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The effect of alcohol availability on road crashes at varying distances from the Central Business District in Perth, Australia from 2005 to 2015

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Title
The effect of alcohol availability on road crashes at varying distances from the Central Business District in Perth, Australia from 2005 to 2015

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Abstract
This study examined the effects of distance from alcohol outlets to alcohol- and non-alcohol-related road crashes across the Perth metropolitan area. A retrospective population-based study was undertaken using measures of alcohol- and non-alcohol-related crashes, and their proximity to alcohol outlets, using a geographic information system and regression modelling. The study included 341,467 crashes that occurred between 2005 and 2015. The highest crash incidence rates occurred in 2007 and in the CBD. Heat maps showed the highest densities of crashes in the commercial and retail centres, with more focused areas of high density alcohol-related crashes. Models indicated crashes with higher number of on-premise outlets and lower number of bottleshops in adjacent buffer zones were more likely to be alcohol-related crashes. Recommendations about the timing and location of roadside alcohol testing are made.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

EXECUTIVE SUMMARY

Introduction

A body of research over the last 90 years has established that alcohol has negative effects on cognition, performance and behaviour. The short-term physiological effects of alcohol include decreased motor coordination, impaired attention, perception and judgement (Cherpitel, 1992), all of which have a negative effect on driving performance.

Previous research has examined the effects of alcohol outlet density[1] on various alcohol-related harms including road crashes (Gruenewald and Ponicki, 1995, LaScala et al., 2001, Gruenewald, 2010, Cameron et al., 2012). Results have been mixed, with associations with crashes differing between on-premise outlets and bottleshops (e.g., Cameron et al., 2012, McCarthy, 2003). One of the reasons for the widely varying results is the different geographic units used across the studies. Using buffer zones, which are set distance bands around crashes, to analyse the associations between alcohol outlets and alcohol-related harms can overcome some of these issues.

Road crashes differ from other alcohol-related harms because of two conflicting mechanisms which potentially link them to alcohol outlets: higher alcohol availability (through easier access to closer alcohol outlets) and greater exposure to driving (through longer driving distances from more distant outlets). By using numbers of alcohol outlets within defined buffer zones to measure alcohol availability, this study aimed to explore the relative effects of these two factors on risk of crash at different distances from alcohol outlets, in metropolitan Perth, Western Australia.

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[1] Alcohol outlet density is the number of alcohol outlets within a defined region and is standardised using residential population or a measure of land area or roadway miles. It is a measure of the physical availability of alcohol to consumers in a given area.

Method

<u>Objectives</u>

The objectives of the study were as follows:

1. Describe the incidence of alcohol- and non-alcohol-related road crashes from 2005 to 2013[2] according to the area of the city.
2. Investigate the changes over time (between 2005 and 2013[2]) in the annual incidence of alcohol- and non-alcohol-related road crashes.
3. Describe spatial patterns of road crashes by crash type and time of occurrence.
4. Explore how associations differ between alcohol- and non-alcohol-related road crashes and number of licensed alcohol outlets at varying distances from the CBD.
5. Develop recommendations regarding enforcement and alcohol outlet licensing according to geographical relationships between road crashes and alcohol outlets.

The study used a longitudinal retrospective ecological study design. The study area was the Perth Greater Capital City Statistical Area as defined by the Australian Bureau of Statistics (ABS).

<u>Data sources</u>

Alcohol outlet licensing information was acquired from the Department of Racing, Gaming and Liquor WA for each year from 2005 to 2015. The street addresses were then geocoded.

Crash data (including data on individual drivers and longitude and latitude of each crash) for the period 1 January 2005 to 31 December 2015 was extracted from the Integrated Road Information System (IRIS) database, which is maintained by Main Roads Western Australia. All crashes which involved at least one driver with a BAC of 0.05% or over (BAC $\geq$ 0.05%) were extracted from this dataset.

Because of the differences in absolute numbers and proportions of crashes with alcohol-affected drivers across the study years, it was concluded the number of crashes recorded with a BAC $\geq$ 0.05% may have been affected by different crash recording methods, levels of police attendance

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[2] Road crash data for 2014 and 2015 was not included in the incidence rate calculations due to issues with the data in these years. These are discussed in detail later in the report

and BAC testing over the study period. To confirm results using crashes with confirmed BACs $\geq 0.05\%$, surrogate measures of alcohol-involvement were developed as alternate definitions of alcohol-related crashes. These were formulated based on previous road safety research and examination of the patterns of Perth crashes over the study period. Weekend single vehicle night-time (SVN) crashes occurring between 18h00 to 04h59 was chosen as the primary surrogate measure of alcohol-involvement in a crash, and used in the analysis.

The non-alcohol related crashes were defined as all day-time crashes from 07h00 to 17h59, and single vehicle day-time crashes from 07h00 to 17h59.

Geographic information system: calculations and maps

A set of maps were created in ArcGIS, a geographic information system (GIS). Postal areas, the ABS approximation of postcodes (ABS, 2012), were the administrative boundaries used in the GIS. Greater Perth postcodes were grouped according to their distance from the central business district (CBD) into four categories or zones:

1. CBD: the road links[3] were approximately 300m (or less).
2. Inner postcodes (inner zone): road links between 300m and 1,000m. Perth postcodes within 7km of the city centre but outside the CBD were included in this category.
3. Middle postcodes (middle zone): road links between 1,000m and 1.5km. Postcodes included were between 7km and 15km from the CBD.
4. Outer postcodes (outer zone): road links greater than 1.5km. Postcodes were more than 15km from the CBD.

The road network distance between alcohol outlets and each crash was measured in ArcGIS so that alcohol outlets could be allocated to buffer zones.

Maps were created to illustrate numbers of crashes by postcode. Heat maps, using kernel density estimation, indicated areas of higher density of crashes across the metropolitan area.

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[3] Road links or road link distance is the distance between traffic signals.

<u>Statistical analysis</u>

Descriptive statistics (including frequency distributions of crash types over time) was undertaken.

Crash data, number of alcohol outlets and distance calculations, and postcode-level socioeconomic and demographic data from the ABS were merged. Regression modelling was undertaken for confirmed alcohol-related crashes and the surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes).

The models included in this study used logistic regression. The outcome variable for the first model was BAC $\geq 0.05\%$ crashes. The outcome variable for the alternate model was the surrogate measure, weekend single vehicle night-time crashes. The predictors of alcohol availability were number of on-premise outlets and number of bottleshops within different buffers (0-2km, 2-5km, 5-10km, and 10-20km) from the crash. Additional predictors were distance from the CBD, postcode-level socioeconomic status and postcode-level demographic factors.

Results

<u>Descriptive statistics</u>

The total number of included crashes from 1 January 2005 to 31 December 2015 in the Perth metropolitan area was 341,467. This ranged from 34,804 (10.19%) in 2007 to 26,293 (7.70%) in 2015.

Incidence rates of all crashes varied across the years studied, with the highest rates occurring in 2007, decreasing gradually until 2013. The incidence rates varied considerably by the zone from the CBD. The highest incidence rates for both BAC0.05%+ and weekend SVN crashes were in the CBD, with lowest incidence rates in the inner and middle postcodes.

The total number of licensed alcohol outlets in Perth has grown from 1,925 in 2005 to 2,467 in 2015. A total of 205 (8.3%) alcohol outlets operated in the CBD, 909 (37%) in the inner postcodes, 759 (31%) in the middle postcodes and 594 (24%) in the outer postcodes of Perth in 2015.

Maps of alcohol outlets and crashes

Maps were used to illustrate BAC ≥ 0.05% crash data for each of three years: 2005, 2010 and 2015. Number of crashes were indicated in deciles[4]. The highest number of BAC ≥ 0.05% crashes were in the southern postcodes from Fremantle and Rockingham on the coast, eastwards to Kelmscott and Armadale. BAC ≥ 0.05% crashes, weekend single vehicle night-time crashes and all day-time crashes in 2015 were compared graphically. Weekend single vehicle crashes included Fremantle, Rockingham, Kelmscott and Armadale as well as other community and retail centres such as Joondalup, and Cannington, while all day-time crashes included Midland as well.

Heat maps were created, using kernel density estimation to estimate areas of high, medium and low density of alcohol outlets or crashes. While all heat maps for both BAC ≥ 0.05% crashes and all day-time crashes showed areas of high density of crashes in the commercial and retail centres, these areas were spread across large parts of these postcodes in the day-time crash maps, while they tended to be more focused on specific parts of postcodes for BAC ≥ 0.05% and weekend single vehicle night-time crashes, possibly relating to specific locations rather than general high volumes of traffic across a postcode which might occur during the day.

Distance to alcohol outlets

In the outer zone of Perth (postcodes beyond 15km from the CBC), the median distance between crashes related drivers with BAC ≥ 0.05% and the two alcohol outlet types were the most similar, with crashes being further from bottleshops (619m) than on-premise outlets (182m). Similar, but more pronounced findings were noted for weekend single vehicle night-time crashes, with differences in median distances to bottleshops (626m) and on-premises outlets (125m) being larger.

Statistical models

Logistic regression models demonstrated that crashes with greater numbers of on-premise outlets and lower numbers of bottleshops up to 2km, 2-5km, 5-10km and 10-20km from the

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[4] Deciles: ten equal groups with the highest decile including the highest number of alcohol outlets or road crashes per postcode, and the lowest decile including the lowest number of alcohol outlets or road crashes per postcode.

crash were more likely to be alcohol-related. Crashes in postcodes outside the CBD were more likely to be alcohol-related than non-alcohol-related.

Discussion and Recommendations

This study explored the spatial relationships between alcohol outlets, and alcohol- and non-alcohol-related crashes. To account for possible under-recording and reporting of alcohol-involvement of crashes, a surrogate measure of alcohol-involvement was used in addition to confirmed alcohol-related crashes.

Incidence of crashes

Incidence rates of all crash types were highest in the CBD area than other parts of Perth metropolitan, for crashes involving drivers with confirmed BAC $\geq 0.05\%$, as well for surrogate measures of alcohol-related crashes (weekend single vehicle night-time crashes) and non-alcohol-related crashes (single vehicle and all day-time crashes). This probably reflects the effects of the road structure on driving in the CBD area (short distances between traffic signals and higher intersection density) and large volumes of traffic often leading to congestion (during the day). Incidence rates for alcohol-related crashes in the outer postcodes were relatively high (compared to incidence rates for non-alcohol-related crashes in the same area), suggesting that the combination of alcohol and the additional distances driven could lead to higher numbers of alcohol-related crashes.

Maps

Comparison of three years across the study (2005, 2010 and 2015) showed that the changes across the years largely mirrored patterns of residential development of Perth, particularly in the outer suburban areas, over the study period. The Perth CBD, and smaller centres of the metropolitan areas, including Fremantle, Rockingham, Mandurah, Midland, Cannington, Armadale and Kelmscott, and Joondalup, were areas of high density of crashes, and these areas of high density were more discrete for alcohol-related crashes than non-alcohol-related crashes.

Statistical models:

Models showed that as numbers of on-premise outlets increase in each buffer zone and numbers of bottleshops decrease in each buffer zone, crashes are more likely to be alcohol-related than

non-alcohol-related. A larger number of on-premise outlets (rather than a single alcohol outlet) nearby was associated with crashes being more likely to be alcohol-related, possibly because of interaction between drivers who have also been drinking, or non-drinkers who reside nearby. The relationship between bottleshops and crashes is more complex as alcohol is not consumed on-site, and so the relationship between distance to a bottleshop may be less important than the ease of access to bottleshops (how many bottleshops are in an area), and how and where alcohol purchased at a bottleshop is consumed.

<u>Recommendations</u>

"Toward Zero", the Western Australian road safety strategy for 2008 to 2020, identifies drink driving as a crash problem behaviour which can benefit from interventions in all four cornerstones of the Safe Systems road safety approach (Office of Road Safety, 2009).

General recommendations
The following general recommendations relate to the 'safe road and roadside', 'safe speeds' and 'safe vehicles' cornerstones of the Safe Systems approach:

1. That locations with a high risk of alcohol-related crashes be identified by Main Roads Western Australia, and that countermeasures be used to reduce crash severity in these locations.
2. That alcohol interlocks be used for repeat drink drivers.
3. That speeds be reduced in high-risk road sections, and around entertainment districts, over weekend nights.

Specific recommendations
Specific recommendations from the results of the report pertain to 'safe road use', primarily through enforcing road rules (Office of Road Safety, 2009):

1. That targeted roadside breath testing be used in the following areas:
    i. Near the areas with clusters of on-premise outlets (such as entertainment districts);
    ii. Closer to primarily residential areas;
    iii. In areas where bottleshops are more scattered;
    iv. On weekends, particularly between 9pm and 2am.

2. That the Department of Licensing, Gaming and Liquor consider the following when granting liquor licences:
   i. The location of on-premise outlets relative to each other;
   ii. Controls on bottleshops regulate aspects such as the size of bottleshops, discounting prices of drinks and the mix of drinks sold, rather than the number of bottleshops.

3. That future research should investigate how these relationships vary across regional and remote parts of Western Australia.

