Post impact trajectory of vehicles at metropolitan intersections

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TITLE

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ABSTRACT

This report describes the path of vehicles following a collision with another vehicle at a metropolitan intersection. The aim was to provide guidance to transport authorities on roadside design at intersections to protect vehicles from secondary impacts with roadside objects. Detailed information from in-depth investigations of 78 intersection crashes was analysed. Crashes at singalised and unsignalised intersections were analysed separately. Thirty two vehicles at signalised and unsignalised intersections (16 at each) were involved in a secondary collision. Nine of these collisions were more severe than the initial vehicle-to-vehicle collision, three at signalised intersections and six at unsignalised intersections. Following the vehicle-to-vehicle impact at both signalised and unsignalised intersections, more than half of the vehicles came to rest within 10 metres of the impact point. However, more than a quarter travelled 15 metres or further and around 10% travelled further than 27 metres. It was found that 40% of vehicles at signalised intersections crossed the designated pedestrian crossing areas following a collision between vehicles. It was also found that 14% of vehicles involved in crashes at signalised intersections departed the roadway. This poses a significant risk to pedestrians who are in the vicinity of junctions at the time of collisions. Graphical representations of the percentage of vehicles that travel through a given sector relative to the impact point following the metropolitan intersection crashes were developed. These can be used to determine the chance of a vehicle having a secondary collision with roadside objects.

KEYWORDS

Crash, Intersection, secondary impact, roadside hazard

Summary

This report describes the path of vehicles following a collision with another vehicle at a metropolitan intersection. The aim was to provide guidance to transport authorities on roadside design at intersections to protect vehicles from secondary impacts with roadside objects. There has been little prior research of this nature.

Detailed information concerning metropolitan intersection crashes was obtained from the Centre for Automotive Research's (CASR) in-depth crash investigation database. Metropolitan road crashes that were investigated by CASR during two separate periods were used in this study: April 2002 to October 2005 and February 2009 to 2012 (ongoing). For this study, any crash involving a vehicle-to-vehicle collision at a metropolitan intersection was sought and crashes were taken from both study periods. Rear end crashes at intersections were not included. In total, 64 intersection crashes were obtained between 2002 and 2005, and 14 from the period 2009 to 2012.

The results of crashes that occurred at signalised intersections and unsignalised intersections were analysed and presented separately as it was thought there were fundamental differences between the two intersection types. There were 35 signalised and 43 unsignalised intersection crashes in the sample. With one exception, speed limits represented combinations of 60 km/h and 50 km/h on the intersecting roads.

Sixteen of the 70 vehicles involved in the 35 signalised intersection crashes were involved in a secondary collision, most commonly with a traffic light pole or a stationary vehicle. Similarly, 16 of the 86 vehicles involved in the 43 unsignalised intersection crashes were involved in a secondary collision most commonly with trees, fences, signs and stobie poles. Nine of these collisions were more severe than the initial vehicle-to-vehicle collision, three at signalised intersections and six at unsignalised intersections.

Following the vehicle-to-vehicle impact at a signalised intersection, more than half of the vehicles came to rest within 10 metres of the impact point. However, more than a quarter travelled 15 metres or more and 9% travelled further than 27 metres. Results were similar at unsignalised intersections. About half of the vehicles came to rest within 10 metres of the impact point. Beyond this, 30% travelled 15 metres or more and 10% travelled further than 27 metres from the impact point.

It was found that 40% of vehicles at signalised intersections crossed the designated pedestrian crossing area following the initial impact. It was also found that 14% of vehicles involved in crashes at signalised intersections departed the roadway. This represents a significant risk to pedestrians who are in the vicinity of the intersection at the time of a collision between vehicles. Vehicles departing the road at unsignalised intersections (27%) also represent a potential danger to pedestrians, though it is less likely that a pedestrian would be present at an unsignalised intersection.

Graphical representations of the percentage of vehicles that travel through a given sector relative to the impact point following the metropolitan intersection crashes were developed. These can be applied using assumed impact points within the intersection. Overlaying the chart on a plan of the intersection relative to the impact point then provides an indication of the chance of a vehicle striking a hazard within a given sector following an initial impact with another vehicle.

Contents

1 Introduction

This report describes the paths of vehicles following a collision with another vehicle at a metropolitan intersection. The aim was to provide information to transport authorities that would assist in roadside design at intersections to protect vehicles from secondary impacts with roadside objects. This research was prompted by anecdotal evidence from CASR's in-depth crash investigations that secondary impacts with roadside hazards following a primary impact with another vehicle were not rare, and on occasion the secondary impact was found to be more severe than the initial vehicle-to-vehicle collision.

A secondary impact of this nature is of concern as following the initial impact between vehicles, passive safety elements to protect vehicle occupants have already been utilised compromising the ability of the vehicle to protect occupants in subsequent collisions. Furthermore, collisions with roadside hazards tend to involve poles and trees leading to more severe impacts.

The current Australian guidelines for road design are not explicit on roadside design at intersections to protect vehicles from secondary impacts with roadside objects. The Austroads Guide to Road Design Part 4 on intersections (Austroads, 2009a) briefly mentions that adequate clear zones should be provided around intersections because a significant number of off-road crashes occur at intersections but there is little guidance or discussion beyond this. There is no explicit reference to clear zone requirements at intersections in the Austroads Guide to Road Design Part 6 on roadside safety and barriers (Austroads, 2009b).

Intersection crashes make up 23.5% of all metropolitan crashes in South Australia over the past 10 years (Table 1.1) and this percentage has remained relatively static over that time period (Figure 1.1). Of the crashes at intersections, about 80% are split almost evenly between intersections controlled by traffic signals and those with no control at all. The remainder are shared between intersections with give way signs and stop signs. In terms of injury severity, crashes at intersections with give way signs are the most likely to be associated with serious or fatal injury severity, though the highest number of fatal crashes occurred at uncontrolled intersections.

Table 1.1
South Australian crash statistics related to metropolitan intersections, 2002 to 2011
(excluding single vehicle, motorcycle, and pedestrian crashes)

	All		Injury		Serious		Fatal	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Total crashes	196,940	100%	51,301	100%	5,938	100%	470	100%
Intersection crashes	46,198	23.5%	11,341	22.1%	1,140	19.2%	83	17.7%
Traffic control of intersection crashes								
No control	17,592	38.1%	3,879	38.1%	339	29.7%	31	37.3%
Give way sign	4,978	10.8%	1,294	10.8%	153	13.4%	17	20.5%
Stop sign	4,997	10.8%	1,318	10.8%	134	11.8%	12	14.5%
Traffic signals	18,631	40.3%	4,850	40.3%	514	45.1%	23	27.7%

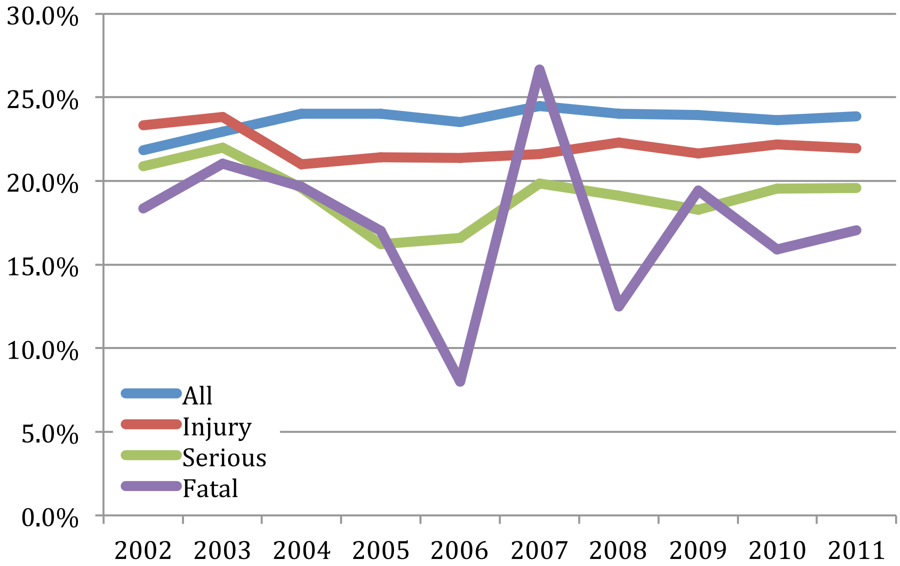

Figure 1.1
South Australian crashes related to metropolitan intersections, 2002 to 2011
(excluding single vehicle, motorcycle, and pedestrian crashes)

There appears to have been limited research on the topic of post-crash trajectories documented in the literature. The majority of prior research into intersection crashes focuses on the pre-crash movements of the vehicles rather than the movement of vehicles after an initial impact. The only study found that made reference to post impact trajectory of vehicles following an intersection crash found that 15 vehicles from a sample of 35 uncontrolled intersection crashes struck a roadside object after the initial collision (McLean et al, 1979). Note that this current work is complemented by an earlier study by the authors that investigated post impact trajectories of vehicles at rural intersections (Doecke, Woolley and Mackenzie, 2011)

2 Method

Detailed information concerning metropolitan intersection crashes was obtained from the Centre for Automotive Research's (CASR) in-depth crash investigation database.

The database consists of information collected through the in-depth investigation of crashes where a crash participant is transported by ambulance to hospital, or suffers fatal injuries. Investigations begin with immediate attendance at the scene of the crash by a team of two personnel. The information collected for each crash includes: photographs/videos of the crash scene and vehicles involved, examination of the road environment, a site plan of the crash scene and vehicle movements during the crash, examination and measurements of the vehicles involved, interviews with crash participants, interviews with witnesses, discussion with police, information from the official police report, information from Coroner's reports (where an occupant has suffered fatal injuries), and hospital injury data for the injured crash participants.

Metropolitan road crashes investigated by CASR during two separate periods were used in this study: April 2002 to October 2005 and February 2009 to 2012 (ongoing). CASR researchers were on call to attend crash scenes between 9am and 4:30pm during weekdays in both periods and sometimes on Thursday night, Friday night and weekends during the first period. Fatal accidents that occurred at any time on any day were also investigated as the South Australia Police Major Crash Investigation teams preserved evidence at the scene allowing CASR researchers to follow up with a *post-hoc* investigation.

Over these two periods 190 crashes were identified as having occurred at intersections, however many were excluded from the final sample of crashes (Table 2.1). Crashes involving only one motor vehicle (vehicle vs pedestrian, vehicle vs motorcycle, vehicle vs pedal cycle and single vehicle) crashes were excluded from the final sample. Rear end collisions were also excluded, as while often occurring due to an intersection, do not tend to happen within the intersection. Rear end crashes are also likely to result in post impact trajectories that have different characteristics to other intersection crashes. There were also some crashes that, while they occurred at the intersection, were unrelated to the intersection and these were also excluded from the sample. There were a number of cases in which the vehicles had been moved prior to the arrival of CASR staff, and therefore final vehicle positions could not be ascertained. As the post impact trajectory was therefore unknown these crashes could not be included in the sample. There were also some crashes that were not considered to fit into the typical intersection crashes category, such as a vehicle conducting a U-turn or a crash involving a mobility scooter.

Table 2.1
Characteristics of intersection crashes that were excluded from the final sample

Category	2002-2005	2009-2012	Total
Total	143	47	190
Final positions unknown	26	12	38
Vehicle vs Pedestrian	18	0	18
Vehicle vs Motorcycle	5	10	15
Vehicle vs Pedal cycle	5	1	6
Rear end	11	3	14
Single vehicle	6	3	9
Unrelated to intersection	2	2	4
Different	6	2	8
Final Sample	64	14	78

Variables collected in the in-depth crash investigations that may have some influence on a vehicles post impact trajectory were analysed within the sample of metropolitan intersection crashes. The variables included in the analysis and their definitions are shown below:

- Geometry - the geometry of intersection where the crash took place (e.g. cross road, T-junction)
- Traffic control - the type of traffic control at the intersection where the crash took place (traffic signals, stop sign)
- DCA code - code that describes the movements of the vehicles involved in the crash (see Figure 2.1)
- Speed limit - the speed limit on the road that the particular unit was travelling
- Impact location on unit - the principle location of the initial impact on the particular unit, separated into general areas by the ends of the unit and the pillars of the unit (e.g. Front to A-pillar, A to B-pillar)
- Injury severity - the highest severity of injury sustained by a particular unit’s occupants (e.g. treated, admitted)
- Unit mass - the approximate mass of the unit, taking into account the occupants and any cargo
- Road type - the road type of a particular unit, based on the intended use of the road in the road hierarchy (e.g. local, arterial)
- Unit remained in intersection - whether or not the particular unit left the intersection, as defined by the pedestrian crossings, stop or give way line or end of the curb radii
- Secondary collision - object that was struck by unit after the initial impact, if any (e.g. traffic signal pole, fence, vehicle - stationary)
- Most severe impact - the most severe impact is determined in cases where a secondary collision occurred by considering the intrusion, airbag deployment on secondary impact, or driver interview statements
- x distance - the distance travelled from the impact point to the rest position of the particular unit in the original direction of Unit 1 (see Figures 2.1 and 2.2)
- y distance - the distance travelled from the impact point to the rest position of the particular unit perpendicular to the original direction of Unit 1 (see Figures 2.1 and 2.2)
- Straight line distance - the distance between the impact point and the furthest point of the final position of the vehicle (see Figure 2.2)
- Angle - the angle between the x axis and the line created by the straight line distance (see Figure 2.2)

Figure 2.1 displays the configuration of the crashes of DCA codes 101, 104 and 202. While more DCA codes are applicable to intersection crashes than the three shown in Figure 2.1 only these three DCA codes were needed to code the 78 in-depth crash investigation cases. Figure 2.1 also displays the sign conventions used in analysing the data. Unit 1 is typically defined as the through vehicle, or, in cases where both vehicles were continuing through the intersection, the vehicle that had the right of way. The positive x direction is always defined as the direction Unit 1 is travelling. The positive y direction is defined as being perpendicular to the x direction and approximates the direction Unit 2 was travelling when struck. Note also that the stop lines shown in Figure 2.1 are for illustrative purpose only; the actual cases may have other forms of traffic control or be uncontrolled.

