Feasibility of using Naturalistic Driving Data to Characterise Vehicle-Pedestrian Crashes and Near-Crashes

Samantha H. Haus, Rini Sherony, Hampton C. Gabler

Abstract Pedestrian safety is a growing problem in the USA. The proportion of pedestrian fatalities has steadily increased over the last 10 years from 11% of all traffic fatalities in 2006 to 15% in 2005. This study examined crashes and near-crashes from the Second Strategic Highway Research Program (SHRP-2) naturalistic driving study, which is a database containing time series vehicle data and forward-facing video of real-world driving interactions. Of the 162 vehicle-pedestrian events examined, scenarios in which the pedestrian was travelling perpendicular to the vehicle accounted for over 60% of the events. In 31% of the events, some sort of visual obstruction was involved, yet the average duration for which the pedestrian was visible was over two seconds. Drivers initiated braking evasive manoeuvres on average 2.3 seconds prior to the proximity impact point. In about 40% of the events, drivers did not initiate braking until one second before the proximity impact point, regardless of lighting conditions. Based on the assumption that one second is needed to detect and respond to an event, an automatic emergency braking (AEB) system would have sufficient time to avoid or mitigate approximately 90% of the events examined. One second is commonly assumed to be the threshold for AEB systems as the system must detect the pedestrian, alert the driver, and initiate braking protocols, but a range of thresholds were examined. This study presents methods for an examination of characteristics associated with real-world vehicle-pedestrian crashes and near crashes to estimate the benefit of pedestrian AEB system in the USA.

Keywords Pedestrian, SHRP-2 Naturalistic Driving Study, AEB, Time-Visible, Crash Modes.

I. INTRODUCTION

Pedestrian safety is a growing problem in the USA, constituting 15% of total traffic fatalities in 2015 compared to 11% in 2006 [1]. In 2015 alone there were 5,376 fatalities and an estimated 70,000 injured pedestrians compared to 4,795 fatalities in 2006 [1]. According to the Insurance Institute for Highway Safety (IIHS) there are three main ways to mitigate pedestrian injuries and fatalities 1) designing pedestrian friendly roads, 2) preventing the increase of road speed limits, and, 3) improving vehicle design to be safer for pedestrians [2].

In Europe, regulations have been put in place to encourage pedestrian friendly vehicles. Vehicle-based interventions include the use of softer front structures and active safety features that prevent or mitigate the collision. One proposed solution to this issue is the use of Automatic Emergency Brakes (AEB) that would be able to detect pedestrians and avoid or mitigate the collision [3]. One second is commonly assumed to be the threshold for AEB systems as the system must 1) detect the pedestrian, 2) alert the driver, and 3) initiate automatic braking [3].

The aim of this study is to characterise the factors associated with vehicle-pedestrian collisions and estimate the benefit of pedestrian AEB in US traffic environments.

II. METHODS

Our approach was as follows:

1. Examine each vehicle-pedestrian crash and near-crash for interaction type, environmental conditions, and the duration pedestrian was visible, and,
2. Apply the information gained from each case to estimate if a pedestrian AEB system would have enough time to mitigate the collision.

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Data Source

This study examined crashes and near-crashes from the Second Strategic Highway Research Program (SHRP-2). SHRP-2 was a naturalistic driving study conducted in six cities across the USA from 2010 to 2013. The collection resulted in over 4,300 years of driving data and recorded 1,836 crashes and 6,881 near-crashes. A total of 3,300 participant vehicles were instrumented to collect vehicle speed, acceleration, yaw rate and brake and gas pedal position in addition to forward, rear, side and driver video. Vehicle time series data were collected at 10 samples per second and video was captured at 30 frames per second.