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1 INTRODUCTION

1.1 Aim

The aim of the study is to examine the effects of licensed alcohol outlets on road crashes in the inner, middle and outer postcodes of the Perth metropolitan area and the association between the distance to a crash and a licensed alcohol outlet.

1.2 Hypothesis

The overall hypothesis is that the risk of a road crash is associated with alcohol availability, and this risk will vary depending on crash type, alcohol outlet type, distance from alcohol outlet to the road crash and the area of the city.

1.3 Objectives

The objectives of this study are as follows:

1. Describe the incidence of alcohol- and non-alcohol-related road crashes from 2005 to 2013[5] according to the area of the city.

2. Investigate the changes over time (between 2005 and 2013[5]) in the annual incidence of alcohol- and non-alcohol-related road crashes.

3. Describe the spatial patterns of road crashes by crash type and time of occurrence.

4. Examine the associations between alcohol- and non-alcohol-related road crashes and number of licensed alcohol outlets at varying distances from the CBD.

5. Develop recommendations regarding enforcement and alcohol outlet licensing according to geographical relationships between road crashes and alcohol outlets.

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[5] Road crash data for 2014 and 2015 was not included in the incidence rate calculations due to issues with the data in these years. These are discussed in detail later in the report.

2 METHODS

2.1 Study Design

The study design was a retrospective population-based study from 2005 to 2015.

2.2 Data Collection

De-identified data was accessed through the Integrated Road Information System (IRIS), which is maintained by Main Roads Western Australia; the Australian Bureau of Statistics (ABS) website; and the Department of Racing, Gaming and Liquor Western Australia.

The study area was the Perth Greater Capital City Statistical Area (GCCSA) as defined by the Australian Bureau of Statistics (ABS, 2011), which is a larger area than the previous Statistical Division of Perth (ABS, 2006). The Perth GCCSA includes Mandurah and Pinjarra to the south.

2.3 Ethics approval

Ethics approval was sought from the Curtin Human Research Ethics Committee. Approval was granted on 29 April 2016. The approval number for the project is RDHS-82-16.

2.4 Alcohol outlet data

Alcohol outlet licensing information was requested from the Department of Racing, Gaming and Liquor WA. The following information was obtained from 2005 to 2015: name of each alcohol outlet; physical address (full street address which is necessary for geocoding); licence type (for example, bottleshop or nightclub) and years that the alcohol outlet was active. The data was received as a Microsoft Excel file with separate spreadsheets for each year. The data was then cleaned using Stata 12 (StataCorp, 2011) and Microsoft Excel, creating consistent formatting for street addresses, suburbs and postcodes. The street addresses were then batch geocoded using the mappify web application (2016), a simple geocoding and routing web-based tool for Australia which uses the freely available G-NAF (Geocoded National Address File) to forward and reverse geocode, that is, convert street address to geographic co-ordinates, and vice versa. Approximately 2% of addresses failed to geocode automatically and were manually geocoded using Google Maps.

2.5 Integrated Road Information System (IRIS)

Permission to use the crash data for the period 1 January 2005 to 31 December 2015 was obtained from Main Roads Western Australia. The data was extracted from the Integrated Road Information System (IRIS) database. The dataset included all drivers related in any reported motorised vehicle crashes. Unit record information was acquired for each 'vehicle controller'

(e.g., driver, rider) related in each crash, including: crash number (referred to as 'accident number' in the IRIS database); sex; age; road user type (e.g., driver of a car, motorcycle rider); date; time; location (including longitude and latitude of the crash); nature and circumstance of a crash, including blood alcohol concentration (BAC) where applicable. Only the driver crash records or motorcycle rider crash details were obtained. There were issues with the 2014 and 2015 crash data so these data were only used in the statistical models.

2.5.1 Processing

Crash data was provided in Microsoft Excel files by Main Roads Western Australia. The data was imported into Stata for processing. The following records were flagged:

1. Single or multiple vehicle crashes [cross-checked by road user movement (RUM) codes (7,8, 64 to 85) and nature of crash codes (7 to 10)];
2. Provisional drivers (by age and recorded licence type);
3. Blood Alcohol Concentration (BAC) > 0%;
4. BAC ≥ 0.05%;
5. Driver of a vehicle.

Records for non-drivers and non-motorised vehicles were removed (i.e., bicycles, pedestrians and towed vehicles). Only records involving crashes in the Perth Greater Capital City area, as defined by the Australian Bureau of Statistics (ABS) were retained (see Appendix table 1 for included postcodes).

A single record was retained for each crash, flagging alcohol involvement by any driver related in the crash. The record contained the geocoded location of the crash, hour of the day, day of the week, BAC of driver in the crash (if provided), and whether the crash related a single vehicle or multiple vehicles.

2.5.2 Validation of surrogate measures

A total of 341,467 crashes from 2005 to 2015 were included in the study. The decision to include the 2014 and 2015 data was taken to provide a larger number for the validation process. The number of crashes per year ranged from 26,293 crashes in 2015 to 34,804 in 2007. Of these, 2.22% (7,564) recorded a driver with a BAC ≥ 0.05%. This ranged from 1.35% (356) in 2015 to 2.86% (890) in 2009.

Because of the differences in absolute numbers and proportions of crashes with alcohol-affected drivers across the study years, it was considered that the BAC records may have been affected by different crash recording methods, levels of police attendance and BAC testing over the study period. To overcome this, surrogate measures of alcohol-involvement were developed as alternate definitions of alcohol-related crashes. This a common practice in alcohol and road safety research. The choice of surrogate measures used in this study was guided by both Australian (Chikritzhs et al., 2000, Briscoe, 2004, Evans et al., 2011) and international (Heeren et al., 1985, Wagenaar and Maybee, 1986, Hingson et al., 1987, Voas et al., 2009) research. Previous road safety research has shown that single night-time crashes are highly likely to involve alcohol (Heeren et al., 1985, Voas and Fell, 2011). Data from police and emergency department research has also demonstrated the higher involvement of alcohol in injuries (including those from road crashes) over the weekend (Young et al., 2004a, Ireland and Thommeny, 1993) including in Perth (Hobday et al., 2015).

Following from this research, time of day, day of the week and the involvement of a single or multiple vehicles were chosen as potential measures of involvement of alcohol in a crash in this study. The temporal patterns of all crashes, crashes involving drivers with BAC $\geq$ 0.05%, and single vehicle crashes are shown in Figure 1. SVN crashes and crashes with drivers with confirmed BAC $\geq$ 0.05% have a similar temporal pattern – low during the day-time hours, and rising from 18h00, then dropping from 2am. In contrast, the graph demonstrates that a higher proportion of all crashes occur during the day-time hours.

Figure 1: Comparison of temporal patterns of different crash types
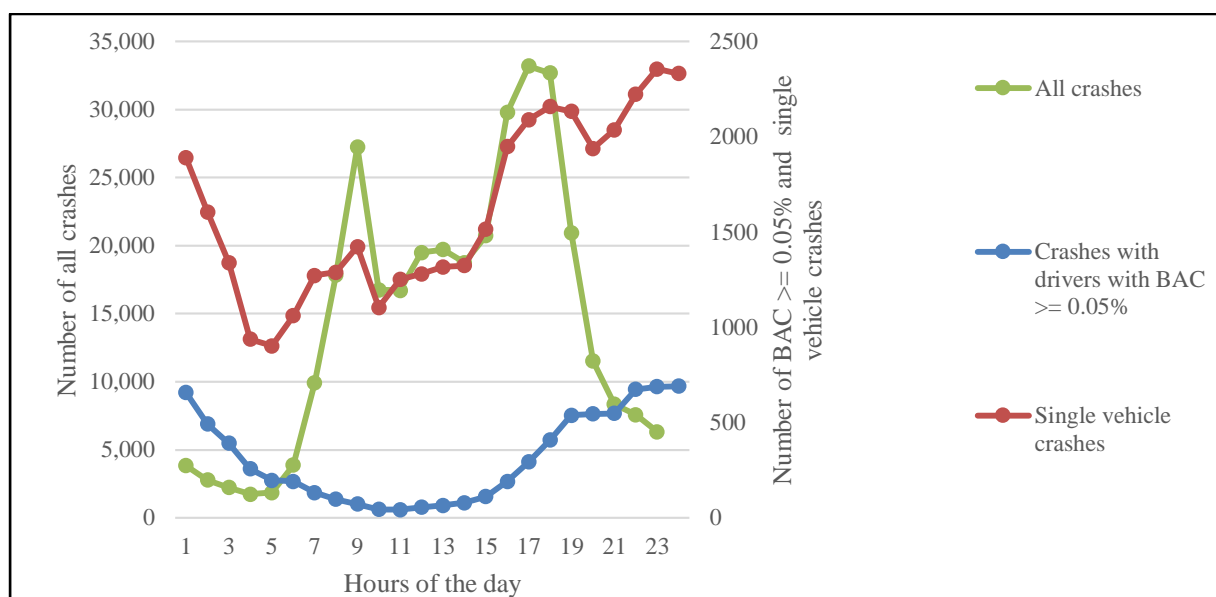
Further examination of the patterns of single vehicle crashes by days of the week compared to crashes involving drivers with confirmed BACs above the legal limit (≥ 0.05%) showed very similar patterns of crash involvement on Friday and Saturday nights, and early Saturday and Sunday mornings (Figure 2).

Figure 2: Comparison of single vehicle crashes by day of the week and crashes involving confirmed BAC ≥ 0.05%, by hour of day, in Perth from 2005 to 2015
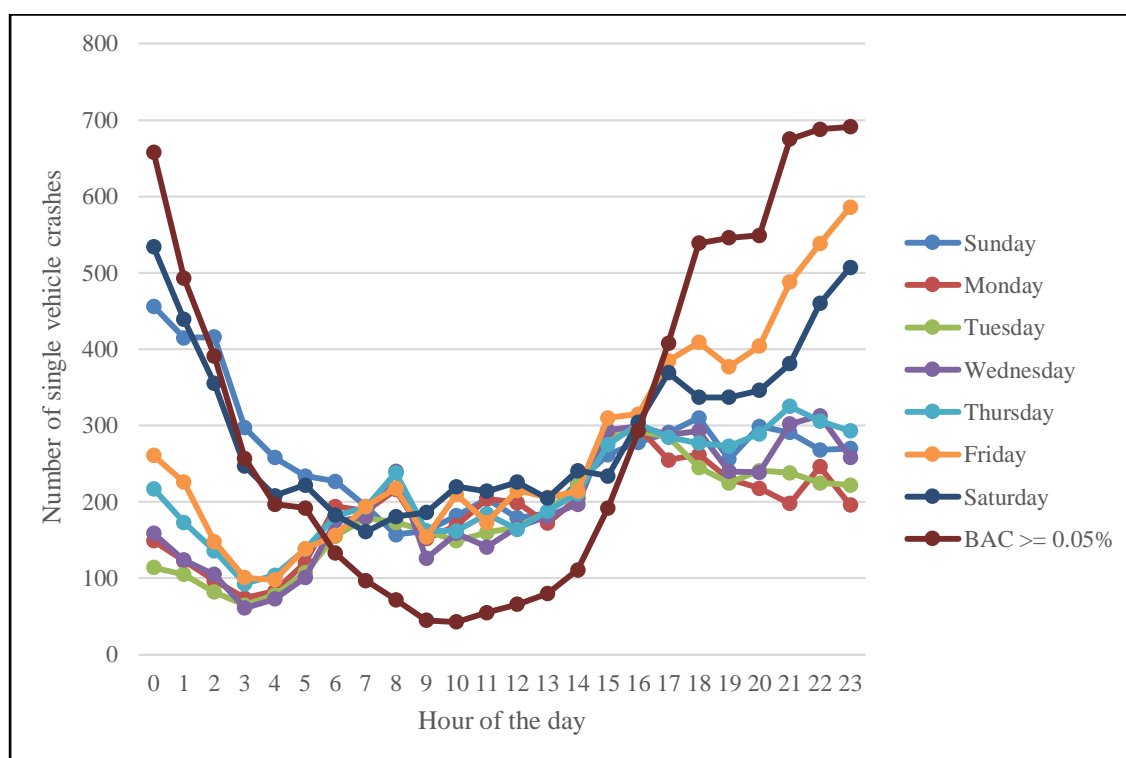
Based on the literature and these findings, several different surrogate measures of alcohol-related crashes were examined, including all night crashes, single vehicle crashes and weekend single vehicle crashes. The hours defining day-time (07h00 to 17h59) and night-time (18h00 to 04h59 the next morning) were similarly based on previous road research on alcohol-involvement in crashes, and the 2005 to 2015 Perth crash data. Because of the high level of specificity and sensitivity of weekend single vehicle crashes, this was chosen as the primary surrogate measure in the study.

Two other measures of alcohol-involvement were also used which were less sensitive and specific: crashes from 18h00 to 04h59, and single vehicle night-time (SVN) crashes from 18h00 to 04h59. Results for these are not contained in the main report but have been included in the Appendix for a more thorough examination of the topic by the reader.

Non-alcohol related crashes were defined as all day-time crashes from 07h00 to 17h59, and single vehicle day-time crashes from 07h00 to 17h59.

