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Pre-impact braking in crashes: insights from event data recorders (EDRs)

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ABSTRACT

This study examined start-of-braking times from event data recorder (EDR) data of 170 bullet (through-vehicle/striking) vehicles involved in crashes in South Australia over the period 2017 to 2020. A formula for calculating the start-of-braking time to an accuracy of 0.05-second time points was derived and applied to the EDR data from the bullet vehicles. A third of bullet vehicle drivers did not apply the brakes before impact, and almost three quarters of bullet vehicle drivers had a start-of-braking time of less than or equal to one second. The average start-of-braking time was 0.87 seconds. Start-of-braking times were found to vary between crash types. No right-angle type crashes had start-of-braking times of greater than 1.5 seconds, with the vast majority of drivers in these types of crashes having a braking time of less than 1 second. In contrast, single vehicle crashes had a wide range of start-of-braking times. Of the common crash types, hit parked vehicle crashes had the highest percentage of drivers that did not brake at all (73%), while right-turn – opposite crashes had the lowest (12%). High speed zones had higher start-of-braking times than low speed zones. A general limitation of this study is that it did not include data from near crashes. This could be rectified in a future study by combining EDR data from crashes with naturalistic driving data from near crashes.

KEYWORDS

Event data recorder (EDR), pre-crash braking times, start-of-braking time, crash-type comparison, speed limit, driver behaviour

Summary

The start-of-braking time is a key variable in determining the impact speed, and therefore the injury outcome of a crash. To the authors' knowledge, the start-of-braking time in actual crash situations has not been quantified. The presence of event data recorders (EDRs) in many vehicles manufactured over the last 15 years provides an opportunity to examine the start-of-braking time in actual crash events in a way that was not previously possible. The Centre for Automotive Safety Research (CASR) has been collecting EDR data from crashed vehicles since 2017 and matching the vehicle to a police report and hospital records to form the CASR EDR database. This report details an analysis of the data contained within the CASR EDR database with respect to start-of-braking time.

The CASR EDR database included 374 EDR files matched to police reports at the time the data was extracted (May 2020). Of these, 170 were bullet vehicles suitable for inclusion in the analysis.

A formula for calculating the start-of-braking time to an accuracy of 0.05-second time points was derived and applied to the EDR data from the bullet vehicles.

The analysis revealed that a third of bullet vehicle drivers did not apply the brake before impact, and almost three quarters of bullet vehicle drivers had a start-of-braking time of less than or equal to one second. The average start-of-braking time was only 0.87 seconds.

Start-of-braking times were found to vary between crash types. No right-angle type crashes had start-of-braking times of greater than 1.5 seconds, with the vast majority of drivers in these types of crashes having a braking time of less than 1 second. In contrast, single vehicle crashes had a wide range of start-of-braking times. Of the more numerous crash types in the sample, hit parked vehicle crashes had the highest percentage of drivers that did not brake at all (73%), while right-turn – opposite crashes had the lowest (12%).

Vehicles that were travelling in high speed zones (≥80 km/h) were shown to have an average start-of braking time 0.94 seconds before the average start-of-braking time of vehicles travelling in a low speed zone (≤70 km/h). This difference may be due to increased sight distances and clear zones, or the difference may simply be a product of a different mix of crash types.

The data was also analysed by driver sex and age. Some differences between these groups was found, however, while detailed statistical analysis was outside the scope of this report, it is likely that a larger sample size would be needed to confirm these results as anything other than a product of random variation.

The start-of-braking times of drivers in crash situations has implications for advanced driver assistance systems (ADAS), such as autonomous emergency braking (AEB), that seek to improve upon human performance in these situations. The results of this study suggest that AEB could provide large benefits for 18% of rear end crashes and moderate benefits for a further 51% of rear end crashes.

A general limitation of this study is that it did not include data from near crashes. The difference between the start-of-braking time for all critical situations and crashes is likely to differ between crash types and this should be borne in mind when interpreting the results. This limitation could be rectified in a future study by combining EDR data from crashes with naturalistic driving data from near crashes.

Contents

1 Introduction

Impact speed has been shown to have a strong positive relationship to the risk of serious injury (Doecke *et al.,* 2020). The impact speed of a vehicle in a crash is dependent on the travel speed of the vehicle, the start-of-braking time (relative to the time of impact), and the level of acceleration achieved during the time spent braking.

To the authors' knowledge, the start-of-braking time in actual crash situations has not been quantified. Much of the research into what occurs seconds before a crash has focussed on quantifying driver reactions times in certain situations e.g. Schweitzer *et al.* (1995). For safety and ethical reasons such research is done in a controlled environment in which an actual crash will not occur. Naturalistic driving studies have the potential to provide data on the start-of-braking time in actual crashes, but the rarity of crashes in such data results in conclusions been predominately drawn from near crashes. For example, Gao & Davis (2017) examined data from the large naturalistic driving study SHRP 2 NDS that involved 3,542 drivers and found only 4 rear end crash events and 98 near crashes to include in their study on drivers' brake reaction time in rear end crashes.

The presence of event data recorders (EDRs) in many vehicles manufactured over the last 15 years provides an opportunity to examine the start-of-braking time in actual crash events in a way that was not previously possible. An EDR detects when a collision has occurred and logs the last few seconds of driving data prior to the crash. Included in this data is information pertaining to brake use.

The Centre for Automotive Safety Research (CASR) has been collecting EDR data from crashed vehicles since 2017 and matching the vehicle to a police report and hospital records to form the CASR EDR database. This report details an analysis of the data contained within the CASR EDR database with respect to start-of-braking time. In so doing, it aims to provide unique insights into the topic.

2 Methodology

2.1 Data collection

EDR data from crashed vehicles was accessed by attending a holding yard of Pickles Auction company at various times during the year, on the day before their weekly auction (when the vehicle yard is open for public inspection). Around 80 to 90% of the insured written off vehicles in South Australia reportedly come through this single holding yard.

Downloading data from crashed vehicles is undertaken using a Bosch Crash Data Retrieval (CDR) tool. This enables access to, and decoding of, the data contained in the crashed vehicle's EDR via the On-Board Diagnostics (OBD-II) port. Photographs are taken around the exterior of the vehicle as well as the interior of the vehicle, and basic measurements of the deformation are recorded.

Typically, 200 to 400 vehicles are auctioned every week, but only around 10% to 15% of these vehicles have an EDR that is supported by the Bosch CDR tool. The majority of vehicles that capture EDR data are vehicles manufactured by Toyota and Holden. On some occasions the OBD-II is not accessible, and the airbag control module (ACM) that contains the EDR data is requested from the purchaser of the vehicle for a monetary value.

Vehicle collision reports from the South Australian Police are obtained by supplying a registration plate number, vehicle identification number, vehicle make, and vehicle model. The police reports received are used to provide coarse injury severity, crash location, and a description of the crash circumstances. Any injured participants from the police report are matched to available hospital records to record injury data. The data is then entered into the CASR EDR database.

This data has been found to be generally representative of crashes in South Australia in terms of injury severity, crash location (Elsegood, Doecke & Ponte, 2020), vehicle model year, and driver age (Doecke & Ponte, 2018).

The CASR EDR database also contains EDR files from vehicles involved in fatal or very serious crashes that are provided by The South Australian Police Major Crash Unit. The results in this report are based only on cases collected from Pickles, and do not include cases collected from the SAPOL Major Crash Unit, to not bias the data toward fatal or very serious crashes.

2.2 Analysis

Defining vehicles and categories of interest

The vehicle of interest with respect to pre-impact braking is the what is often described as the "bullet" (or striking) vehicle. These are vehicles that are travelling in a forward direction and strike another vehicle. Bullet vehicles are ones which have right of way (if travelling through an intersection) and are usually travelling at a greater speed than the other vehicle involved. For crashes where a vehicle is performing a turn across traffic, the bullet vehicle is the through vehicle. In rear-end crashes, the rear-most vehicle is the bullet vehicle. For single vehicle crashes, the vehicle is always classified as the bullet vehicle. In head-on crashes, both vehicles are classified as bullet vehicles. For side-swipe crashes, neither vehicles are classified as a bullet vehicle. See Appendix A for the DCA code diagrams with bullet vehicles highlighted.

The CASR EDR database included 374 EDR files matched to police reports at the time the data was extracted (May 2020). Of these, 21 were excluded as they were not obtained through Pickles and a further 183 were excluded due to the EDR file being from a non-bullet vehicle. This left 170 crashes for inclusion in the analysis.

Start-of-braking time was analysed by crash type, speed zone, recorded sex of driver and age of driver. The crash types were sorted into simple crash type categories based on DCA codes, as shown in Table 2.1.