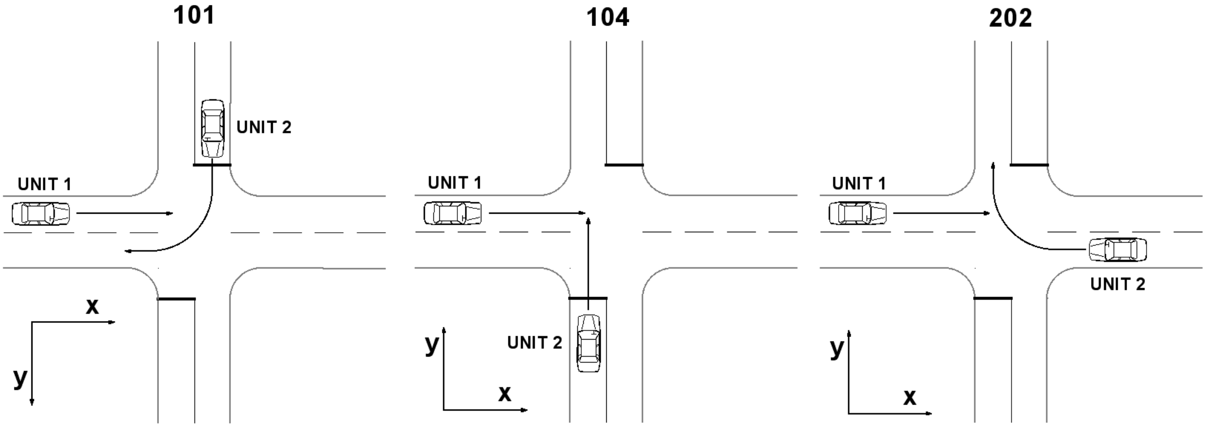

Figure 2.1
DCA code diagrams
(unit and sign conventions are also illustrated)

The measurement technique used to determine the post impact trajectory is shown in Figure 2.2. Note that the impact point is used as the reference from which to measure the straight line distance rather than the centre point of the intersection, as used in the earlier rural study (Doecke, Woolley and Mackenzie, 2011). This change was necessary because metropolitan intersections can have a large number of lanes and be complex in geometry compared to rural junctions.

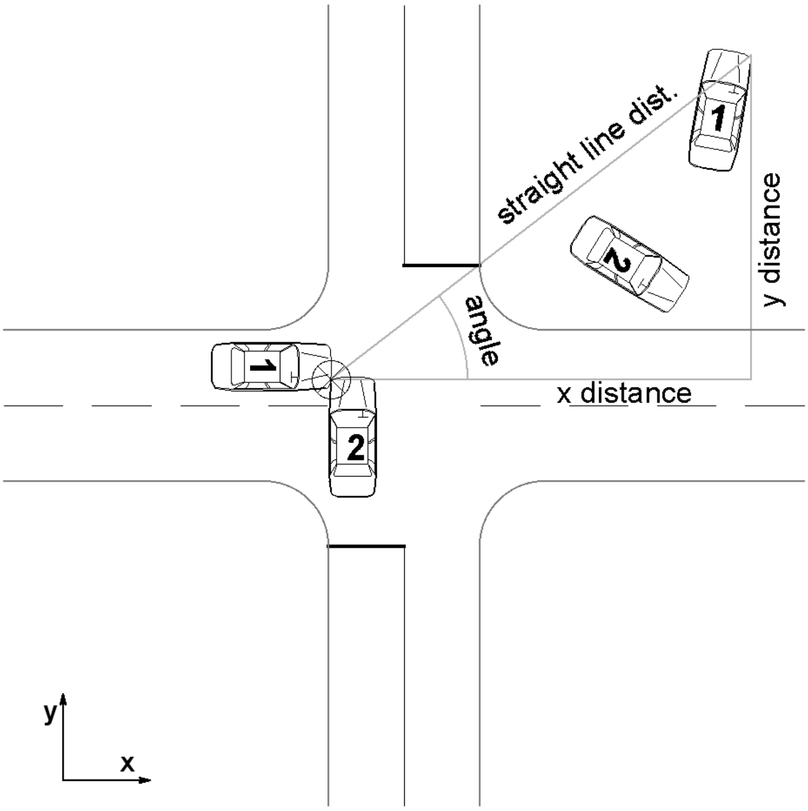

Figure 2.2
Measurement of post impact trajectory

3 Results

The geometry of the intersections and traffic control used at the intersections can be seen in Table 3.1. The majority of the intersections are split equally between cross roads and T-Junctions. The majority of cross roads were controlled by traffic signals, and almost all have some form of control. Conversely, the majority of T-Junctions were uncontrolled. If a T-Junction was controlled in some way it was most likely to be with traffic signals rather than signs. The other types of intersections, Y-Junctions and Multi-leg junctions, were all controlled by traffic signals, though they were very uncommon.

Table 3.1
The metropolitan intersection crashes by geometry and traffic control

Geometry	Traffic Control				
	Traffic signals	Stop sign	Give way sign	Uncontrolled	Total
Cross road	22	8	5	2	37
T-Junction	9	1	2	25	37
Y-Junction	1	0	0	0	1
Multi-leg junction	3	0	0	0	3
Total	35	9	7	27	78

The results of crashes that occurred at signalised intersections and unsignalised intersections were analysed and are presented separately as it was thought that there would be fundamental differences between the intersections and the post impact trajectory of the vehicles at these two types of intersections.

3.1 Signalised intersections

Table 3.2 shows the DCA codes of the metropolitan signalised intersection crashes (see Figure 2.1 for illustrations of the DCA codes). The majority of the crashes at signalised intersections had a DCA code of 202 (a right turn in front type crash configuration). This is not surprising as it is the only DCA code that can occur at an intersection without someone disobeying a traffic signal.

Table 3.2
DCA codes of the metropolitan signalised intersection crashes

DCA code	Number	Percentage
101	7	20.0
104	9	25.7
202	19	54.3
Total	35	100.0

The geometries of the signalised intersections where the crashes occurred are shown in Figure 3.3. Cross roads made up the majority of the intersections (63%), while just over a quarter occurred at T-Junctions. Multi-leg and Y-Junctions were relatively uncommon.

Table 3.3
Geometries of intersections for the metropolitan signalised intersection crashes

Geometry	Number	Percentage
Cross road	22	62.9
T-Junction	9	25.7
Y-Junction	1	2.9
Multi-leg junction	3	8.6
Total	35	100.0

Table 3.4 displays the speed limits that were applicable to each unit involved in the metropolitan signalised intersection crashes. Unit 1 was travelling on a road with a speed limit of 60 km/h in most cases (86%). Unit 2 was travelling on a road with a 60 km/h speed limit the majority of the time, but 50 km/h zones were also common (43%). Only two of the 70 vehicles were travelling on roads with speed limits higher than 60 km/h.

Table 3.4
Applicable speed limits at the metropolitan signalised intersection crashes by unit number

Speed limit	Unit 1		Unit 2	
	Number	Percent	Number	Percent
50	5	14.3%	15	42.9%
60	30	85.7%	18	51.4%
70	0	0.0%	1	2.9%
80	0	0.0%	1	2.9%
Total	35	100.0%	35	100.0%

The location of impact on vehicles involved in the metropolitan signalised intersections crashes is shown in Table 3.5. Most of the vehicles classified as Unit 1 had a frontal impact. Given that Unit 1 is defined as the through vehicle or, if both vehicles are travelling through the intersection, the vehicle with right of way, this finding is not unexpected. If Unit 1 did not have a frontal impact, it was more likely to be struck in front of the B pillar than behind it: only two Unit 1's were struck behind the B pillar. The impact locations on the vehicles classified as Unit 2 were much more varied, though it was also more common for Unit 2s to be struck in front of the B-pillar than behind it.

Table 3.5
Location of impact on vehicles involved in the metropolitan signalised intersection crashes by unit number

Impact location	Unit 1		Unit 2	
	Number	Percent	Number	Percent
Front	28	80.0%	11	31.4%
Front to A-pillar	2	5.7%	11	31.4%
A to B pillar	3	8.6%	9	25.7%
B to C pillar	1	2.9%	2	5.7%
C pillar to rear	1	2.9%	2	5.7%
Total	35	100.0%	35	100.0%

Table 3.6 shows the injury severity of the crashes in terms of most severe outcome within an individual unit. The mostly likely injury severity in both Unit 1 and 2 was hospital treatment, followed by no injury. Eight Unit 1 and Unit 2 vehicles involved serious injury (hospital admission or fatal). One crash involved a fatality to the occupant of a Unit 2 vehicle.

Table 3.6
Injury severity in the metropolitan signalised intersection crashes by unit number

Injury severity	Unit 1		Unit 2	
	Number	Percent	Number	Percent
No injury	8	22.9%	11	31.4%
Minor / Doctor	1	2.9%	2	5.7%
Hospital treatment	22	62.9%	18	51.4%
Hospital admission	4	11.4%	3	8.6%
Fatal	0	0.0%	1	2.9%
Total	35	100.0	35	100.0

The mass ratios of the vehicles that were involved in the metropolitan signalised intersection crashes are shown in Table 3.7. The mass ratio is defined as the ratio of the mass of Unit 1 to the mass of Unit 2. For example, a mass ratio of more than one means that Unit 1 has a greater mass than Unit 2. The majority of the mass ratios where between 0.75 and 1.24, though in nine cases the mass ratio was 1.25 or more compared to only three that had a mass ratio of less than 0.75. In three of the crashes the mass ratio was more than two, meaning that Unit 1 had a mass at least twice as large as Unit 2 (Unit 1 was a heavy vehicle in two of these crashes).

Table 3.7
Mass ratios of vehicles involved in the metropolitan signalised intersection crashes

Mass ratio	Number	Percentage
< 0.50	0	0.0%
0.50 – 0.74	3	8.6%
0.75 – 0.99	14	40.0%
1.00 – 1.24	9	25.7%
1.25 – 1.49	5	14.3%
1.50 – 1.99	1	2.9%
> 2.00	3	8.6%
Total	35	100.0%

Table 3.8 shows the metropolitan signalised intersection crashes by road type of Unit 1 and Unit 2. Unit 1 was almost always travelling on an arterial road, with only three travelling on a collector road and a solitary Unit 1 travelling on a local road. Arterial roads were also the most common road type for Unit 2s to be travelling on but nine were travelling on a collector road and 10 on a local road. The most common combination of road types was for both units to be travelling on arterial roads.

Table 3.8
The metropolitan signalised intersection crashes by road type of Unit 1 and Unit 2

Unit 2 Road Type	Unit 1 Road type			
	Arterial	Collector	Local	Total
Arterial	15	1	0	16
Collector	7	2	0	9
Local	9	0	1	10
Total	31	3	1	35

Following a crash at a metropolitan signalised intersection some vehicles departed the intersection or even the roadway before coming to rest. The number that did so, by unit number, are shown in Table 3.9. Both Unit 1 and Unit 2 departed the intersection following a crash 40% of the time. Only 6% of Unit 1s departed the roadway. Unit 2 was much more likely to departed the roadway than Unit 1, with 23% of Unit 2s departing the roadway following the initial crash.

Table 3.9
Intersection and roadway departures following the metropolitan signalised intersection crashes by unit number

	Unit 1		Unit 2	
Intersection departure	Number	Percent	Number	Percent
No	21	60.0%	21	60.0%
Yes	14	40.0%	14	40.0%
Roadway departure				
No	33	94.3%	27	77.1%
Yes	2	5.7%	8	22.9%

Table 3.10 shows the objects struck in secondary collisions of vehicles involved in metropolitan signalised intersection crashes. Note that for vehicles that have multiple secondary collisions all struck objects are included, resulting in a higher total than the number of vehicles. The majority of vehicles were not involved in a secondary collision. Of those that were involved in a secondary collision, a traffic light pole was the most struck object followed by a stationary vehicle. Unit 2 was the most likely vehicle to be involved in a secondary collision.

Table 3.10
Objects struck in secondary collisions by vehicles involved in metropolitan signalised intersection crashes by unit number

Secondary collision	Unit 1		Unit 2	
	Number	Percent	Number	Percent
None	29	82.9%	25	71.4%
Traffic light pole	3	8.6%	5	14.3%
Building	0	0.0%	1	2.9%
Fence	0	0.0%	1	2.9%
Vehicle – stationary	2	5.7%	4	11.4%
Vehicle – moving	0	0.0%	1	2.9%
Vehicle - parked	1	2.9%	0	0.0%

The most severe impacts in the metropolitan signalised intersection crashes, as determined by the intrusion, airbag deployment on secondary impact, and driver interview statements, are shown in Table 3.11. Only three of the 70 vehicles involved in these crashes were considered to have had a more severe secondary impact, two with a traffic light pole and one with a parked vehicle. For more detail on these cases, including site diagrams and photos of the vehicles, see Appendix A.

