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Method for Estimating Time to Collision at Braking in Real-World, Lead Vehicle Stopped Rear-End Crashes for Use in Pre-Crash System Design

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ABSTRACT

This study presents a method for determining the time to collision (TTC) at which a driver of the striking vehicle in a real-world, lead vehicle stopped (LVS) rear-end collision applied the brakes. The method employs real-world cases that were extracted from the National Automotive Sampling System / Crashworthiness Data System (NASS / CDS) years 2000 to 2009. Selected cases had an Event Data Recorder (EDR) recovered from the striking vehicle that contained pre-crash vehicle speed and brake application. Of 59 cases with complete EDR records, 12 cases (20%) of drivers appeared not to apply the brakes at all prior to the collision. The method was demonstrated using 47 rear-end cases in which there was driver braking. The average braking deceleration for those cases with sufficient vehicle speed information was found to be 0.52 g's. The average TTC that braking was initiated at was found to vary in the sample population from 1.1 to 1.4 seconds. As more automakers provide commercial tools to retrieve their EDR data, this method can be employed to evaluate TTC in real-world crash situations. This is especially pertinent to the design of crash mitigating components of PCS (i.e. brake assist and automatic braking) that rely on driver reaction in crash imminent situations.

INTRODUCTION

Rear-end collisions, when one vehicle's front strikes another vehicle traveling in the same direction as the striking vehicle, are a frequent and costly collision mode. Rear-end collisions accounted for 23% of all frontal towaway crashes in the U.S. from 1997 to 2008 [1]. Furthermore, rear-end collisions in the year 2004 were associated with over 25.7 billion U.S. dollars in medical costs and property damage [2]. The struck vehicle in a rear-end collision can either be stopped, moving at a lesser speed, or decelerating with respect to the striking vehicle. Of all rear-end collisions, approximately two-thirds are collisions that involve the lead vehicle being stopped, such as a vehicle struck while stopped at an intersection.

An active safety countermeasure that has been developed recently is Pre-Crash Systems (PCS). This class of active safety system utilizes millimeter wave radar to track vehicles and objects in front of the equipped vehicle. PCS aims to both prevent and mitigate crashes. When the system determines a collision threat is credible, it can warn the driver through audio, visual, and/or tactile means, pre-charge the brakes to assist the driver when he or she starts to brake, or brake automatically even if there is no driver input. Most PCS use the instantaneous time to collision (TTC) to evaluate collision risk. TTC is the ratio of instantaneous range to range rate. If both vehicles continued traveling at the same constant speeds they were traveling when TTC is measured, the collision would occur after a time of TTC.

An essential factor in the design of PCS is the time at which the components activate. To avoid nuisance, or false positive, system activation these systems are designed to deploy only when a collision is imminent. Designers of PCS must balance avoiding nuisance activations with allowing sufficient time to activate the system in emergency situations. To design the activation timing of the components of PCS, the way in which drivers react to imminent collisions must be understood. This is most often evaluated by using driving simulators or actual driving trials in controlled environments on test tracks [3]. The warning component of PCS aims to warn the driver close to the last point where corrective action could avoid the collision. The brake assist and automatic braking components, however, are meant to mitigate the severity of a collision, activating only when the collision is unavoidable.

Little is known about driver pre-crash maneuvers in real-world driving situations. Because of safety concerns, it is often not feasible to observe driver behavior in collision imminent situations in test track studies. One promising method to study driver pre-crash behavior in real-world crashes is with data retrieved post-crash from Event Data Recorders installed in many late model passenger vehicles. EDRs are typically a component of the vehicle's airbag control module and can record information related to a collision event. Data such as vehicle change in velocity, airbag deployment timing, and system diagnostics are often stored in the memory of the EDR. Currently, there is a publically available EDR data retrieval tool to recover and decode Ford, General Motors (GM), and Chrysler EDRs. Some GM EDR modules, also referred to as sensing and diagnostic modules (SDM), contain information about the driver's pre-crash maneuvers. The vehicle speed, throttle pedal application, and engine speed can be recorded for up to 5 seconds prior to the collision. Brake application can be recorded up to 8 seconds prior to collision. All pre-crash data are recorded at one second intervals prior to the collision.