Table 2.1
Crash type categories by DCA codes of EDR bullet vehicles

Simple crash type	DCA code (position) of bullet vehicle	Frequency	Percentage
Rear-end	130(A), 131(A), 132(A)	57	33.5%
Right-angle	110(B)	9	5.3%
Right-turn - adjacent	113(B)	12	7.1%
Right-turn - opposite	121(B)	25	14.7%
U-turn in front	140(B)	4	2.4%
Head-on	120(A), 120(B), 150(A), 150(B)	9	5.3%
Single vehicle into object	171(A), 173(A), 181(A), 183(A)	35	20.6%
Hit parked vehicle	160(A), 161(A), 162(A), 163(A)	11	6.5%
Hit animal	167(A)	2	1.2%
Rollover	170(A), 172(A), 174(A), 180(A), 182(A), 184(A)	6	3.5%
Total		170	100%

Calculation of braking time

An example of the main information obtained from an EDR report is shown Figure 2.1. For this particular vehicle, the EDR stores 10 pre-impact data points, with a timestep of 0.5 seconds and a resolution of 0.05 seconds. A data point is also recorded at the time of impact, displayed as time 0 (TRG, meaning trigger). In this crash the impact occurred between two timesteps, 0.25 seconds after the most recent timestep recorded, therefore each pre-impact timestep is incremented from the -0.25 timestep. The vehicle speed, accelerator pedal percentage, engine throttle percentage, engine RPM, motor RPM, brake status, brake oil pressure, longitudinal acceleration, yaw rate, steering input, and statuses of other vehicle settings are recorded for each timestep.

Pre-Crash Data, -5 to 0 seconds (Most Recent Event, TRG 3)

Time (sec)	-4.75	-4.25	-3.75	-3.25	-2.75	-2.25	-1.75	-1.25	-0.75	-0.25	0 (TRG)
Vehicle Speed (MPH [km/h])	47.2 [76]	50.3 [81]	53.4 [86]	55.9 [90]	57.8 [93]	59.7 [96]	60.9 [98]	55.3 [89]	45.4 [75]	36.7 [59]	33.6 [54]
Accelerator Pedal, % Full (%)	54.5	48.0	45.5	42.5	41.0	39.5	0.0	0.0	0.0	0.0	0.0
Percentage of Engine Throttle (%)	65.5	62.5	36.0	32.0	37.5	33.0	1.5	0.0	0.0	0.0	0.0
Engine RPM (RPM)	4,200	4,200	4,500	4,500	3,800	3,900	3,900	3,100	2,300	1,700	1,500
Motor RPM (RPM)	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Service Brake, ON/OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON
Brake Oil Pressure (Mpa)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.77	9.12	9.36	9.70
Longitudinal Acceleration , VSC Sensor (m/sec^2)	2.656	3.158	2.441	2.153	1.579	2.010	0.790	-8.039	-6.963	-7.752	-8.973
Yaw Rate (deg/sec)	1.95	1.95	0.49	0.98	1.95	0.98	-2.44	-2.93	10.25	6.34	-4.39
Steering Input (degrees)	3	3	0	3	3	0	-12	-3	24	27	33

Figure 2.1
Example EDR pre-impact data table

The brake status and brake oil pressure for this vehicle shows that the driver of the vehicle applied braking force between 1.75 seconds and 1.25 seconds before the collision. A simple method to estimate the braking time before impact is to use the first timestep with the brake being recorded ON, resulting in this case with 1.25 seconds of braking. The decrease in speed of 9 km/h between 1.75 and 1.25 seconds prior to impact implies braking did not start at 1.25 seconds prior, but rather started somewhere between the two timesteps.

Equation 1 was developed to calculate a more accurate start time of braking. The acceleration (in the negative sense) of the vehicle in the first two time steps where braking is present (t_2, t_3) is used to determine the braking start time through interpolating between the last timestep that braking was not present (t_1), and the first timestep where braking was present (t_2). A constant (0.085s) is added to account for the time taken for the average acceleration level found in the two timesteps following braking to be reached. A derivation of equation 1 is included in Appendix B.

$$t_s = \left| t_2 - \frac{(V_2 - V_1)(t_3 - t_2)}{(V_3 - V_2)} \right| + 0.085 \qquad (1)$$

where:

- t_s is the start-of-braking time
- t_2, t_3 are the times relating to timesteps where braking is ON (t_2 is before t_3)
- V_1, V_2, V_3 are the speeds relating to timesteps where braking pattern is OFF, ON, ON (V_1 is before V_2, which is before V_3)
- 0.085 is the ramping value

For the example case t_2 is -1.25, t_3 is -0.75, V_1 is 98, V_2 is 89, and V_3 is 75. The braking start time t_s is therefore calculated as:

$$\left| -1.25 - \frac{(89 - 98)(-0.75 - -1.25)}{(75 - 89)} \right| + 0.085 = -1.65$$

Cases where the calculated braking start time is before the pre-braking timestep (with braking recorded as OFF) are assumed to have occurred in the milliseconds after the pre-braking timestep was recorded, resulting in a start braking time equal to the pre-braking time value, i.e. $t_s = t_1$.

Cases where there was no speed decrease between the timesteps of changing braking from OFF to ON were assumed to have the start of braking equal to the first post-braking time value, i.e. $t_s = t_2$.

Cases where the third timestep did not exist, i.e. where the braking was only ON for the impact timestep, another similar formula, equation 2, is used to calculate the start-of-braking time.

$$t_s = \left| t_2 - \frac{(V_2 - V_1)}{-28.25} \right| + 0.085 \qquad (2)$$

where:

- t_s is the start-of-braking time
- t_2 is the time relating to impact timestep where braking is ON
- V_1, V_2 are the speeds relating to timesteps where braking pattern is OFF, ON (V_1 is before V_2)
- -28.25 km/h per second is an acceleration value typical to heavy braking
- 0.085 is the ramping value

The acceleration value of -28.25 km/h/s was selected by the authors based on typical heavy braking and changing the coefficient of friction used to calculate this value would result in close to negligible differences in the calculated start-of-braking time. The ramping value was also selected by the authors. Cases where the calculated braking start time is before the pre-braking timestep (with braking recorded as OFF) are assumed to have occurred in the milliseconds after the pre-braking timestep was recorded, resulting in a start braking time equal to the pre-braking time value, i.e. $t_s = t_1$.

All start-of-braking times were rounded to the closest 0.05-second time point for ease of analysis.

3 Results

Figure 3.1 shows the distribution of braking times of the 170 bullet vehicles in the EDR database. Each bar represents a portion of time that each driver started applying the brakes before the crash occurred. Around a third (33%) of bullet vehicle drivers did not apply the brakes before impact, and almost three quarters (74%) of bullet vehicle drivers applied less than or equal to 1 second of braking before impact. The "> Max time" timestep category accounts for the EDR files where braking was ON for the entire recording.

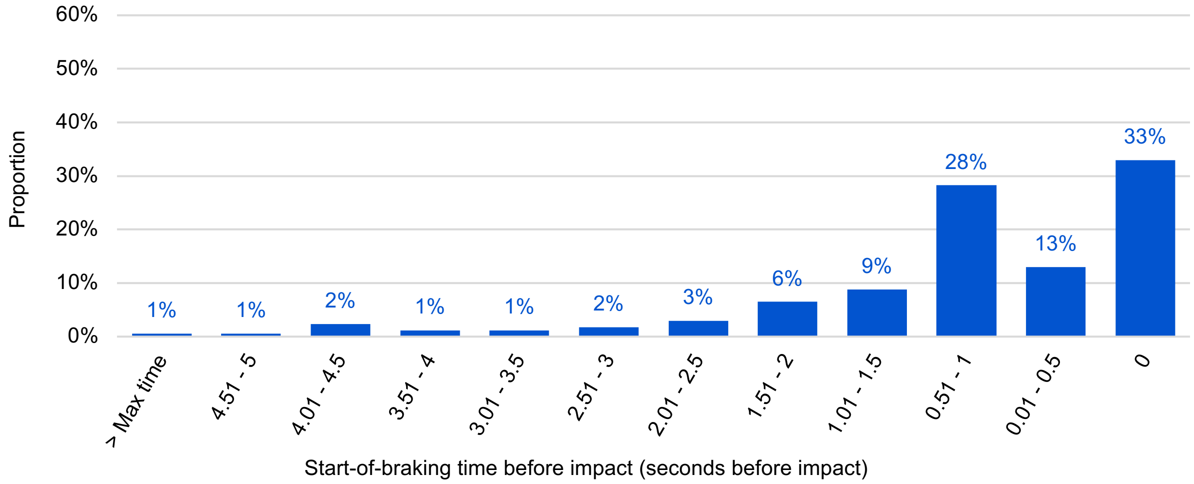

Figure 3.1
Start-of-braking time for all bullet vehicles (n=170)

3.1 Start-of-braking times by crash type

Rear-end crashes

The start-of-braking times for bullet vehicles involved in a rear-end crash are shown in Figure 3.2. The majority (94%) of vehicles in this category started braking after the 2-second-mark before impact. Over a fifth (21%) of the vehicles did not apply the brakes before impact.

