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Towards safer urban roads and roadsides: factors affecting crash risk in complex urban environments

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Abstract

The Australian Road Safety Strategy (2011-2020) identifies the importance of assessing risk on the road network. Accident prediction models have been developed to identify characteristics of the road and roadside that affect crash risk, however, these are mainly restricted to simple road environments like rural roads and freeways. Modelling crash risk in urban areas is complicated due to the difficulty obtaining data to fully characterise complex environments. The aim of this research was to identify the characteristics of the road and roadside, surrounding environment and socio-demographic factors that affect crash risk in complex urban environments, namely, strip shopping centres.

A literature review and consultation with experts resulted in a comprehensive list of data items required for measuring the influence of the road, roadside and other factors on crash risk. Strip shopping segments located on arterial roads in metropolitan Melbourne were identified and separated into midblock segments and signalised intersections. Extensive data describing the characteristics of these segments were collected from a diverse range of sources, e.g. administrative government databases (VicRoads- crashes, traffic volume, speed limit and pavement condition; Australian Bureau of Statistics- socio-demographic information; Department of Justice- liquor licensing), detailed maps, on-line image sources and digital images of arterial roads collected by ARRB for VicRoads. The quality of the collected data was thoroughly checked using secondary sources and errors rectified.

Negative binomial regression was used to investigate risk factors for crashes in urban strip shopping centres. Separate models were developed for midblock and intersection crashes. In this paper, factors associated with midblock crash risk in strip shopping centres will be discussed and implications for the design of evidence-based risk assessment tools will be considered.

Key words: traffic crash; risk assessment; urban environments; safe roads and roadsides

1. Introduction

There is international recognition that making roads safer will reduce the number of road-related fatalities and injuries (WHO, 2010; AASHTO, 2010). The Australian Road Safety Strategy (2011-2020) has two aims that are particularly pertinent to safer roads: the assessment of risk for targeting high risk roads and setting speed limits appropriately for the road and roadside (ATC, 2011).

To achieve these aims, it is essential to be able to systematically identify high risk road sections and locations and the factors that drive this risk. Risk assessment tools based on good evidence exist for this purpose, such as the International Road Assessment Program (iRAP), AusRAP (McInerney and Smith, 2009) and NetRisk (Affum and Goudens, 2008). There is a large body of published research identifying risk factors for crashes on highways and rural roads (e.g. Chang, 2005; Karlaftis and Golias, 2002; Pande and Abdel-Aty, 2009) on which to base such tools. To date, there has been less research on the factors that affect risk in urban areas, and factors that increase risk in rural environments do not necessarily have the same effect in urban environments. Hence, risk assessment tools for urban settings are rare (the US Highway Safety Manual is one exception, AASHTO, 2010).

Highways and rural environments may have been studied more frequently because they are relatively simple and thus easier to characterise than complex urban environments. Obtaining high quality data on potential risk factors is difficult, particularly for complex environments. Previous research has primarily used administrative data sourced from road authorities, which has led to a heavy focus on the investigation of road geometry and traffic volume as potential risk factors. This leaves an abundance of factors that could potentially affect crash risk, particularly in urban environments, that are not often considered. For example, type of development, number and type of facilities in the area, and socio-demographic measures are all possible risk factors that have not been systematically considered. In the limited studies where they are considered, built environment and adjacent land use have been found to contribute to crash risk (e.g. Bonneson and McCoy, 1997; Dumbaugh and Li, 2010). Likewise, socio-demographic factors such as the age distribution of drivers, population density and income have also been found to be associated with crash risk (e.g. Hakim et al., 1991; Noland, 2003). There is a lack of existing research that considers all of the potential risk factors, and interactions between them, for crashes in urban environments.

The aim of this research was to investigate the relationship between a broad range of potential risk factors and crashes in complex urban environments. This paper presents risk factors for crashes in midblock segments of strip shopping centres.

2. Method

2.1. Site selection

Strip shopping centres were purposively sampled for this study because they represent complex urban environments that are highly demanding; with traffic, pedestrians, parked vehicles and road signage existing alongside shopfronts, advertising and non-road signs. Complexity is further increased by the interaction of many different road user types in strip shopping centres – e.g. pedestrians and drivers accessing businesses, vehicles delivering goods and road users simply travelling through the area.