Figure 1 shows the pre-crash maneuvers from the driver of a 2002 Chevrolet S-10 pickup involved in a rear-end collision (NASS / CDS case 2006-74-098). The driver of the S-10 approached stopped traffic on an interstate highway. On approach, the vehicle was traveling at approximately 55 mph. Two seconds prior to the impact, the driver applied the brakes, slowing the vehicle. The time reported in Figure 1 is the time prior to the airbag control module algorithm enable (AE) as recorded on the EDR. This algorithm monitors vehicle acceleration to determine when the airbag will fire. The time of AE will be slightly after the collision begins; however, this difference is small compared to the rate at which pre-crash data is sampled.

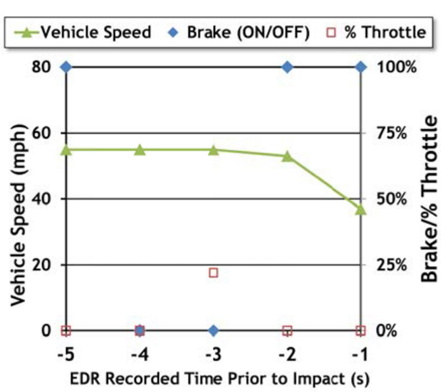

Figure 1. Pre-crash Maneuvers Recovered from Event Data Recorder of a 2002 Chevrolet S-10 Involved in a Rear-end Collision (NASS / CDS 2006-74-098).

OBJECTIVE

The objective of this study is to develop a method to estimate at what time to collision (TTC) drivers involved in lead vehicle stopped rear-end collisions started to brake using event data recorder (EDR) pre-crash data.

METHODOLOGY

CASE SELECTION

Real-world collisions were extracted from the National Automotive Sampling System, Crashworthiness Data System (NASS / CDS) years 2000 to 2009. NASS / CDS is a U.S. Department of Transportation sponsored, nationally representative survey of minor to severe collisions that occur throughout the U.S. Investigation teams located in urban, rural, and suburban regions of the country investigate approximately 5,000 collisions annually. This detailed investigation includes visiting the scene of the accident, conducting interviews with the occupants, retrieving medical and police records, and measuring damage to the vehicles. Collisions are required to involve at least one passenger vehicle and have at least one vehicle towed from the scene due to damage.

Selected cases involved a striking vehicle in a lead vehicle stopped (LVS) rear-end collision that had a recovered EDR that included pre-crash maneuvers. Pre-crash scenarios were determined by a method adapted from Eigen *el al* that examines variables related to maneuver, critical event, and accident type as coded in NASS / CDS [4]. In addition, the first harmful event in selected cases resulted in frontal damage to the striking vehicle. Only cases of sufficient severity to deploy the frontal airbags were included in the dataset. GM EDRs can store both non-deployment and deployment events, however only deployment events are locked into the memory of the EDR after the crash. Cases that contained only a non-deployment event were not used because it can be unclear if the non-deployment event was related to the collision or possibly secondary events after or before the collision. Because this study aimed at looking at maneuver behavior of a normal driving population, drivers with evidence of alcohol consumption were excluded. Vehicles that were not tracking prior to the collision (i.e. skidding) were also excluded as vehicle speed is measured from wheel speed sensors. National weighting factors from NASS / CDS, developed to weight individual cases to create a nationally representative sample, were used.

ESTIMATING TTC AT BRAKING ONSET

TTC is the instantaneous ratio of range to range rate. Figure 2 shows a schematic of vehicle position and speed of the striking vehicle in a lead vehicle stopped rear-end collision. When the driver applies the brakes to avoid a collision, the vehicle is traveling at a speed of $V_{1,0}$ and is a distance of L_0 from the stopped struck vehicle. Because the struck vehicle is stopped, the range rate is equal to the speed of vehicle one.

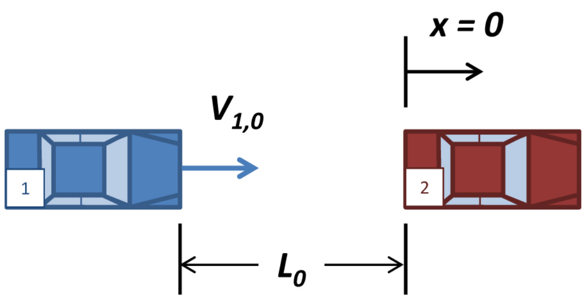

Figure 2. Schematic of Vehicle Speed and Position at the Time of Brake Initiation in a Lead Vehicle Stopped, Rear-end Collision.