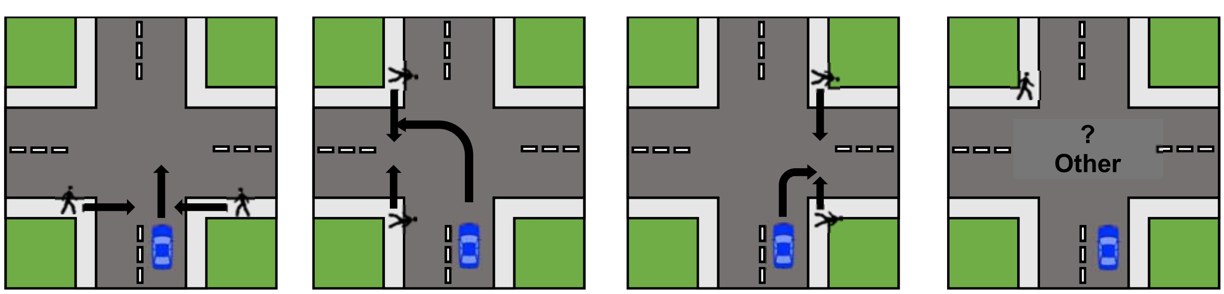
For this study, the database was queried for all events that were pedestrian related, which resulted in 168 events. Six events were excluded because the subject vehicle was a witness to the event and not directly involved in it, meaning that critical information was lacking, leaving only crashes and near-crashes (3 crashes and 159 near-crashes). A crash is defined as an event in which the subject vehicle had any contact with a pedestrian. A near-crash is defined as any situation that required a rapid evasive manoeuvre by the subject vehicle or pedestrian [4]. Additionally, four near-crashes events were excluded because either video or time series data were missing. One of the crash events was excluded after video review because it was determined that the pedestrian intentionally contacted the vehicle with their foot, which is not representative of a normal crash mode. The final data set consisted of 161 events (2 crashes and 159 near-crashes).

SHRP-2 was not designed as a nationally representative sample as the project depended on volunteers that were in proximity to one of the six collection sites. To check how closely SHRP-2 represented the USA pedestrian crash environment we compared the characteristics from the SHRP-2 events with two nationally representative data sets: the Fatality Analysis Reporting System (FARS) and the NASS General Estimates system (GES). FARS is a census of all vehicle-related fatalities that occur on USA public roads, while GES is a database that is based on a weighted sample that reflects all police reported vehicle collisions on USA public roads. Both databases were examined for all pedestrian fatalities and collisions from 2011 to 2015.

Classification of Interaction Types

For each event the forward-facing SHRP-2 video was examined. Events were characterised based on pedestrian, driver, and environmental factors and then compared to the nationally representative US data sets. Each event was also grouped by crash mode. If the pedestrian crossed straight in front of the subject vehicle from the left or right, the crash mode was termed as a Left/Right straight crossing path (LSCP or RSCP, respectively). If the subject vehicle was making a left turn, then the crash mode was termed as left turn across path/opposite direction or same direction (LTAP/OD, LTAP/SD), depending on the pedestrian direction of travel relative to the subject vehicle. If the subject vehicle was making a right turn, the crash mode was labelled following the same pattern as the left-turn scenarios. These crash modes are illustrated in Fig. 1 Any other crash mode was grouped in the "Other" category.

Videos were reviewed manually using a standard set of definitions for pedestrian, driver, and environmental condition. All videos were examined by the same reviewer for consistency. For certain variables, weather conditions lighting conditions, and relation to junction, the reviewers assessment was compared to the assessment of the SHRP-2 professional reductionists. If there was a disagreement, the video was re-examined. The proximity point was also determined by both the reviewer and the SHRP-2 reductionists, for this variable the SHRP-2 reductionist assessment was used, but it should be noted that there was very little difference in the recorded results.



LSCP/RSCP LTAP/OD, LTAP/SD RTAP/OD, RTAP/SD Other

Fig. 1. Crash modes from SHRP-2 video analysis.

Duration Visible

The time duration that a pedestrian was visible was calculated by manual examination of the event video. The timestamp of the moment when the pedestrian was first visible was recorded, whether or not the pedestrian was on the road. If they were not on the road, meaning they were on the sidewalk or the road shoulder, for example, then the timestamp of the moment they first entered the road was also recorded. The duration visible was defined as the time from when the pedestrian was first visible until the time the pedestrian reached the impact proximity point. The impact proximity point was defined as the time at which the subject vehicle first made contact with the pedestrian or, in the absence of contact, when the subject vehicle was closest to the pedestrian.