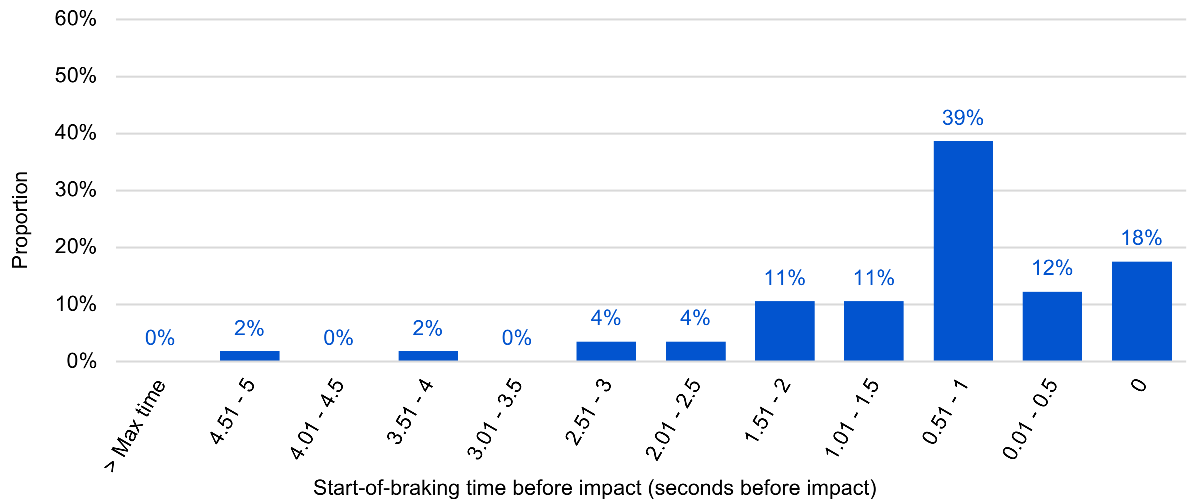

Figure 3.2
Start-of-braking time for bullet vehicles involved in rear-end crashes (n=57)

Right-angle crashes

Start-of-braking times of bullet vehicles involved in right-angle crashes are shown in Figure 3.3. The start-of-braking time was 1.5 seconds or less for all of the right-angle crashes, with the majority (66%) having a start-of-braking time of less than 0.5 seconds or not braking at all.

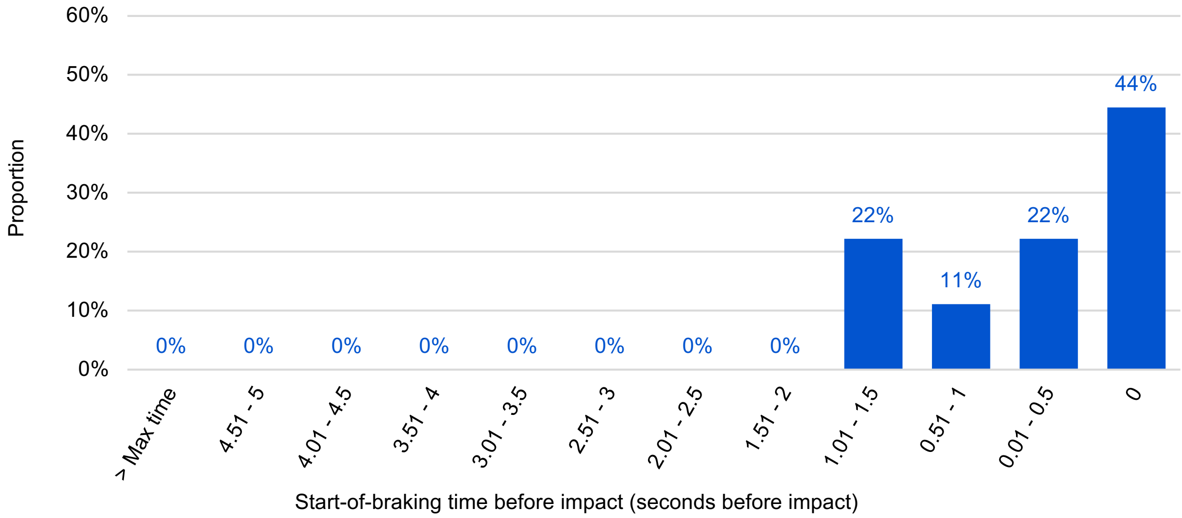

Figure 3.3
Start-of-braking time for bullet vehicles involved in a right-angle crash (n=9)

Right-turn – adjacent crashes

The start-of-braking times of bullet vehicles involved in right-turn crashes where the vehicles were originally travelling in adjacent (perpendicular) directions are shown in Figure 3.4. Around a third (33%) of vehicles in this category did not apply the brakes before impact with the other vehicle occurred.

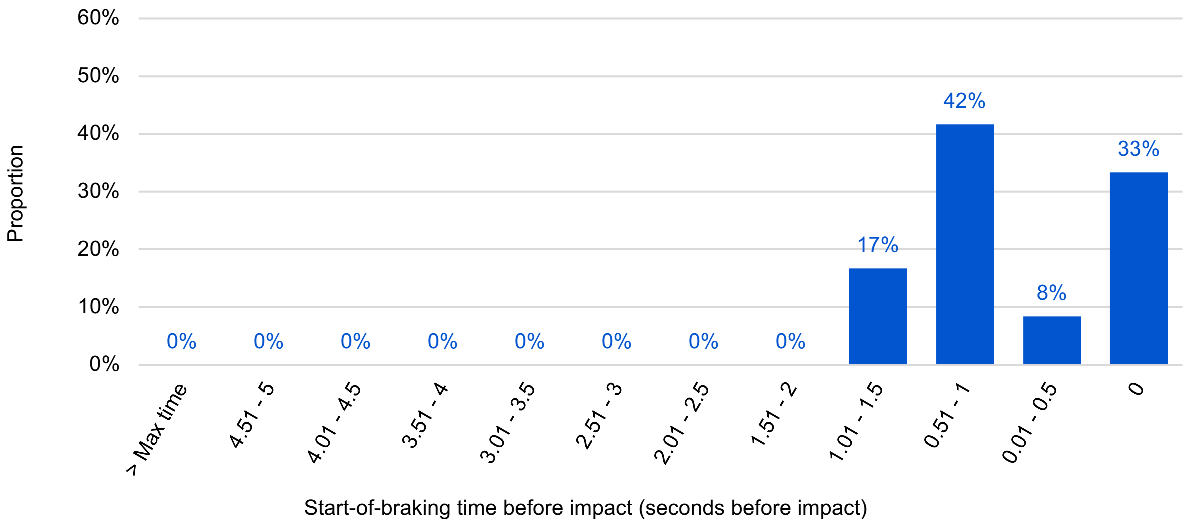

Figure 3.4
Start-of-braking time for bullet vehicles involved in a right-turn - adjacent direction crash (n=12)

Right-turn – opposite direction crashes

Start-of-braking times of bullet vehicles involved in right-turn crashes where the vehicles were originally travelling in opposite directions are shown in Figure 3.5. The majority of drivers involved in these types of crashes began braking between 0.5 and 1 second prior to impact.

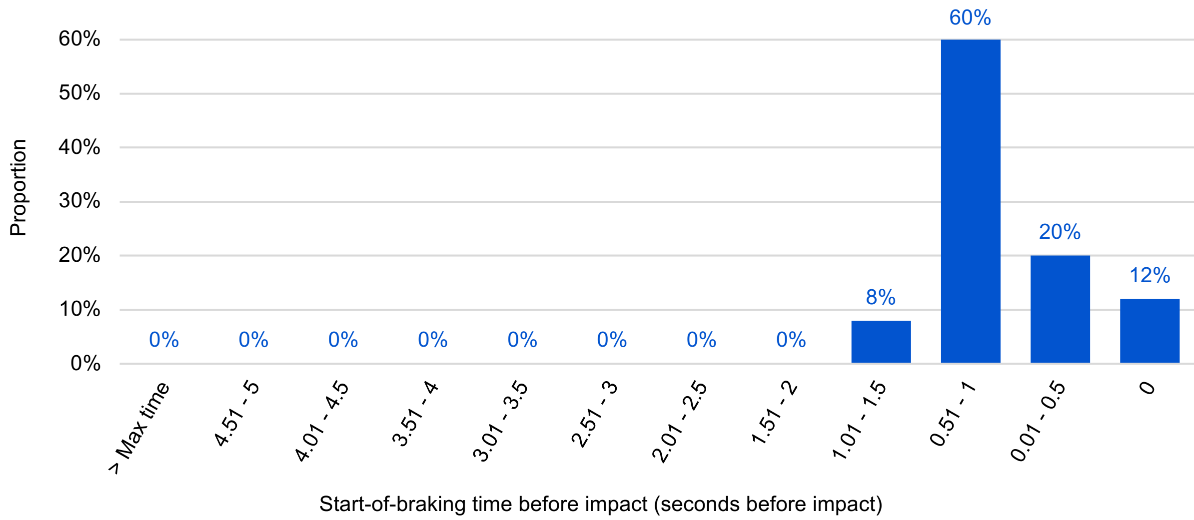

Figure 3.5
Start-of-braking time for bullet vehicles involved in a right-turn - opposite direction crash (n=25)

U-turn in front crashes

The start-of-braking times of bullet vehicles involved in U-turn in front crashes is shown in Figure 3.6.