Table 3.11
The most severe collision of vehicles involved in metropolitan signalised intersection crashes by unit number

Most severe collision	Unit 1		Unit 2	
	Number	Percent	Number	Percent
Initial	32	91.4%	35	100.0%
Traffic light pole	2	5.7%	0	0.0%
Vehicle - parked	1	2.9%	0	0.0%
Total	35	100.0%	35	100.0%

Figure 3.1 shows the final positions of vehicles involved in the metropolitan signalised intersection crashes relative to the impact point. While the majority of cases come to rest within 10 to 15 metres of the impact point there are a number that go well beyond this area with some vehicles travelling more than 50 metres. The vehicles that travelled large distances tend to come to rest close to the x or y axis, with two notable exceptions. Unit 1 vehicles tend to come to rest close to the x axis (their original direction of travel). Unit 2 final positions are more broadly scattered.

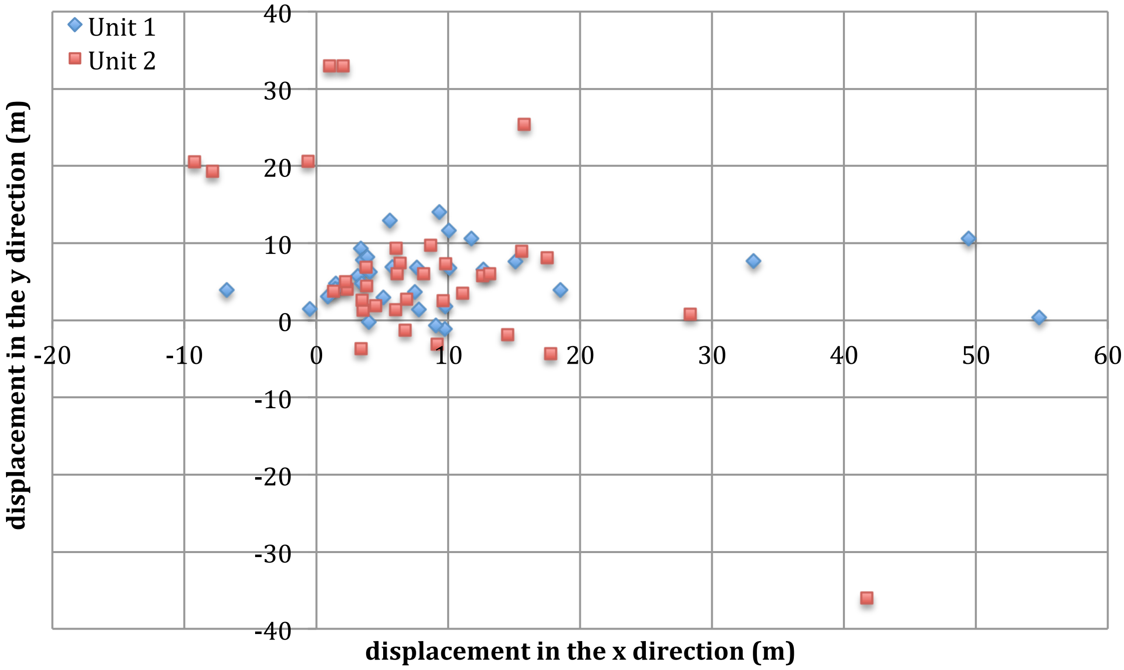

Figure 3.1
Final positions of vehicles involved in metropolitan signalised intersection crashes relative to impact point

The cumulative distributions of the straight line distance that the vehicles travelled from the impact point following the metropolitan signalised intersection crashes for Unit 1, Unit 2 and all the vehicles are shown in Figure 3.2. More than half of the vehicles came to rest within 10 metres of the impact point. However, more than a quarter travelled 15 metres or further and 9% travelled further than 27 metres. The differences in the distributions between Unit 1 and Unit 2 are relatively minor.

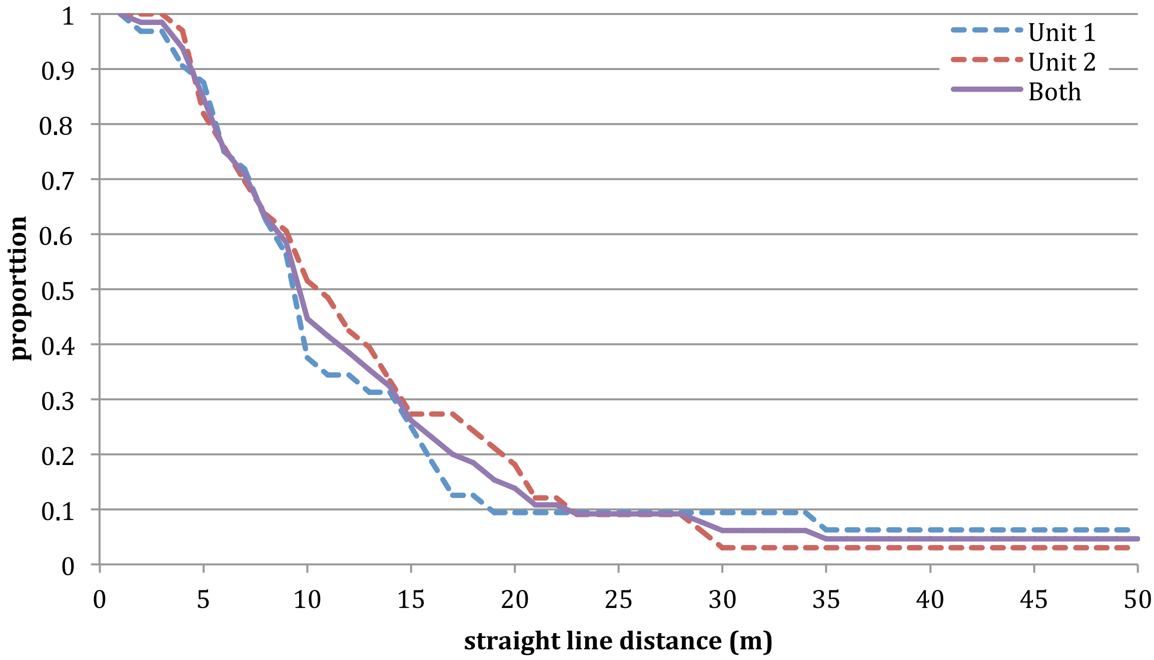

Figure 3.2
Cumulative distribution of straight line distance of the vehicles following the metropolitan signalised intersection crashes relative to the impact point

Tables 3.12 to 3.15 display the post impact trajectory of the metropolitan signalised intersection crashes in terms of straight line distance and angle between the impact point and the final position (see Figure 2.2 for how these are measured) relative to certain variables. Both the median and the mean are presented as the sample is relatively small and outliers may therefore influence the mean.

Although the sample is small, the following observations were made. The DCA code of the crash had no obvious effect on the distance travelled by Unit 1, but Unit 2 travels furthest when the crash has a DCA code of 101 (Table 3.12). The angle of the post impact trajectory of Unit 1 increased slightly from DCA code 101 to 104 and increased more sharply from DCA code 104 to 202. For Unit 2 vehicles, a somewhat similar pattern is apparent though some big differences between the medians and means make it difficult to draw conclusions.

Table 3.12
Post impact trajectory of vehicles involved in the metropolitan signalised intersection crashes by DCA Code and unit number

DCA Code	Unit 1				Unit 2			
	Distance		Angle		Distance		Angle	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean
101 (n=7)	9.1	10.8	19.3	24.3	13.1	17.3	24.8	17.0
104 (n=9)	10.0	16.3	26.2	31.9	9.9	10.3	24.9	32.4
202 (n=19)	8.2	12.1	55.6	56.2	10.1	12.9	36.5	38.2

Table 3.13 shows the post impact trajectory in terms of the speed zone of Unit 1. Differences between median and mean distances make it difficult to draw any conclusions regarding the effect of the speed zone on the distance. Speed zones of 60 km/h for Unit 1 produce a much smaller angle in both Unit 1 and Unit 2 than when the speed zone of Unit 1 is 50 km/h.

Table 3.13
Post impact trajectory of vehicles involved in the metropolitan signalised intersection crashes by speed zone of Unit 1 and unit number

Speed zone of Unit 1	Unit 1				Unit 2			
	Distance		Angle		Distance		Angle	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean
50 (n=5)	11.6	10.4	56.9	66.2	11.2	10.4	57.2	51.2
60 (n=30)	9.1	13.2	37.9	41.0	10.0	13.8	24.7	29.2

The post impact trajectory relative to the impact location on each unit is shown in Table 3.14. For both Unit 1 and Unit 2 being struck between the C pillar and the rear of the car resulted in the furthest distance being travelled between impact point and final position for the three collisions that fell into this category. For Unit 2 vehicles, impacts between the A and B pillar produced the second greatest distance and frontal impacts produce a distance that is smaller than the rest of the impact locations. The angle of Unit 2 increases as the impact moves from a frontal to a side impact and increases further as the impact location moves toward the rear of the vehicle.

Table 3.14
Post impact trajectory of vehicles involved in metropolitan signalised intersection crashes by impact point on vehicle and unit number

Impact location	Unit 1					Unit 2			
	Distance		Angle			Distance		Angle	
	Median	Mean	Median	Mean		Median	Mean	Median	Mean
Front (n=28)	8.6	10.1	49.3	48.6	(n=11)	6.2	7.2	22.3	17.6
Front to A pillar (n=2)	9.1	9.1	23.0	23.0	(n=11)	11.7	13.0	29.7	27.7
A to B pillar (n=3)	10.0	12.1	57.2	46.5	(n=9)	14.5	20.3	36.9	43.4
B to C pillar (n=1)	9.0	9.0	12.1	12.1	(n=2)	10.5	10.5	54.9	54.9
C pillar to rear (n=1)	54.8	54.8	0.4	0.4	(n=2)	20.6	20.6	91.8	91.8

Table 3.15 shows the post impact trajectory of the vehicles involved in metropolitan signalised intersection crashes relative to the mass ratio. There is no clear relationship apparent between the straight line distance and the mass ratio. When the mass ratio is less than 0.75 the angle is higher than 90 degrees for both units.

Table 3.15
Post impact trajectory of vehicles involved in the metropolitan signalised intersection crashes by mass ratio and unit number

Mass ratio	Unit 1				Unit 2			
	Distance		Angle		Distance		Angle	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean
< 0.50 (n=0)	-	-	-	-	-	-	-	-
0.50 - 0.74 (n=3)	7.9	6.6	109.1	100.3	20.6	15.7	91.8	92.3
0.75 - 0.99 (n=14)	8.4	13.7	55.6	42.0	9.7	13.8	44.5	26.5
1.00 - 1.24 (n=9)	9.1	15.6	50.3	40.2	11.2	11.3	24.9	14.7
1.25 - 1.49 (n=5)	14.3	11.9	27.6	34.4	7.9	11.2	37.3	38.3
1.50 - 1.99 (n=1)	5.9	5.9	30.6	30.6	20.8	20.8	112.2	112.2
> 2.00 (n=3)	11.0	11.0	22.1	22.1	14.5	14.8	17.7	9.6

Figure 3.3 is a graphical representation of the percentage of vehicles that travel through a given sector relative to the impact point following the metropolitan signalised intersection crashes. A practical application of Figure 3.3 is to overlay the centre of the diagram on potential impact points identified on intersection plans. The chance of a vehicle striking a hazard within a given sector can then be assessed. For example, an object between three and six metres from the impact point at an angle between 15 and 30 degrees has 15 to 20% chance of being struck by a vehicle following a crash (based on the CASR sample of crashes). Figure 3.3 reveals that the vehicles' most common post impact trajectory was between 60 and 75 degrees but most of these vehicles came to rest relatively close to the impact point. More vehicles travelled beyond 21 metres of the impact point of the intersection at a shallow angle of between 0 and 15 degrees.