Vehicle Time Series Data

For each event, the subject vehicle time series data were examined. The event sample rates differed based on the vehicle and the data type. Brake activation was recorded at a rate of 10 samples per second. Vehicle speed was recorded at a rate of 10 or 1 samples per second, depending on whether the vehicle recorded vehicle speed using the vehicle network system or the speed calculated based on GPS location. For this study network speed was used, when possible, because it had a higher sampling rate. Where network speed was not available, GPS speeds were used instead. When determining travel speed of the vehicle, the vehicle speed was linearly interpolated between the adjacent samples in an effort to compensate for different sampling rates and correct for differences in the sampling rate of the vehicle data and the frame rate of the video. Time to collision (TTC) at braking was defined as the time from the onset of braking to the collision (or proximity impact point).

III. RESULTS

A. Comparison of SHRP-2 to Nationally Representative Datasets

Table I is the comparison of SHRP-2 to GES and FARS, two nationally representative databases. SHRP-2 follows similar trends to both GES and FARS in terms of driver age, driver gender, and weather. In general, SHRP-2 tended to be closer to GES which was expected due to the fact that GES contains incidents of all crash severities whereas FARS is only fatalities. SHRP-2 had more female drivers than GES or FARS and SHRP-2 had a higher proportion of incidents that occurred at intersections that GES or FARS. This may be because there is a higher chance of vehicle-pedestrian interaction at intersections but, not necessarily more police-reported or fatal vehicle-pedestrian crashes. The SHRP-2 "other" category is a large proportion of the observed crash locations. This category is primarily made up of events that occurred in parking lots. The majority of the non-fatal vehicle-pedestrian incidents in both GES and SHRP-2 occurred during daylight hours whereas the majority of fatal vehicle-pedestrian interactions occurred during dark lighting conditions (Table I).

TABLE I
SHRP-2 PEDESTRIAN EVENTS COMPARED TO US DATABASES, GES AND FARS

	SHRP-2 Events	SHRP-2 %	GES Cases (2011–2015)	GES %	FARS Cases (2011–2015)	FARS %
Total	161	100	370,874	100	24,197	100
Driver Age						
Young Adult (< 25)	47	29.2	73,170	19.8	8,540	35.3
Adult	68	42.2	251,573	67.9	12,546	51.7
Senior (≥ 65)	43	26.7	46,129	12.4	3,524	14.3
Driver Gender						
Male	82	50.9	229,190	61.8	15,512	64.1
Female	77	47.8	141,684	38.2	6,264	25.9
Unknown	2	1.2	-	-	2,421	9.9
Lighting						
Daylight	106	65.8	207,578	56	5,692	23.5
Dark-Not Lighted	3	1.9	33,735	9.1	8,361	34.6
Dark-Lighted	48	29.8	112,298	30.3	8,928	36.9
Dawn	1	0.6	4,401	1.2	383	1.6
Dusk	3	1.9	11,168	3	500	2.1
Other	-	-	1,694	0.4	333	1.4
Weather						
Clear	145	90.1	273,992	73.9	21,403	88.5
Rain	15	9.3	40,521	10.9	1,954	8.1
Cold related	-	-	54,434	14.7	265	1.1
Other/Unknown	1	0.6	1,044	0.3	575	2.4
Crash Location						
Non-Junction	48	29.8	153,039	41.3	16,480	68.1
Intersection	58	36	62,309	16.8	2,754	11.4
Intersection Related	16	9.9	137,461	37.1	3,700	15.3
Other	38	23.6	18,063	4.8	1,263	5.2

B. Analysis of SHRP-2 cases: Duration Visible

As shown in Table II, about 33% of the incidents involved visual obstruction of the pedestrian in the time leading up to the incident. Obstructions labelled as "Other" included events in which the pedestrian was obstructed by trees, a building, a telephone pole and a dumpster.

