Using a Spatial Analysis Approach to Investigate Articulated Heavy Vehicle Crashes in Western Australia: 2001-2013

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EXECUTIVE SUMMARY

The aim of this study was to identify hot spots of heavy vehicle crashes by location that occurred between 2001 and 2013 using Geographical Information Systems (GIS) techniques. In order to achieve the aim of this study, three spatially related research questions were identified:

1. Where are the high concentrations, also referred to as, hotspots of articulated heavy vehicles crashes (across State and non-State roads)?
2. What are the trends in time and space of articulated heavy vehicles crashes (spatial-temporal patterns)?
3. Which state roads have the highest crash rate?

This study reflects on one of the first attempts to comprehensively use spatial analysis techniques in understanding articulated heavy vehicles crashes in Western Australia. Using spatial modelling and spatio-temporal analytical methods, allowed for the identification of emerging hotspots on specific roads, which highlight regions of interest and may benefit from further attention. This, in turn, is likely to provide important insights to policy makers and decision-makers. As this is a novel study, it is anticipated that more studies will follow with improved techniques and datasets that are likely to provide better results for decision-makers. The findings of the study suggest that the majority of the heavy vehicles crashes occurred in the vicinity or within the Perth metropolitan area. The findings also highlight areas, which are emerging areas of interest based on spatial-temporal trend analyses. The findings suggested that regions (beyond the Perth metropolitan area) such as: Mandurah, Waroona to Harvey, York and Baverley, and areas in the north, Wongan Hills and Moora were emerging as areas of interest to be statistically and spatially significant over time. Also, within the Perth metropolitan areas, two areas have been identified as intensifying hotspots over time and should be monitored with more attention: near Spearwood in the south and Beechboro in the north.

The following recommendations can be drawn from the findings of this study:

1. Include more in-depth detailed information on vehicle characteristics while running the spatial analysis procedures; this will lead to more fine-grained results in future studies;
2. Investigate the reasons for the spatial patterns of articulated heavy vehicle crashes, this, in turn, may provide crucial evidence to policy- makers in leading future safety interventions;
3. The roads identified as consistent and emerging hotspots should be given more monitoring or attention by road safety authorities. WA road authorities should continue to focus on the improvement of rural and semi-urban roads and prevention of articulated heavy vehicle crashes in these areas;
4. Continued monitoring of spatial and temporal trends for articulated heavy vehicle crashes in Western Australia; and
5. Provide Main Roads WA with spatial analysis data, adding to the continual improvement of its GIS dataset including temporal aspects.

The findings of this study can be used for improvement in road safety such as adoption of a more evidence-based road safety monitoring approach, yet it also could be used to provide a baseline for more advanced GIS studies to follow in the domain of road safety.

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Abstract

The recent developments in Western Australia's economy, including increasing traffic congestion and its impact on road safety are increasingly becoming prominent and gaining widespread attention. Previous studies used predominantly traditional methods such as non-spatial methods or traditional statistical analysis to investigate patterns or characteristics of vehicles crashes or more specifically heavy vehicles crashes. Although useful, statistical analysis alone is incapable of providing a spatial context and is therefore unable to associate existing crash characteristics with a spatial distribution or identify relationships between traffic crashes and the underlying elements within the road network. The aim of this study was to identify concentrations of heavy vehicle crashes from 2001 to 2013 using a spatial analysis approach. The findings of the study suggest that the majority of heavy vehicles crashes occurred in the vicinity or within the Perth metropolitan area. The findings also highlight areas, which are emerging areas of interest based on spatial-temporal trend analyses. The findings suggested that regions such as: Mandurah, Waroona to Harvey, York and Baverley, and areas in the north, Wongan Hills and Moora were emerging as areas of interest to be statistically and spatially significant over time. Also, within the Perth metropolitan areas, two areas have been identified as intensifying hotspots over time and should be monitored with more attention: near Spearwood in the south and Beechboro in the north.