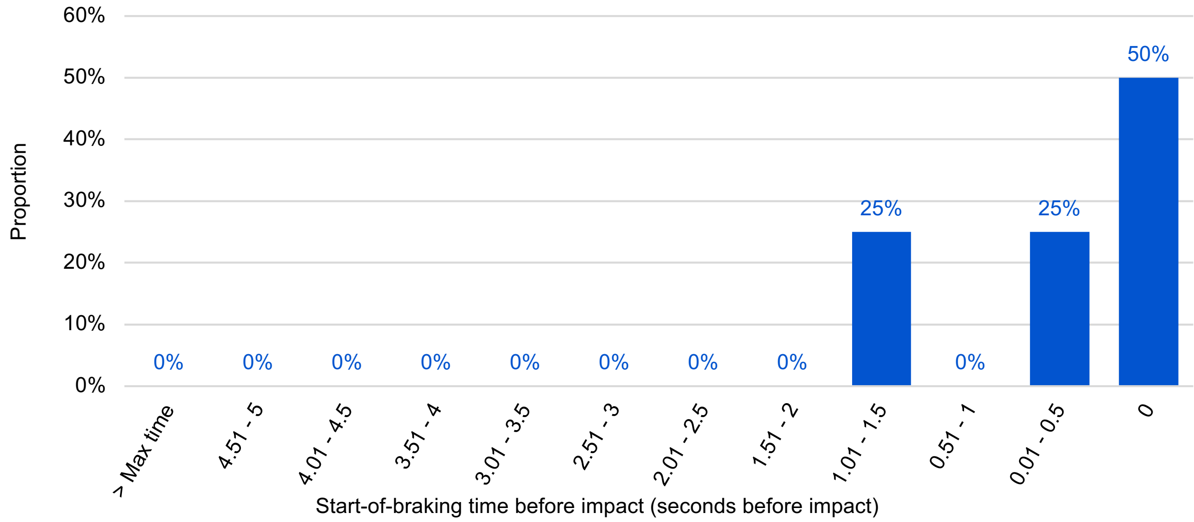

Figure 3.6
Start-of-braking time for bullet vehicles involved in a U-turn in front crash (n=4)

All right-angle/ right-turn/ U-turn crashes

The start-of-braking times of bullet vehicles involved in right-angle, right-turn (adjacent), right-turn (opposite) and U-turn in front crashes combined is shown in Figure 3.7. For all these crash types, the drivers of the through vehicles had a start-of-braking time of no greater than 1.5 seconds before the crash occurred. The vast majority (86%) had a start-of-braking time of less than a second before the crash, including close to a quarter (26%) who did not brake at all.

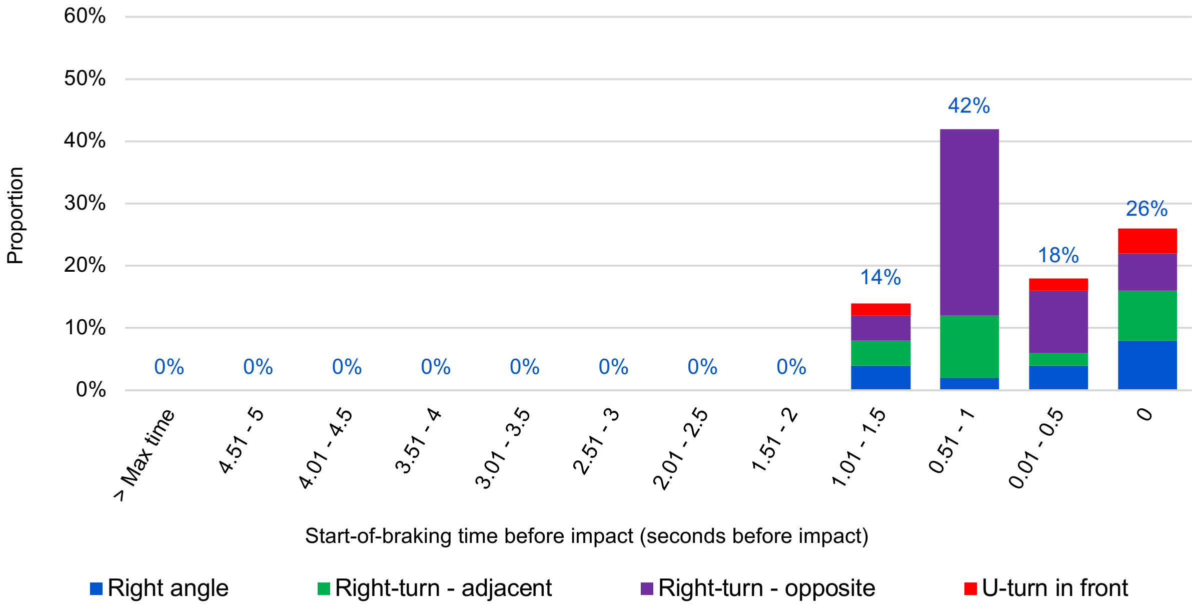

Figure 3.7
Start-of-braking time for bullet vehicles involved in right angle,
right-turn (adjacent direction), right-turn (opposite direction) and U-turn in front crashes (n=50)

Head-on crashes

The start-of-braking times for vehicles involved in head-on crashes is shown in Figure 3.8. More than half of the drivers involved in head-on crashes did not brake at all prior to impact.

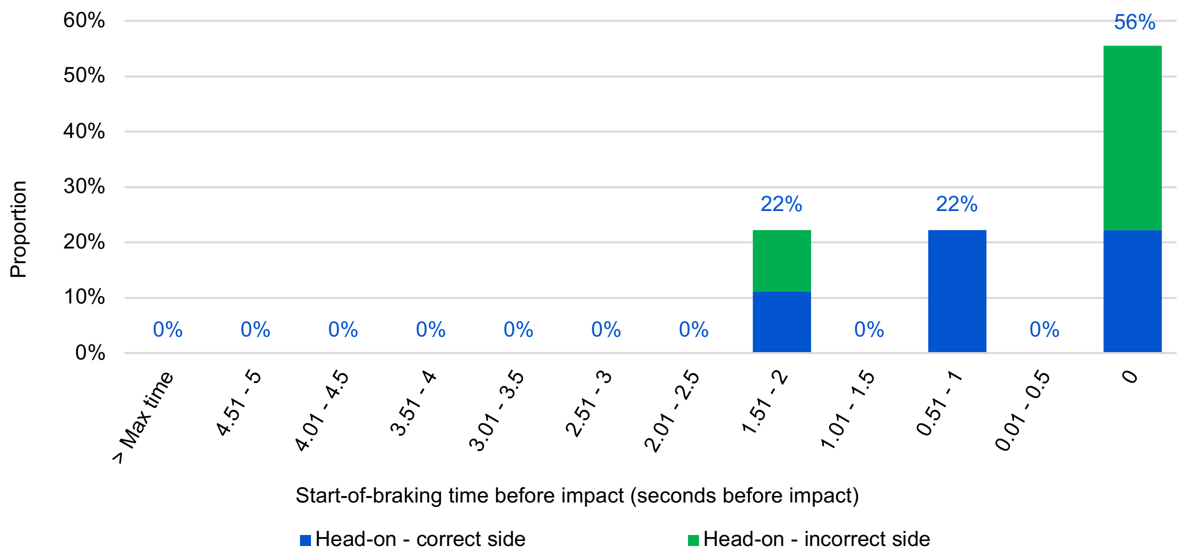

Figure 3.8
Start-of-braking time for vehicles involved in head-on crashes (n=9)

Single vehicle into object crashes

The start-of-braking times of single vehicle into object crashes is shown in Figure 3.9. Almost half (43%) of the vehicles in this category had no braking application before impact.