The TTC at brake initiation is thus,

$$TTC = \frac{L_0}{V_{1,0}} \quad (1)$$

The velocity in equation 1 is evaluated as the vehicle speed at the time when braking began. The initial range at that same point in time is estimated by assuming a constant vehicle deceleration, a, during the braking time. For constant braking deceleration, the position of vehicle 1, x, is

$$x = -L_0 + V_{1,0}t - \frac{1}{2}a\,t^2 \quad (2)$$

where t is the time after braking started and a is the magnitude of deceleration. The delay of the brake system activation is assumed to be negligible. Substituting equation 1 into equation 2 at the time prior to the impact when braking initiated, t_s, yields an expression for TTC:

$$TTC = t_s - \frac{1}{2V_{1,0}}at_s^2 \quad (3)$$

DETERMINING AVERAGE DECELERATION

Average deceleration was found by determining the slope of the vehicle speed during the recorded braking period. Figure 3 shows the schematic of a sample vehicle speed recorded by the EDR. Most vehicles involved in a rear end collision maintain a nearly constant speed before applying the brakes prior to the collision. If the braking period was greater than 1 second, the first and last point during the braking period was used to capture an overall average deceleration. The average braking can be found by

$$a = \frac{V_0 - V_f}{\Delta t} \quad (4)$$

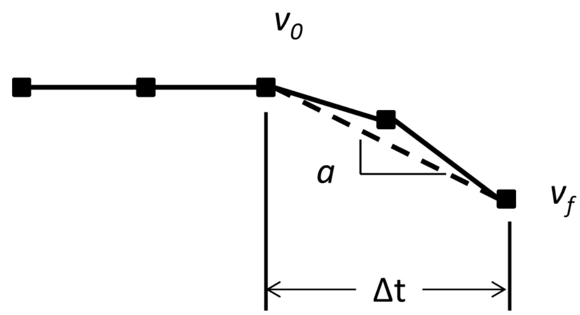

Figure 3. Schematic of Average Vehicle Deceleration during a Braking Event.

Determining when the driver started to brake is a difficult task due to the low time resolution of the data stored in the EDR and otherwise collected by investigators in NASS / CDS. Pre-crash data in GM EDRs is recorded once every second prior to impact. Furthermore, it has been shown that the recorded time on the EDR could have actually occurred up to 1.5 seconds closer to the impact [4-5]. For example, the vehicle speed recorded at three seconds prior to impact could have actually occurred 1.5 seconds prior to the impact. On average, the pre-crash data occurred on the order of 0.5 seconds closer to AE than indicated by the EDR.

Using traditional techniques the investigators in NASS / CDS cases attempt to determine the driver's avoidance maneuver prior to the collision. This is done either through interviews with the driver or examination of the crash scene. Therefore, this information may not be available or accurate in all cases and does not provide any information about the magnitude of the pre-crash braking. The pre-crash EDR data, even at low resolution, provides key insights into driver behavior not available from traditional crash reconstruction methods.

To determine the brake application timing in selected cases, three factors were examined: 1) the pre-crash vehicle speed history, 2) the pre-crash brake history, and, if the pre-crash EDR data was inconclusive, 3) the driver pre-crash maneuver as coded by the NASS/CDS investigator. Figure 4 shows just the pre-crash brake application and vehicle speed for the driver of the Chevrolet S-10 in NASS / CDS case 2006-74-098. Although brake switch status was recorded for eight seconds prior to impact, only five seconds is shown here. All eight seconds of brake switch data was analyzed. The vehicle maintained a constant speed of 55 mph five to three seconds prior to impact. At two seconds prior to impact the vehicle speed dropped to 53 mph and then again to 37 mph one second prior to collision. The deceleration of the vehicle from three seconds prior to two seconds prior to impact was most likely due to the release of the throttle pedal, which was last seen to be applied three seconds prior to impact. Therefore, from examining vehicle speed, the driver started to avoid the impending collision by braking approximately two seconds prior to impact. The vehicle's pre-crash braking was defined as the time prior to the impact that the brake was applied continuously until the end of the pre-crash record. In this case, both the vehicle speed and brake application agree. However, this is not always the case. The average braking deceleration was found using equation 3 to be 0.73 g's.