TABLE II
BREAKDOWN OF SHRP-2 EVENTS WITH OBSTRUCTIONS

	Events	Percent of Total
Total	161	100%
Obstructions	53	32.9%
Moving Vehicle	38	22.4%
Parked Vehicle	11	6.8%
Other	4	2.4%

LSCP and RSCP, scenarios in which the pedestrian was travelling perpendicular to the vehicle, account for over 60% of events and make up the two most common crash modes, as shown in Fig. 2. Fig. 3 shows that the median duration the pedestrian was visible did not differ substantially between crash modes, but that RTAP/SD tended to have lower duration visible than the other crash modes.

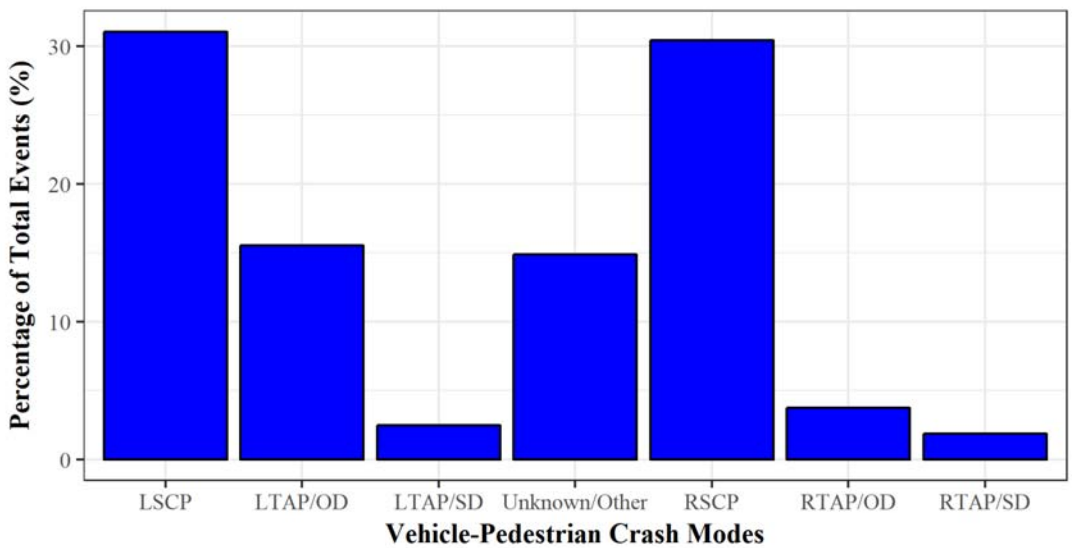


Fig. 2. Incidence rates of the crash modes in SHRP-2.