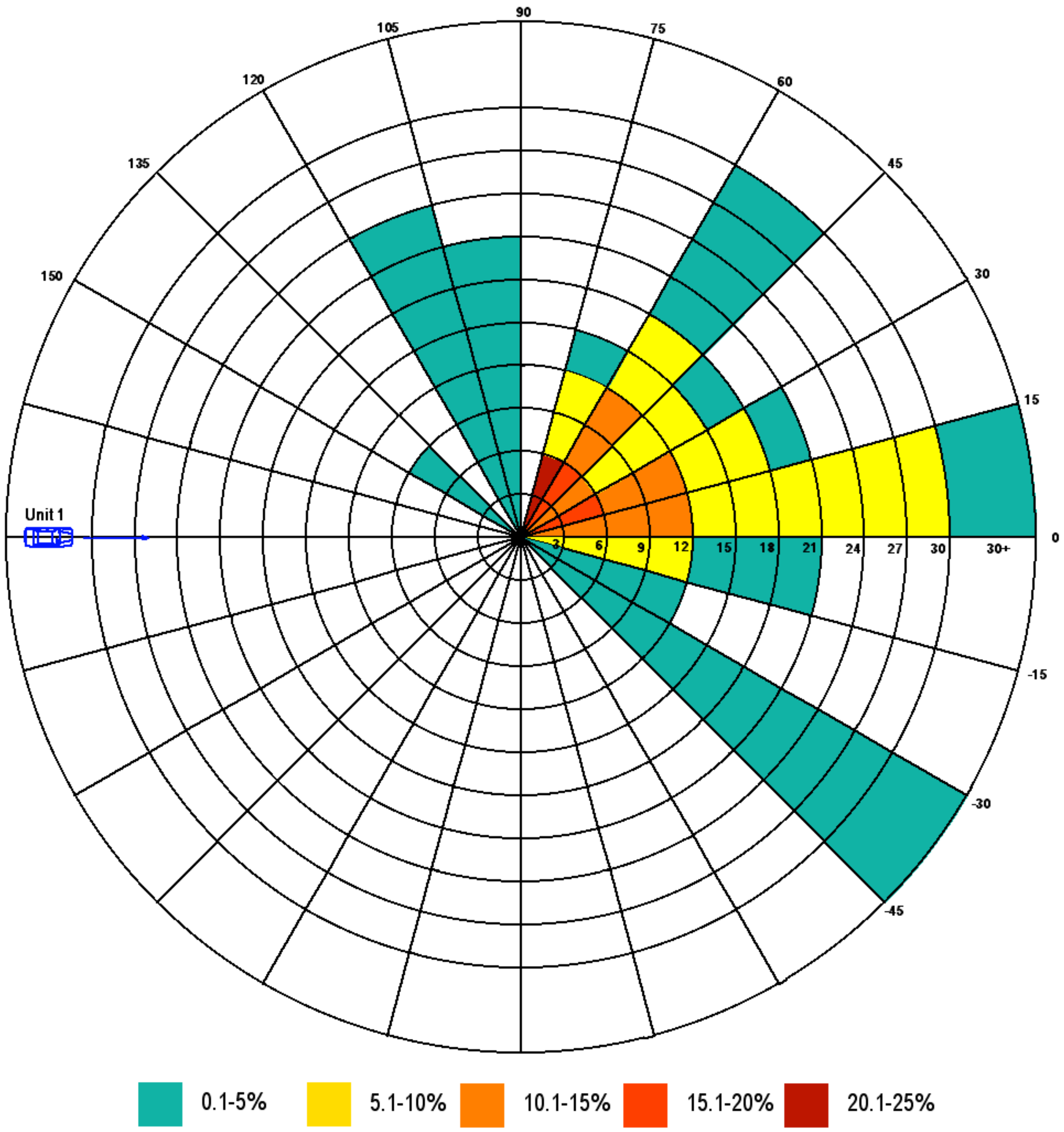

Figure 3.3
Percentage of vehicles that travel through a given sector relative to the impact point following the metropolitan signalised intersection crashes (n=65)

3.2 Unsignalised intersections

Table 3.16 shows the DCA codes of the metropolitan unsignalised intersection crashes (see Figure 2.1 for illustrations of the DCA codes). The majority of the crashes at unsignalised intersections had a DCA code of 104 (a right turn across type crash configuration).

Table 3.16
DCA codes of metropolitan unsignalised intersection crashes

DCA code	Number	Percentage
101	11	25.6
104	24	55.8
202	8	18.6
Total	43	100.0

The geometries of the unsignalised intersections where the crashes occurred are shown in Figure 3.17. T-Junctions made up the majority of the intersections (65%), with the remainder being cross roads. None of the crashes took place at a multi-leg or Y-Junction.

Table 3.17
Geometry of intersections for metropolitan unsignalised intersection crashes

Geometry	Number	Percentage
Cross road	15	34.9
T-Junction	28	65.1
Y-Junction	0	0.0
Multi-leg junction	0	0.0
Total	43	100.0

Table 3.18 displays the speed limits that were applicable to each unit involved in the metropolitan unsignalised intersection crashes. Unit 1 was travelling on a road with a speed limit of 60 km/h in most cases (72%), though 20% were subject to a 50 km/h speed limit. Unit 2 was travelling on a road with a 50 km/h speed limit the majority of the time (81%). Only three of the 86 vehicles were travelling on roads with speed limits higher than 60 km/h.

Table 3.18
Applicable speed limit at metropolitan unsignalised intersection crashes by unit number

Speed limit	Unit 1		Unit 2	
	Number	Percent	Number	Percent
10	0	0.0%	1	2.3%
40	0	0.0%	3	7.0%
50	9	20.9%	35	81.4%
60	31	72.1%	4	9.3%
70	3	7.0%	0	0.0%
80	0	0.0%	0	0.0%
Total	43	100.0%	43	100.0%

The location of impact on vehicles involved in the metropolitan unsignalised intersection crashes is shown in Table 3.19. Most of the vehicles classified as Unit 1 had a frontal impact, though 12 Unit 1 vehicles were struck on the side. Given that Unit 1 is defined as the through vehicle or, if both vehicles are travelling through the intersection, the vehicle with right of way, this finding is not unexpected. The most common impact location on Unit 2 vehicles was between the front of the vehicle and the A pillar (44%) followed by frontal impacts (33%).

Table 3.19
Location of impact on vehicles involved in metropolitan unsignalised intersection crashes by unit number

Speed limit	Unit 1		Unit 2	
	Number	Percent	Number	Percent
Front	31	72.1%	14	32.6%
Front to A-pillar	4	9.3%	19	44.2%
A to B pillar	2	4.7%	5	11.6%
B to C pillar	3	7.0%	4	9.3%
C pillar to rear	3	7.0%	1	2.3%
Total	43	100.0%	43	100.0%

Table 3.20 shows the injury severity of the crashes in terms of most severe outcome within an individual unit. The mostly likely injury severity in Unit 1 was hospital treatment, followed by no injury. This order was reversed for Unit 2 with no injury being the most common and hospital treatment being second. Fifteen had an occupant who sustained a serious injury (hospital admission or fatal). One crash was fatal with this fatality occurring in a vehicle classified as Unit 2.

Table 3.20
Injury severity in metropolitan unsignalised intersection crashes by unit number

Injury Severity	Unit 1		Unit 2	
	Number	Percent	Number	Percent
None	9	20.9%	21	48.8%
Minor / Doctor	3	7.0%	1	2.3%
Treated	23	53.5%	14	32.6%
Admitted	8	18.6%	6	14.0%
Fatal	0	0.0%	1	2.3%
Total	43	100.0	43	100.0

The mass ratios of the vehicles involved in the metropolitan unsignalised intersection crashes are shown in Table 3.21. The mass ratio is defined as the ratio of the mass of Unit 1 to the mass of Unit 2. For example, a mass ratio of more than one means that Unit 1 has a greater mass than Unit 2. The majority of the mass ratios were between 0.75 and 1.24, though in 12 cases the mass ratio was 1.25 or more and in eight the mass ratio was less than 0.75. In two of the crashes the mass ratio was more than two, meaning that Unit 1 had a mass at least twice as large as Unit 2 (Unit 1 was a heavy vehicle in both of these crashes).

Table 3.21
Mass ratio of vehicles involved in metropolitan unsignalised intersection crashes

Mass ratio	Number	Percentage
< 0.50	0	0.0%
0.50 – 0.74	8	18.6%
0.75 – 0.99	12	27.9%
1.00 – 1.24	11	25.6%
1.25 – 1.49	6	14.0%
1.50 – 1.99	4	9.3%
> 2.00	2	4.7%
Total	43	100.0%

Table 3.22 shows the metropolitan unsignalised intersection crashes by road type of Unit 1 and Unit 2. Unit 1 was most commonly travelling on an arterial road. Almost all Unit 2s were travelling on a local road with only four travelling on a collector road and one on an arterial road. The most common

combination of road types was for Unit 1 to be travelling on an arterial road and Unit 2 to be travelling on a local road. Note that one shopping centre driveway was classed as a local road for the purpose of this table.

Table 3.22
Metropolitan unsignalised intersection crashes by road type of Unit 1 and Unit 2

Unit 2 Road Type	Unit 1 Road type			
	Arterial	Collector	Local	Total
Arterial	0	0	0	1
Collector	4	0	0	4
Local	26	6	7	37
Total	29	6	8	43

Following a crash at a metropolitan unsignalised intersection some vehicles departed the intersection or the roadway before coming to rest. The number that did so, by unit number, are shown in Table 3.23. Unit 1 vehicles departed the intersection 61% of the time whereas 37% of the Unit 2 vehicles departed the intersection. Unit 1 was also more likely to depart the roadway than Unit 2, with 33% of Unit 1s departing the roadway following the initial collision and only 21% of Unit 2s doing likewise.

Table 3.23
Intersection and roadway departures following the metropolitan unsignalised intersection crashes by unit number

	Unit 1		Unit 2	
Intersection departure	Number	Percent	Number	Percent
No	17	39.5%	27	62.8%
Yes	26	60.5%	16	37.2%
Roadway departure				
No	29	67.4%	34	79.1%
Yes	14	32.6%	9	20.9%

Table 3.24 shows the objects struck in secondary collisions of vehicles involved in the metropolitan unsignalised intersection crashes. Note that for vehicles that have multiple secondary collisions all struck objects are included, resulting in a higher total than the number of vehicles. The majority of vehicles were not involved in a secondary collision. Of those that were involved in a secondary collision, a tree, a fence, a sign or a stobie pole were common objects struck. Unit 1 was the most likely vehicle to be involved in a secondary collision.

Table 3.24
Secondary collisions of vehicles involved in metropolitan unsignalised intersection crashes by unit number

Secondary collision	Unit 1		Unit 2	
	Number	Percent	Number	Percent
None	34	79.1%	36	83.7%
Stobie pole	2	4.7%	1	2.3%
Tree	2	4.7%	2	4.7%
Fence	2	4.7%	2	4.7%
Fire hydrant	1	2.3%	1	2.3%
Sign	3	7.0%	1	2.3%
Pedestrian handrail	0	0.0%	1	2.3%
Vehicle - stationary	0	0.0%	1	2.3%
Vehicle - parked	1	2.3%	0	0.0%

The most severe impacts in the metropolitan unsignalised intersection crashes, as determined by the intrusion, airbag deployment on secondary impact, and driver interview statements, are shown in Table 3.25. Six of the 70 vehicles involved in these crashes were considered to have had a more severe secondary impact, three with a stobie pole and one each with tree and pedestrian handrail and a parked vehicle. For more detail on these cases, including site diagrams and photos of the vehicles see Appendix A.

Table 3.25
The most severe collision of vehicles involved in the metropolitan unsignalised intersection crashes by unit number

Most severe collision	Unit 1		Unit 2	
	Number	Percent	Number	Percent
Initial	39	90.7%	41	95.3%
Stobie pole	2	4.7%	1	2.3%
Tree	1	2.3%	0	0.0%
Pedestrian handrail	0	0.0%	1	2.3%
Vehicle - parked	1	2.3%	0	0.0%
Total	43	100.0%	43	100.0%

Figure 3.4 shows the final positions of vehicles involved in the metropolitan unsignalised intersection crashes relative to the impact point. While the majority of vehicles come to rest within 10 to 15 metres of the impact point there are a number that go well beyond this area with some vehicles travelling close to 50 metres. The vehicles that travelled large distances tend to come to rest relatively close to the x or y axis. Unit 1 vehicles tend to come to rest close to the x axis (their original direction of travel).

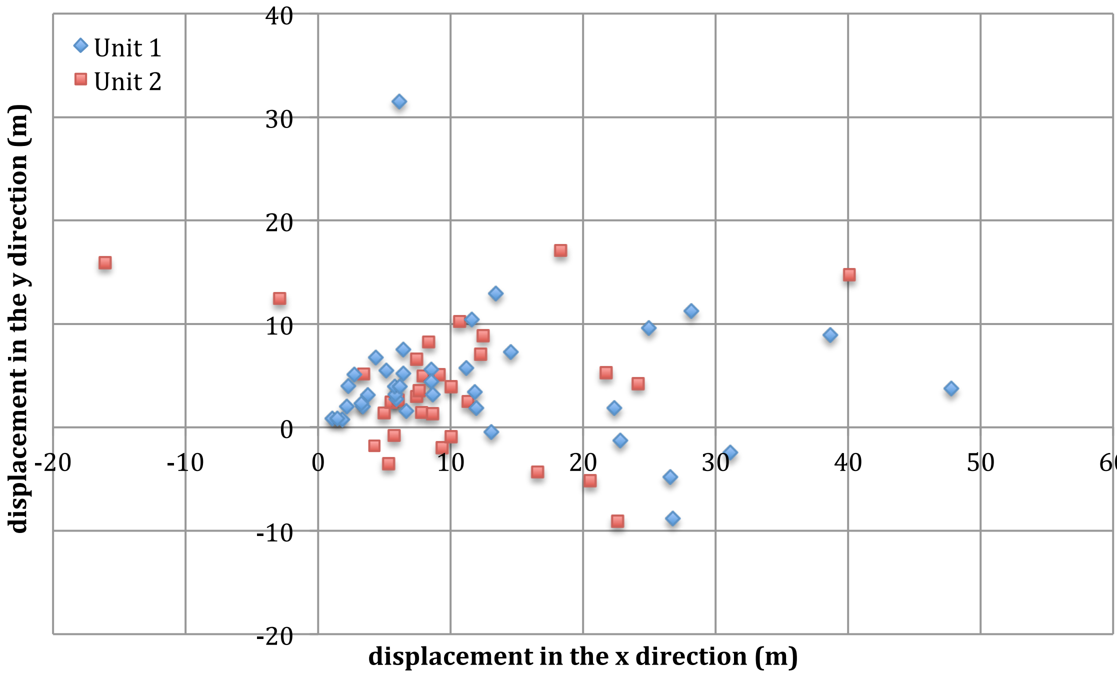

Figure 3.4
Final positions of vehicles involved in the metropolitan unsignalised intersection crashes

The cumulative distributions of the straight line distance that the vehicles travelled from the impact point following the metropolitan unsignalised intersection crashes for Unit 1, Unit 2 and all the vehicles are shown in Figure 3.5. About half of the vehicles came to rest within 10 metres of the impact point. However, 30% travelled 15 metres or further and 10% travelled further than 27 metres. The differences in the distributions between Unit 1 and Unit 2 are relatively minor for most of the distribution. The biggest gap between the two units is around 26 metres of straight line distance, with only 3% of Unit 2s exceeding this distance compared to 21% of Unit 1s.