Road segments that met the following criteria were selected for this study:

- located on an arterial road in the Melbourne metropolitan area
- an area of predominantly retail/commercial buildings with direct frontage onto the main road (or service road) on one or both sides of the road
- at least 200 metres in length

Strip shopping centre road segments were identified using several sources: local council planning schemes, local council websites and the Melway street directory (Melway, 2005-2009). Google Maps with Street View (https://maps.google.com.au/?hl=en) was used to confirm that the segment was a strip shopping centre and to identify the properties at the beginning and end of each segment. The geographical co-ordinates of each segment were then obtained from the Land Victoria, Department of Sustainability and Environment on-line interactive maps (http://services.land.vic.gov.au/). The VicRoads Register of Public Roads (VicRoads, 2008) was consulted to determine if the segment was located on an arterial road. This resulted in the identification of 148 strip shopping centres that met the inclusion criteria for the study.

2.2. Identification of data requirements and data sources

Data requirements were developed in two stages, reported in detail previously (Stephan and Newstead, 2011). Briefly, Stage 1 involved reviewing literature to identify the characteristics of the road and roadside previously found to be associated with crash risk and compiling a list of potential risk factors. Given that previous research has focused mainly on simple environments, a number of other factors that might be expected to affect crash risk in urban environments were also included. In Stage 2, the list was sent to experts in engineering, road user behaviour and law enforcement from VicRoads, Transport Accident Commission, Victorian Department of Justice, Victoria Police and Monash University Accident Research

Centre. The experts were asked to comment on the items on the list, and to add anything they felt might be important for predicting crash risk, particularly in complex environments.

Once the list of potential risk factors was finalised, possible sources of data were investigated. Where possible, data were collected from existing sources. It was not possible, however, to find existing data sources with good quality data for all of the potential risk factors. For those risk factors, data were collected specifically for the project from detailed maps and digital images.

2.3. Data collection

Where required, permission was obtained from appropriate authorities for approval to access and use data. Data were collected for each of the road segments and assimilated into one database.

Data on police-reported casualty crashes that occurred from 2005 to 2009 on the specified road segments were downloaded from the publicly accessible VicRoads CrashStats (http://www.vicroads.vic.gov.au/Home/SafetyAndRules/AboutRoadSafety/StatisticsAndResearch/CrashStats.htm). Where possible, data for other variables were collected for the same period or the midpoint (2007) of that period. For some variables, retrospective data were not available and more recent data were used. For example, liquor licence information was downloaded in February 2011, however there was no reason to suspect a relative change between segments in the number of liquor licences compared to 2005 to 2009.

Data relating to the road and roadside that were not available from existing data sources were collected specifically for the project. In some cases, this involved manually collecting and coding data from street directories (Melway, 2005-2009) and on-line imaging sources. For variables that required a greater level of precision (e.g. accurate distance measurements), data were obtained from calibrated digital images of arterial roads collected by ARRB for VicRoads during the period January 2009 to February 2010. ARRB's team of professional coders were contracted to code the digital image data according to detailed specifications. Data were subjected to an extensive and iterative process of validation and quality checks.

All data collected were specific to the segment of interest, except for sociodemographic data, which were collected for the statistical local area (SLA) in which the segment was located.

2.4. Data analysis

Units of analysis

Of the original 148 segments that were identified, three long segments were split into two sections for analysis because the traffic volume varied considerably between the two sections. Two segments were excluded because no digital image data were available, while a further two were excluded because no traffic volume data were available. Five sites were excluded because major road works were undertaken on those segments under the Safer Roads Infrastructure Program (SRIP) between 2005 and 2009. One remaining site was excluded because the road geometry was so very different to every other site that it would have been problematic to include it in the analysis. That site was dominated by a partly controlled complex roundabout with five arms and tram tracks through the centre. This left 141 segments on which to conduct the analysis of the factors associated with crash risk in midblock strip shopping centre segments. These 141 segments ranged from approximately 200m to 4km in length (median 400m).

