

A Statistical Analysis of Data from Heavy Vehicle Event Data Recorders

William F. Messerschmidt
Messerschmidt Safety Consulting

Jeffery W. Muttart
Accident Dynamics Research Center

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ABSTRACT

The most common trigger for event data collection in Heavy Vehicle¹ ECMs is a sudden decrease in the calculated vehicle speed. The calculated vehicle speed is a by-product of programmed calibrations and measured wheel speed data. In some cases, as is the case with Detroit Diesel ECMs, event data are recorded when the vehicle transitions from a driving state to a stopped state. Event data are reported with respect to time when the calculated vehicle speed change exceeds the preset threshold value or the first recorded 0 mph value. Because the data are not necessarily centered on the collision event itself, determination of impact speed and analysis of driver response can be problematic. A statistical evaluation of crash and non-crash related Heavy Vehicle Event Data Recorder (HVEDR) reports was conducted to identify specific measurable characteristics that can be used to identify the time of impact within reported event data. Statistically significant differences appeared between the data from crash-related reports and data from non crash-related reports, using both within- and between-subjects tests. Specifically, sudden changes in reported vehicle speed (ΔS) during the braking event were statistically significant predictors of the time of impact. By identifying the time of impact, EDR data can be related in time and space to identifiable physical evidence, and driver response time can be evaluated.

¹ The term "Heavy Vehicle" and the acronym "HV" are used in this paper to denote vehicles in Federal Highway Administration Classes 4 and 6 – 13 (buses and trucks with three or more axles, which are commonly equipped with large diesel engines).

INTRODUCTION

It has been established that the data from HVEDRs can be beneficial in accident reconstruction. The most common EDRs are those which exist as a function in the engine control module (ECM). Goebelbecker and Ferrone (2000) described the type of data that may be recorded, the method of collection, general accuracy, and provided case studies where such data had been useful. Ruhl et al. (2003) proposed an algebraic model for understanding calculated vehicle slip and integrating a distance relationship from the speed and time data. Van Nooten and Hrycay (2004) published methodologies for preserving and retrieving the data for forensic evaluation.

Several researchers have also examined the accuracy of these data. Reust (2004) and Reust and Morgan (2006) conducted an extensive series of tests using HVs equipped with Detroit Diesel engines and found that the HVEDR data were generally accurate (2004), and they provided a detailed discussion of the effects of ABS interaction with the reported vehicle speed (2006). Two significant findings, as related to the present research, were that ABS induced an under-reporting of speed by up to 12% (bobtail tractor on wet road); and that at speeds below 20mph (tractor-trailer combinations), and below 30mph (bobtail tractors), the percent error due to ABS was significant.

Van Nooten and Hrycay (2005) performed a series of steady-state braking tests to determine trends in calculated vehicle slip and ΔS , which were defined as the ground speed of the vehicle as measured by a

VBOX accelerometer (V) minus the ECM-reported vehicle speed (V_{ws}). (See Equation 1)

$$\text{Equation 1} \quad \Delta S = V - V_{ws}$$

They determined that at reported speeds below approximately 5mph, the true ground speed of the vehicle was often over-reported.

Van Nooten and Hrycay noted that

A large drop in speed over one second in an event report that results in a deceleration greater than what a tractor-trailer is capable of by brakes alone *may be assumed to be* the point where impact occurred. In some cases this will be true; however it also may be the result of calculated vehicle slip [emphasis added].

The major portion of this paper concerns a statistical analysis of crash-related and non-crash-related HVEDR data for the purposes of determining if this assumption is justified, and, if so, under what circumstances does a statistically significant relationship exist between the change in calculated vehicle speed (ΔS) and the time of impact. In other words, this paper has two goals with respect to the above statement: first, to assign a degree of empirical certainty to the assumption; second, to derive a probability that an observed “large drop” is from the crash event or “calculated vehicle slip.”

METHODOLOGY

DEFINING DATA SETS AND EVENTS

Event data from 71 HVEDR reports were compiled in Excel. These reports included a total of 135 crash and non-crash related events. Event reports were limited to data from Detroit Diesel and pre-2008 Cummins ECMs. This filter was created so that only ECMs that accurately reported a one-second time interval between data samples were considered.

Next, EDR data were reviewed for internal consistency. In some cases involving data from DDEC IV modules, wiring defects or improper installation of the module caused brake data to be erroneously reported. Such cases were easily identified because brake switch status was reported as “off” during every sample of both Hard Brake and Last Stop Records. This was most commonly seen in older tractors and those equipped with automatic transmissions, such as the Eaton Ultra-Shift. These cases were excluded from the analysis.

For each incident, data were only considered from cases where the braking event had occurred at a speed of 30mph or greater. This criterion was used to ensure consistency with Reust and Morgan’s research.

Crash events were evaluated further, to include only events in which the impact took place with a closing speed of 20mph or greater, and the primary harmful event was a collision between the HV and another vehicle. These determinations were made from a review of available evidence, accident scene photos, and the police-reported circumstances of the crash.

For non-crash events, only the Hard Brake Record (Detroit Diesel) and Sudden Deceleration Events (Cummins) were considered. Last Stop Records (Detroit Diesel) that were generated by controlled parking or loading the vehicle on a dolly were disregarded, as were incidents that reported positive calculated vehicle slip.