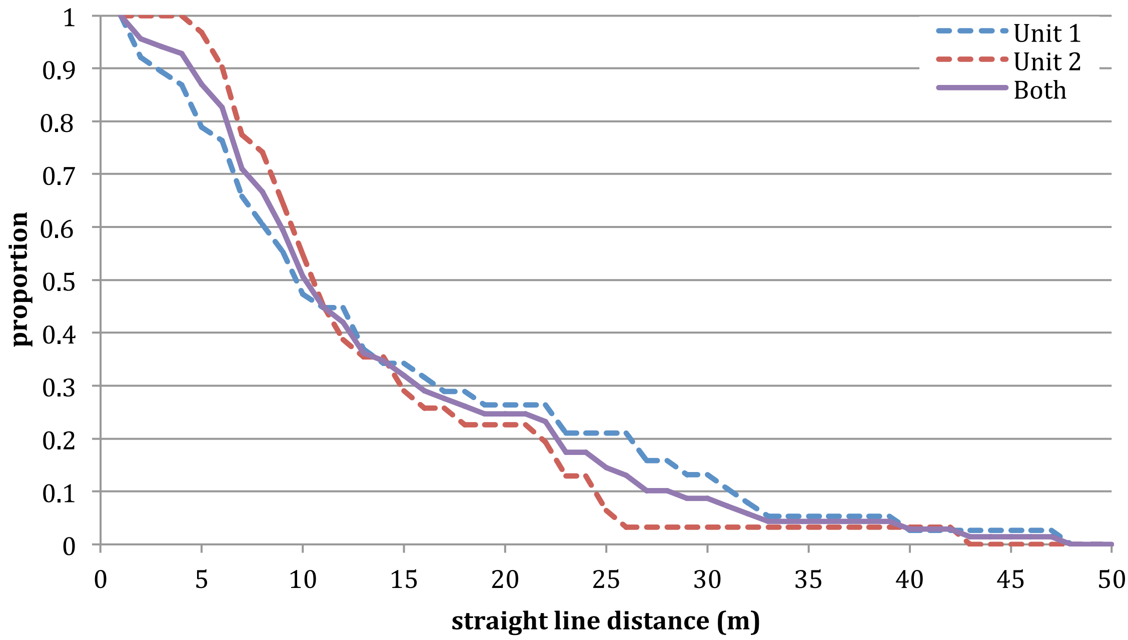

Figure 3.5
Cumulative distribution of straight line distance of vehicles following the metropolitan unsignalised intersection crashes

Tables 3.26 to 3.29 display the post impact trajectory of the metropolitan unsignalised intersection crashes in terms of straight line distance and angle between the impact point and the final position (see Figure 2.2 for how these are measured) relative to certain variables. Both the median and the mean are presented as the sample is relatively small and outliers may therefore influence the mean.

Although based on a small sample, the following observations are made. For both Unit 1 and Unit 2 a DCA code of 101 produced the greatest straight line distance (Table 3.26). A DCA code of 202 produced a slightly higher post impact trajectory angle of Unit 1 than the other DCA codes. For Unit 2, a DCA code of 101 produced a smaller post impact trajectory angle than the other DCA codes.

Table 3.26
Post impact trajectory of vehicles involved in metropolitan unsignalised intersection crashes by DCA Code and unit number

DCA Code	Unit 1				Unit 2			
	Distance		Angle		Distance		Angle	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean
101 (n=11)	12.3	16.2	26.8	28.8	21.2	17.3	13.7	14.0
104 (n=24)	8.3	14.7	28.6	25.4	9.8	12.5	17.8	25.8
202 (n=8)	6.9	7.4	34.1	33.0	9.9	11.6	27.2	20.0

Table 3.27 shows the post impact trajectory in terms of the speed zone of Unit 1. Differences between median and mean straight line distances in 50 km/h and 60 km/h zones and the small sample of 70 km/h zones make it difficult to draw any conclusions regarding the effect of the speed zone on the distance. The post impact trajectory angle of Unit 2 increases when the speed zone of Unit 1 increases.

Table 3.27
Post impact trajectory of vehicles involved in metropolitan
unsignalised intersection crashes by speed zone of Unit 1 and unit number

Speed zone of Unit 1	Unit 1				Unit 2			
	Distance		Angle		Distance		Angle	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean
50 (n=9)	10.0	13.5	29.9	25.7	11.6	14.5	12.5	13.2
60 (n=31	9.6	15.2	28.6	27.1	10.5	13.6	20.2	21.1
70 (n=3)	5.8	6.7	21.9	33.3	9.4	9.9	32.1	39.6

The post impact trajectory relative to the impact location on each unit is shown in Table 3.28. For Unit 1, being struck between the C pillar and the rear of the car resulted in the furthest distance being travelled between impact point and final position for the three collisions that fitted into this category. If a unit had a frontal impact location it would travel further if it was Unit 2, but for all of the side impacts it was Unit 1 that would travel further. Impacts behind the B pillar of Unit 1 produce negative post impact trajectory angles. The angle of Unit 2 increases as the impact moves from a frontal to a side impact and increases further as the impact location moves toward the rear of the vehicle.

Table 3.28
Post impact trajectory of vehicles involved in metropolitan
unsignalised intersection crashes by impact point on vehicle and unit number

Impact location	Unit 1					Unit 2			
	Distance		Angle			Distance		Angle	
	Median	Mean	Median	Mean		Median	Mean	Median	Mean
Front (n=31)	7.1	10.7	33.6	34.4	(n=14)	17.1	15.8	-14.5	-8.5
Front to A pillar (n=4)	10.9	13.3	14.6	15.3	(n=19)	9.1	10.9	18.4	15.2
A to B pillar (n=2)	22.4	22.4	53.1	53.1	(n=5)	14.1	20.0	20.2	21.7
B to C pillar (n=3)	22.8	21.0	-3.2	-5.1	(n=4)	9.9	12.1	50.6	64.6
C pillar to rear (n=3)	31.2	33.0	-4.5	-3.2	(n=1)	12.8	12.8	103.1	103.1

Table 3.29 shows the post impact trajectory of the vehicles involved in the metropolitan unsignalised intersection crashes relative to the mass ratio. There is no clear relationship between the straight line distance or angle and the mass ratio.

Table 3.29
Post impact trajectory of vehicles involved in metropolitan
unsignalised intersection crashes by mass ratio and unit number

Mass ratio	Unit 1				Unit 2			
	Distance		Angle		Distance		Angle	
	Median	Mean	Median	Mean	Median	Mean	Median	Mean
< 0.50 (n=0)	-	-	-	-	-	-	-	-
0.50 - 0.74 (n=3)	22.8	22.3	21.7	23.3	10.2	12.9	22.7	19.2
0.75 - 0.99 (n=14)	7.0	8.5	25.2	24.1	11.6	13.1	10.3	12.8
1.00 - 1.24 (n=9)	13.5	16.5	39.4	30.6	10.0	14.0	28.6	22.4
1.25 - 1.49 (n=5)	9.6	11.9	24.2	28.6	21.2	16.8	13.7	40.8
1.50 - 1.99 (n=1)	11.4	12.0	30.1	26.8	5.9	5.9	19.4	19.4
> 2.00 (n=3)	9.7	9.7	36.2	36.2	12.0	12.0	22.2	22.2

Figure 3.6 is a graphical representation of the percentage of vehicles that travel through a given sector relative to the impact point following the metropolitan unsignalised intersection crashes. A practical application of Figure 3.6 is to overlay the centre of the diagram on potential impact points identified on intersection plans. The chance of a vehicle striking a hazard within a given sector can then be assessed. For example, an object between six and nine metres from the impact point at an angle between 15 and 30 degrees has 10 to 15% chance of being struck by a vehicle following a crash. Figure 3.6 reveals that the vehicles' most common post impact trajectory was between 15 and 45 degrees but most of these vehicles came to rest very close to the impact point. More vehicles travelled beyond 18 metres of the impact point of the intersection at a shallow angle of between -15 and 15 degrees.

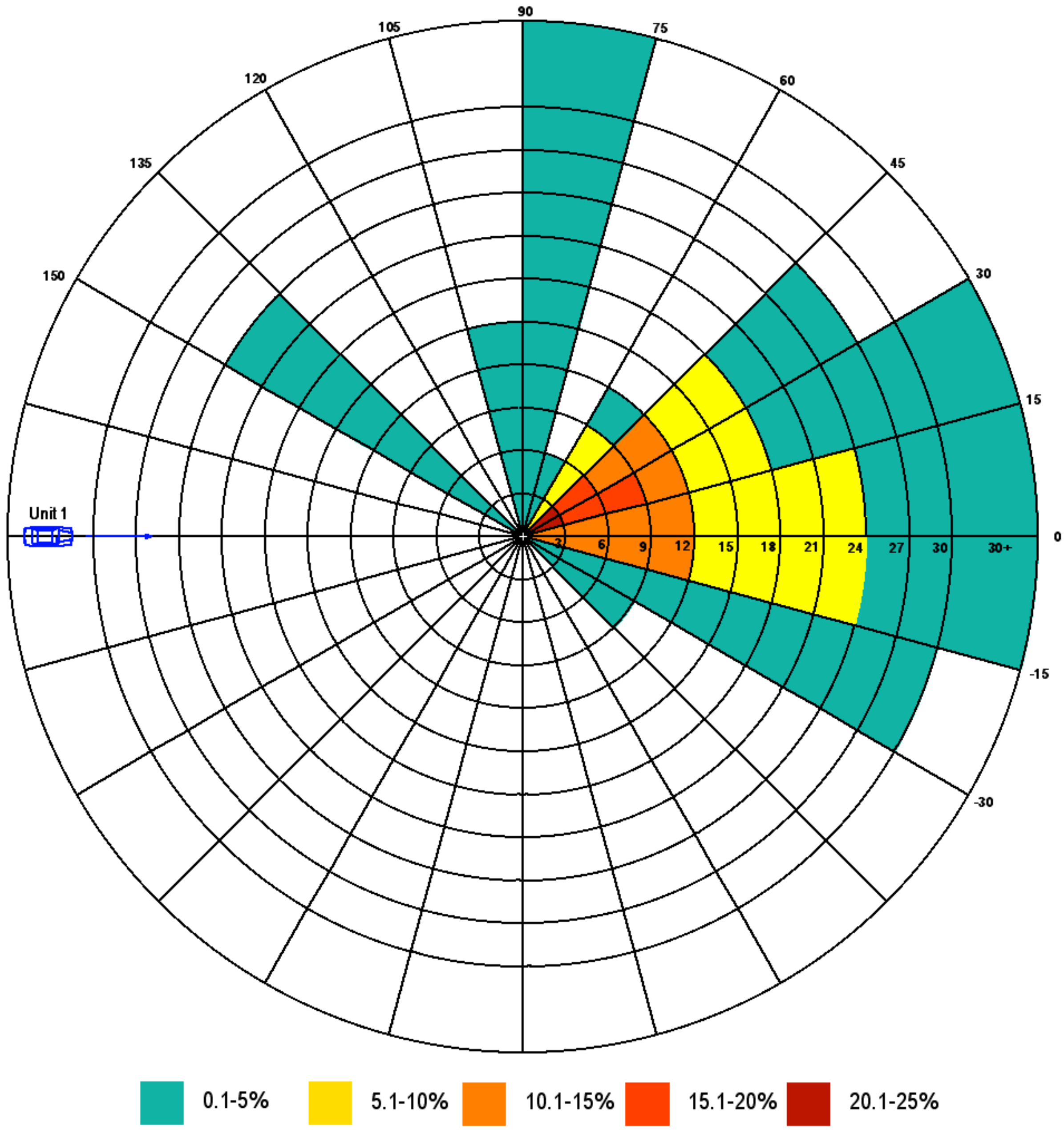

Figure 3.6
Percentage of vehicles that travel through a given sector relative to the impact point following a metropolitan unsignalised intersection crash (n=69)

4 Discussion

As stated in the introduction, this research was prompted by anecdotal evidence from CASR's in-depth crash investigations that demonstrated it is possible for a vehicle to strike a roadside hazard following a collision with another vehicle, and that this secondary impact can be more severe than the initial vehicle to vehicle collision. This was found to occur in three of the 35 signalised intersection crashes (9%) and six of the 43 unsignalised intersection crashes (14%) investigated in this study.

There were some notable differences between crashes at signalised and unsignalised intersections. The majority of crashes at signalised intersections had a DCA code of 202 (right angle) while at unsignalised intersections the majority had a DCA code of 104 (right turn in front). Cross roads were the most common geometry at the signalised intersection crashes but T-junctions were the most common at the unsignalised intersection crashes. The combination of the road types that were intersecting were also different, with signalised intersection crashes being most commonly at the intersection of two arterial roads while the majority of unsignalised intersection crashes occurred at the intersection of a local road and an arterial road. In terms of post impact trajectory, the vehicles that crashed at a signalised intersection had a higher post impact trajectory angle whereas the vehicles that crashed at the unsignalised intersections were more likely to have a shallow post impact trajectory.

