FEASIBILITY OF USING EVENT DATA RECORDERS TO CHARACTERIZE THE PRE-CRASH BEHAVIOR OF DRIVERS IN REAR-END COLLISIONS

Hampton C. Gabler
Virginia Tech
United States

John Hinch
U.S. DOT / National Highway Traffic Safety Administration
United States

Paper Number 09-0452

ABSTRACT

This paper investigates the feasibility of using event data recorders (EDRs) to characterize the crash avoidance behavior of drivers involved in rear end collisions. The study is based upon the records of 112 crashes from NASS/CDS 2000-2007 with associated EDR pre-crash data and of sufficient severity to deploy the frontal air bag. The study examined three factors affecting driver response to an impending rear collision: driver age, driver alcohol use, and road lighting condition. Crash avoidance actions of the drivers were inferred from the pre-crash EDR records of vehicle speed, throttle position, engine speed (RPM), and service brake status five seconds prior to impact. Factors considered included time of brake application prior to impact, peak braking deceleration, and the time history of throttle position. For these cases, this study combined EDR pre-crash records with NASS/CDS case records including scene diagrams and site photos to determine driver crash avoidance actions.

INTRODUCTION

Previous research on driver pre-crash behavior has relied heavily upon controlled driver testing or observation, e.g., as in a driving simulator (Lee et al, 2002) or naturalistic driving studies (Neale et al, 2005). Even when detailed crash reconstructions of real world crashes are conducted, there is significant uncertainty concerning the crash avoidance actions of the driver prior to impact. Event Data Recorders (EDRs) can provide a new tool to study this issue. Because current generation EDRs record up to five seconds of pre-crash vehicle data, these devices have the potential to provide important new insights into pre-crash driver behavior under real world crash conditions.

The focus of this study is on rear-end collisions. An accurate characterization of driver pre-crash actions in rear-end collisions is important in the design of collision-mitigation systems or radar braking systems. Although the study which follows examines rear collisions only, the study of many different collision modes could benefit from the use of EDR pre-crash records. Rear-end collisions have the advantage that this crash mode is readily defined. In addition, the typical crash avoidance maneuvers are braking and throttle reduction – both of which are recorded by current generation EDRs. Other crash modes, e.g. passing collisions or lane departure, could be examined in future studies as EDRs record other pre-crash parameters, e.g., steering inputs and yaw rates.

OBJECTIVE

The objective of this paper is to determine the feasibility of using EDRs to characterize the driver pre-crash behavior in rear-end collisions.

APPROACH

The study was based on cases extracted from the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) 2000-2007 with associated EDR data. The National Highway Traffic Safety Administration (NHTSA) now has the records of over 3,100 EDRs downloaded during NASS/CDS crash investigations. All cases were downloaded by NASS investigators in the field using the Bosch Crash Data Retrieval (CDR) system. The EDRs in this dataset were exclusively from General Motors (GM) cars and light trucks of model year 2000-2006.

The GM EDRs in our dataset recorded 5 seconds of pre-crash data in one-second intervals on vehicle speed, engine speed, engine throttle setting, and brake status. Vehicle speed is in units of miles/hour. Engine speed is in units of revolutions per minute (RPM). Engine throttle setting is reported in percent wide open throttle (% w.o.t). Brake status is limited to on or off, and does not record brake application force.

Composition of Data Set

This study included only EDR cases from GM vehicles in which the EDR recorded pre-crash data and the crash was of sufficient severity to deploy the frontal air bags. In GM EDRs, deployment of the air bag locks in the EDR data so that it can not be overwritten by subsequent events. The dataset was limited to rear-end collisions in which the subject vehicle was the striking vehicle. The resulting dataset contained 112 cases. Synopses of two of the cases in the dataset are presented below.

Example Case 1

Vehicle 1, a 2004 Buick LeSabre, was traveling south on a dry asphalt roadway during clear daylight conditions. Vehicle 2, a 2001 Buick Century, was traveling south in the first lane of the same roadway as vehicle 1. Vehicle 2 then changed lanes in front of vehicle 1 and attempted a left hand turn. The front of vehicle 1 contacted the rear of vehicle 2 causing moderate damage to both vehicles. Vehicle 1 was driven by an 18 year old with, according to the NASS case, no presence of alcohol. The vehicle scene is shown in Figure 1. The frontal damage to vehicle 1 and the rear damage to vehicle 2 are shown in Figure 2 and Figure 3.

