “zero” values are artifacts as described above, and not actual entered data. We recommend that NHTSA change the CDS coding rules for InjNum so that a value of 98 indicates that the person’s medical records were examined and they were found to have no codeable injuries.

Occupants with InjNum=0 and MAIS=0

These 25,943 occupants (type b above) are the most probable to have no codeable AIS/NASS injuries. However, we identified the following groups within the 25,943 occupants using other available CDS variables who are most likely NOT "uninjured". Our categorization of these groups is based on work we have done with state crash and injury data (11,12,13,14).

1. 34 =Died - Deaths were identified using Treatment=Fatal or Fatal ruled disease, Time to Death not zero, or Kabcou=fatal. AIS/NASS is not an outcome scale, so it is possible to die and have no AIS/NASS score. This can also occur because the person was dead at the scene or was not admitted to a medical facility so no medical record was created to code from. The death also could be due to disease or drowning. This highlights the distinction between “No codeable AIS/NASS”and “uninjured”.
2. 916=Received Treatment - These occupants either received treatment of some type or had treatment types of unknown. These occupants had treatment codes of Hospitalized, Treatment at scene, Treatment later, Treatment-Other, Transported to a medical facility-Unknown if Treated, and Unknown.
3. 2319=Transported but released but with a non-zero KABCO score. The non zero KABCO score is an indication of injury, along with the transport.
4. 2639=Non zero Kabcou score. The police coded these occupants with an injury - in the absence of a clear indication that the AIS/NASS coders examined these occupants we believe they should be considered injured.
5. 541=Received Initial Treatment at a Medical Facility - these occupants either received treatment at a medical facility or their treatment was unknown.

The above 5 groups total 6,449 occupants. This is 25% of the 25,943 occupants that are most likely to be “uninjured” with InjNum=0 and MAIS=0 and no AIS/NASS injury codes. It is possible that some of the above individuals received treatment for a medical condition - but that is unknown. The threshold to reach an AIS/NASS severity 1 injury is low (a bruise). On that basis we believe these 5 groups of occupants should not be considered “uninjured”.

Returning to the breakdown of the original 31,799 Occupants without AIS/NASS codes:

a. 1,193 Unknown if Injured
b. 4,663 Injured but unknown severity
c. 6,449 Died, Treated, non-zero KABCO (From groups 1-5)
d. 19,494 Most likely to be uninjured

The use of the original 31,799 occupants would over-estimate persons without any injury by 163% (31,799/19,494). However, this result assumes that the 19,494 occupants of group d above can be confirmed as uninjured.

Test of the Remaining Occupants The remaining 19,494 occupants of the applicable, towed, inspected vehicles have "zero" marked for all the factors used in the last section. It would appear that these persons should be "uninjured". However, a QC check of the NASS data identified cases that disproved this hypothesis. For example, case 2005-04-085 (available online) is an end over end pitch pole roll of an SUV with 3 occupants. The roof is crushed to half height. It is difficult to believe that all three occupants were "uninjured" - not even a NASS-MAIS=1 bruise. Although this is an applicable, towed, inspected vehicle, we note that much of the required "inspection" data is missing for the vehicle (for example occupant seat information that is clearly available from what is shown in the photos). It is possible that this case did not receive the complete investigation or documentation it was supposed to receive and most likely AIS/NASS coding was not attempted and the occupant injury was mistakenly coded as “0" instead of “97=unknown.. This might seem to be an "isolated" case - except it has a weighed value over 1,000 - which means it would dominate thousands of other, possibly more accurately coded cases if NASS-CDS weighted case values are used. This is because the median NASS-CDS crash weight (RATWGT) for 1997-2007 is 124. Eighty-seven percent (87%) of the approximately 51,000 NASS-CDS crashes from 1997-2007 have case weights less than 1,000. We identified other CDS crashes that appear to have the same coding issue as the example above. We have not yet identified a method to reliably identify these types of occupants so they are not considered "uninjured".

Using KABCO - NASS-CDS contains the police injury KABCO scores for a subset of occupants. However, a major problem with using both the KABCO and AIS/NASS injury systems at the same time is that they do not apply to the same group of occupants. The AIS/NASS is a subset of the occupants with KABCO scores. A national estimate of injured occupants in late model applicable vehicles based on KABCO will produce a different result than a national estimate based on MAIS or AIS/NASS scores. This is because the missing record rules are different for the two groups. Attempting to use the KABCO "uninjured" codes to identify the "uninjured" occupants for an AIS analysis errs unless the KABCO scores are taken only for the applicable, towed, inspected vehicles used with the AIS/NASS coded occupants.

An AIS/NASS=1 injury in KABCO

Another issue with KABCO is that a police rating of "uninjured" is unlikely to accurately distinguish between AIS/NASS=0 or 1 injuries. Severity 1 injuries are very "minor" - for example, code 790402.1 upper extremity contusion can be a bruise of any size (lesion sizes are not considered in NASS until they are higher severity). The data discussed in the next section shows that MAIS severity=1 injuries occur in multiple KABCO categories.

KABCO vs AIS/NASS An important issue with the dual use of KABCO and AIS/NASS is the lack of correspondence at the KABCO "Incapacitating" level. The KABCO definition used by NHTSA for FARS, GES and CDS (as well as many state's crash data) is based on an ANSI standard(10). The highest KABCO level injury (without being dead) is an "Incapacitating Injury". The ANSI standard states "An incapacitating injury is any injury, other than a fatal injury, which prevents the injured person from walking, driving or normally continuing the activities the person was capable of performing before the injury occurred." Injuries do not have to be very acute by AIS/NASS standards to reach this level. For example, a dislocation of the foot joint - which certainly prevents "normal activities" and qualifies as an "Incapacitating injury" is an AIS-1 level injury. ANSI does not define "uninjured" except by exclusion. If none of the other higher injury levels are coded for any person in the crash, then all persons involved in the crash are considered "uninjured" because it is a "property damage only" crash. This is similar to the lack of definition for AIS/NASS=0 severity.