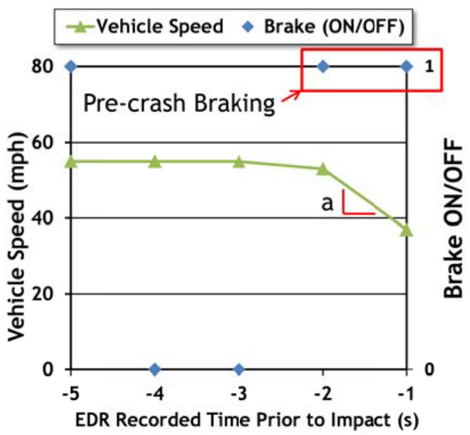

Figure 4. Pre-crash Brake Application and Vehicle Speed for Striking Vehicle in NASS / CDS 2006-74-098

Most, but not all, cases follow this pattern. For example, the brake application and vehicle speed for the striking vehicle, a 2000 Buick Regal, in NASS / CDS case 2005-09-70 is shown in Figure 5. The driver in this crash applied the brakes for the five seconds prior to the impact. However, the vehicle slowed from 98 mph to 96 mph from five to four second prior to impact, followed by 96 mph to 89 mph. Three seconds prior to impact the vehicle slowed from 89 mph to 53 mph one second prior to impact. This last segment was taken to be the braking period, as this was the point where the driver most likely started to take emergency evasive action. The average deceleration during this period was 0.82 g's.

For selected cases the vehicle speed was examined to find the first time when the speed dropped by more than 2 mph. A 2 mph drop in 1 second is a 0.09 g deceleration, which is well below the magnitudes seen in typical emergency braking. Also, if there was weak braking followed by harder braking, the later period of harder braking was used to compute average deceleration and TTC. This result was then compared to the pre-crash braking and adjusted if needed. Because of the differing nature of rear-end collisions, no one algorithm could determine the most likely start of braking in all cases. The pre-crash braking was used exclusively in cases that had no drop in speed that was greater than 2 mph.

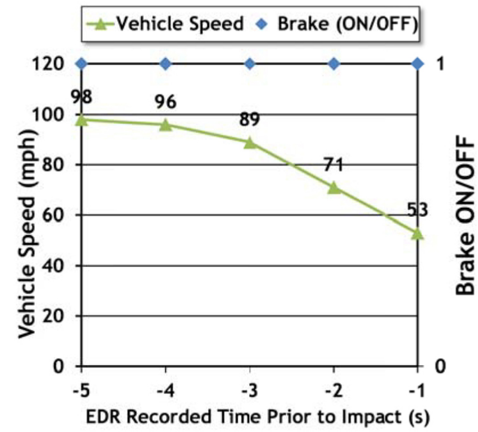

Figure 5. Pre-crash Brake Application and Vehicle Speed for Striking Vehicle in NASS / CDS 2005-09-070

In many cases the driver applied the brakes one second or sooner to impact. In these cases, the brake switch status one second to impact may be "ON," yet no vehicle deceleration would be observed in the vehicle speed. Still another case is that there was no braking recorded by the EDR but NASS / CDS investigators found that the driver had applied the brakes. In these cases, the braking timing was assumed to be one second prior to impact. For cases determined to include last second braking, the braking deceleration was set equal to the average braking deceleration for drivers who started to decelerate 2 seconds prior to the collision, the last EDR recorded time TTC could be computed at. In general, the closer to the collision the brakes were applied, the greater the braking magnitude was observed. Thus, the braking decelerations of drivers who brake far before the collisions were excluded from this average. Any cases that had no recorded braking on the EDR and were coded as having no pre-crash maneuver were excluded.

ACCOUNTING FOR UNCERTAINTY IN EDR RECORDING TIME

The EDR records pre-crash maneuvers of the vehicles every second leading up to the algorithm enable (AE). However, the time prior to AE recorded on the EDR has been found to not correspond to the actual time prior to AE [5]. Wilkinson *et al* found that the time recorded in the pre-crash EDR record actually occurred between 0.3 and 1.5 seconds closer to the collision than recorded [6]. Although the airbag control electronic control unit (ECU) samples at a much greater rate, the EDR records the pre-crash data in a circular buffer every 1 second, overwriting the oldest data point as a new one is received. If a crash occurs after a data point has been recorded but before the next data point is recorded, the time to AE recorded on the EDR will not be the true time to AE, shown schematically in Figure 6. For example, vehicle speed that is recorded on the EDR as occurring 2 seconds prior to AE actual could have occurred between 2 and 1 second prior to AE. In addition, the airbag ECU receives sensor information for the pre-crash record from different ECUs in the vehicle. For example, the vehicle speed is taken from a wheel speed sensor that is part of the powertrain ECU. Thus, it has been speculated that there can be time delays between when the EDR requests pre-crash vehicle information and when it receives it.