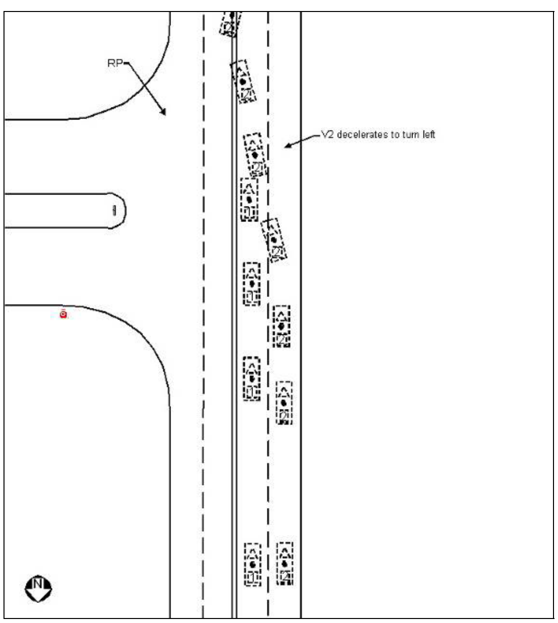

Figure 1. NASS/CDS Case 2004-12-081 scene

Figure 2. NASS/CDS Case 2004-12-081 frontal damage to Vehicle 1

Figure 3. NASS/CDS Case 2004-12-081 the rear damage to Vehicle 2

Both vehicles were towed from the scene of the crash due to damage. Both occupants were wearing their seat belts. Vehicle 1's EDR data are presented in Table 1.

Table 1. Striking Vehicle (V1) Pre-Crash EDR data (NASS/CDS Case 2004-12-081)

Time (sec)	Speed (mph)	Brake	Throttle (%wot)	Engine RPM
-5	55	OFF	6	1600
-4	55	OFF	6	1472
-3	55	OFF	0	1472
-2	55	OFF	0	1408
-1	55	OFF	0	1408

Based on the EDR data, the driver of V1 did not brake at any time. The engine RPM dropped slightly from 1600 RPM at 5 seconds before impact to 1408 at 1 second before impact. The vehicle speed was unchanged in the five samples of pre-crash data.

There was a possibility that the driver of V1 did not see V2 pull in front of their vehicle and stop.

Example Case 2

Vehicle 1, a 2000 Chevrolet Cavalier and Vehicle 2, a 1993 Plymouth Acclaim were traveling south on a four lane, undivided asphalt roadway in the passing lane with the Acclaim ahead of the Cavalier. Vehicle 2 was stopped waiting to make a left turn when the back of vehicle 2 was struck by the front of vehicle 1. The Cavalier was driven by a 44 year old male who attempted both steering and braking intervention prior to the impact. The impact resulted in air bag deployment. The crash scene is shown in Figure 4.

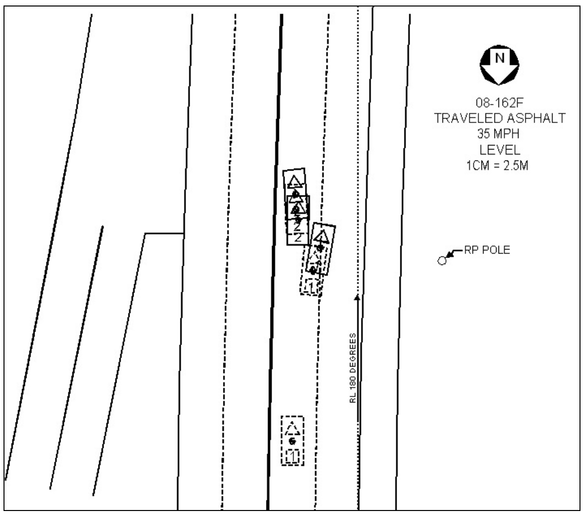

Figure 4. NASS/CDS Case 2004-08-162 scene

The frontal damage to the Cavalier and the rear damage to the Acclaim are shown in Figure 5 and Figure 6.