Despite the above, a number of papers appear to mistakenly equate KABCO "Incapacitating" with AIS/NASS=3 "serious" severity or AIS/NASS MAIS=3. This practice is incorrect and misleading. Table 1 illustrates the large error introduced by equating AIS/NASS MAIS "3=serious" injuries with KABCO "Incapacitating Injury". As expected from the above example, "Incapacitating" is primarily (64% of the time) associated with AIS/NASS MAIS 1=minor and 2=moderate level injuries. It would be more accurate to say that KABCO "Incapacitating" predicts that the maximum AIS/NASS injury is NOT "serious" - exactly opposite what this literature appears to state.

Table 1 also illustrates the issues with KABCO ratings versus coding of AIS/NASS MAIS severity=1 injuries. AIS/NASS coders identified 5,814 persons with AIS/NASS MAIS 1=Minor injuries that were ranked as "No Injury" in the KABCO system. Note that since we cannot accurately account for persons with no codeable injuries, it is unclear how police code those occupants. However, if we use the total 19,494 occupants previously described as marked "uninjured" and account for the 6,006 shown in Table 1 as being marked "uninjured" but having MAIS 1 to 7, their highest possible accuracy is 69% (1-6,006/19,494).

Ninety-seven (97%) of the time KABCO "Possible Injury" corresponds to an AIS/NASS MAIS 1=minor or 2=Moderate Injury. KABCO "Non-Incapacitating Injury" 93% of the time also corresponds to an AIS/NASS MAIS 1=minor or 2=Moderate Injury. KABCO "Killed" has no correspondence with any one AIS/NASS MAIS level, demonstrating again that AIS/NASS is not an outcome measure and that occupants die at all AIS/NASS severity levels. We were surprised at the lack of any correspondence between AIS/NASS "Injured, Unknown Severity" and the seemingly equivalent KABCO "Unknown" and "Injury, Unknown Severity Ratings". These two KABCO groups correspond primarily (over 90%) with AIS/NASS MAIS 1=Minor and 2=Moderate Injuries.

Table 1 also shows that the practice of combining KABCO "Incapacitating" and "Killed" together as a

Table 1.
KABCO Injury Rating versus AIS/NASS MAIS Severity
Unweighted Occupant Counts and Percentages, NASS-CDS 1997-2007

AIS/NASS MAIS Severity	KABCO INJURY RATING (PAR): No Injury		Possible Injury		Non Incapacitating Injury		Incapacitating Injury		Killed		Injury Unknown Severity		Unknown		Total	
1=Minor	5,814	97%	10,957	88%	9,284	77%	9,336	40%	234	6%	445	78%	381	87%	36,451	62%
2=Moderate	163	3%	1,171	9%	1,862	16%	5,670	24%	310	8%	74	13%	33	8%	9,283	16%
3=Serious	18	0%	238	2%	645	5%	5,489	24%	594	15%	36	6%	14	3%	7,034	12%
4=Severe	2	0%	52	0%	153	1%	1,813	8%	708	18%	6	1%	7	2%	2,741	5%
5=Critical	4	0%	8	0%	39	0%	1,017	4%	1,080	28%	6	1%	4	1%	2,158	4%
6=Maximum		0%		0%	1	0%	16	0%	866	22%	1	0%		0%	884	2%
7=Injured - Unknown Severity	5	0%	13	0%	16	0%	38	0%	130	3%	4	1%		0%	206	0%
Total	6,006	100%	12,439	100%	12,000	100%	23,379	100%	3,922	100%	572	100%	439	100%	58,757	100%

KABCO levels as defined in the NASS-CDS Coding Manual
NASS-AIS severity levels as defined in the NASS-CDS NASS-2000 Injury Coding Manual
Percentages may not foot due to rounding
See paper text for methodology

proxy for AIS/NASS "Serious" and above injury (MAIS>=3) is wrong 57% of the time. Fifty-seven percent of occupants with "Incapacitating" or "Killed" KABCO ratings have AIS/NASS MAIS values of 1=minor or 2=moderate (15,550/27,301). Because the KABCO "Killed" group is 14% (3,922/27,301) of the combined "Killed" plus "Incapacitating Injury" group, the combined group is a predictor of nothing - it does not accurately predict the person died (86% wrong) nor does it predict MAIS>=3 accurately (57% wrong). Its use as a proxy for "Serious" is incorrect and misleading.
We also note, that in our experience, state data can vary widely in accuracy and that it is necessary to obtain the relevant police officer crash recording manuals and state database manuals in order perform QC checks on the data to confirm it can be used reliably.

CONCLUSIONS

There is no NASS-93/2000 (or AIS-90/98) injury code with a severity of 0. There is no definition for severity=0 in the above manuals.
Being "Uninjured" and having no AIS/NASS code are not the same. A person may be deceased and not have a AIS/NASS code. A person can be deceased and have no codeable AIS/NASS injury (often called "uninjured").
The identification of occupants with no codeable AIS/NASS injuries is problematic. Even using MAIS=0 and InjNum=0 with applicable, towed,

inspected vehicles is not adequate. The results we show indicate this approach can result in at least a 163% over estimate of occupants without injury. It is possible to improve the accuracy of results by using only applicable, towed, inspected vehicles, and then eliminating the occupants in groups 1-5 that may be injured, as shown in this paper. However, this is a reasonably complex %process, and as discussed in this paper it still leaves cases in the analyses that are questionable, as the example shown illustrates. The problem is exacerbated if case weights are used, as incorrectly coded cases with high case weights can overpower hundreds, or thousands of correctly coded cases.
We recommend that NHTSA consider changing the CDS coding rules to either:

A. Return to the use of "InjNum=00" to indicate occupants whose medical information were reviewed and were found to have no codeable AIS/NASS injuries .

B. Preferably, NHTSA could create an additional argument value for the InjNum variable. This added value, for example InjNum=98, would indicated that the available injury information was reviewed by the AIS/NASS coders and no codeable injuries were identified. This would completely resolve identifying occupants with no codeable injuries and avoid the confusion that can occur with using "00" as a character value.