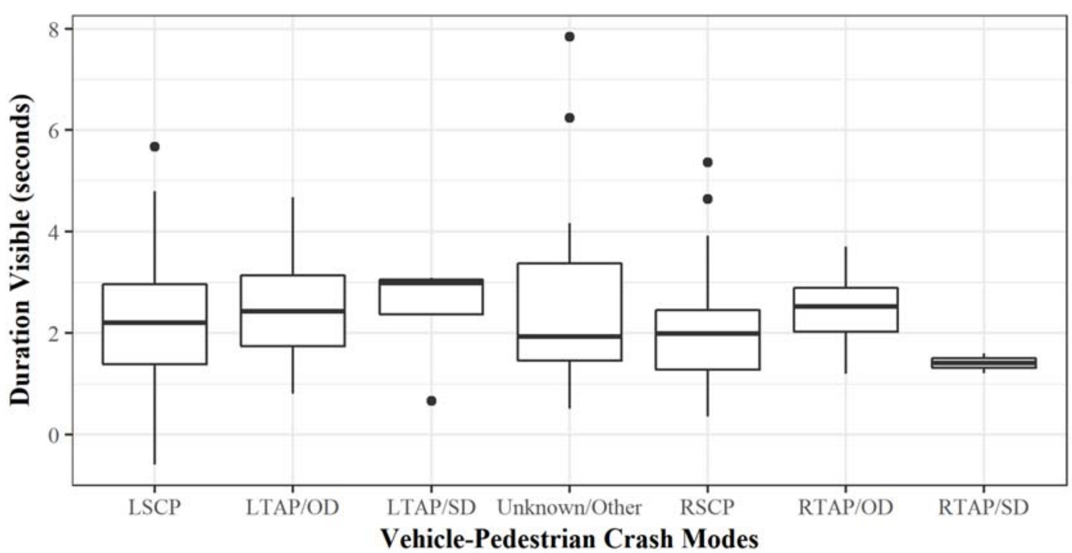


Fig. 3. Duration pedestrian was visible by crash mode. The points above and below the bow and whisker plots are outliers which are defines as points greater than 1.5 times the interquartile range away from the median.

As shown in Fig. 4, in about 90.8% of cases, pedestrians were on the road and visible for longer than one second, 82.4% were visible for at least 1.25 seconds, and 73.2% were visible for at least 1.5 seconds. Total time the pedestrian was visible tended to be longer than the time the pedestrian was visible and on the road meaning that in many cases the pedestrian was visible before they stepped into the road.

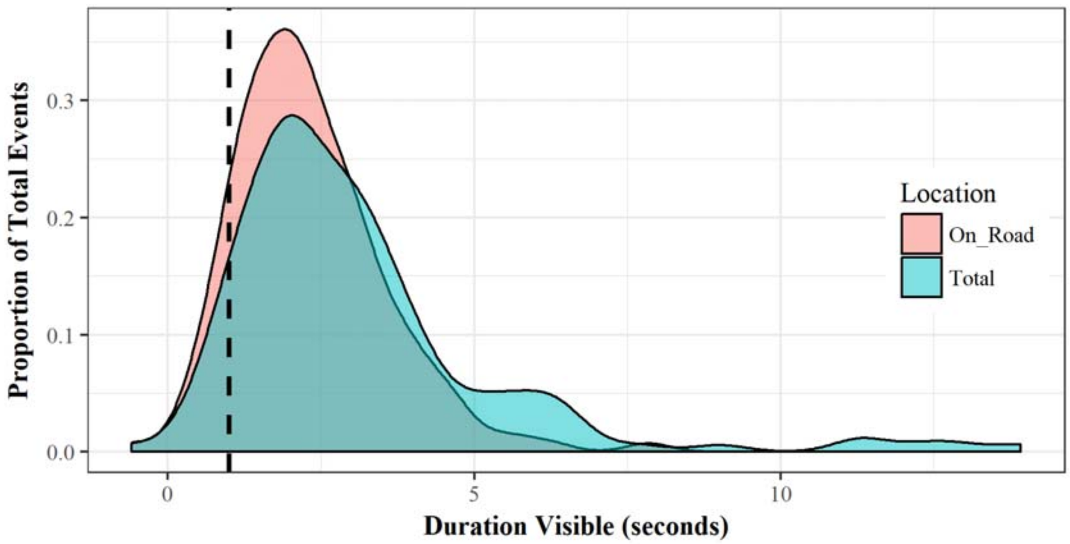


Fig. 4. Distribution plot of duration visible for the total time the pedestrian was visible and the duration visible only for when the pedestrian was on the road. The dotted line is located at one second duration visible which is the assumed minimum time needed for injury mitigation.

C. Analysis of SHRP-2 Cases: Driver Braking TTC

As shown in Fig. 5 the Braking TTC values were not significantly different between the crash modes. RTAP/OD had slightly lower Braking TTC than the other crash modes and LSCP had the largest number of outliers all above 2.5 seconds.