Analysis method

Negative binomial regression was used to measure the association between the number of crashes that occurred and the characteristics of the segment. Negative binomial regression is appropriate for count data (e.g. the number of crashes at each site) where the mean is not equal to the variance (Hilbe, 2008), which is characteristic of traffic crash count data. There was no reason to use zero-inflated models, because only three segments (2.1%) had no crashes occur during the period of interest.

Due to the large number of variables (over 60), the multivariable model was built in stages. First, the variables were categorised according to the segment characteristic they described: exposure, traffic, speed limit, road, roadside, enforcement, facilities or socio-demographics. A separate multivariable regression analysis was run for variables in each of the different categories. The exception to this was exposure (vehicle km travelled, or traffic density), which was included in all the models as a covariate. The variables in each category that were associated most strongly with the rate of crashes were selected. Although a p-value of 0.05 is usually chosen as the level for statistical significance, due to the exploratory nature of this research and the iterative process used, any association with a p-value of less than 0.20 was deemed to be of potential interest at this first stage.

For many segment characteristics, there were several variables that could be used to describe that characteristic. For example, for on-road parking, there were

- a binary variable indicating the presence or absence of parking on that segment,
- variables describing where parking was located, e.g. on how many sides of the road, and
- four variables describing the presence of different types of parking, e.g. parallel in lane parking, parallel sheltered parking, angle parking on the side of the road, or parking in the centre (median)

Initially, models were fitted using the simplest variables for each characteristic. Then, the model was re-estimated using the more complex variables and the model with the best fit was selected. If a more complex variable was not found to add any further information, the simple variable was used. Model fit was measured using the log-likelihood and the Akaike information criterion (AIC).

Within each of the categories, the following variables (or other variants of those variables) were assessed for their relationship to the rate of crashes:

1. Exposure: thousand vehicle km travelled (thousand vehicle km travelled per lane – a measure of traffic density)
2. Traffic mix: percentage commercial vehicles, presence of buses, heavy vehicle approved routes
3. Speed limit: 6 categories (4 categories, or variable indicating whether the segment was a strip shopping centre variable speed zone)
4. Socio-demographics for the Statistical Local Area (SLA) in which the segment was located: Population density, percentage of population aged 75 and over, percentage of population that were males aged 15 to 24, index of relative socioeconomic advantage and disadvantage (IRSAD) decile, passenger vehicle ownership rate, motorcycle vehicle ownership rate
5. Enforcement: Presence of speed/red light cameras
6. Roadside environment: predominant development height, presence of shops on one or both sides, nature strip, offset from buildings, total number of poles on side of road

per km (frangible and non-frangible), total number of poles on median per km (frangible and non-frangible)

7. Facilities in environment: number of late night liquor licences per km, other non-late night on premises liquor licences per km, packaged liquor outlets per km, presence of schools, tertiary institutions, railway stations, community facilities, childcare/kinder facilities, medical centres, hospitals, sporting facilities, places of worship, emergency services, petrol stations.
8. Road characteristics: presence of curves, carriageway width, number of lanes, lane width, divided (median type, median width, number of mid-median accesses per km), number of right turn lanes per km, number of left turn lanes per km, number of driveways/laneways per km, presence of service road, number of service road accesses per km, total number of signalised intersections per km (number of different types of signalised intersections per km), number of minor intersections per km (number of different types of minor intersections per km), number of roundabouts per km, presence of bike lanes (bike lane width, type of bike lane) number of pedestrian crossings per km, presence of fencing at pedestrian crossings, presence of on street parking (presence of different types of on street parking), number of off-street parking facilities per km, presence of clearway on one or both sides, presence of pavement distress, presence and degree of pavement roughness, trams (type of tram-lane), number of bus stops per km, number and type of tram stops per km, road type, presence of low tram wires, low clearance, presence of level crossings.

The variables that were found to be strongly associated with the number of crashes in the category-specific regression models were all entered into an all-category multivariable model, to determine which were associated with the number of crashes, when adjusted for the presence of factors from other categories. At this stage, those variables with a p-value of greater than 0.1 were removed from the model. Then, every other variable was added to the model one by one to determine a) if it was a significant predictor of crash risk, or b) whether it was a confounder of the association between other variables in the model and crash risk. If so, it was retained, and if not, the variable was removed. Finally, those variables for which the overall association with crash risk had a p-value of greater than 0.05 were removed from the model. Once this stable main effects model was developed, further tests were conducted to determine if the effect of traffic density was linear and to assess evidence for a limited number of plausible interactions (primarily those involving speed limit).