2.6   Creation of geographic information systems

A series of 11 maps - one map per year of study - were created using a geographic information system (GIS[6]), ArcGIS 10.4 (ESRI, 2015). Postal areas, the ABS approximation of postcodes (ABS, 2012), were the administrative boundaries used in the GIS analysis to aid in the statistical analysis. The term 'postcode' will be used throughout this document, as it is used in the crash and alcohol outlet datasets to indicate location.

Greater Perth postcodes were grouped according to their distance from the central business district (CBD), using a framework created by the ARRB group while developing speed-flow curves for Perth (Luk et al., 2009) and guided by previous work by the author (Hobday et al., 2016). Using geoprocessing tools in ArcGIS, Perth was divided into four categories, according to the distance between traffic signals (i.e., road link distance):

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[6] A GIS is defined as *'a constellation of hardware and software that integrates computer graphics with a relational database for the purpose of managing data about geographic locations'* RIPPLE, W. J. 1989. *Fundamentals of Geographic Information Systems : a Compendium* Bethesda, Md., American Congress on Surveying and Mapping .

1. CBD: the road links were about 300m (or less).

2. Inner postcodes (inner zone): road links between 300m and 1,000m. Perth postcodes within 7km of the city centre but outside the CBD were included in the category.

3. Middle postcodes (middle zone): road links between 1,000m and 1.5km. Postcodes included were between 7km and 15km from the CBD.

4. Outer postcodes (outer zone): road links greater than 1.5km. Postcodes were more than 15km from the CBD.

Road network spatial data for Greater Perth was obtained from Main Roads Western Australia and added to the GIS. This was used to create an ArcGIS 'network dataset' which enabled the measurement of road network distances using the network analyst tools in ArcGIS. The geocoded alcohol outlets and crashes were plotted in the GIS.

2.6.1 Distance calculations

The distance between alcohol outlets and each crash were measured in ArcGIS (using road network distance) using the relevant geoprocessing tools, so that alcohol outlets could be allocated to buffer zones (up to 2km, 2-5km, 5-10km and 10-20km from each crash). Alcohol outlets were defined as on-premise outlets (where alcohol outlets primarily sell alcohol for on-site consumption, such as hotels/taverns, restaurants and nightclubs) or off-premise outlets [referred to in this report as bottleshops, which sell alcohol purely for off-site consumption (Trifonoff et al., 2011)].

2.6.2 Maps

Maps were created to illustrate the postcode-level number of BAC $\geq 0.05\%$, weekend single vehicle night-time and all day-time crashes. Kernel density estimation was used to create heat maps. Kernel density estimation spreads the value of a known variable at a given point (in this case, either alcohol outlets or crashes per area) outwards so that the highest value is at the given point, and the value decreases to zero as the distance from the point increases. Heat maps indicate areas of high, medium and crash density throughout the Perth metropolitan area.

Maps were also used to depict other surrogate measures of alcohol-involvement and non-alcohol-involvement and crashes per 1,000 roadway kilometres and crashes per 1,000 population per postcode and can be found in the Appendix (Appendix maps 5-26, p.15-36). A similar set of maps were created for alcohol outlets (Appendix maps 1-4, p. 11-14).

2.7 Socioeconomic and demographic data

Socioeconomic and demographic data were obtained from the ABS web-site for the postcodes within Greater Perth (Greater Capital City Statistical Area). This data was used in the multiple variable regression models to control for differences in the socioeconomic and demographic profiles of individuals living in the different postcodes.

The Tablebuilder tool (ABS, 2015) and Census web-site was used to obtain data for the 2006 and 2011 Censuses on the following fields:

1. The number of residents by age-group and gender.
2. The number of residents aged 17 years and older.
3. The number of residents by Indigenous status.
4. The number of residents by employment status.
5. The SEIFA (Socio-economic Indexes for Areas[7]) scores for each postcode in Greater Perth.

Since data was only available for the census years, it was manually interpolated and extrapolated for the non-census years (2005, 2007-2010, 2012-2015) using Stata. This created estimates of the socioeconomic and demographic data for the non-census years.

2.8 Statistical analysis

Data from ArcGIS was cleaned and exported to Stata, and merged to enable statistical analysis. Descriptive and inferential statistics were undertaken.

2.8.1 Statistical models

Logistic regression modelling was used to examine the geographical relationships between road crashes and alcohol outlets, after controlling for relevant socio-demographic characteristics such as distance from the CBD, postcode-level socioeconomic status (SEIFA) and proportion of young males.

Two logistic regression models were created, which compared the odds of an alcohol-related crash compared to the odds of a non-alcohol-related crash. The first model used crashes with at

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[7] SEIFA is a standardised measure that indicates level of advantage/ disadvantage across Australia. SEIFA scores were then divided into quartiles for the analysis. Areas that fall within the lowest scoring quartile (quartile 1) are considered most socio-economically disadvantaged, while the 25% highest scoring areas (quartile 4) are considered the most advantaged areas.

least one driver with a BAC $\geq$ 0.05% (2005-2015) as the outcome variable, compared to all day-time crashes (2005-2015). The alternate model used weekend SVN (2005-2015), the surrogate measure of alcohol-related crashes, as the outcome variable, compared to single vehicle (SV) day-time crashes (2005-2015). The number of on-premise outlets and number of bottleshops within different buffers (0-2km, 2-5km, 5-10km, and 10-20km) were the measures of alcohol availability used in both models.

Two further sets of models, using different measures of alcohol availability, were conducted and included in the Appendix section 1.6.2 and 1.6.3: i) logistic regression using road network distance to the nearest on-premise outlets and distance to the nearest bottleshops (Appendix tables 8-15, p. 40-47); and ii) logistic regression using median road network distance to the closest five on-premise outlets and the closest five bottleshops (Appendix tables 16-23, p. 48-55).

Additional models were created using SVN and all night-time crashes as alternate surrogate measures of alcohol-related crashes which are reported in the Appendix (p. 40-55).

Each set of models was developed for two time periods: 2005 to 2013, and 2005 to 2015, to check for differences because of data issues for the reported crashes in 2014 and 2015. The results were similar. Therefore it was decided to present the 2005 to 2015 models in the main report, and the 2005 to 2013 models are presented in the Appendix (p. 41-62).

3 LITERATURE REVIEW

3.1 Road crashes involving alcohol

A body of research over the last 90 years has established that alcohol has negative effects on cognition, performance and behaviour, which can lead to alcohol-related injuries due to incidents such as assaults and road crashes. The short-term physiological effects of alcohol include decreased motor coordination and balance, impaired attention, perception and judgement (Cherpitel, 1992). These impairments may help to explain the association between alcohol use and injury (Vinson et al., 1995, Bazargan-Hejazi et al., 2007).

Early research into alcohol and driving (Miles et al., 1933) described four effects of alcohol on driving ability: reduced attention to the external environment, slower response of "eyes, hands and feet", varying muscular responses and increased risk-taking behaviour due to reduced inhibition. The authors called for a definitive method of determining the percentage of alcohol in blood or urine to allow charging and prosecution of drivers under the influence of alcohol.

In an early case-control study in Evanston, Illinois, Holcomb (Holcomb, 1938) used the Drunkometer, the first widely-used breath-testing device. The study demonstrated that, as BAC increases, proportion of drinking drivers related in injury crashes increased much in excess of general driving population. This, and other studies in the early years of drink-driving research, had methodological flaws, particularly in the choice of controls. Marshall, in a review published in 1941, noted that opinions and evidence on the link between alcohol use and road crashes was inconclusive (Marshall, 1941). However, over the next four decades, evidence grew demonstrating this link, and establishing that a dose response existed between BAC and crash risk. For example, a survey conducted in Toronto comparing 433 drivers related in crashes to to 2,015 drivers not related in crashes (Lucas et al., 1955) showed that the hazard of a crash was significant when drivers had BACs of greater than 0.10% (compared to at BAC of below 0.05%) and increased to 10 for BACs were greater than 0.15%.A controlled case series of 43 fatally injured drivers in New York in 1959 (McCarroll and Haddon Jr, 1962) demonstrated that a high proportion of those fatally injured had high BACs.

The most influential case-control study of this early period was conducted by Borkenstein using data from 1962 to 1963 in Grand Rapids, Michigan (Borkenstein et al., 1974). The study explored the dose response between BAC and risk of crash involvement, showing rapid increased risk of crash involvement in drivers with BAC greater than 0.08%, and extremely

high risk of crash at BACs greater than 0.15%. Crashes involving drivers with BAC of greater than 0.08% included more single vehicle crashes and related more severe damage and injuries than crashes with sober drivers. Other factors increasing risk of crash were age (young or very old), inexperienced drivers, and those with less formal education. The study also showed that more frequent drinkers had a lower crash risk than non- or infrequent drinkers at lower BACs, and an increased risk of crash at BACs of 0.08 in those under 35 and over 54 compared to 35 to 54 years.

The study made some large assumptions: assuming that a crash was attributable to alcohol because the driver had a BAC of greater than zero; and that single-vehicle crashes were caused by the alcohol-impaired driver but half of all multiple vehicle crashes were caused by drivers who had consumed alcohol; and there were some issues with control selection. However, these did not affect the conclusions drawn from the study (Allsop, 1966). Borkenstein's analysis showed reduced risk of crash involvement in drivers with BACs of 0.01 to 0.049% - compared to BAC of 0 to 0.009%. Researchers have tried to explain this "Grand Rapids Dip", commenting that this effect is a result of differences in the drinking habits (Allsop, 1966, Hurst et al., 1994), age and risk profiles of this group of drinkers compared to the reference group with BACs below 0.01% (Allsop, 1966). Kruger and colleagues (Kruger et al., 1995), in a reanalysis of the Grand Rapids data which included new German data, suggested that most crash risk is associated with drivers with BAC of greater than 0.08% and reducing the legal level to 0.05% would not substantially reduce the number of alcohol-related crashes. The authors further demonstrated that injury data from Germany in 1994 resulted in higher risk of crash than the US in 1962/3, which they hypothesise might be due to "more complex traffic situations" compared to the early 1960s.

Other studies included case-control studies by Perrine and colleagues in Vermont, New England (Perrine et al., 1971) and Farris and colleagues in Huntsville, Alabama (Farris et al., 1976). These studies confirmed that drivers with higher BACs were more likely to be related in crashes involving injuries, that this risk increased with increasing BAC, and that drivers with BACs above zero were more likely to be "at fault" than drivers with negative BACs (Farris et al., 1976). Perrine again noted a minimal increase in risk for BACs below 0.05 but that having a BAC of above 0.08% was "incompatible with safe driving" (Perrine et al., 1971).

McLean and Holubowycz conducted a case-control study in 1979 in Adelaide, Australia (McLean and Holubowycz, 1981). Controls were matched on age-group, sex, time of day, day

of the week and location of crash. Showed consistently higher 'accident-involvement ratios' to the Borkenstein Grand Rapids study (Borkenstein et al., 1974), although the crash ratio to BAC curves followed a similar pattern.

More recent research has shown that, controlling for variables including safety belt use, vehicle deformation, speed and weight, driver age, drinking drivers are more likely to have a serious injury or die than non-drinking drivers (Waller et al., 1986). Reviews have concluded that there is strong evidence that some driving-related skills (including divided attention and information processing tasks) are impaired in drivers with a BAC of above zero, and that most studies report impairment in drivers with BACs of 0.05% and above (Moskowitz et al., 1985, Moskowitz, 1989, Moskowitz and Fiorentino, 2000). Zadar and colleagues showed that older drivers had lower risk than younger drivers, and that young female drivers had lower risk than young male drivers for similar BACs (Zador et al., 2000). The research further showed that, for every increase of 0.02% in BAC, risk of involvement in a fatal single vehicle crash more than doubled among 16 to 20 year old male drivers. This was confirmed by Peck and colleagues (Blomberg et al., 2005, Peck et al., 2008) who, as part of a large case-control study in California and Florida, showed an interaction between age and BAC – those under 21 with positive BAC have higher risk of crash than could be expected by adding the risk of age and alcohol. The authors suggested this could be because of less experience with driving and alcohol, and a tendency towards additional risk-taking behaviour among those under 21s who drink and drive. Recent research has shown that, while the relative risk of being related in a fatal alcohol-related crash has not changed from the mid- 1990s to 2007, risk of involvement in an alcohol-related crash has increased for underage women to the point that it was same as for underage men (Voas et al., 2012, Leporati et al., 2015).

3.2 Surrogate measures of alcohol-related crashes

For many police-attended crashes, data is available on the BAC of one or more drivers. However, this data may be missing in some cases or not collected in police-reported, but not police–attended, crashes. As a result of this, alternate measures of alcohol-involvement (so-called surrogate or proxy measures) have been used in the road safety literature over the last 40 years (Ross, 1973, Douglass et al., 1974, Wagenaar et al., 1981, Hingson et al., 1983, Heeren et al., 1985, Rogers, 1995, Chikritzhs et al., 2000, Voas et al., 2009). These have used the temporal and demographic patterns of alcohol-involvement in crashes (generally night-time, with some using the higher involvement over weekends) and increased involvement of alcohol in single vehicle crashes [noted by Borkenstein (1974)] compared to multiple vehicle crashes.