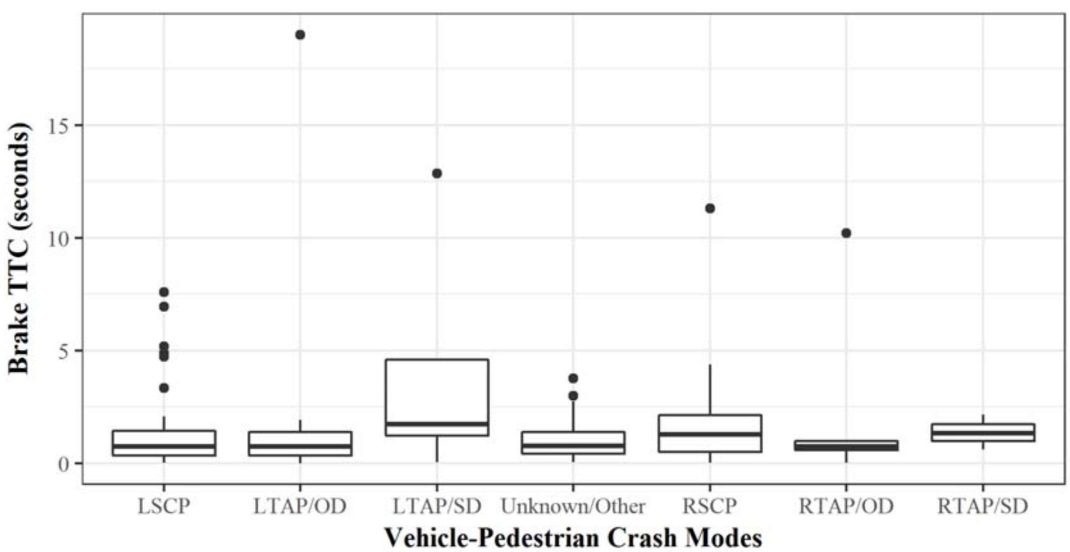


Fig. 5. Braking Time-To-Collision (TTC) by crash mode. The points above and below the bow and whisker plots are outliers which are defines as points greater than 1.5 times the interquartile range away from the median

All but one of the SHRP-2 drivers involved in near-crashes braked, while in both of the pedestrian crash cases the driver took no evasive action. As shown in Fig. 6, the majority of the subject vehicles decreased their travel speed in the last second preceding the impact proximity point. In 10% of the analysed cases, drivers began evasive actions less than one second prior to the potential collision.

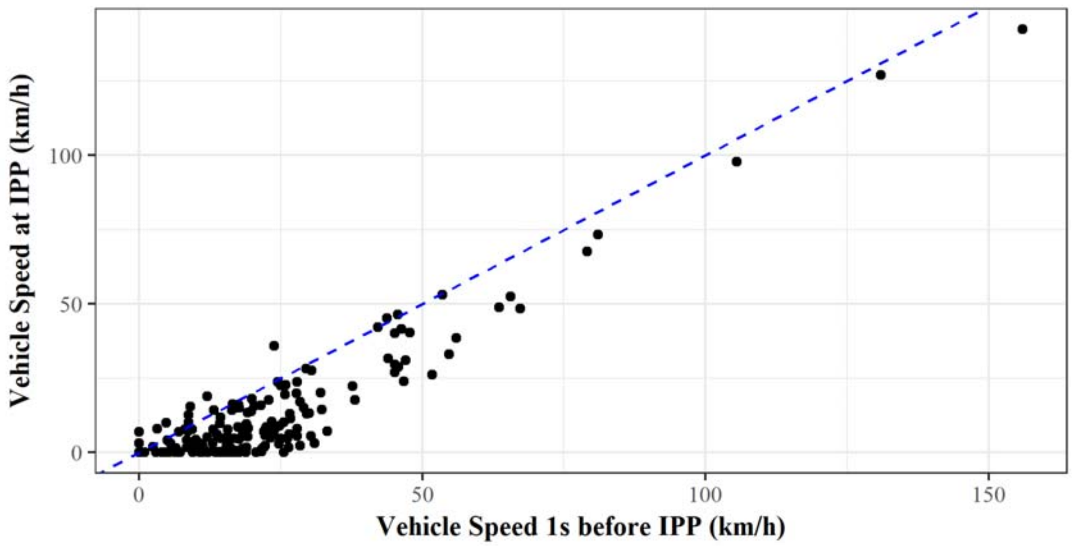


Fig. 6. Comparison of vehicle speed at 1 second before the impact proximity point (IPP). The dotted line is the points were the speed before and at the impact proximity point were the same indicating no braking occurred.