3. Results

3.1. Summary of crash data

Over the five year period from 2005 to 2009, the number of crashes per site ranged from zero to 180, with a median of nine (inter-quartile range (IQR) 12, mean 13.9, variance 336.6). Only three segments (2.1%) had no crashes. Crashes per km ranged from zero to 65.1, with a median of 20.7 (IQR 14.7, mean 23.2, variance 170.1).

3.2. Overall model

Variables that were significantly associated with crash risk ($p<0.05$) in the final model are presented in Table 1. Incidence rate ratios (IRR) are presented, where an IRR greater than one indicates an increase in risk with the presence of that risk factor, and an IRR lower than one indicates a decreased risk. Confidence intervals and p-values are also reported. None of the interactions were significant, so the final model only contains main effects as reported in Table 1.

Traffic density (measured as thousand vehicle km per lane) was strongly associated with crash risk; for every extra thousand vehicle km per lane, the risk increased by 16%. Further testing revealed that risk increased linearly as traffic density increased, within the range measured.

Compared to strip shopping centre segments with a 60 km/h speed limit, risk was 49% lower for segments with a 40 km/h or 50 km/h speed limit, however, segments with variable (40/60 km/h) speed limits or those with 70 km/h or 80 km/h did not show a significant difference in crash risk relative to 60 km/h speed zones.

In terms of the road-related risk factors, primary state arterials were associated with a 36% increase in risk relative to secondary state arterials, even after accounting for other variables in the model, such as traffic density and the number of lanes. For every extra lane, the risk was increased by 8%. Compared to lanes of 3 to 3.3m wide, the narrowest lanes (<3m) were associated with a 25% higher crash risk, while the widest lanes (>3m) were associated with a 19% increase in crash risk.

Maximum median, or traffic island, width was associated with crash risk. Compared to roads with no medians or islands, those with a maximum median/island width of <3m were associated with a significant increase in crash risk (72% to 76%), whereas there was only marginal evidence (p=0.08) for a smaller (18%) increase in crash risk for roads with a maximum median/traffic island width of more than 3m.

For every extra signalised (major) intersection, the crash rate decreased by 4%, however this estimate is most likely biased by the way the crash data was extracted (considered further in the discussion). For every extra unsignalised (minor) intersection per km, the risk of a crash increased by 4%. Presence of the following in the road segment all increased crash risk: service roads (55%), level crossings (34%) and parking on both sides of the road (81%), whereas every extra bus stop per km was associated with a risk reduction of 3%.

The presence of a nature strip on one or both sides of the road was associated with a reduction in crash risk (24% and 51%, respectively).

Finally, in terms of the facilities in the area, for every extra off-street parking facility, the risk reduced by 3%. The presence of medical centres was associated with a 22% increase in crash risk. For every extra late night or non-late night liquor licence per km (for consumption on premises), the risk increased by 8% and 1%, respectively, while for every extra take-away liquor licence per km, the risk in that segment decreased by 5%.

Table 1. Factors associated with number of crashes in strip shopping centres.

	Incidence Rate Ratio (IRR)	**95% Confidence Interval (95% CI)**	**p-value**
Exposure			
Traffic density: Thousand vehicle km per lane	1.16	1.14-1.18	<0.001*
Speed limit			overall 0.002*
40 or 50 km/h	0.51	0.35-0.75	<0.001*
60/40 km/h variable	1.07	0.89-1.28	0.487
60 km/h	Reference	-	-
70 or 80 km/h	0.92	0.71-1.18	0.511
Road			
# lanes	1.08	1.02-1.15	0.009*
# signalised intersections per km	0.96	0.92-0.99	0.009*