Given the issues with identifying AIS/NASS=0 injuries, the simplest approach is to report results only for AIS/NASS injury codes for severities greater than one. All these occupants are guaranteed to have been injury coded. However, as discussed, even with this group, the source of the injury data should still be reviewed in analyses that require the highest accuracy. As mentioned previously, analyses using weighted results are sensitive to any coding error in the high-weight crashes.
KABCO and AIS scores are difficult to use togther in the same analysis without introducing confounding. At the very least, the data collected for both injury systems must come from the same group, generally applicable, towed, inspected vehicles with occupants with InjNum>0 (AIS coded occupants). Otherwise the national estimates (and raw counts) of the two systems are different and the results will be confounded.
There is no such KABCO injury rating as "Serious" and there is no positive correlation between KABCO "Incapacitating" and AIS/NASS MAIS 3=Serious. The use of the term "serious" in describing KABCO incapacitating injuries is misleading, as NASS-CDS shows that the majority of KABCO "Incapacitating" injuries are AIS/NASS MAIS severity 1=minor or 2=moderate. It is more accurate to say that KABCO "Incapacitating Injury" is associated with <u>not</u> having a 3=Serious or higher AIS/NASS severity injury.
We believe the term "serious" should not be used when describing the KABCO injury rating system data in order to avoid any appearance of presenting misleading information. KABCO "killed" does <u>not</u> imply a high AIS/NASS MAIS level - 50% of KABCO "Killed" occupants have MAIS=4 (critical) or less.
The practice of combining KABCO "Incapacitating" and "Killed" as a proxy for AIS/NASS MAIS=3 and above "Serious" injury is wrong 57% of the time.
When using the KABCO police injury rating system, the ANSI defined names should be used to avoid confusion, including the "property damage only" level to describe crashes where no occupant reaches the category of "Possible Injury". The term "serious injury" should not be used to describe KABCO rated injuries.

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Unintended Benefits of the National Motor Vehicle Crash Causation Study: A Highway Perspective

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ABSTRACT

Since its inception, the National Highway Traffic Safety Administration (NHTSA) has been concerned with providing the most complete and technologically feasible crash data collection. The collaboration with the Federal Highway Administration (FHWA) also dates back to the inception of the data sets. Funding issues and interest of primary users have limited coded infrastructure variables and attributes. In 2005, NHTSA embarked upon the congressionally-mandated National Motor Vehicle Crash Causation Study (NMVCCS) data collection. With on-scene reporting, nearly crash-time graphic data became available to end-users. In 2008, the Fatality Analysis Reporting System (FARS) published the first geographical coordinates for its cases. This eventually resulted in the re-release of data from 2001 through 2007. Although not temporally compatible, those interested in infrastructure and ***relevant elements*** would be able to complement the coded variables and attributes. The improved graphic reporting was noted in the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) pursuant to 2007 and potentially drawing from the NMVCCS model.

This paper offers an approach to mine, previously unconsulted NMVCCS data, rooted in precedent and established using FARS and NASS CDS. Using new data sources, the safety community might yield additional insights about crashes and the influence of various factors. In the narrowest sense, the findings might support the knowledge derived from crash testing and the limited extent of in-service evaluations of roadside safety elements that have been undertaken to date. As a natural by-product, this paper suggests that aggregated knowledge might populate an infrastructure dataset to aid those involved in roadway design, especially those addressing roadway departure issues, as supported by the overwhelming FARS incidence. During the feasibility study to identify the roadway elements and the value of image review, the digital image information has been enlightening. Tangentially, unlike NHTSA, FHWA may reference the unweighted data sets, as this furthers understanding of crash causation rather than underpinning rulemaking activities, thereby maximizing the use of unweighted NMVCCS data, predating the sampling plan. In the past, FWHA has consulted state-reported roadway features inventories and their resulting crashes when possible, aspiring to a macro view of roadside element description. As inconsistencies exist in the way that data has been collected, stored, and eventually processed at the state-level, this study seeks to review untapped digital images from national crash reporting, filling a void present in roadway design using a micro approach of roadside element description based upon crash scene locations. The present study seeks to address highway safety data needs by leveraging new data resources and tools.

INTRODUCTION

NHTSA contemplated barrier data inclusion in early NASS CDS documentation. FHWA expressed the need for additional guardrail data, recognizing that barriers were involved in many fatal crashes and resulting in the development of the Longitudinal Barrier Special Study (LBSS, Ray, 2003), conducted in 1982. Under the NASS CDS architecture, LBSS was envisioned to sample and investigate 82 crashes per stratum with priority given to collisions involving breakaway cable terminal (BCT) end treatment and transition from guardrail to bridge rail. Through this effort, precedent exists for barrier data collection under the aegis of NASS CDS.

In the NASS CDS Coding Manual (NHTSA, 1979) the first harmful event could be described by an attribute known as impact attenuator. This attribute was defined as "barriers placed in front of fixed objects on the highway to absorb energy and to thus mitigate the injury effects of collisions at such sites" and examples of these barriers were found in the

Appendix C: 1979 NASS CDS Guardrail Codification. LBSS described the barrier, provided the roadside cross-section, qualified the extent of damage, reconstructed vehicle dynamics, drew the vehicle trajectory, and assessed the performance of the barrier. As suggested earlier, the investigators were provided with specific instructions regarding digital image capture designed to identify the roadside element condition, infer damage (provided the element had not been repaired,) describe the vehicle trajectory at uniform increments leading to the impact location and beyond, if redirection occurred.

From 1979 to the release of NMVCCS data in 2008, relatively little was known about the environment in which the vehicles were operated. Well-intentioned researchers recorded a number of rudimentary roadway characteristics, which disallowed any profound analysis of roadside elements or their influence on vehicle damage and occupant injury severity. The film photography, and eventually digital image capture, was based upon guidelines supporting basic occupant injury and vehicle kinematics study.

With NMVCCS, however, a complete crash scene chronicling was mandated. Further, the researcher endeavored to arrive as soon after the crash as notification time and distance permitted. In most cases, the unspoiled crash scene image was digitally captured, but occasionally under harried and sometime perilous conditions. In a hand-full of crashes, however, the roadway traffic conditions or notification window made it impossible for detailed, on-scene digital images to be recorded. In this model, NASS CDS roadway elements were better recorded from 2007, owing to the responsiveness of NHTSA, within the constraints of funding.