In the set of Detroit Diesel data, each crash-related Last Stop Record contained a corresponding Hard Brake Record. In all but one case, the Hard Brake Record was used and the Last Stop Record was discarded as redundant. In one case, the Last Stop Record appeared to have a fuller account of the crash. Specifically, this record showed the onset of engine fault codes, while the Hard Brake Record did not. Although other engine-reported data, including calculated vehicle speed were identical in these two reports, in this case the Hard Brake Record was discarded and the data in the Last Stop Record were included in the final data set.

Applying these filters left a sample of 29 crash events and 29 non-crash events. In 13 of these 29 cases, crash and non-crash records were available from the same vehicle, being operated by the same driver. These cases were used for additional within-subjects analysis. Therefore, the data were analyzed in two ways, 13 entries were compared in a within-subject design and 29 entries were compared in a between-subject design.

After creating the sample set, the recorded data were reduced to include only the portion related to the braking event or braking and crash event. Very few events were characterized by a steady-state deceleration from pre-event speed to stop. Therefore, it was necessary to define the beginning and the end of the crash event.

Events were defined as beginning with the first second before reported brake switch application. Care was taken to identify cases such as those noted by van Nooten & Hrycay (2005), in which brake switch status appeared to be reported “late,” or after the actual application of the service brake and the onset of braking. In these cases, the event was defined as beginning with the first second before a reduction in calculated vehicle speed of greater than two miles per hour in one second. The end of the event was defined as the first point at which speed reached 5mph (per van Nooten & Hrycay’s findings), leveled off at a non-zero value, or began to increase.

ANALYSIS

In order to determine when, if at all, large changes in calculated vehicle speed can be attributed to the crash event, it was first necessary to determine if calculated vehicle speed changes in known crashes differed significantly from calculated vehicle speed changes in known non-crashes. Reust and Morgan (2006) and van Nooten and Hrycay (2005) found that large calculated vehicle slip values can occur during steady-state braking on a test track (where no crash occurred), and this appears to have led van Nooten and Hrycay (2005) to add the caveat that such large changes “also may be the result of calculated vehicle slip.” Because large reported vehicle speed changes can occur without any impact, it is important to determine the degree of statistical difference between crashes and non-crashes.

In order to determine how meaningful large changes in ΔS are, the maximum reported ΔS from each event was calculated from Hard Brake (DDC), Sudden Deceleration (Cummins), and Last Stop Records (DDC). Reported ΔS was calculated as seen in Equation 2.

$$\text{Equation 2} \quad \Delta S = S_{s,final}^{ft} - S_{s,initial}^{ft}$$

for each two adjacent values in the ECM-recorded event data.

The descriptive statistics for ΔS values are represented in Table 1:

Table 1 Descriptive statistics for change of speeds between one-second data points in non-crash events.

ΔS Values for all Non-Crash Events	
Median ΔS	12.46ft/s
Maximum ΔS	21.99ft/s
Minimum ΔS	10.26ft/s
Standard Deviation	2.80ft/s

For crash events, the descriptive statistics for ΔS are represented in Table 2:

Table 2 Descriptive statistics for change of speeds between one-second data points in crash events.

ΔS Values for all Crash Events	
Median ΔS	21.26ft/s
Maximum ΔS	38.12ft/s
Minimum ΔS	10.99ft/s
Standard Deviation	8.42ft/s

The complete data set from which these descriptors were derived is contained in Appendix 1. An example of large ΔS , potentially associated with a crash, is seen in Figure 1.

Time	Vehicle Speed (mph)	Engine Speed (rpm)	Brake	Clutch
-0:19	64.0	1526	No	No
-0:18	64.0	1520	No	No
-0:17	63.5	1513	No	No
-0:16	63.5	1509	No	No
-0:15	63.5	1507	No	No
-0:14	63.0	1518	Yes	No
-0:13	40.0	982	Yes	No
-0:12	49.0	1167	Yes	No
-0:11	38.5	878	Yes	No
-0:10	30.5	722	Yes	No

Figure 1

A screen capture of a Hard Brake record which shows a large reduction in wheel speed reported by a Detroit Diesel ECM

In each of the examined cases, the minimum value required to trigger data collection was consistent with the factory defaults for the engine type (10.26ft/s for Detroit Diesel and 13.2ft/s for Cummins). Therefore, the minimum value to trigger data collection for any record in the sample was 10.26ft/s.

In all cases, the data that were analyzed were “raw data,” as reported by the ECM. No adjustments were made for calculated vehicle slip or ABS interaction prior to conducting the analysis.

Data for the 13 samples used for within-subjects comparison were similar to the entire data set. The within-subjects cases compared a non-crash related event to a crash-related event, where both events were created in the same truck with the same operator. Table 3 shows a comparison of the within-subjects testing data. The complete data are contained in Appendix 2.

Table 3 Descriptive statistics for change of wheel speed between one-second data points used in within-subjects testing

ΔS Values for Within-Subjects Testing		
	Non-crashes	Crashes
Median	12.46ft/s	26.39ft/s
Maximum	21.99ft/s	33.72ft/s
Minimum	10.26ft/s	11.00ft/s
Standard Deviation	3.37ft/s	8.04ft/s

Figure 2 shows a histogram of the maximum calculated vehicle speed change data for all crashes and non-crashes.