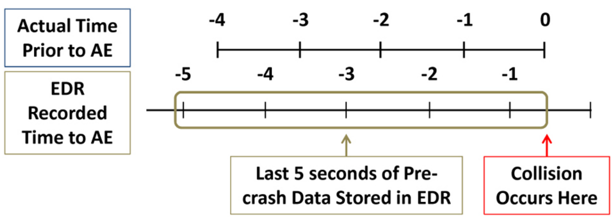

Figure 6. The Difference between the EDR Recorded Prior to AE and the Actual Time Prior to AE.

Because the pre-crash data recorded on the EDR can actually occur closer to the collision than recorded, it is likely that the actual time that braking started may vary from the value recorded by the EDR. To account for this discrepancy, all of the EDR pre-crash data was shifted forward by 0.5 seconds, the average time deviation found by Wilkinson *et al.* This 0.5 second shift toward the start of the collision was considered the nominal event timing. Upper and lower bound estimates of TTC were found by using the EDR recorded pre-crash time and shifting the time 1.0 seconds toward the collision, respectively. An example of the way time was shifted to account for the difference in EDR recorded time and actual time prior to the impact is shown in Figure 7, where the pre-crash vehicle speed from the striking vehicle in NASS / CDS case 2006-74-098 is shown as recorded and shifted forward.

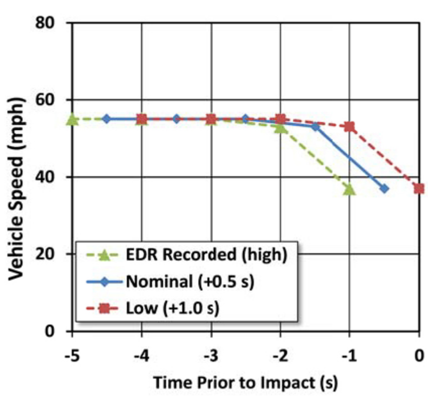

Figure 7. Example of Shifting EDR Recorded Pre-crash Data to Account for Differences in EDR Recorded Time and Actual Time (NASS/CDS 2006-74-098).

RESULTS

SELECTED CASES

Table 1 summarizes the number of cases that met the criterion for this study. There were 5,702 cases that were classified as a lead vehicle stopped, rear-end collision in NASS / CDS years 2000 - 2009, which corresponded to approximately 4.5 million crashes after the national weighting factors were applied. Of these cases, only 140 cases (2% of all weighted LVS cases) had a GM EDR with a locked deployment event recovered from the striking vehicle. Of the EDR cases, 88 had a complete pre-crash record (i.e. vehicle speed and braking) recorded on the EDR. Next, cases where the driver was intoxicated or the vehicle was not tracking prior to collision were removed, leaving 59 cases. Of the 59 normal driving population cases, in 12 cases, or 20% of cases, it appeared that the driver did not apply the brakes at all prior to the collision leaving 47 cases to determine TTC at the onset of driver braking. Of the 47 cases, 29 cases had observable deceleration in the vehicle speed history which was used to compute average deceleration.

Table 1. Summary of Cases Eliminated at Each Stage of Filtering.

Stage of Case Elimination	Raw Cases
LVS in NASS / CDS (2000 – 2009)	5,702
LVS with EDR	140
LVS with Complete Pre-crash	88
Normal Driving Population	59
Cases Analyzed for TTC	47
Cases Analyzed for Average Deceleration	29

Table 2 shows the age group and sex of drivers in selected cases. There were 47 cases that met all the criteria of this study, which corresponded to approximately 21,756 crashes. The largest group of drivers was in the adult driving population of 30 to 64 years old (56%). Just over half (53%) of drivers were male.

Table 2. Age and Sex of Selected Drivers in Lead Vehicle Stopped Rear-end Collisions for NASS 2000 - 2009.

		Unweighted	Weighted	%
Number of Cases		47	21,756	-
Age Group (years)	16-22	11	2,649	12%
	23-29	4	3,419	16%
	30-64	24	12,215	56%
	65+	8	3,473	16%
Sex	Female	21	10,128	47%
	Male	26	11,628	53%

AVERAGE DECELERATION

Of the 47 selected cases, 29 had vehicle speed history from which average deceleration could be computed from. Figure 8 shows the distribution of average braking deceleration for the vehicle speed at which braking started for the 29 known cases. In general, the later the driver applied the brakes, the greater the applied braking magnitude.