Early research examining road casualties who had presented in Victorian hospitals between 1978 and 1980 demonstrated that higher proportions of drivers presented with BACs over the limit (0.05% in Australia) on weekends over the night hours (McDermott and Hughes, 1983).

In the most thorough earlier analysis of alcohol-related crash surrogates, Heeren et al. (1985) compared a surrogate of non-alcohol-related crashes (day-time crashes) to two definitions of fatal night-time crashes (9pm to 4:59am, or 8pm to 6:59am) for each of i) all crashes, ii) single-vehicle crashes, iii) male driver crashes, iv) male drivers under 26 years, and v) weekend crashes. They found no significant differences between the two night-time definitions but suggested using the wider time period to include a higher number of crashes. They further concluded that all night-time fatal crashes provided the best proxy measure of alcohol-involvement, with both the highest percentage of crashes involving alcohol and the highest number of crashes of all the candidate surrogate measures.

However, single vehicle night-time crashes (commonly referred to SVN crashes in the literature) has been the most frequently used measure of alcohol-involvement. Rogers examined changes in legally permissible BAC levels and license suspension laws, using several measures of likely alcohol-involvement in crashes. Rogers concluded that SVN crashes were a stronger indicator of alcohol-involvement than total night-time crashes (Rogers, 1995).

Hingson and colleagues (Hingson et al., 1987) used SVN fatal crashes to monitor the effects of driving-under-the-influence legislation in two states in the US, and lower legal blood alcohol limits for young drivers (Hingson et al., 1994). Wagenaar and colleagues have used surrogate measures to test the effect of increasing the legal drinking age (Wagenaar and Maybee, 1986), design education programs for servers of alcohol at alcohol outlets (Wagenaar and Holder, 1991b), assess the effects of the privatisation of state monopolies (Wagenaar and Holder, 1991a) and mandated server training (Holder and Wagenaar, 1994).

The Australian "National Alcohol Indicators Projects" (Chikritzhs et al., 2000) examined trends in serious alcohol-related crashes (resulting in death or hospital admission) between 1990 and 1997, using surrogate measures of alcohol-involvement. The research included data on all states and territories in Australia except Victoria. The results suggested a time-based surrogate of alcohol-related serious crashes: weekend night-time crashes occurring between 10 pm and 2 am.

More recently, Voas and colleagues used a case-control study using data from 1997 to 1999, and 2004 to 2006 in two US states to evaluate surrogate measures of alcohol-related crashes (Voas et al., 2009). The authors confirmed the validity of using night-time fatal and non-fatal crashes, and property damage only crashes as indicators of alcohol-related crashes (Voas et al., 2009).

However, surrogate measures have limitations. Road crash surrogates may successfully identify likely alcohol-related crashes and drink-drivers, but they cannot estimate alcohol-involvement in injured passengers (Treno and Holder, 1997). Furthermore, certain surrogate measures may not reflect trends in alcohol-related crashes over time as well as alcohol-involvement measures by BAC (Heeren et al., 1985). The use of BAC data, supplemented by more than one surrogate measure of alcohol-involvement in crashes, would provide a better overall picture of alcohol-involvement in road crashes.

3.3 Alcohol availability and crash literature

The term 'alcohol outlet density' is used to describe the number of alcohol outlets within a defined region and is standardised using residential population or a measure of land area or roadway miles (Chikritzhs et al., 2007). Alcohol outlet density is a measure of the physical availability of alcohol to consumers in a given area.

Previous research has examined the effects of alcohol outlet density on various alcohol-related harms including road crashes (Gruenewald and Ponicki, 1995, LaScala et al., 2001, Gruenewald, 2010, Cameron et al., 2012). Results have been mixed, with associations with crashes differing between on-premise outlets and bottleshops (e.g., Cameron et al., 2012, McCarthy, 2003). Furthermore, much earlier research has examined a mixture of outcomes [for example, drink driving and cirrhosis mortality (Watts and Rabow, 1983)], rather than focusing specifically on road crashes.

In early research, Colón and Cutter demonstrated that higher on-premise outlet density was associated with reduced crash fatalities [used as a surrogate measure of alcohol-related crashes (1983)]. The authors hypothesised that, in areas with higher alcohol outlet density, the distance to alcohol outlets would be less, so drinkers would drive shorter distances to obtain alcohol. This would decrease their exposure to the road resulting in a decrease in the risk of road crashes.

A later study used an alternative measure of physical availability, i.e., the distance travelled to access legal alcohol, from each 'dry' county (where the sale of alcohol is illegal) to the border of a 'wet' county [where alcohol sales are permitted (Giacopassi and Winn, 1995)]. The study found that, in contrast with Colón and Cutter's earlier study (Colón and Cutter, 1983), shorter distances (i.e., being closer to legal alcohol) was associated with increased rates of alcohol-related crashes.

Scribner and colleagues explored the association between the density of four types of alcohol outlets and road traffic crashes at city-level (Scribner et al., 1994), showing that mini-market and restaurant densities were positively associated with rates of crashes resulting in injuries, and restaurant and bar density were positively associated with crashes entailing property damage. Gruenewald and colleagues (Gruenewald et al., 1996) demonstrated that restaurant density, both locally and in the adjacent geographical areas, was significantly associated with single vehicle night-time crashes. This study, and a subsequent study by the same authors, failed to show an association between driving after drinking and alcohol outlet density (Gruenewald et al., 1996, Gruenewald et al., 2002).

Jewell and Brown analysed the association between alcohol outlet density (per miles of roadway) and alcohol-related road crashes (1995). The authors used miles of roadway as the denominator of alcohol outlet density to provide a measure of the distance 'cost' of travelling to access alcohol. The authors were able to quantify how an additional alcohol outlet would add to the number of alcohol-related fatal and non-fatal collisions.

A case-control study in the US (Stevenson et al., 1998) showed no association between distance from crash site to the nearest on-premise outlet and alcohol-related crashes, nor evidence of clustering of alcohol-related crashes around alcohol outlets. In a later study, Meliker and colleagues (Meliker et al., 2004) again found no significant associations between alcohol-related crashes and distance to alcohol outlets, or differences in the distance from alcohol-related and non-alcohol-related crashes to alcohol outlets. However, both studies used a BAC of 0.10% or more to define a driver as alcohol-impaired and therefore designate a crash as 'alcohol-related'. Since impairment in driving begins to occur at any BAC above zero (Borkenstein et al., 1974), and most jurisdictions now use a BAC of either 0.05% or 0.08% as the legal limit for driving, this case definition may have masked associations between alcohol-involvement in a crash and distance to alcohol outlets.

Baughman and colleagues (Baughman et al., 2001) explored road crashes in 'wet' and 'dry' counties in Texas in the US, showing that local access to alcohol (through living in a 'wet' county) was associated with fewer than expected crashes, although local access to spirits was associated with higher risk of crash than access to beer and wine only. Similar results were demonstrated by Tang (2013). This suggests that reduced risk of crash may relate to travelling shorter distances to purchase alcohol, resulting in less 'exposure' to the road – demonstrating the 'distance effect' (Tang, 2013).

In contrast, a longitudinal study using six years of data showed that higher local off-premise outlet and bar densities were associated with more alcohol-related crashes, with larger effect sizes for off-premise density (Treno et al., 2007). A New Zealand study by Cameron and colleagues (Cameron et al., 2012) confirmed the former association, with an additional off-premise outlet being associated with 10 further road crashes, but found no association between on-premise density and crashes. These results demonstrate the 'availability effect' [as compared to the distance effect described above by Tang (2013)]. Availability theory posits that greater population-level availability of alcohol leads to increase in consumption through changes to cost (both real price and convenience cost) and alcohol-related harm among at-risk sub-groups of the population (Stockwell and Gruenewald, 2003).

Han and colleagues (Han et al., 2014) explored the results of a policy change leading to a large increase in off-premise outlet density using time-series analysis. There were small effects on total crashes, and not significant effects on SVN crashes. They suggest that the greater availability resulting from increased off-premise outlet density is balanced by decreased travel immediately after drinking, resulting in the null findings.

Recent research in Victoria, Australia demonstrated an association between bar density and alcohol-related crashes, but a negative association between off-premise outlet density and crashes (Morrison et al., 2016).

One of the reasons for the widely varying results is the different geographic units used across the studies. Using administrative boundaries may cause misleading results due to the arbitrary placement of administrative boundaries - the so-called Modifiable Areal Unit Problem – MAUP (Donnelly et al., 2006), which the use of buffer zones (see below) can at least partly mitigate. Another potential issue is the cross-sectional nature of many of the studies – the use of longitudinal data produces more robust and reproducible results. A further issue might be the level of alcohol outlet density – it may be that beyond a certain threshold, a higher alcohol outlet

density has no effect on the levels of alcohol-related harms including road crashes (De Boni et al., 2013, Livingston, 2008).

3.3.1 The use of buffer zones and proximity in alcohol outlet density literature

As discussed above, alcohol outlet density can be misleading when certain geographic units have very large or small populations relative to their sizes (Truong and Sturm, 2007). Geographic units are frequently artificial administrative units (e.g., postcodes or census units), which do not necessarily reflect geographical features of the area, such as rivers or bridges, or account for how people interact with their environment through transport routes and community facilities.

Using buffer zones to analyse the associations between alcohol outlets and alcohol-related harms can overcome some of these issues. Murray and Roncek describe buffer zones as: *"...the creation of a type of frame around a particular object on a map. This frame, or buffer, can be easily and accurately created through software designed to frame objects in any shape or size"* (p. 201 Murray and Roncek, 2008). Instead of administrative units, buffer zones can act as the geographic units of analysis (Burgess and Moffat, 2011).

Alcohol outlet density research tends to use buffer zones at specific distances from a central point (such as a place of residence, an alcohol outlet or road crashes) (Pollack et al., 2005, Truong and Sturm, 2007). The appropriate size of a buffer zone is related to the nature of the central point and the type of outcome to be counted. For example, if counting the number of assaults that occur around a nightclub, the size of the buffers would be relatively small, as assaults tend to occur close to the place of drinking (Murray and Roncek, 2008, Burgess and Moffat, 2011). Conversely, alcohol-related road crashes may occur at greater distances from alcohol outlets and so larger buffer zones would be more appropriate. The current studies uses a range of buffer zones (up to 20km from alcohol outlets to crashes) to allow for this.

Two methods can be used to calculate distance: straight-line distance ('as the crow flies'), and the road network distance (Groff, 2011). The straight-line distance method is limited as it ignores barriers to travel (such as a river) and the road network (Groff, 2011). The road network distance could be an appropriate method of measuring distance if: i) there is an accurately geocoded place of origin (e.g., a road crash or place of residence); ii) major topographical features such as bodies of water may affect access to alcohol outlets, making straight line distances misleading; and iii) the assumption is made that people travel purely by road to access alcohol. For research involving road crashes, road network distance is a logical choice.

Analyses of a range of distances around each central point can be used to track how associations increase or decrease over distance, depending on the alcohol-related harm or alcohol outlet type. For example, risk of alcohol-related crash may be highest closest to an alcohol outlet, if the alcohol outlet is located in a built-up area, with complex road structure, shorter link distances and higher volumes of traffic. Risk may reduce as traffic situations reduce in complexity, but increase again further from the alcohol outlet as the final drink consumed by the driver is absorbed and the BAC rises.

Alternate methods of measuring proximity of alcohol outlets to places of residence or alcohol-related harm which have been used in the literature include: mean (Scribner et al., 2000) or median (Day et al., 2012) distance to the nearest alcohol outlet, distance to the nearest alcohol outlet (Hay et al., 2009, Wilkinson and Livingston, 2011, Young et al., 2013) and mean distance to closest five alcohol outlets (Donnelly et al., 2006). Thus far, studies using these measures of alcohol availability have primarily explored outcomes such as drinking behavior and harms such as assault, rather than road crashes. Road network distance from each road crash to the closest on-premise outlet and bottleshop has been used by Hay and colleagues (Hay et al., 2009) to examine if proximity to alcohol (i.e. road network distance to the closest alcohol outlet) varied by area-level socioeconomic deprivation. They used a measure of the centre of a neighbourhood (the census meshblock), rather than the location of place of residence or alcohol-related harm. Ellaway and colleagues (Ellaway et al., 2010), and Young and colleagues (Young et al., 2013) also used a measure of the closest alcohol outlet, again from a centroid (of a data zone) rather than from an alcohol-related harm, while Schonlau and colleagues (Schonlau, 2008) used this measure from place of residence to alcohol outlet. Stevenson and colleagues (Stevenson et al., 1998) calculated the distance from each alcohol-related crash to the closest on-premise outlet (but not bottleshop), finding no association between the two. Donnelly and colleagues (Donnelly et al., 2006) measured the mean distance from the centroid of a Collector District to the five closest alcohol outlets (and closest five alcohol outlets of each licence type).

The current study includes a similar measure of proximity to Donnelly and colleagues' study (2006), the median road network distance from each road crash to the closest five on-premise outlets and closest five bottleshops, as well the distance to the closest alcohol outlet (as used by Hay et al., 2009, Wilkinson and Livingston, 2011, Young et al., 2013).