Figure 5. NASS/CDS Case 2004-08-162 frontal damage to Vehicle 1

Figure 6. NASS/CDS Case 2004-08-162 the rear damage to Vehicle 2

Both vehicles came to rest just a few feet south of the point of impact and both were towed from the scene due to damage. The driver of Vehicle 1 was using his seat belt. The EDR data is presented in Table 2 and graphically in Figure 7.

Table 2. Striking Vehicle (V1) Pre-Crash EDR data (NASS/CDS Case 2004-08-162)

Time (sec)	Speed (mph)	Brake	Throttle (%wot)	Engine RPM
-5	48	OFF	4	1728
-4	46	OFF	4	1664
-3	47	OFF	38	2624
-2	47	ON	4	1728
-1	17	ON	4	1024

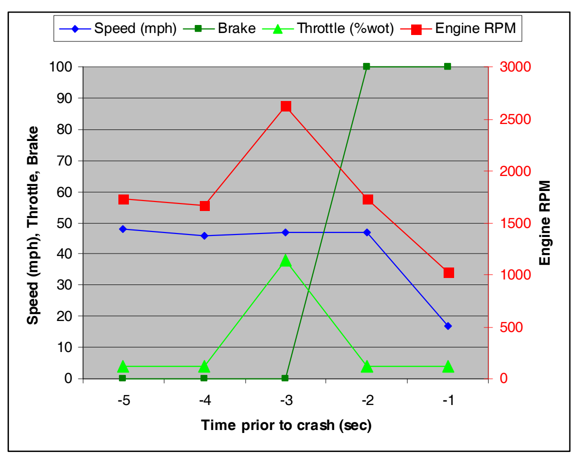

Figure 7. Striking Vehicle (V1) Pre-Crash EDR data (NASS/CDS Case 2004-08-162)

Based on EDR data, the driver of V1 first undertook crash avoidance actions about 2 to 3 seconds prior to the crash. Note that at 3 seconds before impact, the driver appeared to have stepped on the accelerator although this resulted in only a negligible increase in speed. At about 2 seconds prior, the driver applied the vehicle service brake, which significantly slowed the vehicle.

Factors expected to affect pre-crash driver behavior

This study examines the crash avoidance actions of drivers just prior to a rear-end collision. The specific parameters of interest are the time prior to collision at which the driver took one of two actions: braking or release of the throttle. Other crash avoidance actions, e.g. lane changing or swerving, are also possible. However, these actions are not recorded by most current generation EDRs.

We hypothesize that a number of driver or environmental factors could affect the time a driver requires to react to an impending rear-collision. This paper examined driver age, driver alcohol involvement and road lighting. Driver age was disaggregated into three groups: teens (13-19 years old), adults 20-64 years of age, and older drivers 65 years or older. A driver was designated as alcohol involved if (a) driver blood alcohol concentration was not zero or (b) if the police accident report indicated that the driver was drinking. It is expected that this method will miss a small number of drivers who had been drinking. But as our dataset was composed predominantly of non-drinkers (over 90%) this error is not expected to greatly affect our results. Lighting condition of the highway was divided into two groups: daylight crashes and non-daylight crashes. Non-daylight crashes included crashes on dark, but lighted, highways, dark unlighted highways, and crashes at dark or dusk.

Driver Pre-crash actions

The EDRs in our dataset recorded five seconds of pre-crash data prior to impact in one second increments. The EDRs did not record pre-crash data at or just prior to the time of impact. Data for the following vehicle parameters was available: (1) status of the brake (on/off), (2) percent throttle, (3) engine speed (RPM), and (4) vehicle speed (mph). These parameters were only available on GM vehicles for vehicles from approximately model year 2000 onward. Older EDRs did not record pre-crash data.

As markers of when the driver began to attempt to avoid an impending crash, we computed the first time during this 5 second pre-crash interval that the brake was applied, and the time at which the driver removed his/her foot from the accelerator and in turn decreased the engine throttle. This calculation includes both those drivers that took crash avoidance actions and those that did not as reported by the EDR.

It should be noted that these markers are estimates of the time when a driver took crash avoidance action. Because EDR pre-crash data is captured at the relatively slow rate of one sample per second, driver actions taken between samples will not be measured until the pre-crash parameters are read one second later. These pre-crash parameters are not measured synchronously (Chidester et al, 1999). Also, their time of measurement may differ from the timing indicated in the Bosch CDR download (Wilkinson et al, 2006). In this study, we assume that the average of many cases will approach a 1 second interval between measurements.