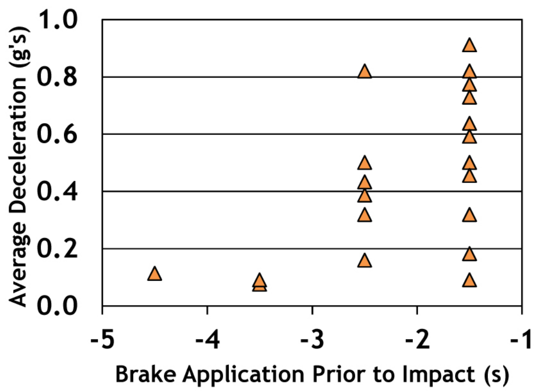

Figure 8. Average Braking Deceleration for Brake Application Prior to Impact for Computed Cases.

Table 3 summarizes the average braking deceleration by the time prior to impact that braking was initiated. In the majority of the cases, the vehicle started to decelerate two seconds prior to the collision. The average braking deceleration for all computed cases was 0.52 g's.

Table 3. Average Braking Deceleration by Time Prior to Impact Braking was Initiated.

Time Prior to Impact	Average Braking Deceleration	Number of Cases
-1.5	0.59	20
-2.5	0.44	6
-3.5	0.08	2
-4.5	0.11	1
Total:		29

ESTIMATED TIME TO COLLISION AT BRAKE INITIATION

Figure 9 shows the time of brake initiation as determined by the pre-crash brake history and from examination of the pre-crash vehicle speed. Points that fall above the solid line indicate that the deceleration was observed on the vehicle speed history before the braking history. On the other hand, points that fall below the line indicate that brake activation was observed before the vehicle speed decreased. Twenty-three cases fell above the line, four below the line, and 20 on the line. Of the cases where deceleration was observed before brake activation, all fell were 1 second from agreement. To determine the brake initiation timing that was used to compute TTC, the speed and braking results were examined, with priority given to the results of the vehicle speed.

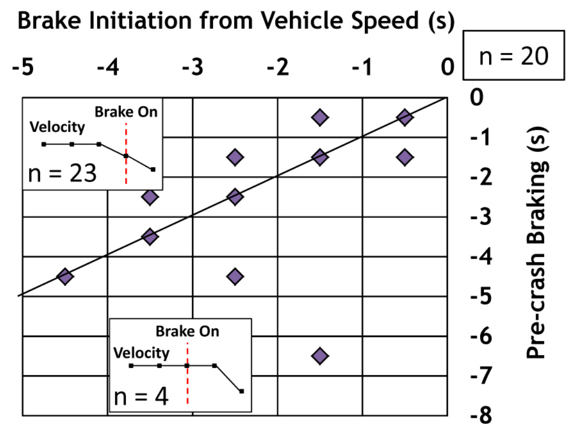

Figure 9. Time of Brake Initiation as Determined from Pre-crash Braking and Vehicle Speed.

Figure 10 shows the TTC at the time of brake initiation vs. the time prior to impact braking was initiated. The time of brake application is equivalent to the time the brakes were actually applied prior to the collision. As the pre-crash braking magnitude becomes greater, the TTC at activation becomes less than the actual braking time. Points that fall on the solid line would indicate a crash where there was no braking. The further below the solid line that points falls, the greater the braking deceleration relative to the initial speed. For crashes where the driver applied the brakes 0.5 seconds prior to the collision, the TTC at brake activation was almost 0.5 seconds. However, for crashes where the driver applied the brakes −1.5 and −2.0 seconds prior to the collision, the TTC was less than the time brakes were applied.

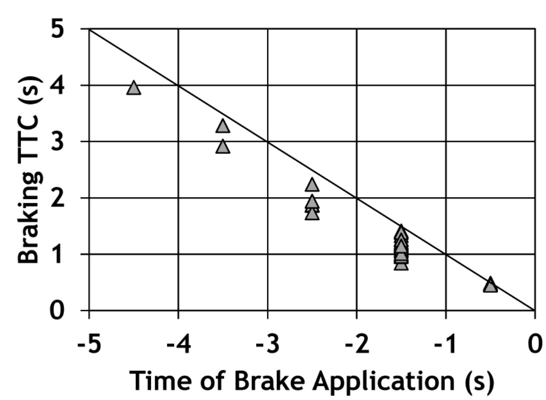

Figure 10. TTC at the Time of Brake Initiation by Time Prior to Impact.

Table 4 shows the average nominal, lower, and upper bound estimates of TTC at brake initiation by time prior to the collision braking was initiated. This table shows similar results than Figure 10. As brakes were applied closer to the collision, the difference between TTC and brake application time went up. The average TTC at brake initiation computed for the selected cases varied from 1.1 to 1.4 seconds. The lower bounds of braking initiated 0.5 seconds prior to impact is no braking, as the time shift caused the start of braking to be 0 seconds prior to impact.