Film Photography and Digital Image Review - Opportunity and Precedent

In 2008, FARS released the geographical coordinates for crashes. Recently, geographical coordinates were released for crash years 2001 through 2007. Although images for the roadway segments did not coincide with the crash date, it was noted that roadway infrastructure was generally constant and roadway elements were repaired or replaced with similar technology.

The analysis of crash scene graphic images was not new. It was rooted in precedent, as has been used in NCHRP 17-22 (Mak, et. al., 2010) and 22-15 (Eskandarian, 2004) conducted by the Midwest Roadside Safety Facility and George Washington University, respectively. Both studies relied on photographic images to better understand the crash scene, with varying degrees of cold crash scene access. This was not deemed an issue owing to the relative constancy in roadway element placement.

For the roadway safety community, crashes involving roadway departure have been of special interest. First, owing to their overwhelming contribution to fatality and injury statistics, roadway departure has merited special consideration. Its disaggregation has also been merited by the varying countermeasures required to address the roadway departure subaggregates. Additionally, many roadway departure crashes involved elements easily discernible by photographic and digital image data examination.

Definitions

Relevant elements have been chosen to describe a subset of roadside safety elements or devices readily identifiable via digital image review. Table 1 harmonized the concept of relevant elements with attributes provided in FARS, NASS CDS, and NMVCCS.

Table 1.
***Relevant Element Attribute*, by Dataset**

Relevant Element	FARS	CDS	NMVCCS
Impact Attenuator	x	x	x
Guardrail Face	x		
Concrete Barrier	x		x
Other Longitudinal Barrier	x	x	x
Guardrail End	x		
Cable Barrier	x	x	
W-Beam Guardrail		x	
Nota Bene: W-Beam attribute available starting in NASS CDS, 2008			

Event disaggregation for ***relevant elements*** was accomplished by consulting the data, as published. For FARS and NMVCCS, the events were selected at the vehicle level. NASS CDS, however, reports events at the crash level, requiring manipulation of the data to arrive at a vehicle event level. For this reason, the chronology, established by the police accident report for FARS and the researcher determined sequencing of events for NASS CDS, was used to establish the presence of a ***relevant element*** impact. For NASS CDS, the first crash event, the most harmful, or the second most harmful vehicle event was selected. This method was sound for single vehicle crashes, however, multiple event crashes occasionally yielded uninvestigated vehicles, which were deemed suitable for the population of the supplementary dataset but would lack in-depth vehicle and occupant data. As this study, sought to improve understanding of the roadway environment and vehicle interaction, any vehicle subject to ***relevant element*** impact was deemed to add values.

Film photography and digital photography was distinguished for purposes of this study. This was meant to account for technological advances present and exploited in this study. Film photography would have been present in the preparation of LBSS, as NASS transitioned from film in 1997 to digital image capture, with the advent of the Electronic Data Collection System, supporting CDS.

Temporal classification was a further classification of images resting with the time of capture. Crash-time referred to images taken on-scene, such as those taken by NMVCCS researchers. Near crash-time images referred to those taken within a specified data sampling cycling, such as those taken by NASS CDS researchers. Finally, images which were temporally non-current identified the conditions under which FARS geographical coordinates were used to extract Google Earth images. For the FARS crashes, there was no specified cycle during which the image was captured. Instead, the image provided corroboration of the crash location and possible trajectory clues, upon consulting coded elements.

Roadway Departure Context

In 2009, the FHWA Office of Safety issued a roadway departure definition (Nicol, 2009), based upon FARS data elements, in response to the overwhelming contribution of this crash type in FARS. The data definition was coined to encourage individual states to adopt uniform reporting practices. These were concerned with first event impacts, owing to the disaggregation of vehicle events and basic crash initiation. Its extension to the NMVCCS data was considered as a context for the ***relevant element*** digital image review.

Although NMVCCS was initially identified as a substantial and untapped resource in describing the roadside environment (ESAR, 2010), its true contribution was not appreciated until FARS 2008 published geographical coordinates, with which the satellite images were used to study the crash scene and associated infrastructure, thereby enacting a digital image data extraction feasibility study. ESAR 2010 allowed for a rudimentary digital image review based upon images of infrastructure condition, within the context of vehicle damage and occupant outcome. Based upon the FARS study, supplementary issues of vehicle trajectory and multiple vehicle and event interactions were incorporated into crash understanding, as supported by the externally compiled crash scene images. Nicol (2009) provided the full FARS data definition, and its contents were used as the disaggregation for the FARS data and translated for use with NMVCCS variables and attributes. The current NMVCCS iteration yielded many unknown entries, owing to the focus and size of the sample, as well as attributes restricted by privacy concerns.

Table 2 provided an overview of the currently codified data, data desired but unavailable, and uncodified data but potentially available through digital image review. Although FARS, NASS CDS, and NMVCCS data allowed for greater data opportunity, the depth and breadth of supplementation was tempered by the privacy protocols and data collection mandate.

Table 2.
Summary of Data, by Availability

Data Type	Data Elements		
	Codified	Unavailable	Uncodified
Basic	Basic Vehicle Data		
Basic	Basic Occupant Demography		
Crash	General Vehicle Contacts	Precise vehicle trajectory	Specific Type of Element
Crash	*Geographical Location*		Roadway, Roadside Description

❑*Geographical Location* given for FARS, providing Google Earth Coordinates
❑NASS CDS and NMVCCS provide scene photographs

As the roadway departure issue had been defined as a substantial issue, with over half of fatalities attributable to this crash configuration, FHWA decided that this rubric required additional consideration and disaggregation. Many different countermeasures might address the crashes known, in aggregate, as roadway departure, and before 2009 defined within the NHTSA public health and safety context, for which vehicular and occupant protection countermeasures might be best defined. For FHWA, however, the data could conduct to better roadway solutions, by filtering and disaggregating by groups that might have similar countermeasures and conducting toward the NMVCCS Application of the roadway departure definition and analysis.