The time of first brake application was defined to be that time when the brake transitioned from brake-off to brake-on. EDR records of the time of first brake application could range from -5 to -1 seconds prior to collision. If the EDR had no record of driver brake application, our analysis arbitrarily set the brake application time to 0 seconds. The time of throttle release was defined to be that time when the percent throttle equaled zero after being non-zero at the previous time step. The EDR record of the time the throttle was released prior to collision could range from -5 to -1 seconds. If the EDR had no record of throttle release, the time of throttle release was arbitrarily set to 0 seconds. In some cases, the throttle was zero throughout the entire 5 second pre-crash interval. The throttle release time for these cases was arbitrarily set to -5 seconds. The period of non-throttle use may have been longer, but the EDR would not include a record earlier than -5 seconds. The average response time for braking or throttle released was computed for each group. NASS/CDS weights were applied in the computation of all averages to provide a national estimate of driver response to rear collisions.

GM EDRs only indicate whether the service brake has been applied rather than brake application force. For this study, brake application force was estimated from the pre-crash time history of vehicle speed. Maximum brake deceleration in G's was computed using the maximum ΔV in one second. The EDR records wheel speed not the actual vehicle speed. Cases in which the brakes appeared to lock-up, e.g. from braking on ice or gravel, were omitted from the analysis as vehicle speed is incorrectly recorded in these cases. In some cases, the brake and throttle were applied simultaneously. Our method made no compensation for the engine throttle.

RESULTS

Table 3 shows the distribution of cases by driver age, driver alcohol involvement and lighting condition.

Table 3. Composition of the Data Set for Rear-End Collisions with Pre-Crash EDR Data from GM MY 2000+ vehicles (NASS/CDS 2000-2007)

Variable		Raw Number of Cases	Weighted Number of Cases
All		112	50,762
Driver Age			
	13-19 yrs	19	4,131
	20-64 yrs	77	36,698
	65+ yrs	14	9,645
	Unknown	2	288
Alcohol			
	Not Drinking	100	48,779
	Drinking	12	1,983
Lighting Condition			
	Daylight	72	36,641
	Not Daylight	40	14,121

Figure 8 and Figure 9 present the distribution of times for first brake application and throttle release. On average, the drivers in our dataset first applied the brakes on average 1.7 seconds prior to impact. On average, drivers released the throttle 2.1 seconds prior to impact. For over 20% of drivers, the EDR contained no record of brake application prior to impact. For approximately 30% of drivers, the EDR record did not contain any evidence that the throttle was released prior to impact.

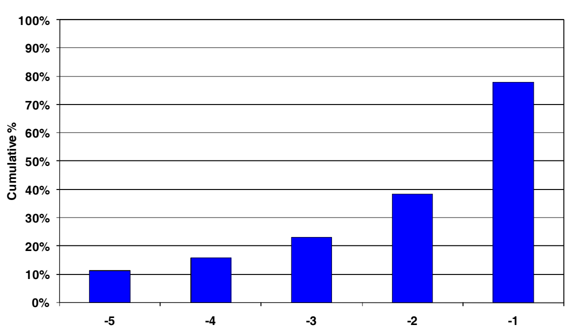

Figure 8. Cumulative percent of drivers applying brakes as a function of time to collision (NASS/CDS 2000-2007, GM MY 2000+ vehicles)

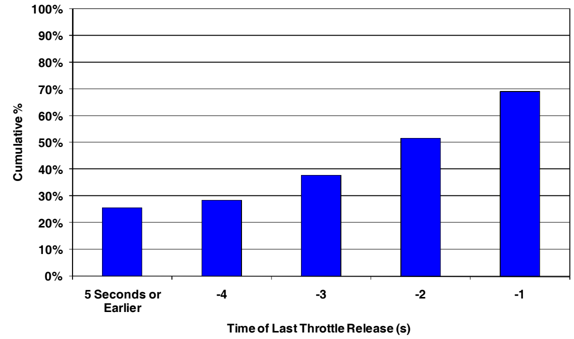

Figure 9. Cumulative percent of drivers releasing the throttle by time to collision (NASS/CDS 2000-2007, GM MY 2000+ vehicles)

Effect of Driver Age

Figure 10 presents the influence of driver age upon the average time of brake application for drivers who struck another vehicle in a rear-end collision. Reaction time clearly declines with driver age. Older drivers 65 years and older were the slowest drivers to respond to an impending rear-end collision. Teen drivers, despite being the least experienced drivers, were the quickest to apply brakes. On average, teens applied the brakes 2.2 seconds prior to impact whereas older drivers delayed until 1 second prior to impact to apply the brakes.