	Incidence Rate Ratio (IRR)	95% Confidence Interval (95% CI)	p-value
# unsignalised intersections per km	1.04	1.02-1.06	<0.001*
# bus stops per km	0.97	0.95-0.99	0.001*
Presence of service road			
No Yes	Reference 1.55	- 1.22-1.96	- <0.001*
Road type – Primary state arterial			
No Yes	Reference 1.36	- 1.15-1.60	- <0.001*
Maximum median/island width			overall <0.001*
No median <1.2m wide 1.2-3m wide >3m	Reference 1.76 1.72 1.18	- 1.43-2.17 1.44-2.05 0.98-1.42	- <0.001* <0.001* 0.078^
Presence of parking on both sides of road			
No Yes	Reference 1.81	- 1.46-2.26	- <0.001*
Maximum lane width			overall 0.025*
<3m 3-3.3m >3.3m	1.25 Reference 1.19	1.03-1.51 - 1.01-1.40	0.021* - 0.038*
Level crossing in segment			
No Yes	Reference 1.34	- 1.11-1.62	- 0.002*
Roadside environment			
Nature strip			overall <0.001*
No nature strip 1 side 2 sides	Reference 0.76 0.49	- 0.59-0.99 0.39-0.63	- 0.038* <0.001*
Facilities in environment			
# off street parking facilities per km	0.97	0.95-0.99	0.006*
# late night liquor licences per km	1.08	1.05-1.12	<0.001*
# non-late night liquor licences per km	1.01	1.01-1.02	<0.001*
# take-away liquor licences per km	0.95	0.93-0.99	0.004*
Presence of medical centres			
No Yes	Reference 1.22	- 1.03-1.45	- 0.025*

* indicates statistical significance at the 0.05 level, ^indicates a p-value of between 0.05 and 0.10.

4. Discussion and further research

Extensive data were collected relating to a large number of potential risk factors beyond those usually considered in road safety research. A range of factors relating to exposure, speed limit, the road, roadside and facilities in the surrounding environment were found to be associated with crash risk in strip shopping centres in metropolitan Melbourne.

Similar to previous studies (e.g. Abdel-Aty and Radwan, 2000; Chang, 2005; Greibe, 2003; Milton and Mannering, 1998; Pande & Abdel-Aty, 2009; Shankar et al., 1997;), and, as expected, the results indicate that traffic and road segment characteristics that reflect an increased opportunity for conflict between road users, increased visual complexity in the environment and increased workload for the driver increase crash risk. Traffic density (thousand vehicle km per lane), an increased number of lanes, an increased rate of minor intersections, narrow lanes (<3m wide), parking on both sides of the road and the presence of level crossings in a segment were all found to increase crash risk. Primary state arterials were also found to have a higher crash risk than secondary state arterials, even after taking traffic density and the number of lanes into account.

There were exceptions to this; an increase in the rate of bus stops and signalised intersections were associated with a decrease in crash risk, despite the increased opportunity for conflict, increased complexity and increased workload for the driver. When considering bus stops, however, this potential increase in risk only occurs for a relatively small interval of time while the bus is present. Due to their size, it is obvious when a bus is present and the road rules state that drivers must give way to buses indicating that they want to re-enter the traffic stream. Therefore drivers may be prepared to respond to the situation, helped no doubt by trained bus drivers who drive predictably and are aware of other vehicles. Vehicles changing lanes to avoid the bus are also a source of potential risk, but again, this behaviour is likely to be predictable given the presence of the bus. It is possible that drivers respond to the potential increased risk by modifying their behaviour, e.g., slowing down. Regarding the rate of signalised intersections, the comparison is biased by the way the crash data were selected. Results presented here are for mid-block crashes, that is, crashes that occurred at signalised intersections were excluded. Yet the segment length reflects the entire length, including intersections. Unfortunately, it was not possible to accurately measure the length of major intersections and subtract this to determine the true midblock length for a segment. As such, the reduced crash risk associated with rate of major intersections is entirely expected. The inclusion of this term in the model can be considered as an adjustment for the crash selection method (i.e. exclusion of major intersection crashes). It is possible there is a residual effect of major intersections on the risk of midblock crashes, however this cannot be quantified in the present study.