On average, drivers initiated braking evasive manoeuvres an estimated 1.5 s prior to the potential collision, with 50% of drivers initiating braking at a TTC of 0.97 s or less (Fig. 7 and Fig. 8). Assuming a threshold of one second, an AEB system would be activated before the driver's evasive action in about 52.8% of the observed events.

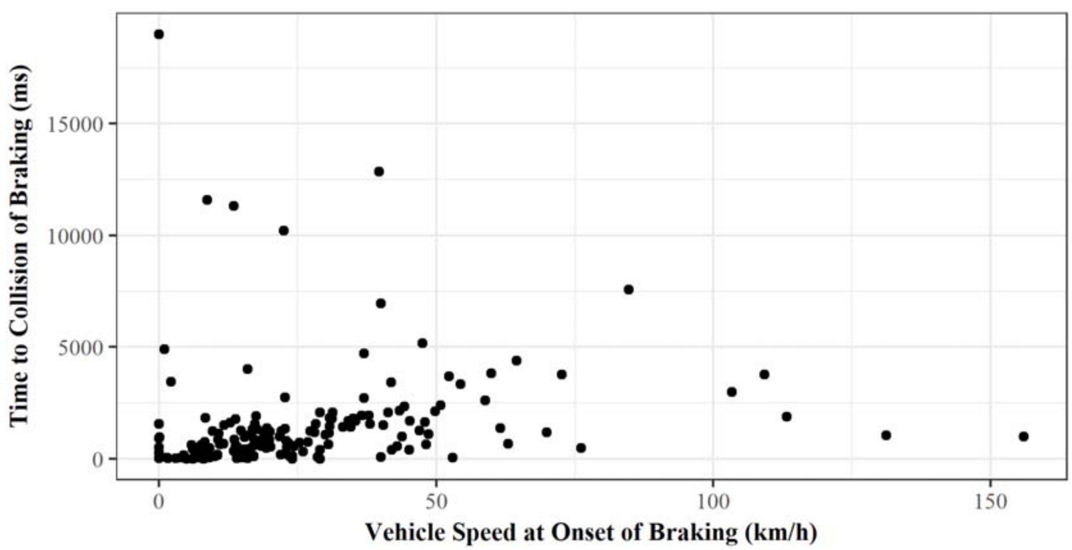


Fig. 7. Time-to-collision of braking compared to the subject vehicle speed at the onset of braking.