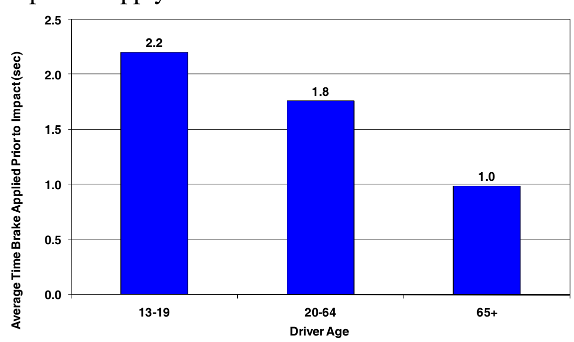

Figure 10. Average time of brake application prior to rear-end collision as a function of driver age (NASS/CDS 2000-2007)

By contrast, there was little difference in the time at which the throttle was released between the three age groups as shown in Figure 11. On average, all three groups of drivers released the throttle approximately 2 seconds prior to impact.

The number of drivers who took no evasive action varied by age group. 16% of teen drivers never applied the brakes whereas nearly 30% of drivers 65 years and older did not apply the brakes. Approximately 30% of drivers of all age groups either did not release the throttle or released the throttle within 1 second of impact. Note that these figures are based on a small number of cases (19 teen drivers, 77 adult drivers, and 14 older adult drivers), and should be revisited when larger data sets are available.

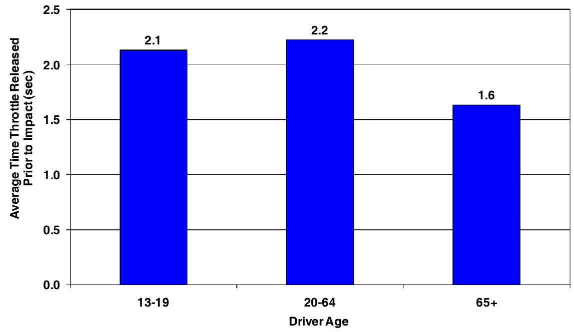

Figure 11. Average time of throttle release prior to rear-end collision as a function of driver age (NASS/CDS 2000-2007)

As shown in Figure 12, younger drivers applied the brakes with greater force than did older drivers. Average maximum vehicle deceleration for younger drivers was 0.61 G, but was only 0.16 G for drivers 65 years and older. For purposes of comparison, normal braking decelerations are typically 0.20-0.25 Gs. It is unknown if this age difference is due to a overreaction by younger drivers or a lack of strength by older drivers. One limitation of this calculation is that the EDRs in our dataset did not have the ability to measure deceleration in the final second preceding impact. Because older drivers did not apply brakes until approximately one second before impact on average, this limitation may have led to an underestimate of the braking level applied by this category of drivers.

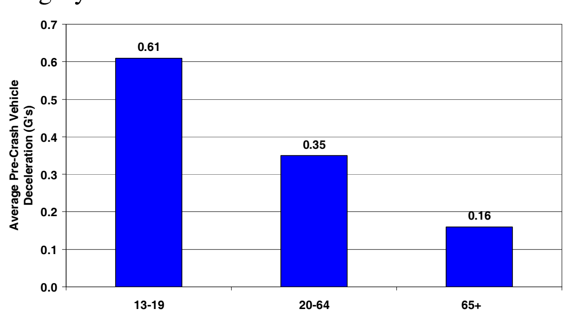

Figure 12. Average pre-crash vehicle deceleration prior to rear-end collision by driver age (NASS/CDS 2000-2007)

Effect of Driver Alcohol Involvement

Figure 13 and Figure 14 show the effect of alcohol-involvement upon driver rear-end collision avoidance actions. On average, alcohol-involved drivers reacted substantially slower to an impending crash than did drivers without alcohol involvement. Drivers without alcohol involvement applied their brakes an average of 1.7 seconds prior to impact while drivers with alcohol involvement delayed until 0.7 seconds prior to impact.