Table 4. Nominal, Lower, and Upper Bound Estimates of TTC.

Time of Brake Application	Nominal TTC (s)	Lower Bound of TTC (s)	Upper Bounds of TTC (s)
-0.5	0.47	-	0.86
-1.5	1.13	0.84	1.35
-2.5	1.92	1.63	2.17
-3.5	3.10	2.71	3.48
-4.5	3.96	3.57	4.34
Total:	1.1	1.2	1.4

Figure 11 shows the TTC at which braking started by the vehicle speed at the same point. TTC was not affected greatly by vehicle speed for braking that initiated at the last moment (i.e. 1 second prior to collision). The R^2 value of a linear regression fit to the data is 0.00007, suggesting there is little or no correlation between speed and TTC at the time of brake activation.

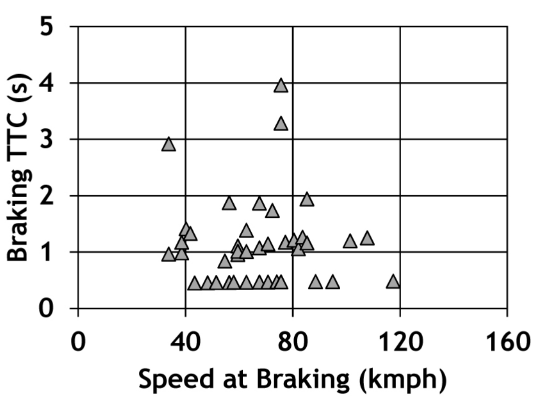

Figure 11. TTC at the Time of Braking for Vehicle Speed when Braking was Initiated.

ADVANCED EDRS

General Motors and Ford EDRs have been collected as part of NASS/CDS since the case year 2000. However, other automakers have also recently added support for publicly available download tools. Starting in case year 2008, NASS / CDS investigators also collected Chrysler EDRs. Only 5 Chrysler EDRs were collected in 2008 and 30 in 2009, compared to 504 GM EDRs collected in 2009. The Chrysler EDR cases were not included in the preceding analysis in order to maintain a consistent set of GM EDRs with similar capabilities. However, examination of one Chrysler case (2009-12-228) exemplifies the potential of advanced EDRs. In this example case, a LVS rear-end collision occurred between a 2007 Chrysler Pacifica and a 1998 Pontiac Trans Sport. Unlike GM EDRs, Chrysler EDRs record pre-crash maneuvers every 0.1 seconds for 2 seconds prior to the collision.

Figure 12 shows the EDR recorded pre-crash maneuvers of the striking vehicle. The striking vehicle was maintaining a speed of 37 mph on a two-lane road when it approached the struck vehicle which was stopped attempting to turn into a private drive. The driver of the striking vehicle released the throttle 0.8 seconds prior to the collision and applied the brakes at 0.5 seconds prior to the collision. The average deceleration was 0.33 g's and the TTC at brake initiation was 0.48 seconds. If the same crash was experienced by a GM EDR, the braking event may have not been captured because it occurred between 1 and 0 seconds prior to the collision. Due to the difference in EDRs, the time delay between the EDR recorded time and actual time was not accounted for. However, if mechanisms are similar between Chrysler and GM EDRs, the effect of any recording delays should not be as pronounced for Chrysler EDRs.

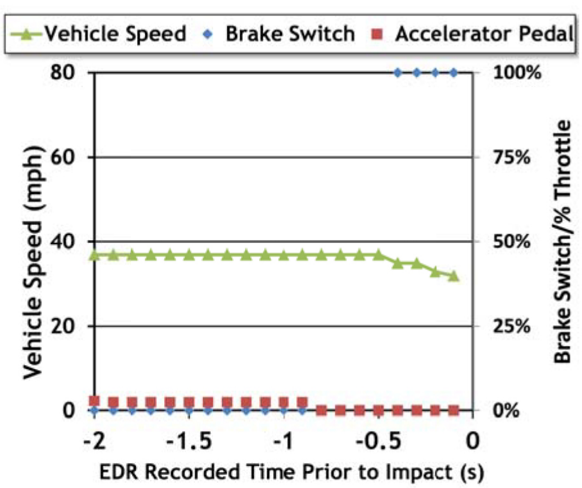

Figure 12. EDR Pre-crash Vehicle Maneuvers for Striking Vehicle (veh. 1) in NASS/CDS Case 2009-12-228

DISCUSSION

This paper has presented a methodology which uses EDR data to determine the TTC at which a driver applies brakes in a rear-end crash. Because there were a limited number of cases that had a recovered EDR with the necessary information, the results presented here should not be viewed as conclusive, but rather as a preliminary glimpse of what might be obtained from a large sample of the general population. The results of the current sample of EDRs illustrated the feasibility of this method.

