

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.

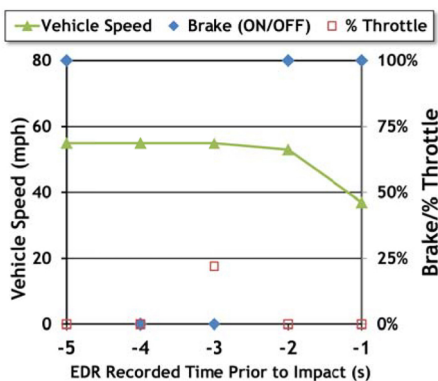


Figure 1. Pre-crash Maneuvers Recovered from Event Data Recorder of a 2002 Chevrolet S-10 Involved in a Rear-end Collision (NASS / CDS 2006-74-098).

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 *et 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.

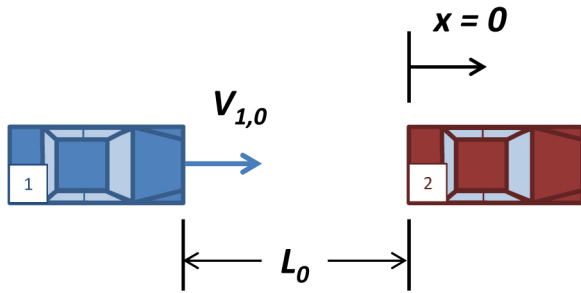


Figure 2. Schematic of Vehicle Speed and Position at the Time of Brake Initiation in a Lead Vehicle Stopped, Rear-end Collision.

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

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

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

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

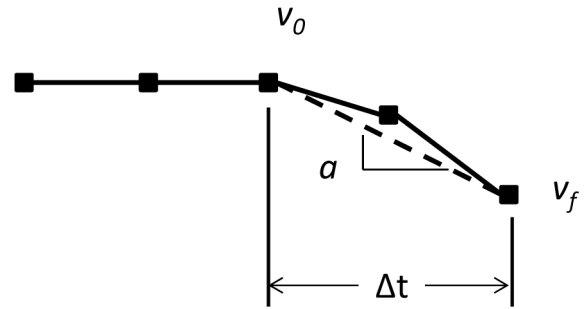


Figure 3. Schematic of Average Vehicle Deceleration during a Braking Event.

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