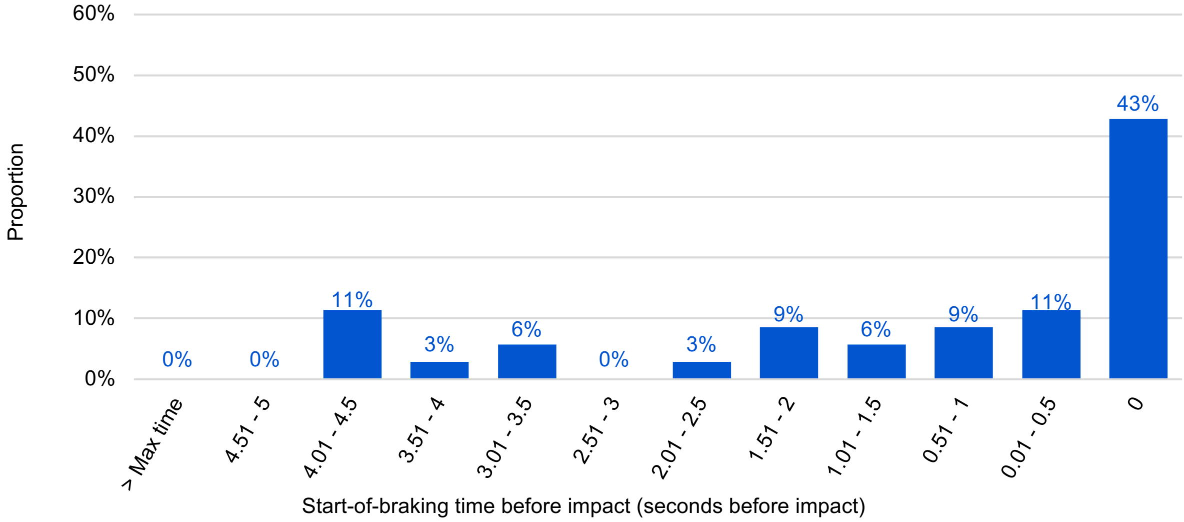

Figure 3.9
Start-of-braking time for vehicles involved in single vehicle into object crashes (n=35)

Hit parked vehicle crashes

The start-of-braking times of hit parked vehicle crashes is shown in Figure 3.10. Close to three-quarters (73%) of the EDR vehicles in this category applied no braking prior to impact with the object.

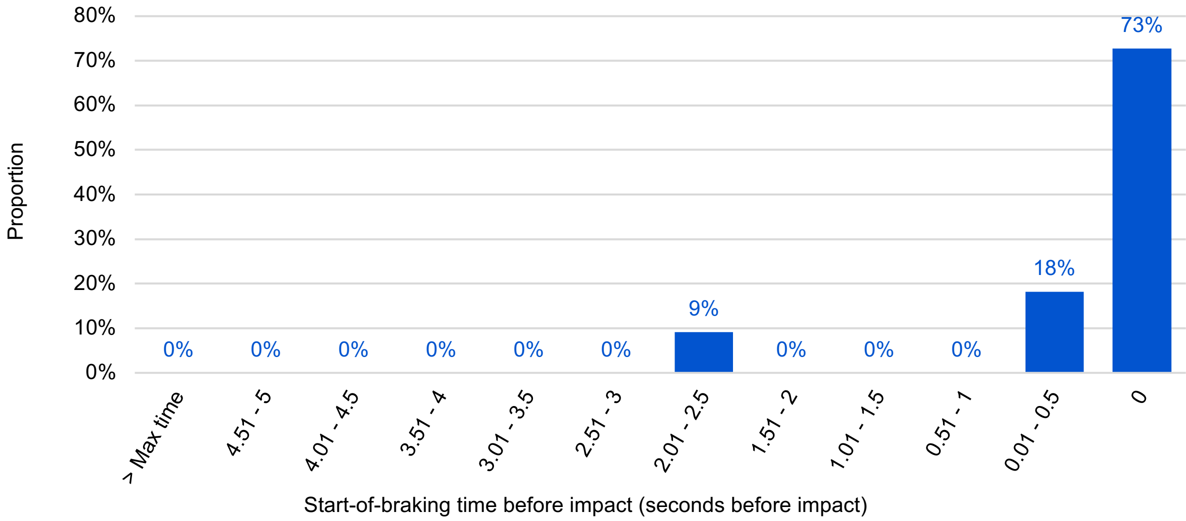

Figure 3.10
Start-of-braking time for vehicles involved in hit parked vehicle crashes (n=11)

Hit animal crashes

For the two cases in the EDR dataset that have braking data and have been categorised as hitting an animal, there was no braking applied by the drivers of the vehicles before impact.

Rollover crashes

The start-of-braking times of single vehicle rollover crashes is shown in Figure 3.11. Half of the vehicles in this category had no braking application before impact.

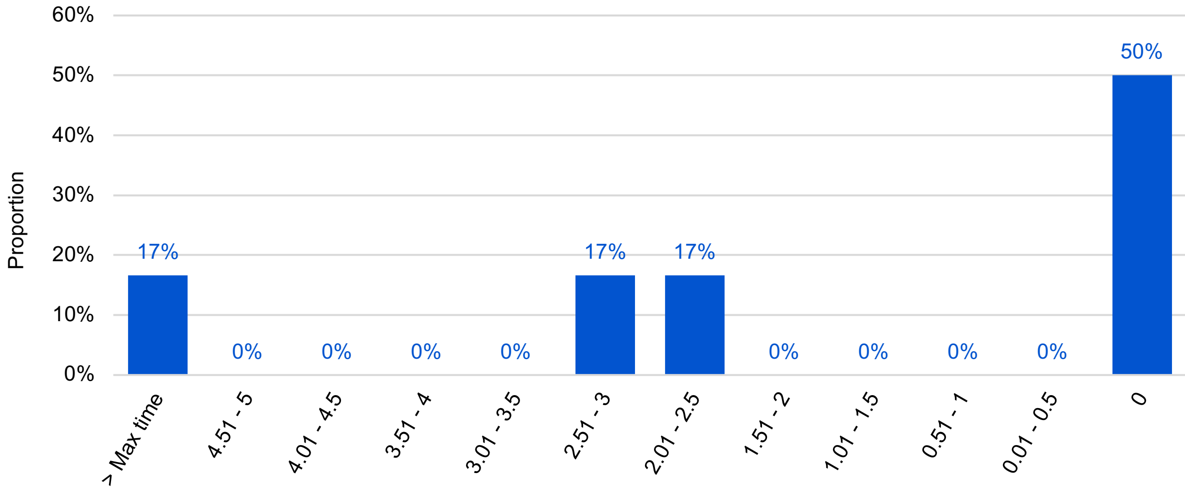

Figure 3.11
Start-of-braking time for vehicles involved in rollover crashes (n=6)

Crash type comparisons

The cumulative distributions of the start-of-braking times for each crash type of bullet vehicles indicate some recurring similarities between crash categories. Figure 3.12 shows the cumulative distributions for each crash type. The curve increases represent increases in the proportion of EDR drivers starting the application of the vehicle brakes. The curves do not reach 100% as some of the EDR vehicle drivers do not apply braking before impact. This graph is accurate to 0.05 second timesteps using the values calculated from the formulas in Section 2.2. An example interpretation of this graph is that at 2.25 seconds before an impact, 50% of 'rollover' crash-involved vehicles had braking applied, and 20% of 'single vehicle into object' crash-involved vehicles had braking applied. The order of crash-types shown at the impact point (0 seconds) also shows the rankings of highest proportions of drivers braking before impact, i.e. 'rear-end' crash-involved vehicles had the highest proportion of drivers braking before an impact occurred and 'hit animal' crash-involved vehicles had the lowest proportion of drivers braking before impact.