It would be expected that road and roadside characteristics that reduce opportunities for conflict would decrease crash risk. This was the case for off-street parking facilities (which also complements the finding that on-road parking increases risk) and the presence of nature strips which may make the environment appear less complex for motorists and provide a buffer between pedestrians and motorists, allowing more time to react to each others' movements.

The opposite effect, however, was found for the presence of service roads and wide lanes, which both increased crash risk, despite providing less opportunity for conflict, lower driver workload and being less visually complex. Previous research has suggested that drivers choose higher travel speeds when service roads and wide lanes are present (see SWOV, 2012 for a review), which could explain the increased risk. Choice of travel speed on a road segment is strongly related to the appearance of that segment and is a strong moderating factor in terms of the risk and severity of a casualty crash. Speed choice is also related to speed limit, and casualty crash risk was significantly reduced on roads with speed limits of 40 or 50 km/h compared to segments with higher speed limits, or those with variable 40/60 km/h speed zones.

The maximum median/traffic island width in a segment was also significantly associated with crash risk. Compared to segments with no medians or traffic islands, those with narrow (<3m) medians or traffic islands had a significantly higher crash risk, although those with wider (>3m) medians were not significantly different. Although this seems counterintuitive, it is important to remember that this does not mean that medians are ineffective. This measure reflects the maximum (not the most common) median width on a segment. Thus it may indicate the width of a traffic island that is only present for some of the segment, or a median that is present for all of it. It is unclear, however, why segments with a maximum median/traffic island width of less than 3m have a higher risk that those with no traffic islands or medians at all. This requires further investigation.

Facilities present in the segment influence the number and type of people who visit the area, which in turn may affect crash risk. An increased density of liquor outlets with licences for consumption on premises, particularly late at night, was associated with a higher risk of casualty crash occurrence. This could be due to these establishments attracting more people to an area, or may be due to the presence of alcohol impaired road users. Future development of separate risk models for alcohol-related crashes may help to clarify this matter. In contrast, an increase in the rate of take-away liquor outlets in a segment was associated with a decreased crash risk in that same segment. In this study, however, crash analysis was restricted to shopping strip segments only. It is possible that take-away liquor outlets are associated with increased crash risk when considered on a larger scale than simply the segment in which the outlet is located. Finally, the presence of medical centres in a shopping segment was associated with increased risk of crash occurring. It is impossible to determine however, if the road users involved in the crashes were visiting the medical centre. It is possible that the presence of medical centres is a surrogate indicator for shopping strips that have a range of other facilities available rather than simply shopping facilities. This in turn, would be expected to affect the number and nature of people attracted to the area.

4.1. Study limitations

Discussion of these results has highlighted some of the weaknesses of the current study. First, there was no data available on several important risk factors, such as actual travel speeds, pedestrian volumes, and cyclist volumes. Although some councils collect this information, it was not available for all segments. Secondly, the difficulty in interpreting some of the results is possibly in part due to intercorrelations between the variables. Attempts were made to address this problem by modelling category-specific risk factors first in order to select variables to enter into the final model and by not including variables in the same model that essentially described the same characteristic. However, there are still likely to be many partial intercorrelations and further work needs to be performed to try to understand their effect. This is the nature of “natural experiments” where the researcher does not have control over the study segments.

4.2. Future research

The next steps of this research program involve developing separate models to investigate risk factors for different types of crashes, for example pedestrian-vehicle crashes, cyclist-vehicle crashes, young driver crashes and alcohol-related crashes. Finally, although accident prediction models can identify factors associated with increased risk, they cannot provide information about the mechanisms by which risk is affected. However, the results of such research can be used to derive testable hypotheses about human behaviour (e.g. that drivers may travel faster when lanes are wider) that can be tested using other methods, such as experimental studies in driving simulators or naturalistic on-road studies.

5. Conclusions

The results presented here represent a preliminary analysis from a broader study program that has identified a range of factors related to the road, roadside and facilities in the surrounding environment that impact on crash risk in strip shopping centres. The range of factors influencing crash risk extend well beyond the traditionally considered categories of traffic volume and roadway design and those used in risk assessment models and for speed setting criteria. There is significant variation in risk amongst sites with the same speed limits that can be explained by the presence of these other influential risk factors. These and future results can contribute to the design of better risk assessment tools for urban road segments.

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