The average braking deceleration for all selected cases was found to be 0.52 g's. This is comparable with results found in a study by Aoki *et al*, in which volunteers were subjected to a LVS crash situation in a high-fidelity driving simulator [7]. The average braking deceleration was found in this study to be 0.39 g's. Aoki *et al* also examined EDR data from 70 LVS rear-end collisions in NASS / CDS and found the average deceleration to be 0.38 g's. Although both this and Aoki *et al* both examined LVS rear-end collisions, the cases selected were slightly different. Because both examined a relatively small population, subtle differences in case selection can significantly impact the resulting average deceleration. This is a limitation of the sample size selected in both of these studies. Also, Aoki *et al* included non-deployment events saved in the EDR, while these cases were excluded from the present study. Van der Horst found that the TTC at brake initiation of drivers instructed to brake at the last possible moment increased slightly with speed [8]. This effect was not observed in the dataset examined here, possibly because of the limited range of vehicle speeds observed. The average TTC for hard braking in Van der Horst *et al* was 1.3 to 1.8 s, depending on the speed. This is comparable to the present study where the average TTC was 1.1 seconds. The maximum TTC at which braking started was 4.4 seconds and the minimum was 0.45 seconds.

The major limitation of this approach is the current lack of precision in the recording of pre-crash data on the EDR. When estimating TTC using the method presented here, the brake calculation is more sensitive to the initiation timing of braking closer to the collision. Because PCS is designed to deploy very close to the collision, the crashes of interest are often those in which the driver applied the brake later rather than earlier. Newer Chrysler EDRs, such as the one presented above, have a much finer time resolution. This finer precision of measurements will provide a better estimate of TTC. As more automakers start to provide commercial solutions to retrieve EDR events, the amount and quality of data is likely to improve. The NHTSA rule 49 CFR Part 563 describes a standard for EDR records and could greatly improve the availability of this type of data in the future. Although this regulation does not require EDRs, it does standardize the data elements required if a vehicle is equipped with an EDR. The most current regulation specifies that vehicle speed and brake application are to be sampled at least twice per second [9, 10].

The small number of suitable EDR cases also limits the ability to expand the results presented here to the entire driving population. There are approximately 4,000 cases in NASS / CDS with associated EDR data, of which only about half have deployment events recorded. The method described here placed very strict requirements on suitable cases: out of 10 years of cases there are only 47 cases with sufficient information to perform this method. Furthermore, the specific configuration and circumstances of the rear-end crashes can vary from one another. As a result, there is a large amount of scatter observed among drivers. We expect that this issue will improve as larger numbers of EDRs become available.

This method also makes several simplifying kinematic assumptions in order to estimate TTC. First, the driver braking is assumed to be constant throughout the braking period. This may not always be the case. Because data is only collected up until one second prior to impact, braking is extrapolated to the collision. Second, the lead vehicle is assumed to be still for the entire approach and braking period. In practice, these scenarios often can involve traffic that is slowing ahead of the striking vehicle. Although the struck vehicle may have been stopped when the collision occurred, it could have been moving during the approach period, which would affect TTC estimation.

CONCLUSION

This study presents a method for estimating the instantaneous TTC at the point when a driver of the striking vehicle applied the brakes to avoid a lead vehicle stopped, rear-end collision. First, a method for estimating TTC at the time of brake initiation was developed that examined the pre-crash brake application and vehicle speed. If the lead vehicle was stopped, the TTC can be estimated using the average deceleration during the braking period, the time prior to impact at which braking started, and the vehicle's speed when braking started. Of the 59 cases with complete EDR records, 12 drivers (20%) appeared to not apply the brakes at all. The method for determining TTC at braking onset was demonstrated using 47 lead vehicle stopped, rear-end collisions. The average braking deceleration of those cases that had sufficient vehicle speed data was found to be 0.52 g's. The average TTC of drivers in the selected cases varied from 1.1 to 1.4 seconds. The results of this preliminary study agree well with several previously published studies, and should be viewed as a glimpse of the potential of a larger sample of the general driving population. This study demonstrates the feasibility of using EDR data to predict TTC in real-world situations.

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