3.4   Conclusion:

Road crashes differ from other alcohol-related harms as they are potentially associated with both alcohol availability (through easier access to closer alcohol outlets) and greater exposure to driving (through driving longer distances from alcohol outlets). By using distance to alcohol outlets, and different sized buffer zones, this longitudinal study will explore the relative effects of availability and distance on risk of crash, in metropolitan Perth, Western Australia.

4   RESULTS

The results are presented in section 5. In section 5.1, the descriptive statistics of alcohol-related and non-alcohol-related crashes are reported. In section 5.2, incidence rates of confirmed alcohol-related crashes (crashes with drivers with a BAC $\geq$ 0.05%); the surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes); the surrogate measure of non-alcohol-related crashes (single vehicle day-time crashes); and all day-time crashes are described. Descriptive statistics for alcohol outlets are reported in section 5.3. Maps of number of crashes and heat maps are described in section 5.4. Section 5.5 reports the median distances from each crash type to the closest alcohol outlets. Finally, the results of the statistical models are described in section 5.6.

4.1   Alcohol and non-alcohol-related crash descriptive statistics

A total of 341,467 crashes were assessed for inclusion in the study (Table 1).

Table 1: Descriptive statistics of crashes involving drivers with a confirmed BAC $\geq$ 0.05%, and surrogate measures of alcohol- and non-alcohol-related crashes, from 2005 to 2015

Outcome measures	n	%
Confirmed alcohol-related crashes (crashes with drivers with BAC $\geq$ 0.05%)	7,564	2.22
Surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes)	11,591	3.39
Surrogate measure of non-alcohol-related crashes (single vehicle day-time crashes)	16,698	4.89
All day-time crashes	252,923	74.07
Total	**341,467**	**100**

Day-time crashes: 07h00 to 17h59 Night-time crashes: 18h00 to 04h59
Weekend: Friday night to Monday morning

4.2   Incidence rates of crashes

Incidence rates (number of crashes per 10,000 population) are presented for the following crashes: i) confirmed alcohol-related crashes (crashes with drivers with a BAC $\geq$ 0.05%); ii) the surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes); iii) the surrogate measure of non-alcohol-related crashes (single vehicle day-time crashes); and iv) all day-time crashes. Only incidence rates from 2005 to 2013 are reported here due to the problems with the data in 2014 and 2015.

Incidence rates of confirmed alcohol-related crashes, the surrogate measure of alcohol-related crash (weekend SVN crashes), the surrogate measure of non-alcohol-related crashes (single vehicle day-time crashes) and all day-time crashes varied across the years studied, with the highest crash rates occurring in 2007, gradually decreasing over time (Table 2). This decrease

was particularly noticeable among crashes involving drivers with a confirmed BAC ≥ 0.05%. Incidence rates decreased from 7.5 crashes per 10,000 population in both 2007 and 2008, to 3.8 crashes per 10,000 in 2013. Similar decreases in incidence rates were observed in weekend SVN crashes: 11.5 crashes per 10,000 population in 2007 to 6.0 crashes per 10,000 in 2013. In contrast, incidence rates of day-time crashes dropped from a high of 211 crashes per 10,000 population in 2005 to 148.6 per 10,000 in 2013.

Table 2: Incidence rates per 10,000 population by crash type in Perth metropolitan area by year from 2005 to 2013

Outcome measures	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Confirmed alcohol-related crashes (crashes with drivers with BAC ≥ 0.05%)	6.08	6.89	7.48	7.48	6.90	5.28	4.90	4.59	3.75	5.86
Surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes)	9.83	10.86	11.48	10.43	10.14	8.44	7.86	6.95	6.03	9.00
Surrogate measure of non-alcohol-related crashes (single vehicle day-time crashes)	14.14	14.05	14.34	14.18	12.01	11.98	11.74	11.43	10.02	12.56
All day-time crashes	211.25	208.61	210.69	192.35	175.73	185.84	168.34	159.90	147.64	182.98

Day-time crashes: 07h00 to 17h59 Night-time crashes: 18h00 to 04h59 Weekend: Friday night to Monday morning

The incidence rates confirmed alcohol-related crashes, the surrogate measure of alcohol-related crash, the surrogate measure of non-alcohol-related crashes and all day-time crashes varied depending on the zone from the CBD as illustrated in Table 3. Overall, incidence rates were highest in the CBD, and lowest in the middle postcodes (7km to 15km from the CBD). However, this varied considerably according to crash type. Day-time crashes were highest in the CBD (1,054 crashes per 10,000 population), dropping to 253 per 10,000 in the inner postcodes, 185 per 10,000 in the middle postcodes and 113 per 10,000 in the outer postcodes. However, weekend SVN crashes, the surrogate measure of alcohol-related crashes, showed highest incidence rates in the CBD, followed by the outer postcodes, with lowest incidence rates in the inner and middle postcodes: the incidence rate of weekend SVN crashes was 25 crashes per 10,000 population in the CBD, 7.4 per 10,000 in the inner postcodes, 8.2 per 10,000 in the middle postcodes and 11 crashes per 10,000 population in the outer postcodes. The highest incidence of BAC $\geq 0.05\%$ crashes was in the CBD (17 crashes per 10,000 population) with incidence rates of approximately 6 per 10,000 in the other postcode zones.

Table 3: Incidence rates per 10,000 population by crash type by zone from the Perth CBD from 2005 to 2013

Surrogate measures	CBD	Up to 7km from CBD	7km to 15km from CBD	Beyond 15km from CBD	Total
Confirmed alcohol-related crashes (crashes with drivers with BAC $\geq$ 0.05%)	17.47	5.98	5.37	6.15	5.86
Surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes)	24.57	7.42	8.20	10.89	9.00
Surrogate measure of non-alcohol-related crashes (single vehicle day-time crashes)	66.31	11.34	11.36	13.98	12.56
All day-time crashes	1,053.56	252.90	185.22	112.51	182.98

Day-time crashes: 07h00 to 17h59 Night-time crashes: 18h00 to 04h59 Weekend: Friday night to Monday morning

4.3 Alcohol outlets

The total number of licensed alcohol outlets in Perth has grown from 1,925 in 2005 to 2,467 in 2015 (Table 4), an increase of 28%. Throughout this time period, bottleshops (off-premise outlets) made up approximately 15% of all licensed premises. The number of bottleshops has increased from 290 in 2005 to 383 in 2015, an increase of 32%. Among the categories of on-premise outlets, the largest increases were hotels/taverns from 294 in 2005 to 451 in 2015 (53%), and restaurants from 523 in 2005 to 763 in 2015 (46%). The number of nightclub premises serving alcohol decreased by 16% (from 38 in 2005 to 32 in 2015).

Table 4: Alcohol outlets by type in Perth from 2005 to 2015

Alcohol Outlet type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Club	495	494	498	508	516	521	530	531	538	537	535
Hotel/Tavern	294	296	304	329	349	363	388	408	424	433	451
Nightclub	38	38	37	37	35	34	34	34	33	32	32
Other on-premise outlets	285	289	294	298	301	302	297	296	297	293	303
Restaurant	523	549	561	566	581	597	618	650	689	724	763
Total on-premise outlets	*1,635*	*1,666*	*1,694*	*1,738*	*1,782*	*1,817*	*1,867*	*1,919*	*1,981*	*2,019*	*2,084*
Bottleshops	*290*	*290*	*300*	*312*	*330*	*342*	*347*	*357*	*366*	*369*	*383*
Total	**1,925**	**1,956**	**1,994**	**2,050**	**2,112**	**2,159**	**2,214**	**2,276**	**2,347**	**2,388**	**2,467**

A total of 205 (8.3%) licensed alcohol outlets operated in the CBD, 909 (37%) in the inner zone, 759 (31%) in the middle zone and 594 (24%) in the outer zone of Perth in 2015 (Table 5). Very few clubs (9, 1.7%) and bottleshops (5, 1.3%) were located in the CBD. Most nightclubs (17, 53%) and restaurants (368, 48%) were located in the inner zone of Perth. Hotels/taverns were spread across the inner, middle and outer zones, although the highest proportion (152, 34%) were located in the inner zone. Bottleshops (off-premise outlets) were spread evenly across the inner, middle and outer zones.

The postcodes with the highest number of alcohol outlets were located around the CBD and Subiaco (and to the north and west towards the coast), as well in the Fremantle, Midland, Guildford/Caversham and Joondalup areas. Other areas with high numbers of alcohol outlets were Rockingham, Hamilton Hill/Bibra Lake, Mandurah and Wanneroo. These patterns were consistent from 2005 to 2015.

Table 5: Alcohol outlets by type and zone from the CBD in Perth in 2015

Alcohol Outlet type	CBD	Inner zone	Middle zone	Outer zone	Total
Club	9	179	200	147	535
Hotel/Tavern	85	152	111	103	451
Nightclub	6	17	3	6	32
Other on-premise outlets	48	88	110	57	303
Restaurant	52	368	191	152	763
Total on-premise outlets	*200*	*804*	*615*	*465*	*2,084*
Bottleshops	*5*	*105*	*144*	*129*	*383*
Total	**205**	**909**	**759**	**594**	**2,467**

4.4 Maps of road crashes

For confirmed alcohol-related crashes (BAC ≥ 0.05%), two sets of three maps are displayed demonstrating crash data for three years: 2005 (left-hand map), 2010 (middle) and 2015 (right-hand map). The first set of maps (Map 1) shows the absolute number of crashes per postcode. The number of crashes are indicated in deciles[8] on each of the maps, with the highest decile indicated in red, the middle in yellow and the lowest in blue. The second set of maps (Map 2) are heat maps − created using kernel density estimation in ArcGIS − and indicate areas of high density of crashes or alcohol outlets (red), medium density (yellow) and low density (blue).

Two further sets of maps (number of crashes − Map 3 − and heat maps − Map 4) compare confirmed alcohol-related crashes (BAC ≥ 0.05%), the surrogate measure of alcohol-involvement (weekend single vehicle night-time crashes) and all day-time crashes in 2015.

4.4.1 Road crashes

Confirmed alcohol-related crashes (drivers with a BAC ≥ 0.05%)

There were consistently high numbers of crashes involving a driver with a confirmed BAC ≥ 0.05% in Rockingham, Mandurah, Hamilton Hill/Bibra Lake, Jandakot/Success, Kelmscott and Armadale in 2005, 2010 and 2015 (Map 1). Postcodes stretching from Fremantle on the coast to Kelmscott further west also had a higher numbers of confirmed alcohol-related crashes. Relatively more crashes occurred in the southern suburbs of Jandakot/Success, Kelmscott and Armadale in 2015 than in earlier years.

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[8] Deciles: ten groups of equal size, obtained by ranking each postcode by the number of crashes or alcohol outlets which occurred in each postcode, and creating ten groups. The highest decile consists of the group of postcodes with the highest number of crashes or alcohol outlets. The lowest decile consists of the group of postcodes with the lowest number of crashes or alcohol outlets.