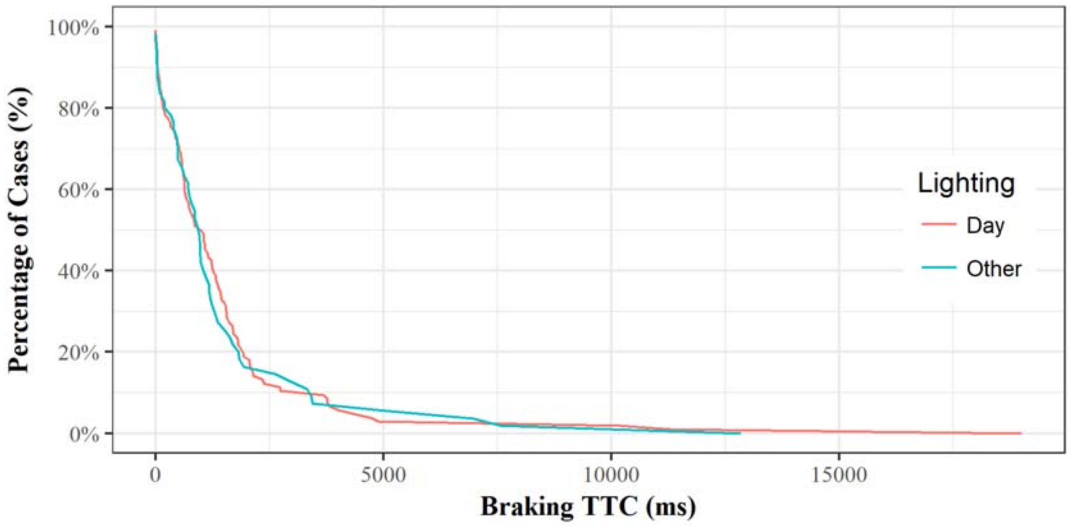


Fig. 8. Cumulative distribution plot of time-to-collision of braking for daylight and non-daylight lighting.

IV. Discussion

The SHRP-2 naturalistic driving study is a useful tool because it contains important information e.g. TTC at braking, which is unavailable in traditional datasets. The drawback of using a database like SHRP-2 is the small sample size of rare events such as crashes. To compensate for this limitation, near-crash events were included as they are much more common events. Near-crashes have been shown to be representative of crash events, but to check this assumption SHRP-2 was compared to GES and FARS. SHRP-2 events were shown to be more similar to GES, but generally followed the same trends. SHRP-2 had a larger proportion of events that occurred at intersections than GES or FARS which may be attributed to more vehicle-pedestrian interactions at intersections. GES and FARS may have lower recorded vehicle-pedestrian interactions at intersections because cars tend to go at lower speeds meaning that police-reported and fatal interactions are less likely.

One potential method to mitigate the increasing vehicle-pedestrian problem is the use of active safety systems to detect and avoid pedestrians through the use of automatic emergency braking (AEB) systems. Most AEB systems depend on a combination of radar and camera to detect pedestrians, and require at least one second to detect and initiate an evasive manoeuvre. To estimate the benefit of AEB the duration the pedestrian was visible to the forward facing camera was calculated. In about 33% of the cases there was some sort of obstruction that decreased the amount of time the pedestrian was visible. It was also found that on average the duration visible was shorter when the vehicle made a right turn into the path of a pedestrian traveling in the same direction as the vehicle (RTAP/SD). This information indicates that RTAP/SD interaction may be more difficult for AEB systems to prevent and/or mitigate than other crash modes.

Current AEB systems have a threshold TTC that must be reached before a response is initiated. This threshold is necessary in order to encourage adoption of the technology and keep unnecessary AEB activation to a minimum. Based on the assumption that one second is needed to detect and respond to an event, an AEB system would have sufficient time to mitigate approximately 80% of the events examined. Mitigation means that the severity of the crash was reduced either by avoidance of the collision, reduction of impact speed, or another change in the crash scenario that reduces injury.

In many cases the driver initiated braking before the one second TTC threshold was reached meaning that AEB system activation would have occurred after the driver initiated evasive action. Therefore, AEB activation was examined at various AEB braking thresholds in relation to the TTC of the driver's first evasive action. For this analysis the TTC threshold refers to the amount of time before vehicle-pedestrian interaction occurs, not the amount of time the system needed to recognise and respond to the pedestrian. A limitation of this analysis is that the duration pedestrian was visible was not considered, only the TTC of the driver's first evasive action affected the results. As expected, the sooner the AEB system braked the more likely the AEB system would brake before the driver.

V. CONCLUSIONS

This study presents an examination of characteristics associated with real-world vehicle-pedestrian crashes and near crashes to estimate the benefit of pedestrian AEB system in the USA. The use of naturalistic driving data allows the investigation of crucial parameters for active safety design, which are not available in retrospective police reported crash databases. These crucial parameters include the time-to-collision of driver evasive manoeuvres, pedestrian evasive manoeuvres, time the pedestrian was visible and the incidence of obstructions. This information can be used to estimate the benefit of active safety systems, such as AEB, on mitigating pedestrian traffic-related fatalities and injuries.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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