NMVCCS Application

Upon using NMVCCS for a study of valuable clues in crash causation yielded from on-site digital image capture, it was found that the condition of elements was available and also useful. In this way, not only the greater confidence of a vehicular impact point owing to the paint transfer but also deformation characteristics, depending upon the element type and digital image detail. The yielded benefits outweighed the present disbenefits.

Most limitations relevant to this study involved the ability for the researcher to obtain meaningful crash scene digital images. This was compounded by NASS privacy protocols. Geographical coordinates were not provided owing to protocols protecting crash victim information in place for NASS. In the absence of geographical coordinates, the end-user was limited to the digital images offered by the NMVCCS researcher. Further, roadway conditions dictated the specificity of the image capture. In congested or complex roadway environments the researcher was forced to obtain capture images while driving past and slowing near the crash scene for his protection and those involved in the investigation. Researcher-determined views, vehicle kinematics, predominant crash-producing trajectory and damage driven were enumerated among strengths and weaknesses of the reporting. These disbenefits were tempered by yielded benefits.

The benefits of digital image review were found in the majority of cases reviewed for the roadway departure and selected other crashes. The images were found to provide insights on the crash scene and ***relevant elements*** involved in the impacts. These crash images went beyond mere corroboration of the elements, as was seen in the FARS study, owing to the temporal concurrence with which these images were captured. Many of the images were of strong enough quality to feed a supplementary ***relevant element*** data set.

FARS and NASS CDS Methodology

In contrast to the FARS methodology, in which the geographical coordinates were entered into Google Earth, yielding the requested roadway segment, the researcher captured images were the only basis for supplementary data. Occasionally, there was some guess work when assessing seemingly similar, contiguous roadway segments, as seen in Figure 3 for FARS cases. The graphic revealed the seeming guesswork involved in trajectory disentanglement. This was the sacrifice made for camera view autonomy.

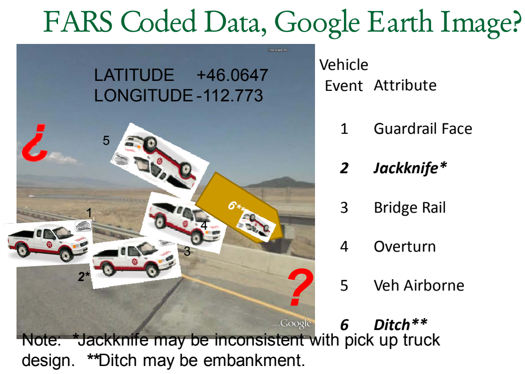

Figure 3: FARS Supplemental Data Review using Google Earth.

The temporally non-current digital images allowed for identification of the crash scene, ordering of vehicle events, and identification of at least one possible vehicle trajectory. Subject to image, type of ***relevant element*** might be identified, as well as its gross performance during the crash. The issue of design for planar crashes rather than rollover crashes yielded most crashes, although ending in fatality with ***relevant elements*** performing as designed. The design characteristics, however, may have been exceeded and examination of application might be warranted for specific situations. These situations included but not were not limited to: vehicle attitude, multiple impacts, and other vehicle interactions. It was also noted that cases were identified in which solutions might involve vehicle sensor and roadside hardware improvements to best mitigate the crash scenario. This would encourage the continued dialogue sustained by NHTSA and FHWA.

With near crash time data collection present in NASS CDS, although sacrificing specific location, increased confidence in the crash location and the elements captured in the images. Scene diagrams and crash summaries allowed for more accurate disaggregation of the crash into the constituent events, through the objects contacted, as seen in Figure 4.

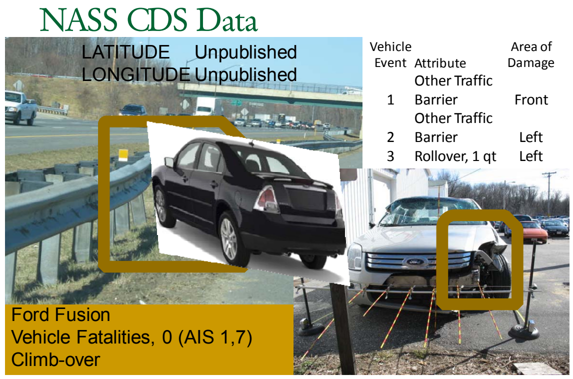

Figure 4: NASS CDS Digital Image Data Review.

As of 2007, crashes in which interaction with a ***relevant element*** occurred might have been appreciated through vehicle approach and detailed digital capture of the element. Although obscured by the sample image overlay in Figure 4, the guardrail deformation corresponding to the vehicle damage shown was matched to the post-crash vehicle image, to the left of Figure 4. The deformation corresponded to the vehicle hitting the guardrail and corroborated by the vehicle digital image. Additionally, further review might have been required to determine whether the planar capacity was within the bounds of retention in the travel direction, or whether the barrier contributed to the change in vehicle attitude, as suggested by the climb-over rollover type. In this case, however, vehicle technologies provided occupant protection. In the absence of any element of occupant retention, the outcome might have varied.

Limitation of FARS and NASS CDS

As seen in Figure 3, the overlay provided one possible representation of the vehicle events. Owing to the difference in timing between crash occurrence and digital image capture, important clues might have been lost or uncaptured. Further, Figure 3 suggested the identification of a classic problem: an inadequate connection of the stiffened guardrail transition elements to the bridge rail itself, but the evidence of an induced roll suggested that something upstream yielded too much allowing the vehicle to mount the barrier. With the limitations in coding and the non-temporal concurrence of the image, this was one of the theories that might accompany the proposed progression of events. In Figure 4, however, the timeline might have been such to capture damaged elements; however, the lack of scaling plagued most image review. The images might have been deemed for a qualitative review of the crash scene and the damaged elements but lack the detail or on-scene quality needed to assess barrier performance and vehicle interaction.