Map 1: Number of crashes involving drivers with a BAC ≥ 0.05% and higher in the Perth metropolitan area, by postcode, in 2005, 2010 and 2015
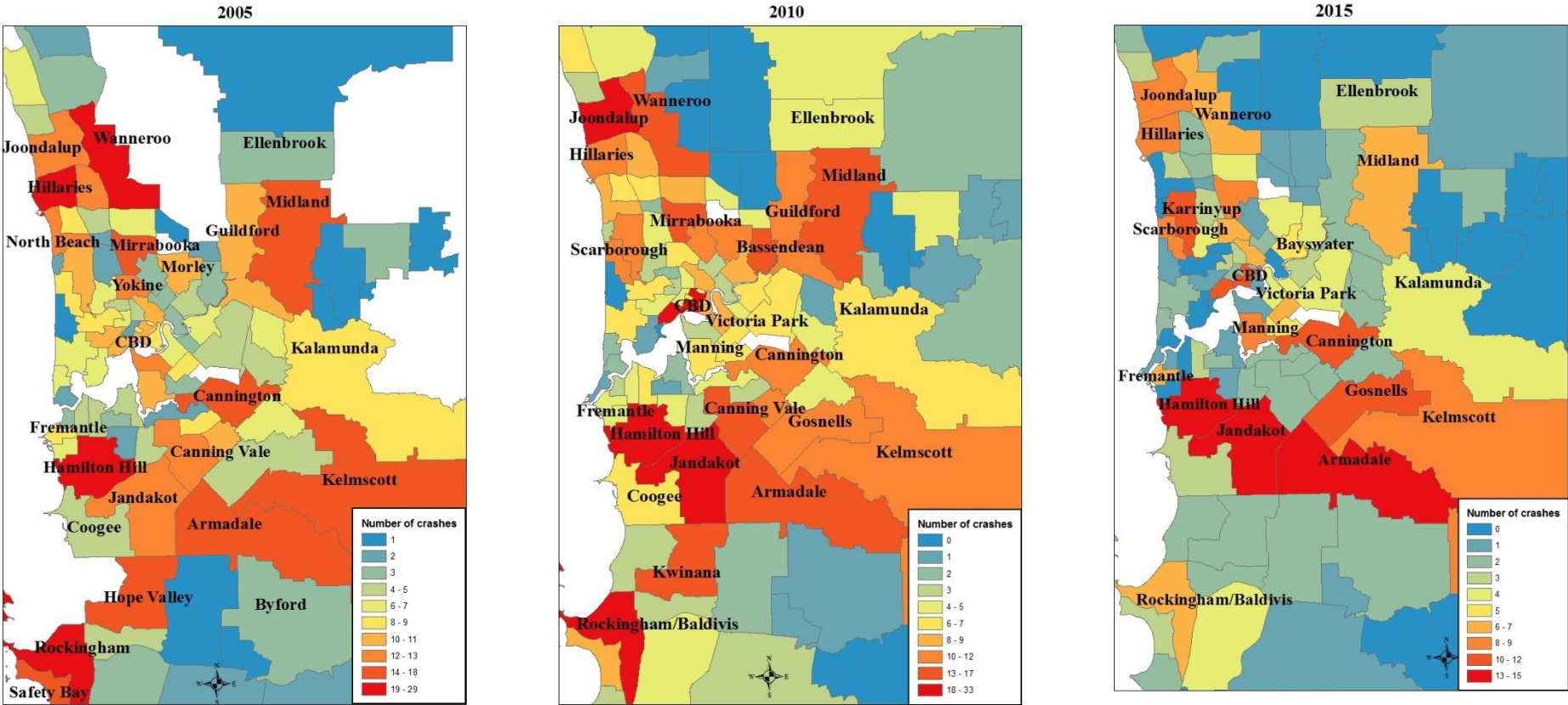
The below heat maps (Map 2) show the dropping density of reported crashes with a driver with a BAC above the legal limit ($\geq 0.05\%$) over time, with reported BAC $\geq 0.05\%$ crashes dropping from 697 and 698 in 2005 and 2010, to 356 in 2015. However, all maps show similar areas with high densities of crashes: over the entertainment district near the Perth CBD, in Fremantle, Rockingham, Mandurah, Victoria Park and also in parts of the coast north of the river and in Canning Vale. A larger number of areas of higher crash density occurred in the postcodes further from the CBD in the latter two years, possibly due to increasing residential development and movement of the population to these areas, as well with issues with crash data in the latter years.

Map 2: Heat maps of crashes involving drivers with a BAC ≥ 0.05% and higher in Perth metropolitan area, in 2005, 2010 and 2015
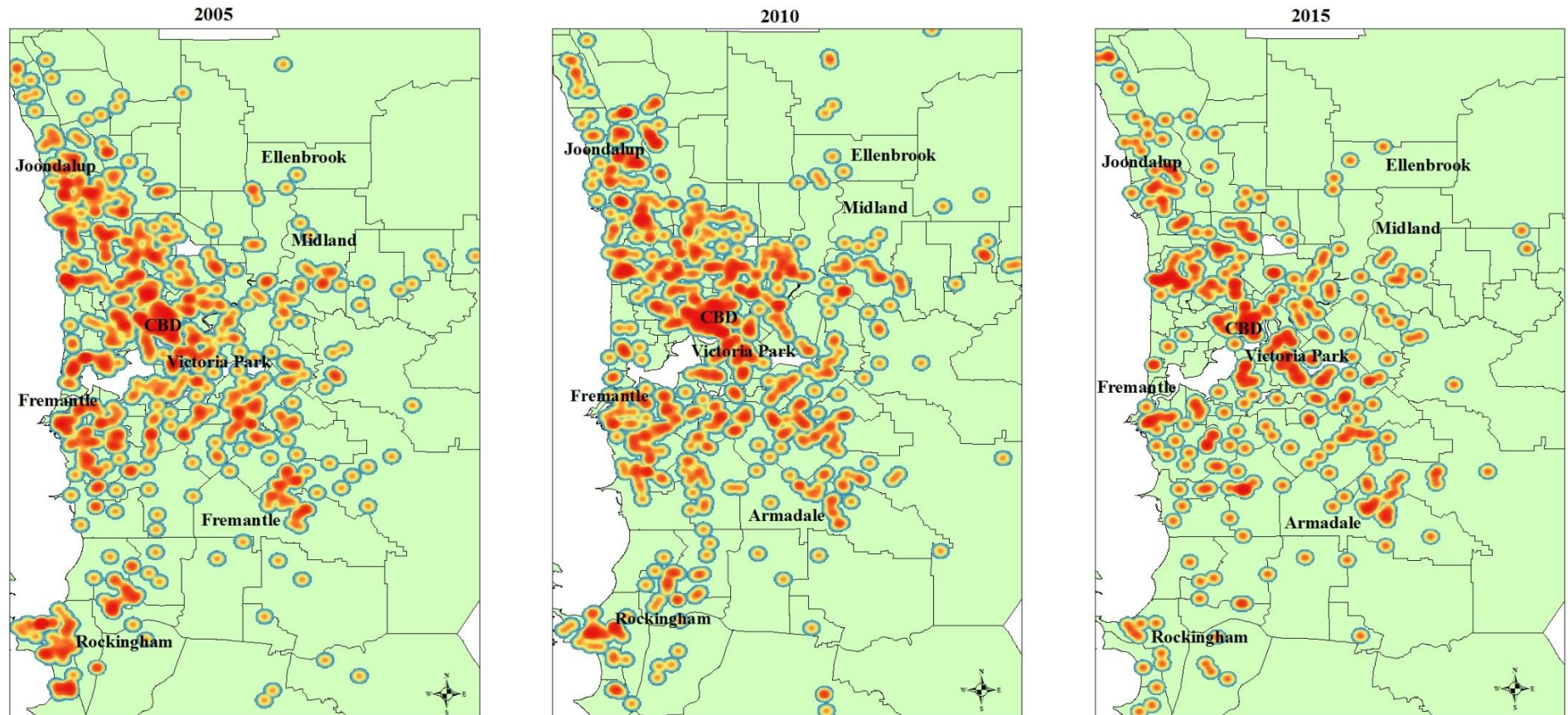
Map 3 compared numbers of confirmed alcohol-related crashes (BAC $\geq$ 0.05%), surrogate measures of alcohol-related crashes (weekend single vehicle night-time crashes) and all day-time crashes in 2015. There were high numbers of all three crashes in the southern suburbs of Hamilton Hill/Bibra Lake, Jandakot/Success, Armadale and Kelmscott, as well as in the CBD, Cannington and Joondalup. There were larger numbers of all day-time crashes in Midland, but not large numbers of BAC $\geq$ 0.05% and weekend SVN crashes in this area.

Map 3: Number of confirmed alcohol-related crashes, the surrogate measure of alcohol-related crashes (weekend single vehicle night-time) and all day-time crashes in the Perth metropolitan area, by postcode, in 2015
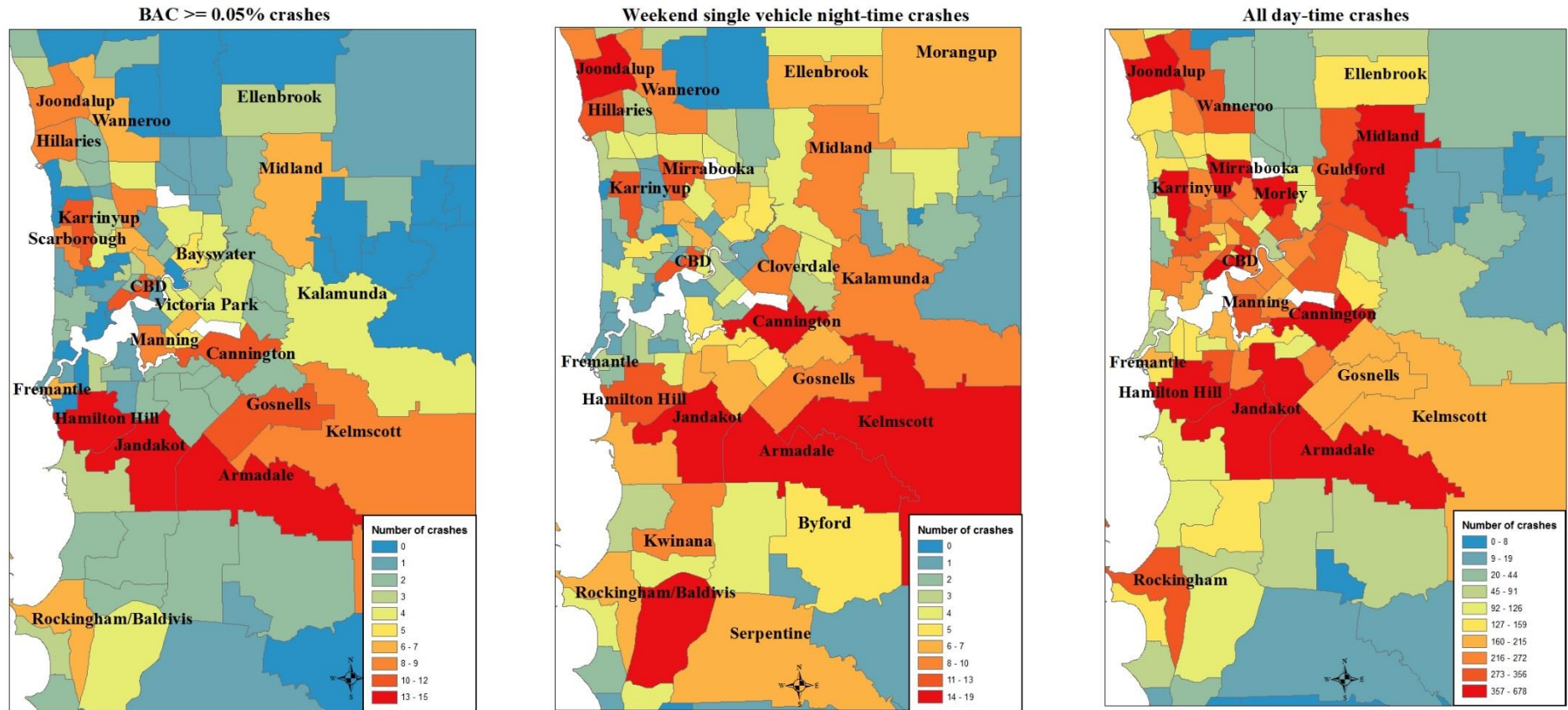
Map 4 displays three heat maps comparing BAC ≥ 0.05% crashes, weekend SVN crashes and all day-time crashes for 2015. The much larger number of day-time crashes is clearly visible in the right-hand map. More focused areas of high density are visible in the BAC ≥ 0.05% crashes, and weekend SVN crashes (the surrogate measure of alcohol-related crashes) than for the all day-time crashes map. Weekend SVN crashes are spread further from the centre of the city than BAC ≥ 0.05% crashes.

Map 4: Heat maps of confirmed alcohol-related crashes, the surrogate measure of alcohol-related crashes (weekend single vehicle night-time) and all day-time crashes in Perth metropolitan area, 2015
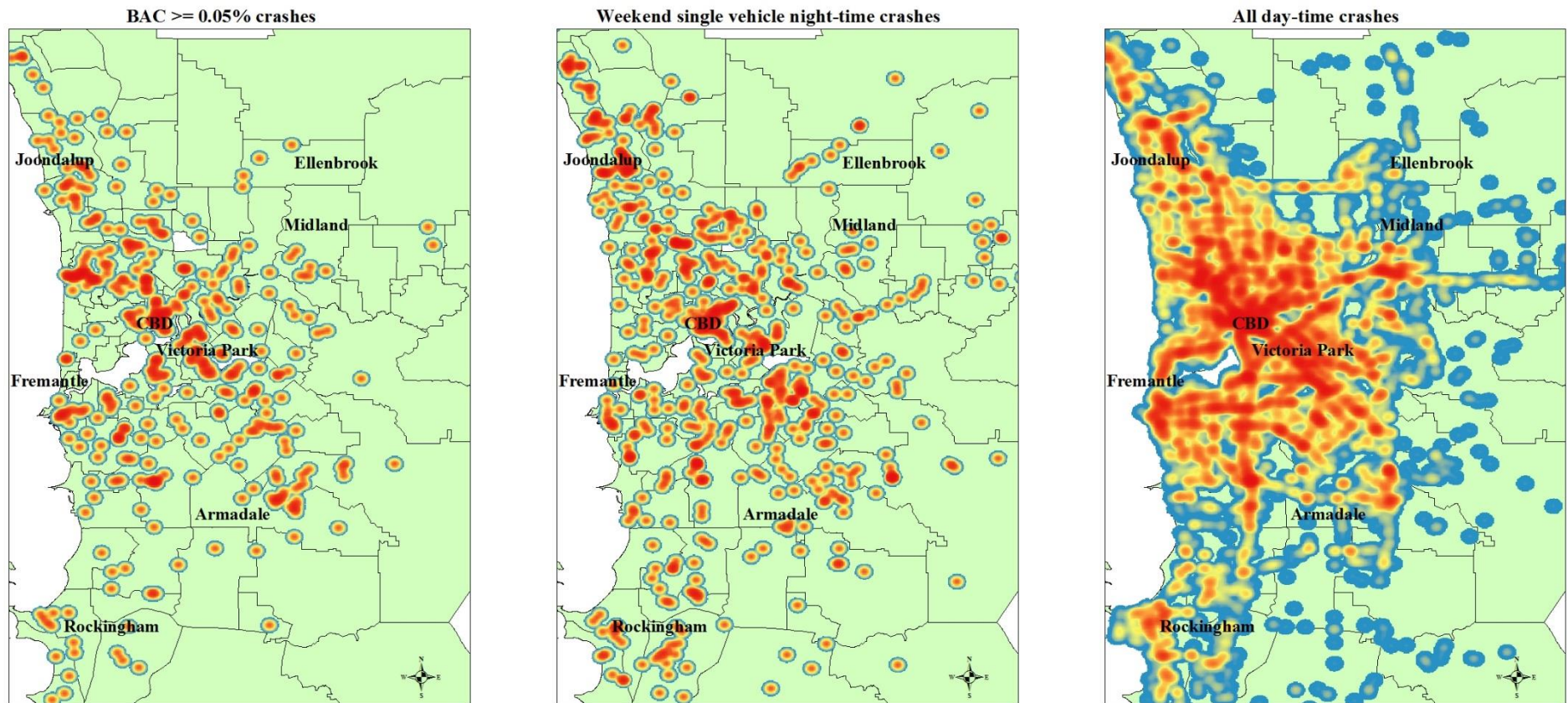
4.5 Distances between a crash and the closest licensed alcohol outlets