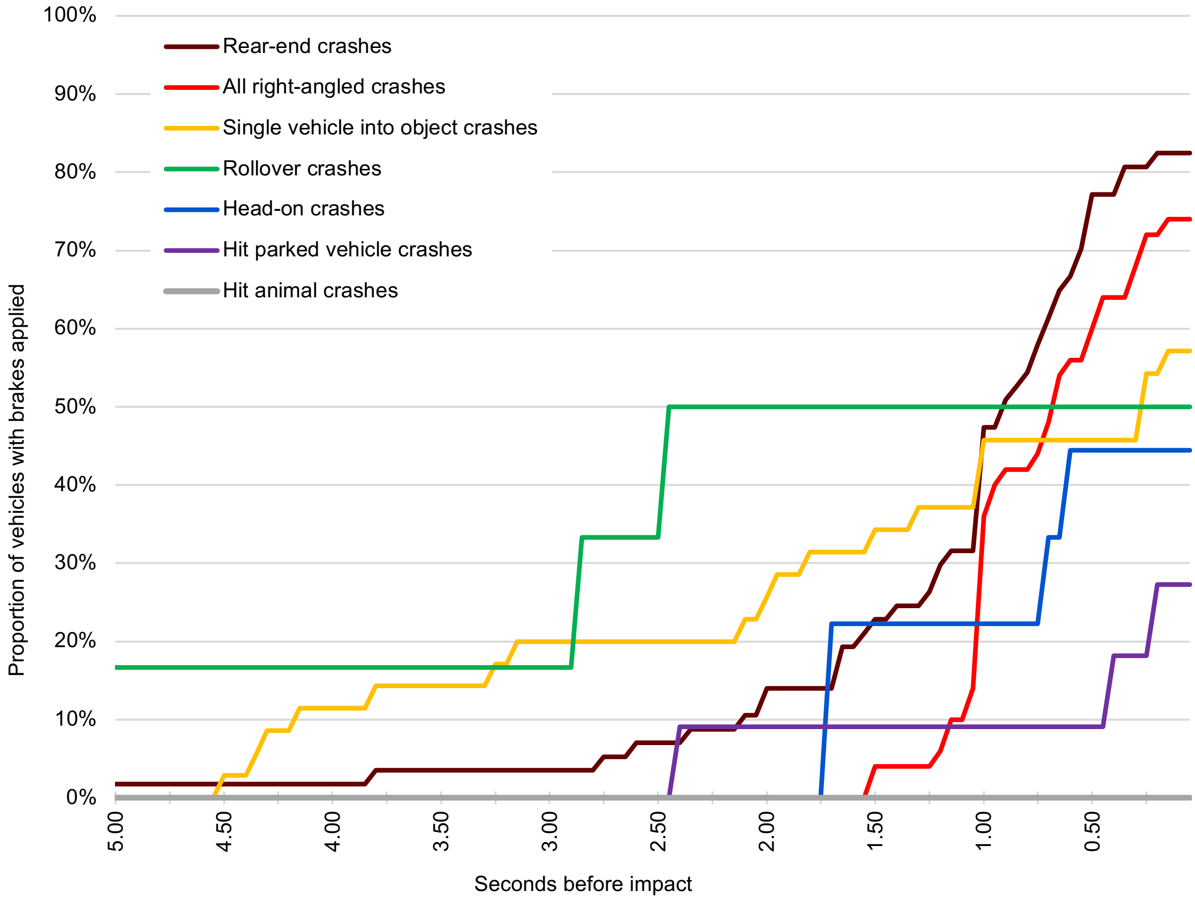

Figure 3.12
Cumulative distribution of all bullet vehicle start-of-braking times by crash type (n=170)

The total average braking time (including the cases with no braking) is shown in Table 3.1. The table also shows the percentage of vehicles with no application of braking and percentage of vehicles with a start-of-braking time greater than 1 second prior to impact.

Table 3.1
Start-of-braking characteristics by crash type

Simple crash type (bullet vehicles only)	Number of crashes	Average start-of-braking time (seconds before impact)	Proportion with no braking	Proportion with braking for greater than 1 second
Rear-end	57	1.02	17.5%	31.6%
Right-angle	9	0.42	44.4%	22.2%
Right-turn - adjacent	12	0.58	33.3%	16.7%
Right-turn - opposite	25	0.72	12.0%	8.0%
U-turn in front	4	0.36	50.0%	25.0%
Head-on	9	0.52	55.6%	22.2%
Single vehicle into object	35	1.20	42.9%	37.1%
Hit parked vehicle	11	0.27	72.7%	9.1%
Hit animal	2	0.00	100.0%	0.0%
Rollover	6	1.72	50.0%	50.0%
All right-angled crashes	50	0.61	26.0%	14.0%
All bullet vehicles	170	0.87	32.9%	25.9%

3.2 Start-of-braking times by speed zone group

The start-of-braking times for all bullet vehicles based on the speed zone of the road is shown in Table 3.2. Figure 3.13 shows the cumulative distributions of the start-of-braking times for all bullet vehicles by speed zone group. The speed zone groups have similar percentages of drivers who do not brake at all, but the vast majority of braking in low speed zones starts in the two seconds preceding impact, while in high speed zones it is more evenly distributed across the 4.5 seconds preceding the impact.

Table 3.2
Start-of-braking times of bullet vehicles by speed zone group

Timestep of start-of-braking (seconds)	Low speed (≤70 km/h) zone		High speed (≥80 km/h) zone	
	Count	Percent	Count	Percent
>Max time recorded	1	0.7%	-	0.0%
4.51 – 5	-	0.0%	1	2.8%
4.01 – 4.5	-	0.0%	4	11.1%
3.51 – 4	1	0.7%	1	2.8%
3.01 – 3.5	-	0.0%	2	5.6%
2.51 – 3	1	0.7%	2	5.6%
2.01 – 2.5	2	1.5%	3	8.3%
1.51 – 2	9	6.7%	2	5.6%
1.01 – 1.5	13	9.7%	2	5.6%
0.51 – 1	41	30.6%	7	19.4%
0.01 – 0.5	20	14.9%	2	5.6%
0 (no braking)	46	34.3%	10	27.8%
Total	134	100.0%	36	100.0%
Average braking time	0.67s		1.61s	

Figure 3.13
Cumulative distribution of bullet vehicle start-of-braking times by speed zone group (n=170)

3.3 Start-of-braking times by recorded sex of driver

The start-of-braking times for all bullet vehicles by the recorded sex of the driver is shown in Table 3.3. Figure 3.14 shows the cumulative distribution of the start-of-braking times for all bullet vehicles based on speed zones. Females had a slightly higher proportion of no braking applied compared to males (35.5% compared to 30.4%) and a lower start-of-braking time. The sex of two drivers was unknown.

Table 3.3
Start-of-braking times of bullet vehicles by recorded sex of driver

Timestep of start-of-braking (seconds)	Female		Male	
	Count	Percent	Count	Percent
>Max time recorded	-	0.0%	1	1.1%
4.51 – 5	-	0.0%	1	1.1%
4.01 – 4.5	2	2.6%	2	2.2%
3.51 – 4	-	0.0%	1	1.1%
3.01 – 3.5	-	0.0%	2	2.2%
2.51 – 3	3	3.9%	-	0.0%
2.01 – 2.5	1	1.3%	4	4.3%
1.51 – 2	4	5.3%	7	7.6%
1.01 – 1.5	3	3.9%	12	13.0%
0.51 – 1	24	31.6%	24	26.1%
0.01 – 0.5	12	15.8%	10	10.9%
0 (no braking)	27	35.5%	28	30.4%
Total	76	100.0%	92	100.0%
Average braking time	0.72s		0.98s	

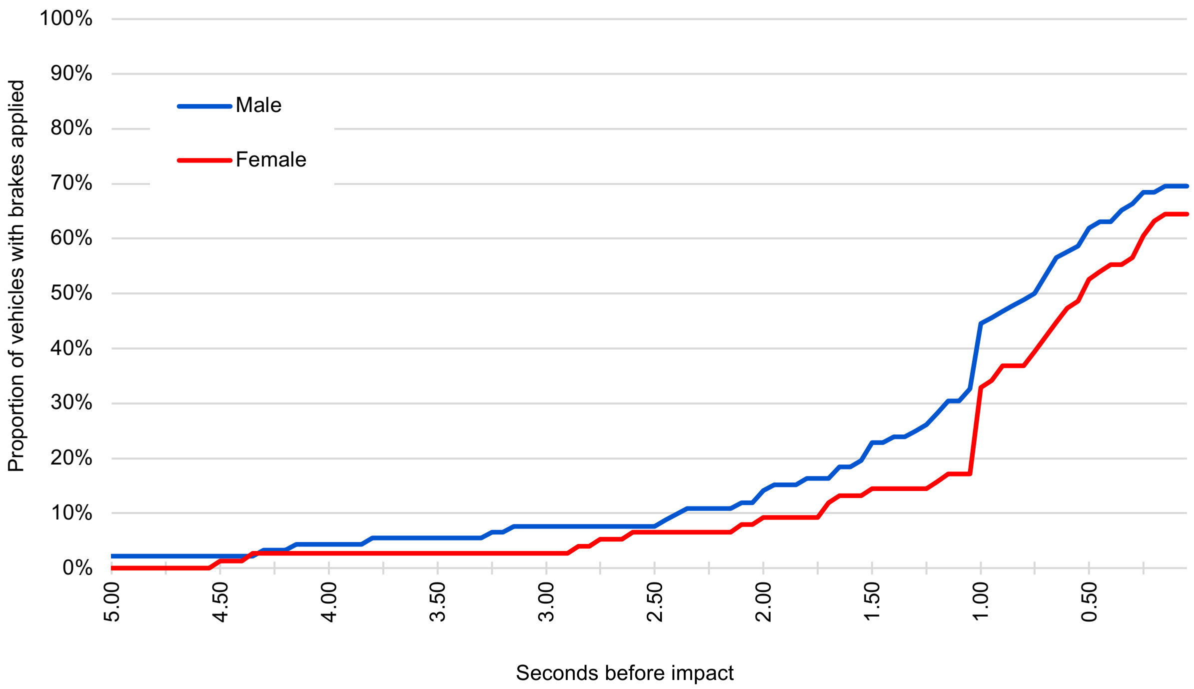

Figure 3.14
Cumulative chart of all bullet vehicle start-of-braking times by recorded sex (n=168)

3.4 Start-of-braking times by age of driver

The start-of-braking times for all EDR bullet vehicles by driver age group is shown in Table 3.4. Figure 3.15 shows the cumulative distribution of the start-of-braking times by driver age group. The age of three drivers was unknown. In general, the cumulative distributions appear to be quite similar. The average braking time did increase with increasing age, but some caution should be taken in interpreting the results due to the small sample of drivers aged 65 years and over.