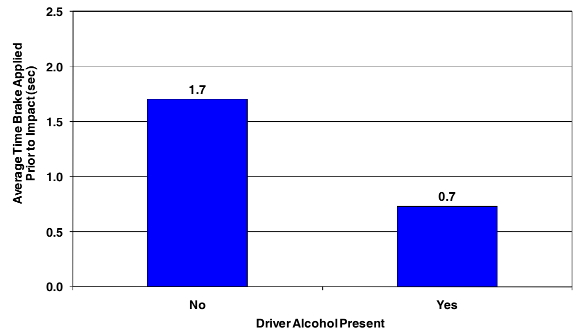

Figure 13. Average time of brake application prior to rear-end collision as a function of driver alcohol use (NASS/CDS 2000-2007)

As shown in Figure 14, drivers with alcohol involvement were similarly slower to respond to an impending collision by releasing the throttle. Drivers without alcohol involvement released the throttle, on average, 2.2 seconds prior to impact whereas drivers with alcohol involvement released the throttle only one second prior to the collision. 36% of drivers with alcohol involvement did not release the throttle or released the throttle within 1 second of impact. For drivers with alcohol involvement, 31% of drivers did not apply the brakes prior to the rear-end collision.

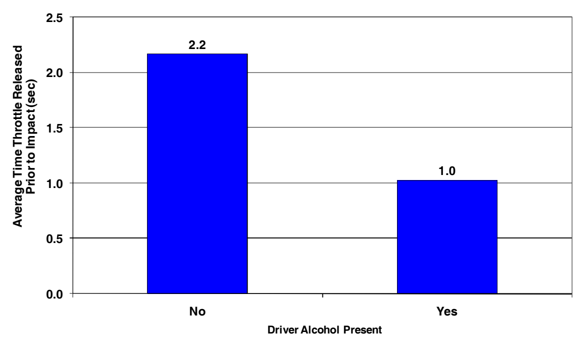

Figure 14. Average time of throttle release prior to rear-end collision as a function of driver alcohol use (NASS/CDS 2000-2007)

Note that these figures are based on a small number of cases (110 drivers without alcohol involvement and 12 drivers with alcohol involvement), and should be revisited when larger data sets are available.

Effect of Roadway Lighting Condition

Figure 15 and Figure 16 examine how driver crash avoidance actions are affected by highway lighting conditions. Drivers in daylight were quicker to apply the brakes (1.9 seconds prior to impact) than drivers in non-daylight conditions brakes (1 second prior to impact). By contrast, there was little difference in the time of throttle release. On average throttle release occurred approximately 2 seconds prior to collision regardless of lighting condition.

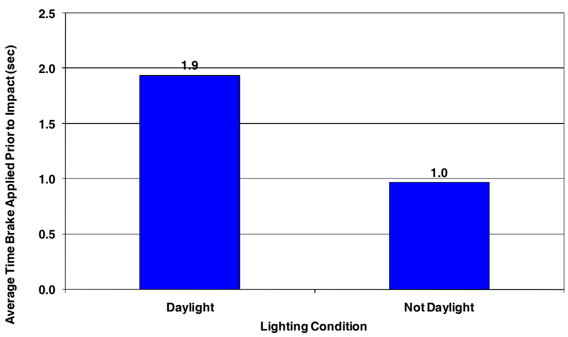

Figure 15. Average time of brake application prior to rear-end collision as a function of highway lighting condition (NASS/CDS 2000-2007)

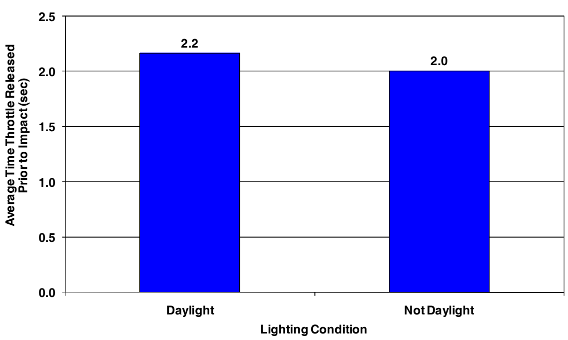

Figure 16. Average time of throttle release prior to rear-end collision as a function of highway lighting condition (NASS/CDS 2000-2007)

The fraction of drivers who took no evasive action by brake application or throttle release was a strong function of lighting condition. In daylight, only 13% of drivers failed to apply the brakes prior to impact. In contrast, nearly half (46%) of drivers in non-daylight conditions did not apply the brakes before impact. Likewise, almost half (43%) of drivers operating at night did not release the throttle or released the throttle within 1 second of impact, as compared to 27% of drivers operating in daylight.