As with NASS CDS, NMVCCS provided valuable pictographic data with respect to type of hardware, interaction point with vehicle, damaged components, and complexity of damage. This information was envisioned to provide a micro view of the ***relevant elements*** populating the crash scene. With varied state reporting of roadway element inventories, providing a macro view of the overall roadway inventory, it has been difficult to understand the national roadway system, in terms of the placement and type of concrete barriers, guardrails, and impact attenuators. These, however, were better identified, predicated on digital image quality, as seen in Figure 5. For crash locations with the vehicle still at final rest, the ability to backtrack through the vehicle events has been facilitated. Not only has hardware been clearly identified but the condition of both the vehicle and hardware was better matched. Coded data and vehicle summaries provided the remaining interpretation clues necessary for translating most digital image data. Although some mystery still existed in these crashes, it transcended all understanding previously yielded through the near crash time or temporally non-current image data sets.

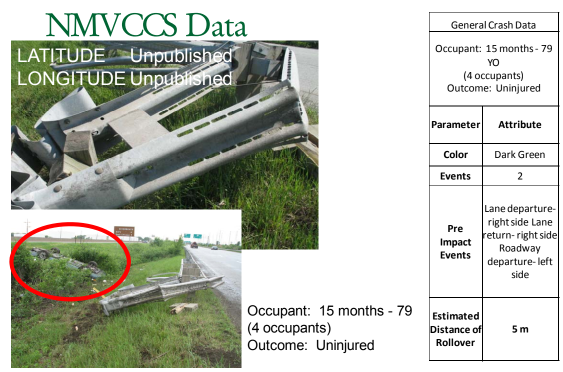

Figure 5: NMVCCS Digital Image Data Review.

The red circle in Figure 5 delineated the vehicle final rest, pursuant to a rollover crash involving a guardrail. The two-events, involved a planar interaction and a subsequent rollover crash. The digital image suggested a slotted kinking end terminal (SKT), designed to collapse. The rollover, however, might have been attributed to tire deflation or crash moment, as the vehicle moved toward the barrier. Although occupants were uninjured, it should be noted that not all occupant outcomes match this one. In fact, Figures 4 and 5 were selected owing to the clarity of the ***relevant elements*** rather than the vehicle damage and occupant outcomes. This was done to highlight the digital image data codification possibilities when assessing planar design capacity and rollover exigencies beyond envisioned design parameters.

Unlike the FARS and NASS CDS, the on-scene condition of the barrier yielded complementary coded elements and researcher enterprise in relating hidden information unaccommodated in the coded elements, as seen in Figure 6.

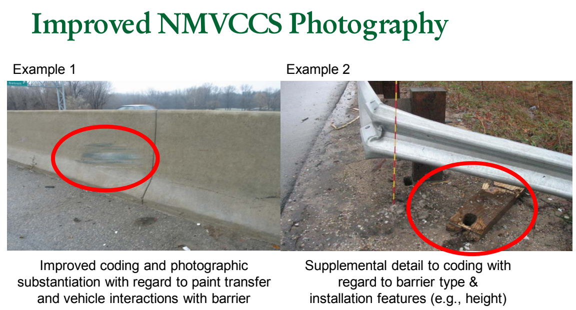

Figure 6: NMVCCS Available Digital Image Data.

Vehicle color reporting has been useful in reconstructing vehicle trajectory and understanding roadway element influence on vehicle damage and occupant outcome, as seen in Example 1. Although outside of the crash reporting norms, the vertical placement of vehicle damage measurement rod provided valuable information regarding guardrail height and damage location. The presence of measurement rods might be the only opportunity to obtain quantitative measurements of roadside hardware contained in the digital images, as related to the crash scene. True barrier height has become an area of interest, with variations pursuant to maintenance or roadside erosion. Another issue, absent from previous photographic and digital image capture and data collection, has been the constituent components of the ***relevant element***. The digital image capture yielded damaged components, whose shape and moisture seemed to be consistent with the digitally-captured crash scene.

NMVCCS Digital Image Data, Specific Examples and Improvements – Crash-Time versus Near Crash-Time and Non-Temporally Consecutive Data

Through the FARS feasibility study, relevant codified variables were identified. Additionally, variables of interest, but unavailable via forensic analysis were identified. As noted in Table 2, perfect information will never be available from data sets designed to address issues of public health and vehicle design, however, it has been shown that the data sets might be repurposed to yield valuable data to the roadside design community, unavailable to date.

Many but not all ***relevant element*** crashes were able to be identified as roadway departure crashes. It should be recalled that the roadway departure definition was prepared using FARS variables and adapted to the working roadway departure definition applied by FHWA, Office of Safety. To that end, the roadway departure definition was retained as an additional descriptor; however, the ***relevant element*** crashes were eligible from any rubric. The subsequent examples provided major ***relevant elements*** types identified in NMVCCS and yielded proposed variables and attributes readily extractable pursuant to digital image review of qualified crashes.

Example 1: Concrete Barrier

Figure 7 yielded information relevant to a single vehicle and single event crash, with possible injury as most serious injury reported for this vehicle per KABCO rating. The vehicle stayed on the roadway but left the original travel lane with concrete barrier impact. The path to final rest provides clues regarding its trajectory, toward the top of the image. The vehicle impact point was corroborated by light blue paint transfers, coded as the vehicle color. This was classified as a roadway departure, with fixed object. Although designed as temporary measures, concrete barriers have been retained tacitly as long-term roadway design elements, meriting additional consideration.

Figure 7: NMVCCS Trajectory and Impact Point, Concrete Barrier.

A FARS case would have relied on the geographical coordinates to identify the specific concrete barrier section. Further, an observational injury rating might have been obtained. The information relevant to path and trajectory, which might have been used to interpret the digital image, would have been very basic and not enjoyed the possibility of the vehicle final rest in the image. The limitations would have existed in the reconstruction of the crash events and the interpretation of crash scene digital image.

Example 2: Cable Barrier

Figure 8 yielded information relevant to a single vehicle and multiple event crash, with no reported injuries for this vehicle, per KABCO rating. The vehicle stayed in the original travel lane, as the cable barrier was contiguous to the roadway. The path to final rest provided clues regarding its trajectory, which were confounded owing to the presence of an object falling from a vehicle, precipitating the motion causing two subsequent barrier impacts. The barrier retained the vehicle in the travel direction, although rotating it to face traffic. Ultimately, the barrier impeded the departure on to the opposing roadway. The barrier was deemed to have performed as designed with the added benefit of no occupant injury and minimal vehicle damage. Again in this case, the paint transfer did not come into consideration. Instead, the depth of detail of the vehicle impact, with damaged guardrail support toward the top right of the image provided clues relevant to barrier durability, while performing as designed. This was classified as a roadway departure, with fixed object.