The median distance between a road crash and the closest alcohol outlet for alcohol-related and non-alcohol related crashes are shown in Tables 6 to 9. In the outer zone of Perth (postcodes beyond 15km from the CBD), the median distance between a road crash for a driver with a BAC ≥ 0.05% and the two alcohol outlet types were similar, with crashes occurring closer to non-premise outlets (1,381m) than bottleshops (1,894m – Table 6). In the CBD and postcodes up to 7km from the CBD (the inner zone), crashes with a BAC ≥ 0.05% were closer to on-premise outlets (182m and 503m respectively) than bottleshops (619m and 826m respectively).

Table 6: Median distance (in metres) from a BAC ≥ 0.05% crash to the closest licensed alcohol outlets by postcode

Median distance (IQR[1]) to outlet in metres	BAC ≥ 0.05% Crashes	
	Bottleshop	On-premise outlet
Total	1,327 (688-2,421)	920 (398-1,771)
CBD	619 (267-1,067)	182 (65-624)
Up to 7km from CBD	826 (437-1,362)	503 (213-956)
7km to 15km from CBD	1,399 (794-2,466)	1,014 (513-1,771)
15km+ from CBD	1,894 (1,053-3,362)	1,381 (712-2,562)

[1]IQR: Interquartile range [2]BAC ≥ 0.05%: crash has at least one driver with a BAC ≥ 0.05% or more

Similar, findings were found for weekend single vehicle night-time crashes, with differences in median distance to bottleshops and on-premises outlets being larger (Table 7). Overall, the distances from weekend SVN crashes to alcohol outlets were larger than from BAC ≥ 0.05% crashes to alcohol outlets.

Table 7: Median distance (in metres) from a weekend single vehicle crash to the closest licensed alcohol outlets by postcode

Median distance (IQR[1]) to outlet in metres	Weekend Single Vehicle Night-time Crashes	
	Bottleshop	On-premise outlet
Total	1,569 (861-2,924)	1,000 (474-1,981)
CBD	626 (368-1,072)	125 (46-370)
Up to 7km from CBD	974 (567-1,588)	511 (220-929)
7km to 15km from CBD	1,518 (878-2,775)	1,021 (542-1,825)
15km+ from CBD	2,226(1,302-4,329)	1,504 (739-2,866)

[1]IQR: Interquartile range

Distances from single vehicle day-time crashes to outlets were smaller in the CBD compared to BAC ≥ 0.05% and weekend single vehicle night-time crashes (Table 8). They were similar, but slightly larger than weekend SVN crashes in postcodes outside the CBD.

Table 8: Median distance (in metres) from a single vehicle day-time crash to the closest licensed alcohol outlets by postcode

Median distance (IQR[1]) to outlet in metres	Single Vehicle Day-time Crashes	
	Bottleshop	On-premise outlet
Total	1,504 (779-2,927)	944 (396-2,001)
CBD	495 (288-779)	92 (37-216)
Up to 7km from CBD	933 (505-1,525)	476 (194-890)
7km to 15km from CBD	1,516 (840-2730)	989 (472-1,841)
15km+ from CBD	2,432 (1,308-5060)	1,638 (785-3,451)

[1]IQR: Interquartile range

Overall, median distances from day-time crashes to both outlet types beyond 15km from the CBD were lower than other crash types (bottleshops: 1,703m, on-premise outlets: 1,157m – Table 9). Distances to outlets in the middle postcodes were similar to BAC ≥ 0.05% crashes.

Table 9: Median distance (in metres) from a day-time crash to the closest licensed alcohol outlets by postcode

Median distance (IQR[1]) to outlet in metres	All Day-time Crashes	
	Bottleshop	On-premise outlet
Total	1,177 (597-2,134)	707 (280-1,429)
CBD	548 (309-847)	113 (54-259)
Up to 7km from CBD	896 (468-1,504)	453 (186-890)
7km to 15km from CBD	1,384 (754-2,436)	883 (412-1,699)
15km+ from CBD	1,703 (879-3,135)	1,157 (518-2,224)

[1]IQR: Interquartile range

4.6 Association between number of outlets and crashes

A total of two logistic models were undertaken. Both models included the number of on-premise outlets and number of bottleshops within buffer zones (or distance bands) from each crash as predictors of alcohol-involvement in a crash. The buffer zones were: less than 2km from the crash, 2km to up to 5km from the crash, 5km to up to 10km from the crash, and 10km to 20km from the crash.

4.6.1 Logistic regression model using confirmed alcohol-related crashes (BAC ≥0.05% crashes)

The results which examined alcohol-related crashes (where the driver had a BAC of $\geq 0.05\%$) compared to non-alcohol-related crashes (all day-time crashes) found that higher numbers of on-premise outlets less than 2km, and 10km to 20km from road crashes (Table 10 - OR=1.002; 95% CI: 1.000-1.003, and OR=1.001; 95% CI: 1.00-1.001 respectively) were significantly more likely to be associated with confirmed alcohol-related crashes (a driver with a BAC $\geq 0.05\%$ and above) than day-time crashes. Higher numbers of bottleshops 2km to 5km from crashes were significantly more likely to be associated with BAC $\geq 0.05\%$ crashes than day-time crashes (OR=1.011; 95% CI: 1.001-1.022). Higher numbers of bottleshops 5km to 10km, and 10km to 20km from crashes were significantly less likely to be associated with BAC $\geq 0.05\%$ crashes than day-time crashes (OR=0.990, 95% CI: 0.984-0.996 and OR=0.993; 95% CI: 0.990-0.996 respectively).

BAC $\geq 0.05\%$ crashes were more likely to occur in postcodes in all zones beyond the CBD (inner: OR=1.584; 95% CI: 1.246-2.015, middle: OR=1.678; 95% CI: 1.303-2.162 and outer: OR=2.899; 95% CI: 2.235-3.760 respectively) than in the CBD. BAC $\geq 0.05\%$ crashes were less likely to occur in postcodes in SEIFA quartiles 3 and 4, the postcodes in the top 50% of the socioeconomic index (OR=0.852; 95% CI: 0.753-0.964, and OR=0.846; 95% CI: 0.737-0.970 respectively) than postcodes in SEIFA quartile 1 (lowest socioeconomic index group). Crashes occurring in postcodes with higher percentages of unemployed residents and an older mean age were less likely to be BAC $\geq 0.05\%$ crashes than day-time crashes (OR=0.960; 95% CI: 0.926-0.996, and OR=0.967; 95% CI: 0.956-0.978 respectively).

Table 10: Logistic regression model using the number of alcohol outlets within specified buffer zones of crashes with a driver with a BAC ≥ 0.05%, in Perth metropolitan area, from 2005 to 2015

Crash involving driver with BAC ≥ 0.05%	OR[1]	95% CI[2]		p-value
Number of on-premise outlets less than 2km from crash	1.002	1.000	1.003	0.020
Number of on-premise outlets 2km up to 5km from crash	1.000	0.999	1.000	0.470
Number of on-premise outlets 5km up to 10km from crash	1.000	0.999	1.000	0.395
Number of on-premise outlets 10km up to 20km from crash	1.001	1.001	1.001	0.000
Number of bottleshops less than 2km from crash	0.988	0.967	1.010	0.294
Number of bottleshops 2km up to 5km from crash	1.011	1.001	1.022	0.036
Number of bottleshops 5km up to 10km from crash	0.990	0.984	0.996	0.001
Number of bottleshops 10km up to 20km from crash	0.993	0.990	0.996	0.000
Natural log of population density (km^2)	1.003	0.970	1.037	0.868
Year				
2005	1.000			
2006	1.108	0.994	1.234	0.064
2007	1.194	1.073	1.329	0.001
2008	1.367	1.227	1.523	0.000
2009	1.398	1.250	1.563	0.000
2010	1.022	0.905	1.154	0.726
2011	1.029	0.907	1.168	0.654
2012	1.063	0.933	1.212	0.359
2013	0.908	0.788	1.047	0.184
2014	0.746	0.640	0.870	0.000
2015	0.666	0.565	0.785	0.000
Zone from the CBD				
CBD	1.000			
Up to 7km from the CBD	1.584	1.246	2.015	0.000
7km to 15km from the CBD	1.678	1.303	2.162	0.000
More than 15km from the CBD	2.899	2.235	3.760	0.000
SEIFA[3] quartiles				
Quartile 1	1.000			
Quartile 2	0.998	0.911	1.092	0.957
Quartile 3	0.852	0.753	0.964	0.011
Quartile 4	0.846	0.737	0.970	0.017
Proportion of unemployed people	0.960	0.926	0.996	0.028
Proportion of people of Indigenous origin	1.029	0.991	1.069	0.136
Mean age	0.967	0.956	0.978	0.000
Proportion of males between 17 to 24 to all 17 years and older	0.991	0.969	1.013	0.399

[1]OR: Odds Ratio [2]95% CI: 95% Confidence Interval [3]SEIFA: Socio-economic Indexes for Areas

4.6.2 Logistic regression model using the surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes)

The second model used a surrogate measure of alcohol-related crashes (weekend single vehicle night-time crashes) and compared it to non-alcohol-related crashes (single vehicle day-time crashes). This was done to substantiate the results.

When examining the association between a licensed on-premise alcohol outlet and weekend SVN night time road crashes (Table 11), higher numbers of on-premise outlets less than 2km, 2km to 5km, and 10km to 20km from crashes were significantly more likely to be associated with weekend single vehicle night-time crashes than single vehicle day-time crashes (OR=1.001; 95% CI: 1.000-1.003, OR=1.002; 95% CI: 1.001-1.003, OR=1.002; 95% CI: 1.001-1.002, and OR=1.002; 95% CI: 1.001-1.002 respectively). Higher numbers of bottleshops less than 2km, 2km to 5km, 5km to 10km, and 10km to 20km from crashes were significantly less likely to be associated with weekend single vehicle night-time crashes than single vehicle day-time crashes (OR=0.942, 95% CI: 0.920-0.965, OR=0.980, 95% CI: 0.969-0.991, OR=0.977, 95% CI: 0.971-0.983, and OR=0.988, 95% CI: 0.985-0.977 respectively).

Weekend single vehicle night-time crashes were more likely to occur in postcodes in all zones beyond the CBD (inner: OR=1.384; 95% CI: 1.082-1.769, middle: OR=1.726; 95% CI: 1.331-2.238 and outer: OR=2.152; 95% CI: 1.644-2.816 respectively) than in the CBD. Weekend SVN crashes were more likely to occur in postcodes in SEIFA quartiles 2, 3 and 4 (OR=1.204; 95% CI: 1.092-1.327, OR=1.212; 95% CI: 1.065-1.379, and OR=2.2.2; 95% CI: 1.037-1.392) than in postcodes in SEIFA quartile 1. Crashes in postcodes with a higher population density [(natural log) OR=1.136; 95% CI: 1.101-1.171], higher proportions of Indigenous residents (OR=1.047; 95% CI: 1.007-1.088) and with higher proportions of young males (OR=1.046; 95% CI: 1.024-1.069) were more likely to be weekend single vehicle night-time vehicle crashes than single vehicle day-time crashes.