The bulk of the objects that were struck in a more severe secondary collision were narrow objects: traffic light poles, stobie poles or a tree. The Austroads Guide to Road Design Part 6B: Roadside Environment states that there is often no opportunity to shield traffic light poles from vehicles and that it is not practical to make the poles frangible, though it does not elaborate on what these practical reasons are (Austroads, 2009c). However, as far back as 1984 Epstein and Hunter (1984) state that it is possible to make traffic signals frangible. Rather than making the poles frangible another option may be to set the poles back further from the intersection by either using mast arms or wires. If none of these are viable options an impact absorber could be used. Although semi-frangible traffic signal poles are used in metropolitan Adelaide, not all perform well when struck and many are also non-frangible.

The Austroads guide states that, from a road safety point of view, the best way to reduce the risk posed by utility poles is to underground the services and therefore eliminate them. If this is not possible the next option is to relocate the poles to increase their distance from the road and lastly if neither of these is possible to install a barrier in front of the poles. The Austroads Guide to Road Safety Part 9: Roadside Hazard Management describes a similar method for dealing with trees, with the exception of the middle option of relocation (Austroads, 2008). Figures 3.3 and 3.6 can be used to determine the risk of a roadside object being struck and therefore aid in the treatment decision.

It is interesting to note the effect that the impact point has on the post impact trajectory of a vehicle, although this has no direct bearing on the design of the intersection. Generally the worst impact, in terms of post impact trajectory, is an impact behind the C pillar. Such an impact would be well behind the centre of gravity of a typical vehicle and would therefore induce an uncontrolled yaw into the vehicle without slowing it down significantly. While such an impact in itself may not be severe the subsequent high speed loss of control may result in a severe impact with a roadside hazard.

Most of the vehicles involved in the metropolitan intersection crashes were travelling on roads with speed limits of 50 or 60 km/h, however there were a few cases where the speed limit was 70 km/h and one where it was 80 km/h. It appears these cases had a higher level of injury severity, with four of the five resulting in someone being admitted to hospital. However, none of these vehicles were involved in a more severe secondary impact.

Pedestrians are often in close proximity to the roadway in metropolitan areas, particularly at signalised intersections that provide an opportunity for them to cross the road with priority. It was found that 40% of vehicles at signalised intersection departed the intersections and therefore crossed the part of the roadway designated for pedestrian crossings. It was also found that 14% of vehicles involved in crashes at signalised intersections departed the roadway. This represents a considerable risk to pedestrians who are very vulnerable to injury if struck by a vehicle. Vehicles departing the road at unsignalised intersections (27%) also represent a potential danger to pedestrians, though it is less likely that a pedestrian would be present at an unsignalised intersection.

4.1 Limitations

A limitation of this study, in particular Figures 3.3 and 3.6, is that vehicle trajectories have been assumed to be linear from the centre point of the intersection to the final resting position of the vehicle. In real life the path the vehicle travelled may be curved. This mostly affects the sectors close to the impact point in Figures 3.3 and 3.6.

The small number of metropolitan intersection crashes available in this study limited the specificity of the results. Ideally the results, especially Figures 3.3 and 3.6, would have been further broken down into the type of junction (e.g. cross roads) but this would have resulted in too small a number of crashes within each category.

Impact speeds were not known for a sufficient number of cases to classify the collisions according to resulting crash energy. The speed zone was used as a proxy for impact speed but impact speeds may vary considerably within a given speed zone.

The sample of crashes have a bias towards serious injury and daytime working hours. The effect of night time and weekend driving patterns were not represented in the study.

5 Conclusions

Collisions at metropolitan intersections can result in secondary collisions, usually with roadside hazards, and these secondary collisions can on occasion be more severe than the initial collision between two vehicles.

The bulk of the objects that were struck in the more severe secondary collisions were narrow objects: traffic light poles, stobie poles or trees. Unit 1, the vehicle that was travelling straight ahead and had right of way, was found to travel the furthest from the impact point when it was struck behind the C-pillar, though such impacts were rare.

It was found that 40% of vehicles at signalised intersections crossed the designated pedestrian crossing areas following a collision between vehicles. It was also found that 14% of vehicles involved in crashes at signalised intersections departed the roadway. This poses a considerable risk to pedestrians who are in the vicinity of junctions at the time of collisions

The diagrams developed in this report (Figures 3.3 and 3.6) can be used to determine the risk of a roadside object being struck and therefore aid in the development of intersection design and treatment.

Acknowledgements

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The views expressed in this report are those of the authors and do not necessarily represent those of the University of Adelaide or the funding organisations.

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Appendix A – Secondary collisions that were more severe

Further information on the secondary collisions that were more severe than the initial collision is contained in this appendix. Note that the unit numbers shown in the site diagrams are not necessarily the same as the unit numbers assigned for the purposes of this report. The site diagrams are shown for each case as are selected pictures that show the damage from both the initial and secondary collisions.

Signalised intersections

Case: M086

Object Struck: Traffic light pole

Injury severity of more severe secondary collision vehicle: Hospital Treated

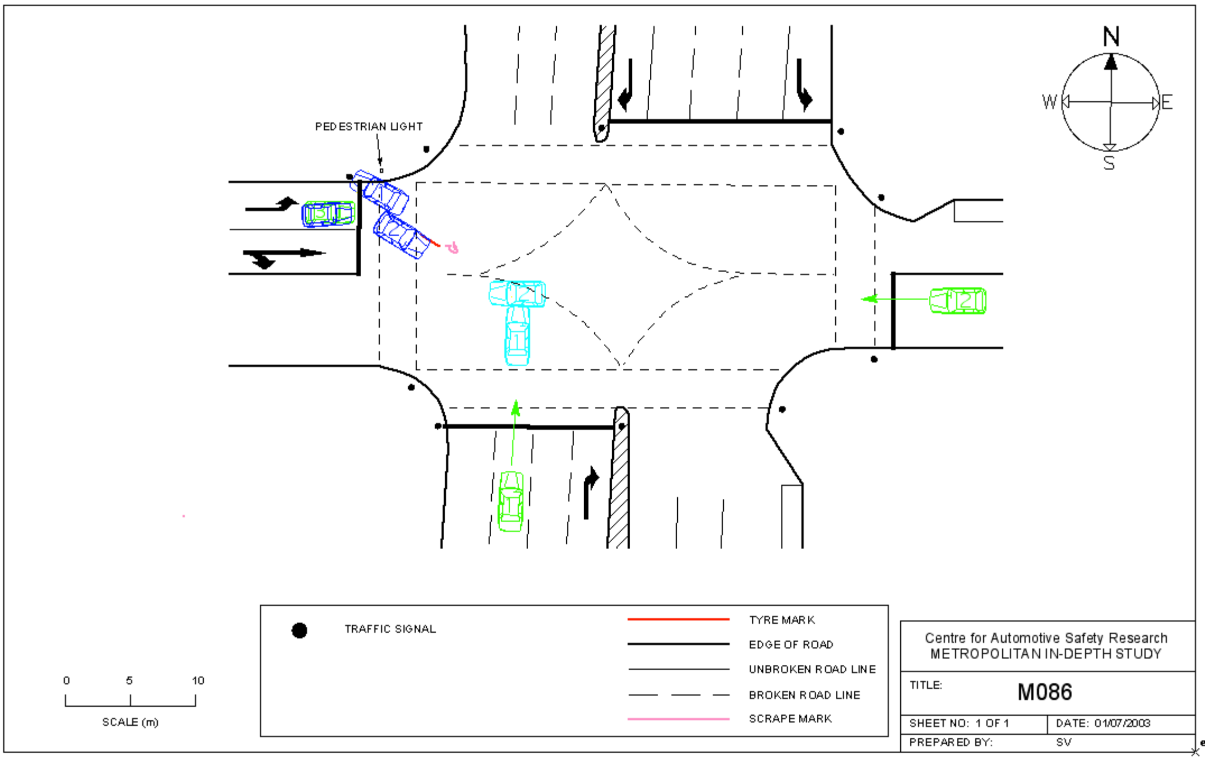

Figure A.1
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M086

Figure A.2
Unit 1 after the crash. The initial impact and secondary impact are shown in this picture as they were both frontal impacts. The traffic light pole is also shown

Case: M189

Object Struck: Traffic light pole

Injury severity of more severe secondary collision vehicle: Hospital Treated

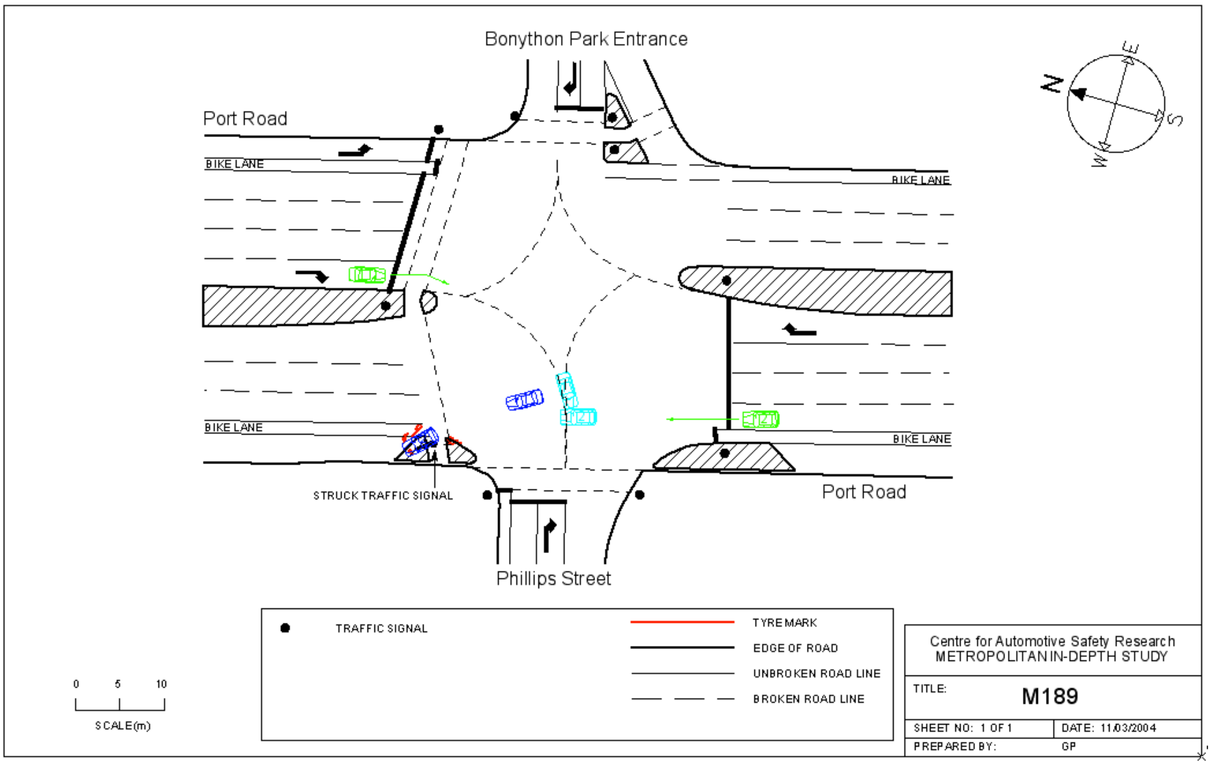

Figure A.3
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M189

Figure A.4
Unit 2 after the crash showing the damage from the initial impact

Figure A.5
Unit 2 after the crash showing the damage from the secondary impact with the traffic light pole

Case: M228

Object Struck: Parked vehicle

Injury severity of more severe secondary collision vehicle: Hospital Treated

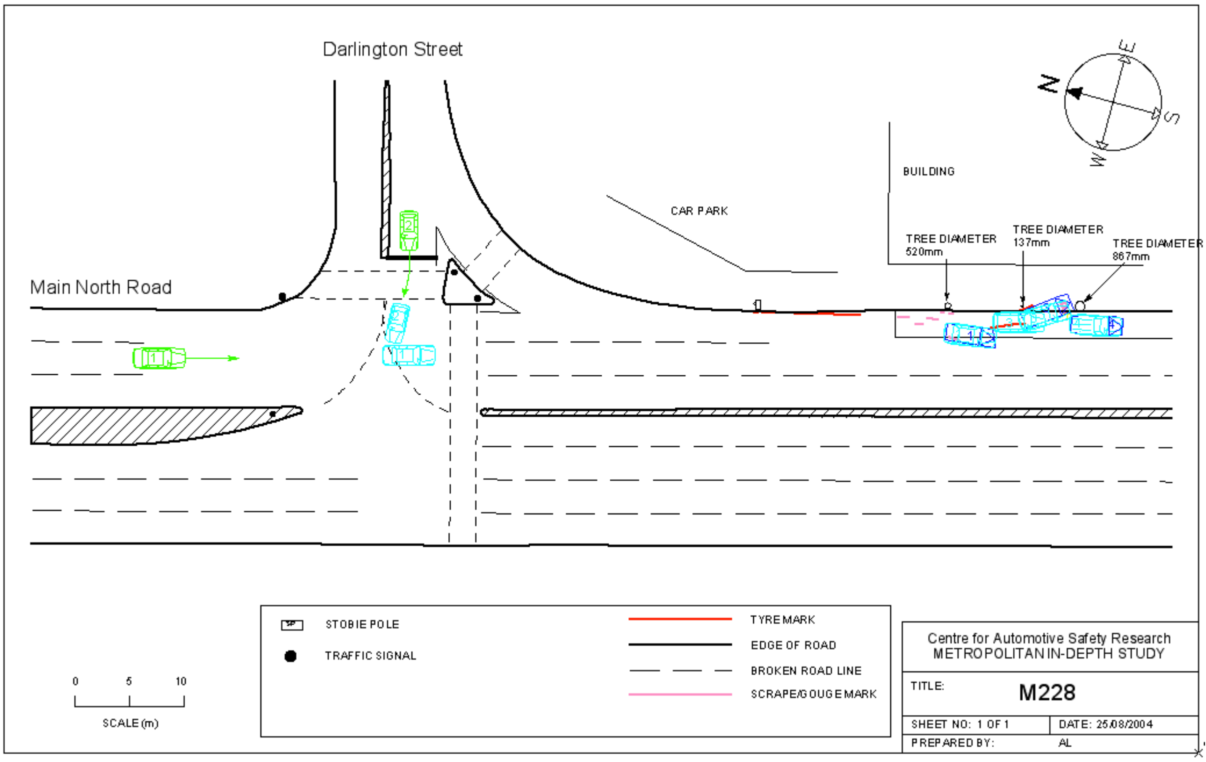

Figure A.6
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M228

Figure A.7
Unit 1 after the crash. The damage at the front is from the secondary impact with the parked vehicle. The impact at the rear is from the initial impact