Figure 8: NMVCCS Trajectory and Impact Point, Cable Barrier.

FARS coders generally have categorized concrete barriers effectively, however, for barrier permutation; discernment varies by police officer and, ultimately, coder. The burden was somewhat eased by release of geographical coordinates. Until 2008, the engagement of the vehicle with a cable barrier would have been lost within an aggregated NASS CDS ***relevant element*** attribute, other barrier including guardrail, and possibly recounted in a crash summary. As there was no template for information included in the NASS CDS crash summary, this merely formed part of the universe of remote inclusion possibilities. This NMVCCS image allowed final rest point to retroactively reconstruct the crash events using objects contacted, and trajectories, compared with the digital image, yielding vehicle retention and damage information.

Example 3: W-Beam Guardrail

Figure 9 yielded information relevant to a single vehicle and multiple event crash, with no reported injuries for this vehicle, per KABCO rating. The vehicle departed the roadway, mounted the guardrail, dislodged and impacted a speed limit sign. Although a concept of the trajectory was available, it was evident that the addition of even one event introduced ambiguity, with regard to the influence of the ***relevant element***. This was tempered by the extreme improvement over roadside crash assessment, now available through the NMVCCS crash reporting. In this case, paint transfers were not visible, owing to the aspects offered through the digital image capture, obfuscated by the timing of vehicle removal and investigation conduct. This was classified as a roadway departure, with fixed object. The digital image suggested that a weak post system was in place owing to the accompanying guardrail deflection. The absence of reported injuries, also supported this contention, as the strong post and fixed guardrails were generally associated with higher injury severities (Ray, 2003). Additionally, it was surmised that insufficient entry speed was present, thereby retarding vehicle rollover.

Figure 9: NMVCCS Trajectory and Impact Point, W-Beam Guardrail.

Of interest in Figure 9 would be the orientation, generally absent from coding found in FARS. NASS CDS crash summary and scene diagram might have effectively conveyed this condition. Its role in the crash versus mitigation might have been lost within coded details. Digital image review was considered the only true means of gaining a qualitative understanding of this crash.

Example 4: Impact Attenuator

Figure 10 yielded information relevant to a multiple vehicle and multiple event crash, resulting in a non-incapacitating injury reported as most serious for the vehicle per KABCO rating. The vehicle departed the roadway. As in Figure 9, potential vehicle trajectories were available. Uncertainty was added with the presence of another vehicle. Owing to the severe deformation of the guardrail, paint transfers were not visible. The type of supports and their condition were readily evident in digital images other than those seen in final impact point image. Also, additional detailed digital images were provided in the case file, potentially supplementing the data shown in Figure 10. This was classified as crash type other or unknown, potentially owing to the limitation of translation of the FARS roadway departure data definition applied to NMVCCS variables .and attributes. The image suggested that the barrier performed as designed with the rails sliding back and managing energy by collapsing plastic cells and posts, as shown.

Figure 10: NMVCCS Trajectory and Impact Point, Impact Attenuator.

Even with detailed on-scene crash information, the presence of multiple vehicles and their subsidiary crash events, the crash scene was very complex. The digital images provided a plausible ordering for the coded elements, as well as chronicled the damage caused during this crash. This added level of detail would have been impossible to discern from FARS or NASS CDS, owing to the near crash or non-temporally concurrent data collection.

Discussion

Figures 7 through 10 illustrated the range of roadside data that might be identified by querying NMVCCS for ***relevant elements***. Through the feasibility study, a data set concept has been conceived. Additionally, the contribution to the roadway departure problem and the role of the ***relevant element*** in the crash might be better understood.

Through the FARS feasibility study, the ***relevant elements*** were identified through Google Earth image. These shaped the filter applied to NMVCCS data. All NMVCCS ***relevant element*** cases yielded acceptable digital images. This was understandable owing to the fresh crash scene and detailed digital image capture. This was in contrast to FARS with nearly 30 percent of unusable ***relevant element*** crash images. The digital image capture did vary in quality owing to the prevailing roadway traffic and investigation conditions.

With the feasibility study, the range of variables and attributes possible for collection have been identified. For clear and detailed images, the type of ***relevant element*** might be described. Further, the contact points might be described, coincident to the vehicle impacts. The role of the element might be identified as causal to the outcome or serving in designed capacity. In some cases, exceeded design parameters might be identified. This might be extended to the role of vehicle attitude in the performance of the ***relevant element***. Condition of the element might also be identified. In one case sample seen in the feasibility study, a measurement rod provided valuable information regarding guardrail placement. Some data might be readily coded from all crashes, while other attributes might be reserved for capture from the best images. A baseline of data capture does exist, as seen in the Figures 7 through 10.

The degree of detail might have been dependent upon prevailing roadway conditions, which precipitated digital image capture as the vehicle moved past the crash scene. This might not have yielded the most intricate clues but served to better define the ***relevant element*** type.

With codification parameters established through the FARS feasibility study, Google Earth images governed the non-temporally consecutive digital images, however, the stability in ***relevant element*** choice allowed for review to provide additional facets to roadway study. This was applied to NASS CDS and NMVCCS, in the absence of roadway location but benefiting from the descriptive image capture. As seen in the examples, additional micro information might supplement the findings from those states with roadway element inventories of comparable detail for a balanced macro view. In the absence of standardized state roadway inventories, the micro view will provide valid insights into damage-producing crashes.

Data available from digital image capture to determine ***relevant element*** effectiveness might be inadequate. With regard to the micro inventory approach inventory, the possibility of populating a detailed inventory of ***relevant elements*** and their crash parameter exists. These include but would not be limited to damage measurements, influence of speed, and description of model and type of selected roadway elements.