Table 3.4
Start-of-braking times by age group of driver for all EDR bullet vehicles

Timestep of start-of-braking (seconds)	16 – 25 years old		26 – 64 years old		65+ years old	
	Count	Percent	Count	Percent	Count	Percent
>Max time recorded	1	2.3%	-	0.0%	-	0.0%
4.51 – 5	-	0.0%	1	0.9%	-	0.0%
4.01 – 4.5	1	2.3%	3	2.8%	-	0.0%
3.51 – 4	-	0.0%	-	0.0%	1	6.3%
3.01 – 3.5	-	0.0%	2	1.9%	-	0.0%
2.51 – 3	-	0.0%	2	1.9%	1	6.3%
2.01 – 2.5	3	7.0%	1	0.9%	1	6.3%
1.51 – 2	2	4.7%	9	8.3%	-	0.0%
1.01 – 1.5	4	9.3%	9	8.3%	2	12.5%
0.51 – 1	10	23.3%	35	32.4%	3	18.8%
0.01 – 0.5	7	16.3%	12	11.1%	2	12.5%
0 (no braking)	15	34.9%	34	31.5%	6	37.5%
Total	43	100.0%	108	100.0%	16	100.0%
Average braking time	0.82s		0.87s		0.93s	

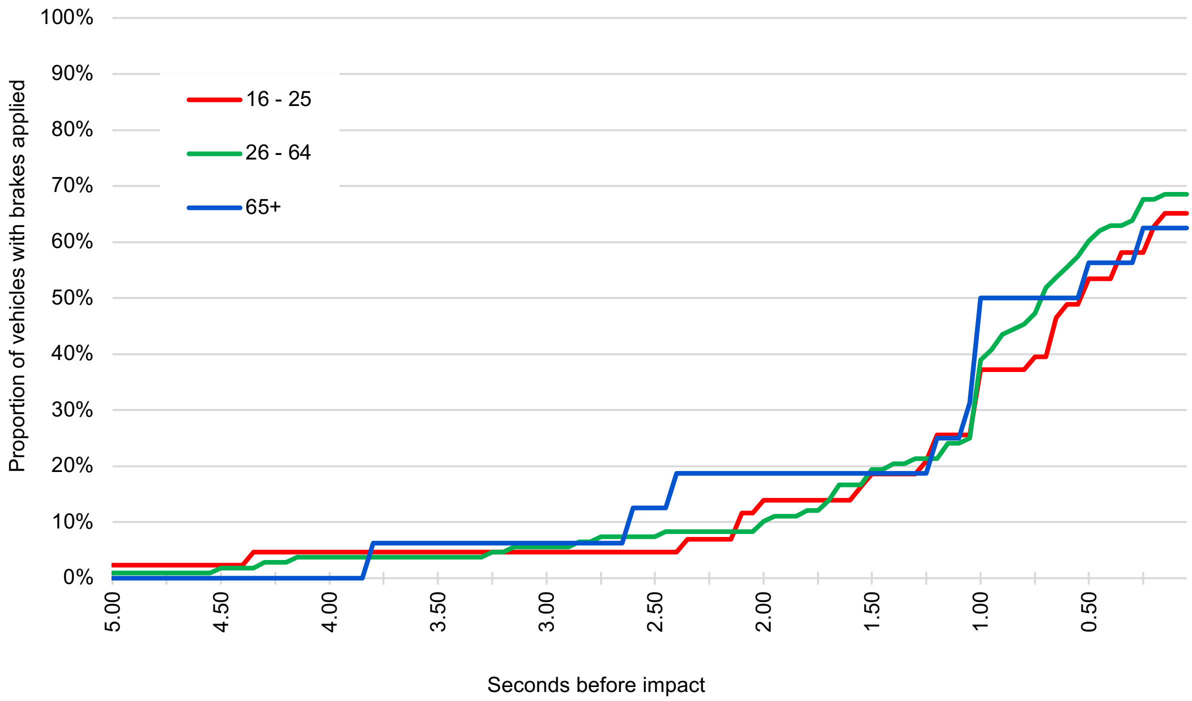

Figure 3.15
Cumulative distribution of all bullet vehicle start-of-braking times by age group (n=167)

4 Discussion

The analyses presented in this report used EDR data to examine the start-of-braking time in real world crashes. Clear differences in start-of-braking time due to crash type and speed zone categories were found. Some evidence of differences related to sex and age were found, but a larger sample size would likely be required to determine if these are true differences or a result of random variation with the sample.

A general limitation to crash data, including EDR crash data, is that it does not include cases when a near crash was successfully avoided. The results of this study therefore only represent the situations where the start-of-braking time was too late to avoid the crash. The difference between the start-of-braking time for all critical situations and crashes is likely to differ between crash types. It seems reasonable to assume that there are a greater percentage of near crashes that are successfully avoided in rear end crashes than in right-angle or single vehicle crashes, and this should be borne in mind when interpreting the results. A future study could combine EDR data, that captures the crash situations, with naturalistic driving data, which captures near crashes but few crashes, to quantify the start-of-braking time in all critical situations. This was outside the scope of the present study.

The combination of right-angled crashes showed that when another vehicle travelled across the bullet vehicle's direction of travel, there is a minimal amount of time for the vehicle to slow down. The explanation for this lies in the trajectories of the vehicles involved. As the turning vehicle performs the turning manoeuvre, it travels somewhat perpendicular to the trajectory of the through vehicle and is in the path of the bullet vehicle for a shorter time period than other crash types, such as rear-end crashes. In the case where the turning vehicle performs the turning manoeuvre earlier, the through vehicle may have an appropriate time to slow the vehicle to avoid the collision.

Bullet vehicles involved in 'rear-end' crashes and 'single vehicle into object' crashes were shown to have a diverse range of start-of-braking times. This may be due to some drivers being aware of the impending crash, and some not (e.g. a distracted or fatigued driver). It may also represent different driver reactions to such an event. Some drivers may predominantly rely on steering as an evasive action and some may commit to braking once they judge they have reached a 'point of no return', as Doecke and Woolley (2010) suggest occurs in single vehicle run off road crashes.

The majority of head-on crashes and hit parked vehicle crashes involved no pre-impact braking. For hit parked vehicles this suggests that in most cases the driver is either suffering from inattention, distraction, impairment, or a medical condition. For head-on crashes where the vehicle was on the incorrect side the same may be implied, though for head-on crashes where the vehicle is on the correct side this may simply be due to a lack of time to react, or the reaction being primarily to perform evasive steering rather than to brake. It is also possible that the lack of braking in both crash types is due to a loss of control. This could be confirmed by individual case examination of these crashes in the CASR EDR database, but such an exercise was outside the scope of the present study.

High speed zones were found to be associated with longer braking times. This may be due to increased sight distance and clear zones, or the difference may simply be a product of a different mix of crash types. Regardless, it is beneficial that vehicles that are travelling in higher speed zones are braking sooner. What remains to be seen is if this earlier braking actually translates into higher reductions in speed that, at least in part, balances the risk associated with increased speed. Doecke and Ponte (2018) found that fatality rates for all crash types increased with increasing speed limit, with few exceptions. This suggests that these earlier braking times do no entirely compensate for the higher speed limit, when considered by crash type.