LIMITATIONS

This study has a number of limitations summarized below:

- The study was based on a limited dataset. The findings of this study should be revisited when a larger EDR dataset is available. Our study provides numeric estimates of the delays in crash avoidance actions caused by these factors. Nevertheless, the results presented here should be viewed primarily as the trends that will be observed when this method is applied to a larger dataset.
- The dataset was composed exclusively of GM cars and light trucks. It is not known how the results generalize to drivers of other vehicles.
- The GM precrash EDR data used in this study is sampled at the relatively slow rate of once per sample. Hence, the recorded time of driver actions may be delayed by up to one second. This limitation will be improved upon implementation of NHTSA Rule 563 [NHTSA, 2008] which requires that precrash data to be recorded at one sample per 0.5 second.
- In addition, the GM precrash EDR data used in this study is not sampled precisely at 1 second intervals. In this study, we assume that the average of many cases will approach a 1 second interval between measurements.
- There may be cross-interactions between the factors which control rear-end collision avoidance actions. For example, alcohol involved drivers may preferentially drive at night. Because of the small dataset, the magnitude of these interactions could not be determined.
- The analysis of driver actions which affect driver reaction time to an impending rear-end collision did not consider road conditions which may have obscured the struck vehicle. A more complete analysis with a larger dataset should also consider the effect of road curvature, glare, hillcrests, and other conditions which could obscure the road and ahead.
- Braking deceleration levels were computed based on vehicle pre-crash speed. Because the last speed recorded by EDRs is at one second prior to impact, brake deceleration level could not be estimated during the one second prior to impact. In some cases, the braking force applied in the final second may have exceeded the peak deceleration computed earlier in the event, and would cause peak deceleration to be underestimated.

CONCLUSIONS

This paper has investigated the feasibility of using EDRs to characterize the driver pre-crash behavior in rear-end collisions. The study has examined the influence of driver age, driver alcohol involvement and the lighting condition of the highway the time required by a driver to react to an impending rear-collision.

- Time of first brake application slows with driver age. The older drivers in our sample were slower to apply brakes than all other drivers (1 second prior to impact). Teen drivers were the quickest to apply brakes (2.2 seconds prior to impact). Teen drivers also applied the brakes with greater force than did older drivers (0.6 G vs. 0.1 G's). Driver age had little influence on the time that the throttle was released.

- Drivers who had used alcohol were substantially slower to take crash avoidance actions than non-drinkers. Alcohol usage delayed both brake application and throttle release.

- Brake application was slower at night than during daylight presumably because the vehicle ahead was more difficult to see. Lighting conditions did not however change the time of throttle release.

This study has shown the potential of using EDR pre-crash records to determine how the timing of crash avoidance actions is affected by both driver condition and the state of the environment. Although the study focuses exclusively on rear-end collisions, the study of many different collision modes could benefit from the use of EDR pre-crash records.

REFERENCES

1. Chidester A, Hinch J, Mercer TC, Schultz KS, "Recording Automotive Crash Event Data", National Transportation Safety Board (NTSB) International Symposium on Transportation Recorders, Washington, DC (1999)
2. Lee JD, McGehee DV, Brown TL, & Reyes ML Collision warning timing, driver distraction, and driver response to imminent rear end collisions in a high-fidelity driving simulator. Human Factors, 44(2), p. 314-334 (2002)
3. Neale VL, Dingus TA, Klauer SG, Sudweeks J, Goodman M, "An Overview of the 100-Car Naturalistic Study and Findings" Proceedings of the 19th International Technical Conference of the Enhanced Safety of Vehicles, Paper Number 05-0400 (2005)
4. Wilkinson CC, Lawrence JM, Heinrichs BE and King DJ, "The Timing of Pre-Crash Data Recorded in General Motors Sensing and Diagnostic Modules", SAE Paper 2006-01-1397 (2006)
5. NHTSA Final Rule on Event Data Recorders, 49 CFR Part 563 (2008)