Opportunities

A thorough data mining of all the barrier impact cases in NMVCCS, and to a lesser extent, FARS and NASS CDS, using available data resources has been envisioned. This might yield several hundred cases that when stratified by type of barrier would potentially offer the safety community some new insights about such crashes and the influence of various factors. At minimum, the findings should support the knowledge yielded from crash testing and the limited extent of in-service roadway safety element evaluations that have been undertaken to date. This effort might be likened to one-time data capture of LBSS; however, any effort to review information might be suited to a searchable resource for future researchers. In light of the inconsistencies in state inventories and their associated crash experience, this micro approach has been suggested as a complement and a deepening of understanding beyond the macro state compilations. Although a mix of coded data and video logs has been employed, the micro repository might provide some nexus to the state offerings. Although efforts are underway to standardize state data inventories with the Model Inventory of Roadway Elements effort, the micro approach will provide data that is currently available and house results of immediate interest to the safety community.

Case Pool and Repository

The feasibility component has been completed for FARS crash years 2006 through 2009. In adherence to the roadway departure definition, application to crash years 2004 and 2005 will be undertaken, however, geographical location data has been made available for 2001 through 2003, also. NASS CDS digital image protocols seemed to improve in concurrence with the close of NMVCCS, in 2007. For that reason, 2007 through 2009 will be considered. Finally, all qualifying crashes will be included in the feasibility study. To date, the NMVCCS roadway departure classified crashes have been qualified for codification and work has started to qualify those crashes classified as other or unknown. A summary of the population from which the supplemental data set might be drawn is shown in Table 3.

It is noted that the film and digital crash images are not without limitations. This information does fill a void of identification and qualitative condition data. Refinements might be possible with respect to raw image files but limitations are outweighed by the wealth of previously unavailable data available for extraction from the images.

Table 3.
Data Sets, by *Relevant Element* Vehicle Impact Event and Attitude

Potential Crashes for Review				
Dataset	Years	Relevant Vehicles	Rollover among Relevant Cases	Relevant Vehicles to Total
NMVCCS	2005-2007	126,384 (439)	26% (20%)	3.1%
NASS CDS	2005-2009	1,542,633 (848)	16% (20%)	7.6%
FARS	2001-2009	794	45%	0.2%

Upon completion of the feasibility study, identifying candidate cases for digital image codification, data identified in the discussion will be codified to form a supplementary ***relevant element*** data set, as set forth in Appendix A, Figure A1, with possible augmentation in areas such as ***relevant element*** deflection. This would become the repository for data collected and described above. Such an inventory might be useful to State Departments of Transportation to identify successful applications, determine replacements, and design safer solutions.

Next Steps

The feasibility study was limited to impacts, easily discernible in digital images and relevant to the roadway departure community. Upon completion of this phase, the extension to review all roadside features, using digital image capture supplementation, was suggested. Further, extension of the study to review ***relevant element*** impacts occurring during any event during the crash rather than first event might be considered. Although the complication of multiple event crashes was noted in the NMVCCS Specific Examples, it was suggested that the condition of the guardrail, if captured would provide useful insight from an environmental condition rather than a vehicle damage perspective.

Potential Benefits to Safety Community

Ultimately, the data is envisioned to be made available to anyone interested in roadside safety. The dataset might also yield better understanding of crashes by vehicle attitude and crash mode. This is also foreseen to better explain the roadway departure definition by supplementing extracted graphic data. Each year, increased codified data drawn from compilation precedent will form a dataset from which answers might be drawn. Finally, synergies drawn from continued interagency cooperation will yield desired results by continuing to support the effort of the FHWA Roadside Departure Team and the safety community at-large.

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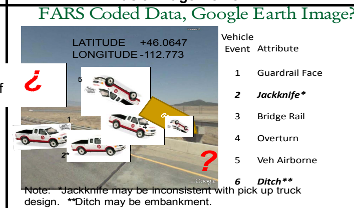
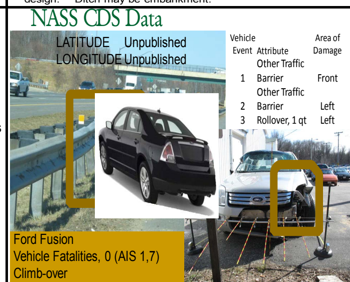
DISCLAIMER

Appendix A: Proposed Data Synthesis

Dataset	Years	Rationale	Basic Image Review	Composite Image Review	Anatomy of Data Synthesis
Fatality Analysis Reporting System	2004-2009	Original Application of Roadway Departure Definition		unavailable owing to non-temporal concurrence, image to crash	Query for relevant elements. Extract geographical coordinate and vehicle events Input geographical coordinates into Google Earth Scan yielded image(s) and place event(s) Develop trajectory scenario(s)
National Crashworthiness Sampling System Crashworthiness Data System	2007-2009	Photographic improvements made pursuant to NMVCCS data collection		unavailable owing to non-temporal concurrence, image to crash	Query for relevant elements. Scan image(s) and place event(s) Review images for researcher or police markings on elements. Review researcher crash summary. Develop trajectory scenario(s).
National Motor Vehicle Crash Causation Study	2005-2007	Dataset span owing to the on-scene data collection			Query for relevant elements. Scan image(s) and place event(s) Review images for researcher or police markings on elements. Review vehicle final rest images, when available. Review researcher crash summary. Develop trajectory scenario starting with vehicle final rest. Assemble images supporting final rest path and relevant impact.
Proposed Supplementary Dataset Variables and Attributes	2004-2009	Based upon review of FARS, NASS CDS, and NMVCCS photographs			Concatenate findings for all data sets. Note the data set and case number. Provide information, as data set and image permits.

Variables	Element	Perform,	Causal	Damage	Paint	Not required Element	Height, Element	Width, Element	Depth, Element	Attribute, Element
Attributes, for proposed Variables	Type	per Design	Damage	Type	Transfer	rod measure	with units	with units	with units	guardrail base
	concrete barrier, specify	redirect, planar	yes	scuff	yes, color	other, specify				damage height
	cable median barrier	exceeded design, planar	no	scrape	no					guardrail top
	W-beam barrier	exceeded design, rollover		paint transfer						debris, specify
	??			displace						
				dislodge						
				deform						

Figure A1: Proposed Dataset Extraction Schema, for Relevant FARS, NASS CDS, and NMVCCS Crashes