Unsignalised Intersections

Case: M158

Object Struck: Parked vehicle

Injury severity of more severe secondary collision vehicle: Hospital Treated

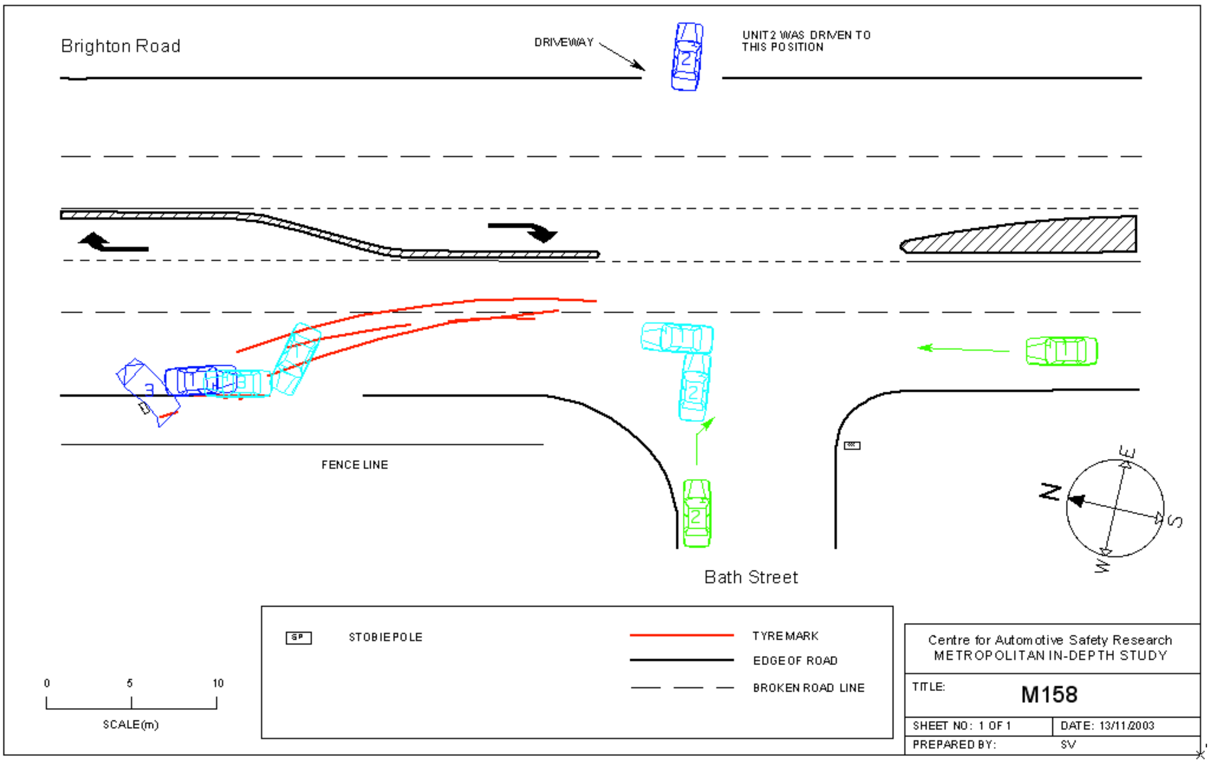

Figure A.8

Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M158

Figure A.9

Unit 2 after the crash showing the damage from the initial impact on the left rear quarter panel

Figure A.10
Unit 2 after the crash showing the damage from the secondary impact

Case: M030

Object Struck: Pedestrian handrail

Injury severity of more severe secondary collision vehicle: Non Injury

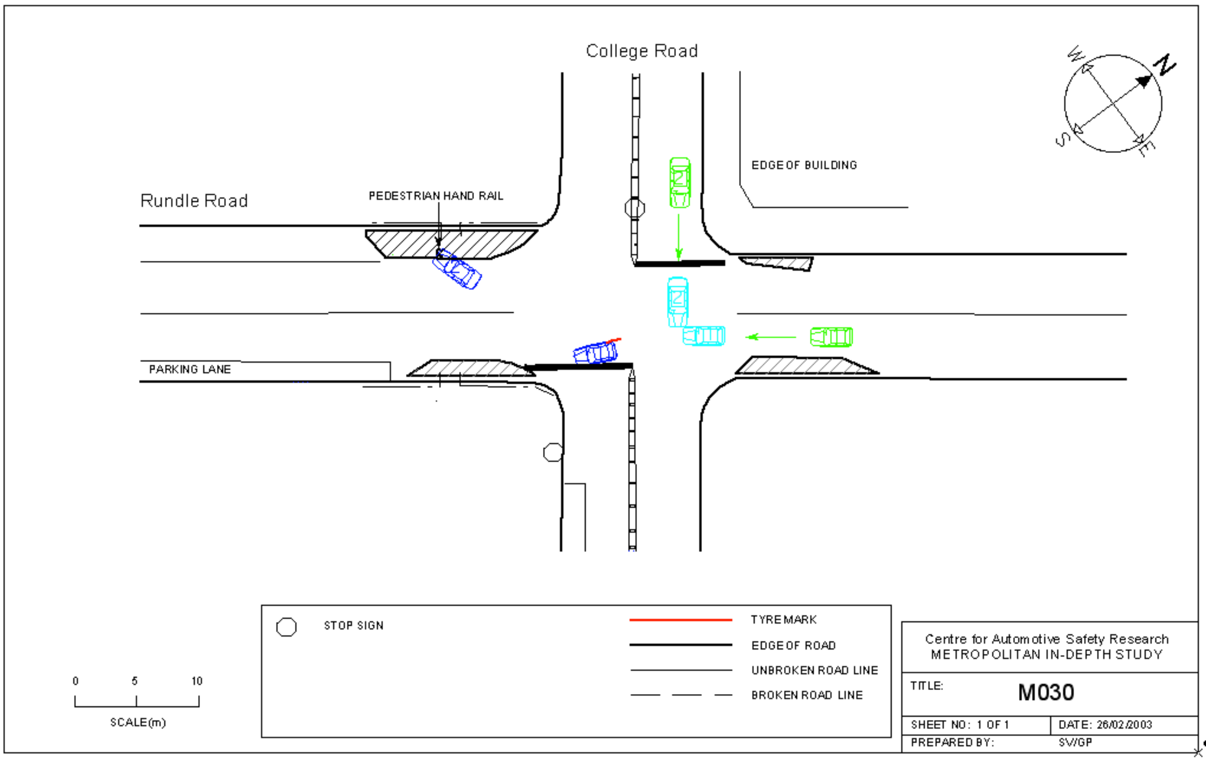

Figure A.11
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M030

Figure A.12
Unit 2 after the crash. The initial impact and secondary impact are shown in this picture as they were both frontal impacts. The pedestrian handrail is also shown

Case: M107

Object Struck: Tree

Injury severity of more severe secondary collision vehicle: Hospital Admission

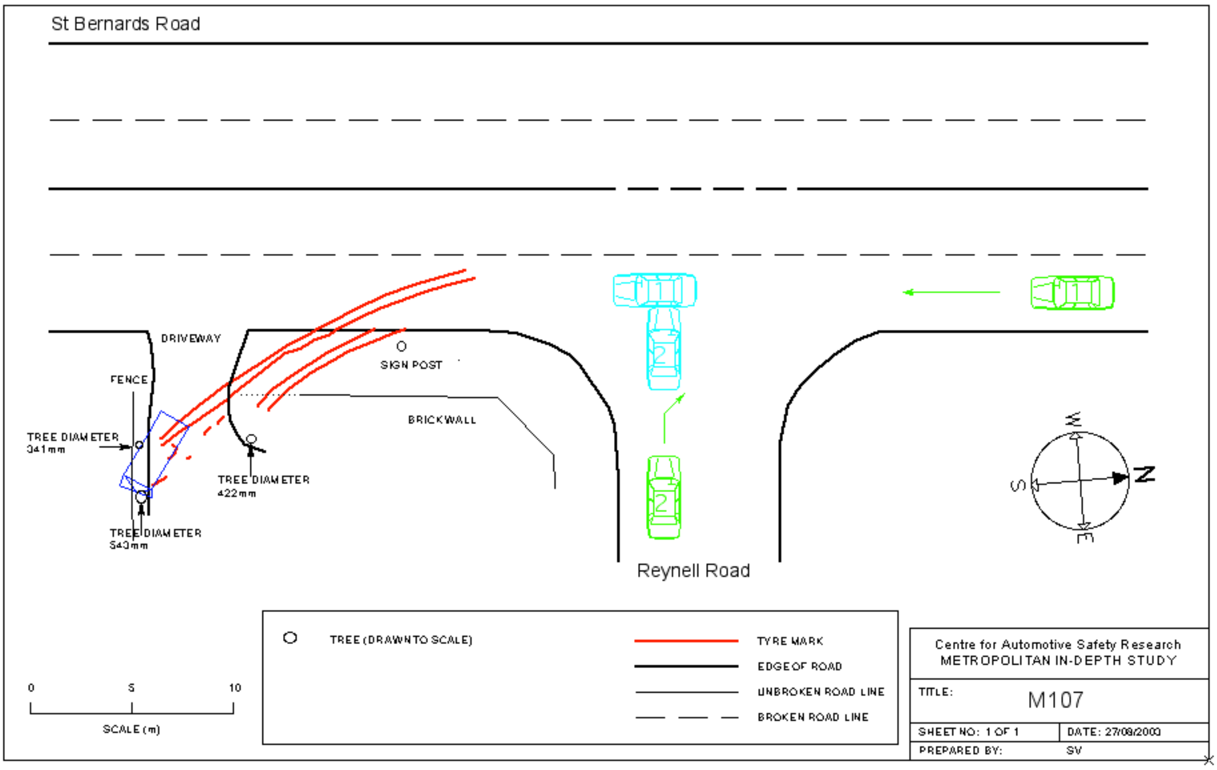

Figure A.13
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M107

Figure A.14
Unit 2 after the crash showing the damage from the initial impact on the left rear quarter panel

Figure A.15
Unit 2 after the crash showing the damage from the secondary impact with the tree

Case: M251

Object Struck: Stobie pole

Injury severity of more severe secondary collision vehicle: Hospital Treated

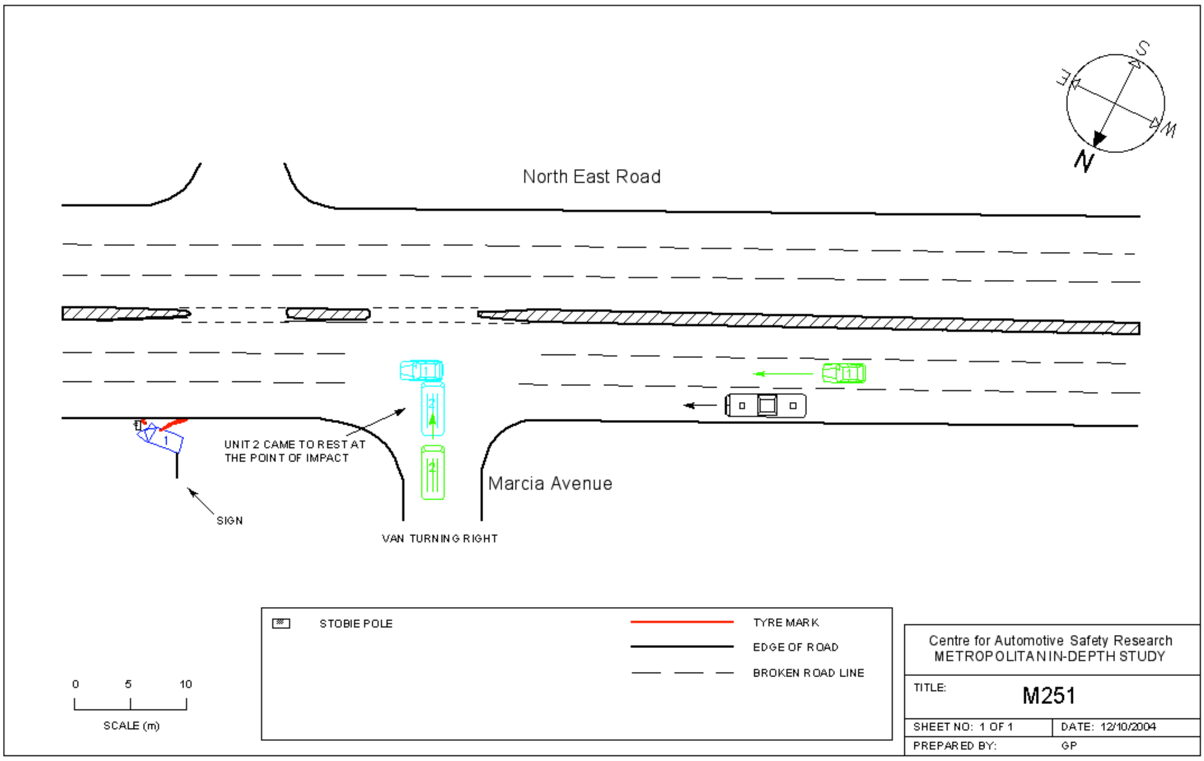

Figure A.16
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M251

Figure A.17
Unit 1 after the crash showing the damage from the initial impact on the left rear door