A limitation of the method to calculate the start-of-braking time is that it does not identify the start of emergency braking (braking in which the driver is attempting to avoid an impending crash). In some cases, the bullet vehicles may be slowing normally for traffic before applying emergency braking. While the prevalence of non-emergency braking is unknown, this limitation implies the start-of-braking times related to the driver response to the crash situations may be lower than the results found in this study. A possible study to investigate the timing of start-of-emergency braking could involve determining a time point in the EDR data where the vehicle acceleration (in the negative sense) is above a certain defined level, though the resolution of the majority of EDR data (0.5s intervals) may result in such an analysis producing an underestimate.

Another limitation of the method is that it does not identify the braking intensity over the period of braking. Not all drivers may have applied full braking when they did react to an impending crash. The high prevalence of brake assist systems in the light vehicle fleet (Anderson and Baldock, 2008), which are designed to detect when a driver is braking for an emergency situation and ensure full braking, suggests that full braking should be present in the majority of the crashes. Brake assist systems are less prevalent on light commercial vehicles therefore these vehicles may have less speed reduction for a given start-of braking time.

The start-of-braking times of drivers in crash situations has implications for advanced driver assistance systems (ADAS), such as autonomous emergency braking (AEB), that seek to improve upon human performance in these situations. For example, AEB would most likely provide a significant improvement over the performance of the driver in the 18% of rear-end crashes where no braking was applied before the crash. AEB may also improve upon the performance of the 51% of crash involved drivers who braked within a second of the impact, but it would most likely offer little improvement for the 32% of drivers that braked more than a second before impact.

5 Future work

The analysis revealed several areas that warrant further investigation. One of these is the amount of speed loss produced by pre-impact braking. Analysis of speed loss due to braking would aid in applying threshold impact speeds to policy on travel speed and speed limits.

Another area that warrants further investigation is the start-of-braking times in near crashes. Combining such an analysis with the results of this report would provide an overall understanding of start-of-braking time in critical situations.

Further work investigating the reasons for differences in the start-of-braking times in low and high-speed zones would also be justified. Such work could include an examination of the effect of certain intersection design parameters, such as sight distance, on the start-of-braking time.

The minor differences between the start-of-braking times due to sex and age group found in this report should be further explored once a larger sample of EDR data is available.

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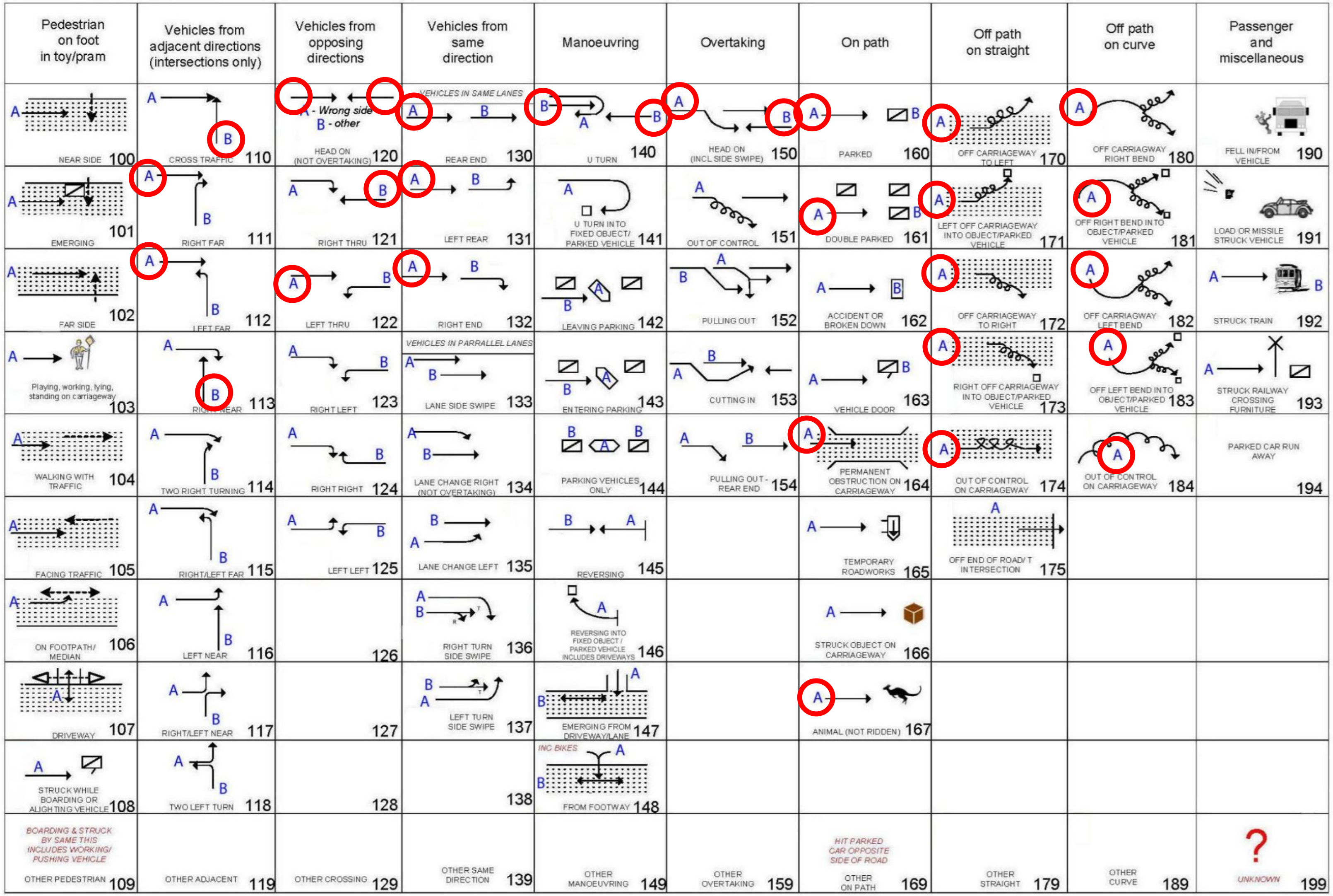
Appendix A – DCA code diagram with bullet vehicles highlighted



Appendix B – Derivation of formula to calculate start-of-braking time

The derivation of the formula used to calculate the start-of-braking time is shown below.

The following Figure shows the braking timesteps of the example used in Section 2.1.

Time (sec)	-2.25	t_1 -1.75	t_s -1.25 t_2	-0.75 t_3	-0.25	0 (TRG)
Vehicle Speed (MPH [km/h])	59.7 [96]	V_1 60.9 [98]	V_s 55.3 [89] V_2	45.4 [75] V_3	36.7 [59]	33.6 [54]
Accelerator Pedal, % Full (%)	39.5	0.0	0.0	0.0	0.0	0.0
Percentage of Engine Throttle (%)	33.0	1.5	0.0	0.0	0.0	0.0
Engine RPM (RPM)	3,900	3,900	3,100	2,300	1,700	1,500
Motor RPM (RPM)	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Service Brake, ON/OFF	OFF	OFF	ON	ON	ON	ON
Brake Oil Pressure (Mpa)	0.00	0.00	6.77	9.12	9.36	9.70

The red and blue variables indicate the values used in the formulas and derivation.

The last timestep where braking is OFF is determined. This timestep has the variables assigned for time and speed: t_1 and V_1 respectively.

The timesteps following the previously determined timestep are where the braking is ON. These two timesteps are assigned variables for time and speed similarly, t_2 and V_2, and t_3 and V_3.

The start-of-braking time is between t_1 and t_2, so two variables, V_s and t_s, are created to be between the two timesteps to indicate the speed at the start of braking and the time at the start of braking.

The acceleration between two timesteps is equal to the change in velocity divided by the change in time. For the acceleration between timesteps 2 and 3, the equation is:

$$a_{2-3} = \frac{(V_3 - V_2)}{(t_3 - t_2)}$$

The acceleration between timesteps 2 and 3 may be considered to be roughly the same acceleration between the start of braking and timestep 2. Hence:

$$a_{s-2} = \frac{(V_2 - V_s)}{(t_2 - t_s)} = a_{2-3} = \frac{(V_3 - V_2)}{(t_3 - t_2)}$$

But, it can be assumed that $V_s = V_1$ as the speed decrease before braking in a very short time would be negligible in most cases. Therefore:

$$\frac{(V_2 - V_1)}{(t_2 - t_s)} = \frac{(V_3 - V_2)}{(t_3 - t_2)}$$

Rearranging the equation to focus on t_s:

$$t_s = t_2 - \frac{(V_2 - V_1)(t_3 - t_2)}{(V_3 - V_2)}$$

Due to the negative time values of the timesteps, t_s needs to be converted to a positive value. A ramping time of 0.085 is also added to the braking time to account for the time it takes for the average driver to apply the brakes from 0% to the desired level. The equation then becomes:

$$t_s = \left| t_2 - \frac{(V_2 - V_1)(t_3 - t_2)}{(V_3 - V_2)} \right| + 0.085$$