Table 11: Logistic regression model using the number of alcohol outlets within specified buffer zones of weekend single vehicle night-time crashes, in Perth metropolitan area, from 2005 to 2015

Weekend single vehicle night-time crashes	OR[1]	95% CI[2]		p-value
Number of on-premise outlets less than 2km from crash	1.001	1.000	1.003	0.028
Number of on-premise outlets 2km up to 5km from crash	1.002	1.001	1.003	0.000
Number of on-premise outlets 5km up to 10km from crash	1.002	1.001	1.002	0.000
Number of on-premise outlets 10km up to 20km from crash	1.002	1.001	1.002	0.000
Number of bottleshops less than 2km from crash	0.942	0.920	0.965	0.000
Number of bottleshops 2km up to 5km from crash	0.980	0.969	0.991	0.000
Number of bottleshops 5km up to 10km from crash	0.977	0.971	0.983	0.000
Number of bottleshops 10km up to 20km from crash	0.988	0.985	0.991	0.000
Natural log of population density (km^2)	1.136	1.101	1.171	0.000
Year				
2005	1.000			
2006	1.096	0.978	1.228	0.115
2007	1.155	1.031	1.293	0.013
2008	1.067	0.951	1.198	0.269
2009	1.273	1.130	1.434	0.000
2010	1.075	0.949	1.217	0.257
2011	1.000	0.879	1.138	0.997
2012	0.928	0.810	1.063	0.282
2013	0.890	0.771	1.029	0.115
2014	0.629	0.534	0.740	0.000
2015	0.804	0.680	0.950	0.011
Zone from the CBD				
CBD	1.000			
Up to 7km from the CBD	1.384	1.082	1.769	0.010
7km to 15km from the CBD	1.726	1.331	2.238	0.000
More than 15km from the CBD	2.152	1.644	2.816	0.000
SEIFA[3] quartiles				
Quartile 1	1.000			
Quartile 2	1.204	1.092	1.327	0.000
Quartile 3	1.212	1.065	1.379	0.004
Quartile 4	1.202	1.037	1.392	0.014
Proportion of unemployed people	0.966	0.931	1.002	0.067
Proportion of people of Indigenous origin	1.047	1.007	1.088	0.021
Mean age	1.006	0.995	1.017	0.294
Proportion of males between 17 to 24 to all 17 years and older	1.046	1.024	1.069	0.000

[1]OR: Odds Ratio [2]95% CI: 95% Confidence Interval [3]SEIFA: Socio-economic Indexes for Areas

5   DISCUSSION

This study is one of the first to specifically examine the effects of licensed alcohol outlets on alcohol- and non-alcohol-related road crashes in the CBD, inner, middle and outer postcodes of the Perth metropolitan area and how these differed according to the distance between road crashes and licensed alcohol outlets.

Incidence rates for crashes involving drivers with confirmed BAC of $\geq 0.05\%$ were higher in the CBD area than other parts of Perth metropolitan area, weekend SVN crashes, and for day-time crashes. This overall higher incidence may be indicative of the road structure in the CBD area (shorter distances between traffic signals and higher intersection density) and large volumes of traffic often leading to congestion (during the day). The residential population of this area is small relative to the transient population, who travel into the area to work during the day, and to visit restaurants and nightclubs in the evening. This may artificially inflate the incidence rates in the CBD compared to postcodes located further from the CBD which have larger residential populations and smaller transient populations.

Incidence rates for BAC $\geq 0.05\%$ and weekend SVN crashes in the outer zone (beyond 15km from the CBD) were similar or higher than incidence rates in the inner zone (up to 7km from the CBD), which is consistent with previous research in Perth (Hobday et al., 2015). Distances travelled in the outer postcodes are larger, and retail outlets (including on-premise outlets and bottleshops) are probably located greater driving distances from places of residence. The combination of alcohol and the additional distances driven potentially contributed to a higher numbers of alcohol-related crashes.

The use of GIS maps in the study illustrated that the changes in crash locations across the years which largely mirrored the patterns of residential development of Perth, particularly in the outer suburban areas. The population of Perth has grown from 1,544,977 in 2005 to 2,039,193 in 2015 (ABS, 2016), leading to developing commercial and retail centres, and residential areas, further from the Perth CBD. Data from the ABS demonstrates that most growth has occurred in the outer suburbs including Baldivis/Rockingham, Harrisdale/Armadale and Ellenbrook, and further north and south (ABS, 2016) which is reflected in relatively higher numbers of weekend SVN crashes (the surrogate measure of alcohol-related crashes) in these areas in the later years of the study.

Overall the study results found that, as number of on-premise outlets increased in each buffer zone, and number of bottleshops decreased in each buffer zone, crashes were more likely to be alcohol-related than non-alcohol-related.

The strongest positive association between number of on-premise outlets and BAC $\geq$ 0.05% crashes was in the closest (0-2km) buffer zone. This association may be the result of interactions between drivers who have also been drinking at different alcohol outlets, or non-drinkers who reside nearby, rather than the result of the presence of a single nearby alcohol outlet affecting crash risk. The so-called amenity effect, discussed in the alcohol literature (Livingston et al., 2007), relates to how the presence of alcohol outlets affects the interaction and behaviour of people (many of whom have consumed alcohol, and may be drunk) in and around alcohol outlets. Clusters of on-premise outlets are more common in built-up areas, and may be associated with more complex traffic situations (because of road design and more drivers, who may have also been drinking, on the road). Built-up areas are harder to navigate because of the impaired attention, perception and judgement (Cherpitel, 1992) associated with alcohol consumption.

The association between number of alcohol outlets and weekend SVN crashes (the surrogate measure of alcohol-related crashes) was strongest in the outer buffer zones (further from crashes) than in the closest buffer zone. Drivers who have consumed a final drink just before leaving a venue may be subject to a rise in risk of crash after driving, as BAC takes approximately 30 to 60 minutes to peak, depending on the beverage type consumed (Mitchell et al., 2014). This may explain the higher risk among weekend night-time crashes, which occur a time in which drinking levels and BACs tend to be at their highest (Young et al., 2004b, Ireland and Thommeny, 1993).

The negative association between weekend single vehicle night-time crashes and number of bottleshops was strongest up to 2km from crashes: a higher number of bottleshops in this buffer zone being less likely to be associated with alcohol-related crashes. This was not a significant finding in the model using BAC $\geq$ 0.05% crashes. It has also been suggested that bottleshops do not have a 'distance effect' on the probability of crash (i.e., that the probably of crash is affected by the distance between alcohol outlet and home after drinking), but that this 'distance effect' is important for on-premise outlets and crashes (Tang, 2013). This may partly explain the inconsistent results across the difference measures of off-site alcohol availability used in this report.

People tend to buy larger volumes of alcohol at bottleshops because of the lower prices for bulk purchases, and the price differential between on-premise outlets and bottleshops. They will tend to consume this alcohol at locations some distance from bottleshops in Perth, for example in their own homes, at the homes of family or friends, or at restaurants that allow BYO (bring your own) alcohol. Consumers, particularly young people, may also engage in preloading (drinking before arriving at on-premise outlets) both to save money and for social reasons (Devilly et al., 2017). Driving (and crashing on the way) to on-premise outlets may be associated with alcohol purchased at bottleshops. Research in metropolitan Australia (including Perth) suggests that consumers prefer to purchase alcohol at bottleshops close to home: 86% of participants would usually travel less than 10km to purchase alcohol at a bottleshop (Hobday et al., 2017), indicating a close relationship between place of residence and place of purchase of alcohol. A large number of bottleshops may lead to travelling shorter distances to purchase alcohol (including top-up purchases during parties), resulting in a lower exposure and reduced risk of crash. A total of 42% of drivers stopped late at night at RBT locations in metropolitan Perth with a BAC of above zero had last consumed alcohol at a private residence (Clark and Palamara, 2014). These findings suggest that the relationship between place of purchase of alcohol and crash may be complex and difficult to quantify.

The study also showed that, when number of alcohol outlets and postcode-level socioeconomic and demographic variables were controlled for, alcohol-related crashes were more likely to occur beyond the CBD. This association became stronger as the distance from the CBD increased. This is probably related to the nature of urban structure further from the CBD – people tend to travel greater distances to work and to retail outlets, as postcodes become increasingly residential. While pockets of retail and light industrial activity occur, these areas tend to be surrounded by residential areas. Consequently, driving exposure increases.

5.1 Strengths and limitations

The strengths of the study include the use of eleven years of data which resulted in more robust results. Using a single, potentially atypical year of data could result in misleading results and conclusions.

The study also used a validated surrogate measure of alcohol-related crashes (weekend SVN crashes) to substantiate the results using confirmed alcohol-related crashes (with a driver with a BAC $\geq 0.05\%$.) Because BAC is not tested for every driver (and may not be reported

when it is tested), not every crash with a driver with a BAC above the legal limit is recorded in the crash database, leading to an underestimation of alcohol-related crashes. The use of surrogate measures of alcohol-related crashes attempts to overcome this limitation and is an accepted method within both the alcohol and road safety literature. In the absence of reliable routinely collected data, the use of a well-defined surrogate measure can maximise the number of alcohol-related crashes identified while minimising inclusion of non-alcohol-related crashes, maximising both sensitivity and specificity (Stockwell and Chikritzhs, 2000, Brinkman et al., 2001).

Previous studies have used buffer zones in analysing the association between distance and alcohol availability, and other alcohol-related harms such as assault or problem drinking. This is the first longitudinal study to use several methods to measure the effect of the proximity of alcohol outlets on road crashes, using multiple buffer zones or distance bands, and including both on-premise outlets and bottleshops. Furthermore, road network distance, as opposed to straight-line distance as used by previous studies (Donnelly et al., 2006, Truong and Sturm, 2007, Picone et al., 2010), is well-suited to examining road crashes specifically because they occur on the road network and are a more functional measure of distance than straight line distance.

A further strength of the study was the use of GIS maps to visualise areas of high alcohol outlet density and high risk areas for road crashes. These highlighted postcodes with high numbers of alcohol outlets and crashes, but also, by using heat maps, smaller areas of high, medium and low density of these outcomes. The maps provide an accessible tool for police and policymakers.

Some limitations in this study need to be noted. There was reduction in the overall number of crashes reported during and particularly after 2013, despite large increases in Perth's population over the study period. This reduction was larger for night-time crashes than day-time crashes, and for single vehicle crashes than multiple vehicle crashes. There was a large reduction in reported BAC crashes (from a high of 932 in 2008 to 356 in 2015). This suggests that changes in reporting and coding procedures may have contributed to this reduction, and that this varied across the crash dataset. These issues have been noted in other projects, and are currently being investigated further. To allow for these issues, additional measures of alcohol- and non-alcohol-related crashes were used, and regression models were done separately for 2005 to 2013, and

2005 to 2015. Similar findings were found for both year ranges, indicating the robustness of the results.

No data was included on enforcement levels (e.g., RBT locations and times). As a result of this limitation, the study has not been able to address the extent to which RBT operations may have targeted areas approximating on-premise alcohol outlets and therefore potentially reduced the number of crashes around such outlets. Future studies looking at smaller geographic areas should aim to include this data.

Other commonly used measures of alcohol availability are alcohol sales volumes data and trading hours of alcohol outlets which were not available for this study. However, including this data in future projects could give a more complete picture of alcohol availability and how it affects crash risk.

6 RECOMMENDATIONS AND CONCLUSION

"Toward Zero", the Western Australian road safety strategy for 2008 to 2020, identifies drink-driving as a 'crash problem behaviour' which can benefit from interventions involving all four cornerstones of the Safe Systems road safety approach – 'safe road use', 'safe road and roadside', 'safe speeds' and 'safe vehicles' (Office of Road Safety, 2009).

6.1 General recommendations
The following general recommendations relate to the 'safe road and roadside', 'safe speeds' and 'safe vehicles' cornerstones of the Safe Systems approach:

1. That locations with a high risk of alcohol-related crashes be identified by Main Roads Western Australia, and that strategies such as flexible wire barriers along the sides of high risk roads be used to prevent run-off-road crashes, since a high proportion of alcohol-related crashes are single vehicle crashes.
2. That alcohol interlocks be used for repeat drink drivers.
3. That speeds be reduced in high-risk road sections, and around entertainment districts, over weekend nights.

6.2 Specific recommendations

Specific recommendations from the results of the report pertain to 'safe road use', primarily through enforcing road rules (Office of Road Safety, 2009):

1. That targeted roadside breath testing focus on the following areas:
   i. Near the areas with clusters of on-premise outlets (such as entertainment districts);
   ii. Closer to primarily residential areas;
   iii. In areas where bottleshops are more scattered;
   iv. On weekends, particularly between 9pm and 2am.

2. That the Department of Licensing, Gaming and Liquor consider the following when granting liquor licences:
   i. The location of on-premise outlets relative to each other, including restricting the number of on-premise outlets in close proximity to each other;

ii.   Controls on bottleshops regulate other aspects such as the size of bottleshops, discounting prices of drinks and the mix of drinks sold, rather than focusing on the number of bottleshops.

3. That future research should investigate how these relationships vary across regional and remote parts of Western Australia. Further information on place of last drink and current enforcement practices should ideally be included as predictors of alcohol involvement in crashes.

6.3   Conclusion

This study explored the spatial relationships between alcohol outlets and road crashes in Perth metropolitan area. It indicated areas of high density of alcohol outlets and crashes, particularly around entertainment districts, retail and commercial centres. The results of the study suggested that larger number of on-premise outlets within certain distances from crashes were more likely to involve alcohol. However the results for relationships with bottleshops were less clear. Recommendations include targeting the time and location of police enforcement and blood alcohol concentration testing: early hours of the morning especially on weekends, and including other centres further from the CBD.

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