Figure A.18
Unit 1 after the crash showing the damage from the secondary impact and the stobie pole

Case: M039

Object Struck: Stobie pole

Injury severity of more severe secondary collision vehicle: Hospital Admission

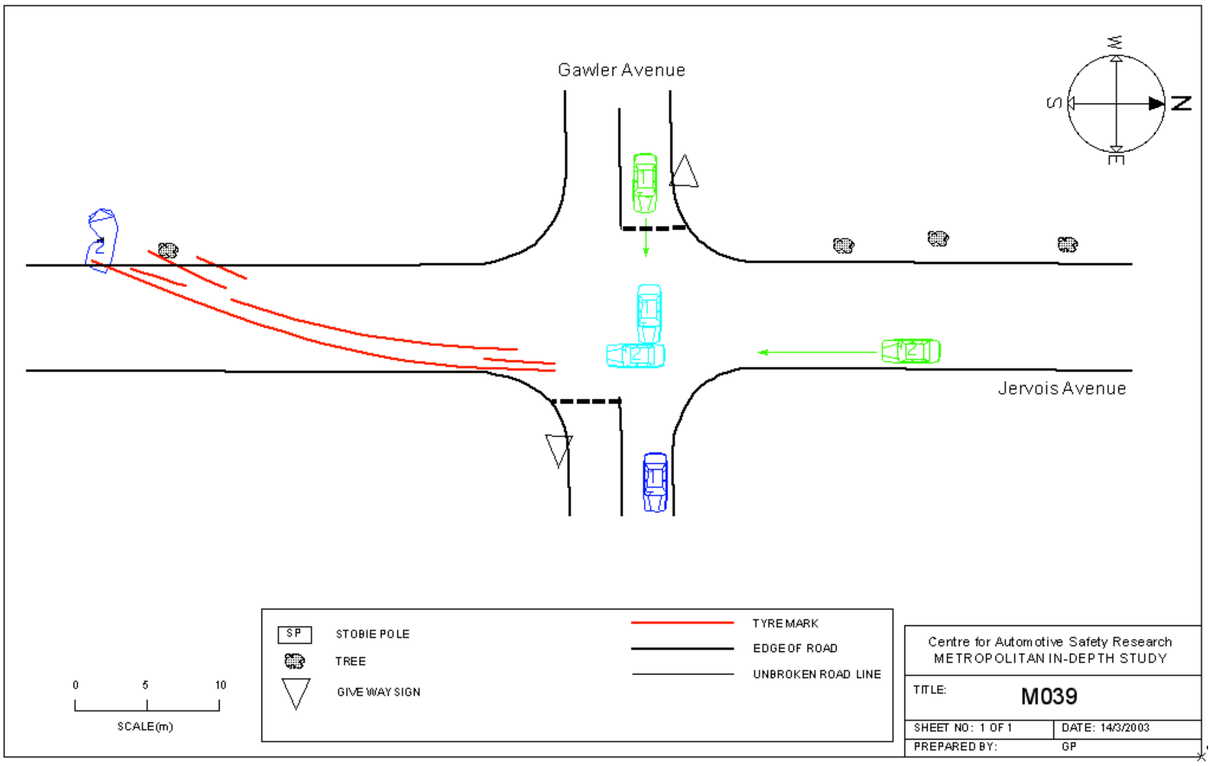

Figure A.19
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M039

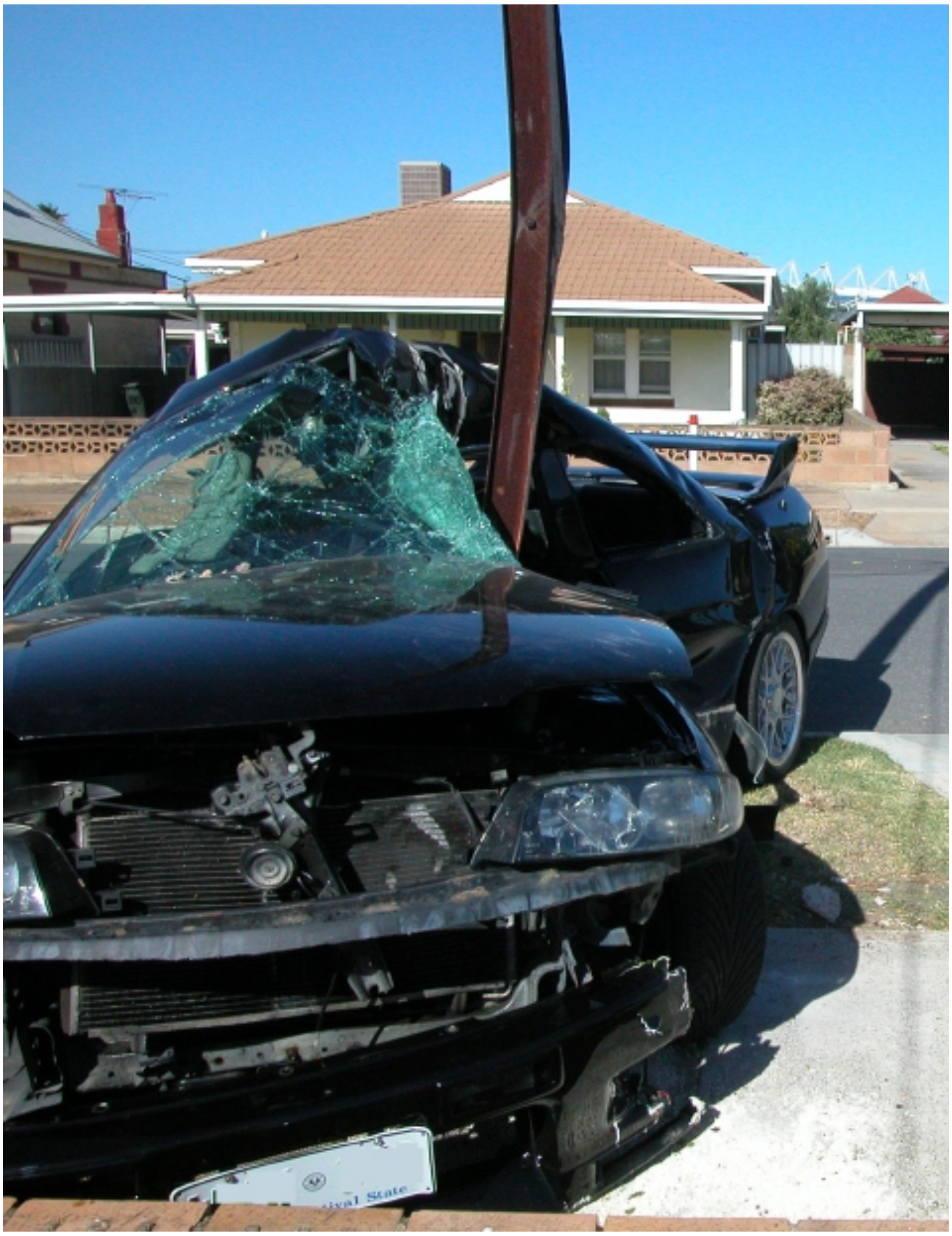

Figure A.20
Unit 2 after the crash showing the damage from the secondary impact
and the stobie pole (damage from the initial impact was not discernable on Unit 2)

Case: M264

Object Struck: Stobie pole

Injury severity of more severe secondary collision vehicle: Hospital Treated

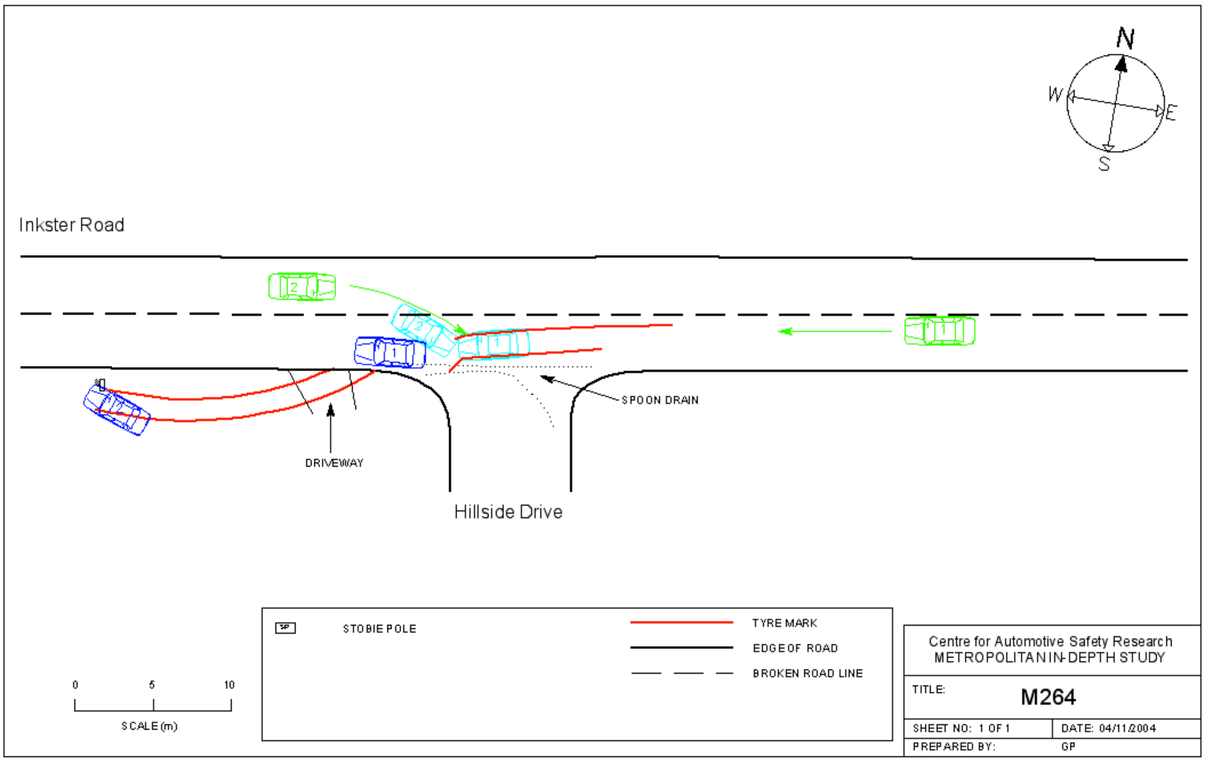

Figure A.21
Site diagram of metropolitan signalised intersection collision where the secondary collision was more severe, M264

Figure A.22
Unit 1 after the crash showing the damage from the initial impact on the front of the vehicle

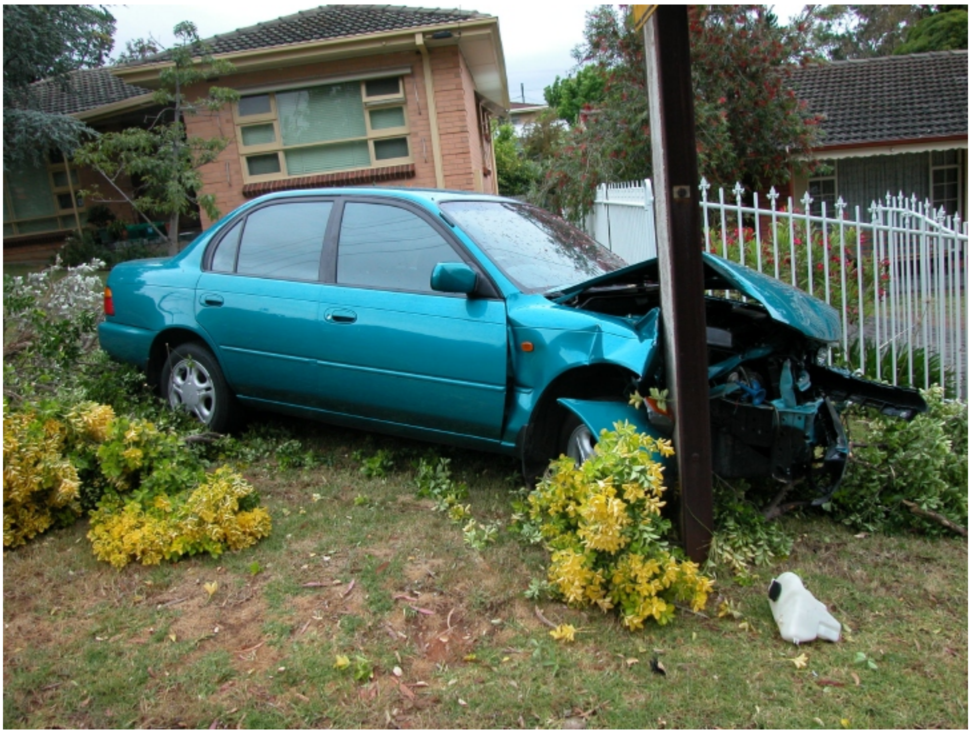

Figure A.23
Unit 1 after the crash showing the damage from the secondary impact on the right front of the vehicle and the stobie pole