In summary, this study was one of the first attempts to adopt a spatial analysis approach in studying heavy vehicle crashes in Western Australia. Applying spatial methodologies to road safety data has the potential of obtaining previously undiscovered insights which is likely to provide important insights for policy and decision-makers in road safety.

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1. Introduction

The aim was to identify concentrations of articulated heavy vehicle crashes by location using Geographical Information Systems (GIS) from 2001-2013.

2. Research Questions

In order to address the study objectives, three spatially related research questions were identified - of which the first three have been addressed in this interim report.

- Where are the high concentrations, also referred to as, hotspots of articulated heavy vehicles crashes (across State and non-State roads)?
- What are the trends in time and space of articulated heavy vehicles crashes (spatial-temporal patterns)?
- Which state roads have the highest crash rate?

3. Significance of the study

The study is important, as it is one of the first attempts to comprehensively use a spatial analytical approach in understanding the location of articulated heavy vehicles crashes in Western Australia. This, in turn, is likely to provide important insights for policy and decision-makers.

3.1 Metadata

It is crucial when working with multiple datasets that there is an understanding of the data that is provided so that correct inferences can be made between the two sets. The information pertaining to each dataset is typically provided as metadata and describes the content of each field. After consultation with Main Roads WA staff and a detailed evaluation of the files provided, it was found that there were inconsistencies between the datasets. Whenever uncertainty between fields was encountered, further information was sought and obtained from the data providers.

4. Literature review

The recent developments in Western Australia's economy, including increasing traffic congestion and its impact on road safety are increasingly becoming prominent and gaining widespread attention. To that end, a variety of road related information is being collected by regional authorities (e.g., Main Roads WA, Royal Automobile Club (RAC)) and Australian Automobile Association), enabling statistical analysis to be conducted using a range of data mining methodologies. Although useful in its own right, statistical analysis alone is incapable of providing a spatial context and is therefore unable to associate existing crash characteristics with a spatial distribution. Adopting spatial analysis approaches in investigating crashes are not new to the field of GIS (Chen, 2012), (Charlotte Plug, Jianhong (Cecilia) Xia, & Craig Caulfield, 2011), (Zhixiao Xiea & Jun Yan, 2013), (Michal Bíl, Richard Andrásik, & Zbynek Janoska, 2013; V. Prasannakumara, H. Vijitha, R. Charuthaa, & Geetha, 2011). However, in WA the extent to which GIS approaches have been used in an attempt to understand articulated heavy vehicle crashes across Western Australia is limited. It was therefore important to learn from recent studies involved GIS in investigating traffic crashes patterns elsewhere. For instance, Erdogan *et al.* (Erdogan, Yilmaz, Baybura, & Gullu, 2008) provided an interesting overview about a crash study in Turkey. This study discusses how GIS systems can aid in taking precautionary steps to prevent traffic crashes on highways through the identification of "hot spots" - where crashes occur most frequently. One of the challenges these authors faced was that traffic crash reports were made in textual formats, making it difficult to analyse crash reports. This article explained how a system was developed to transform this textual data into a tabular form, from which data was geo-referenced onto the highways network. Hot spots were identified and determined using two different methods: 1) Kernel Density Analysis; and 2) Repeatability Analysis. It was found that the identified hot spots, using these methods, were often problematic sections of the roads such as roundabouts, junctions and crossings. This spatial allocation of traffic crashes, together with their associated and accumulated statistical data, was subsequently used by road authorities to help find solutions within these problematic areas. For instance, the authors were able to use this data and continue researching by exploring the crash conditions at the hotspots locations. Some of the variables analysed included driving conditions such as: time of year (summer, winter etc.); time of day (morning, afternoon, evening); day of the week (Monday, Tuesday etc.); causes such as: carelessness; hit from behind; speeding; disobeying traffic signs and lights; improperly overtaking other vehicles; and finally hot spot type which included: cross roads for villages and small cities; hairpin turns; slippery areas during wet seasons; and Junctions.

Other studies such as Cela *et al.,* (Cela, Shiode, & Lipovac, 2013) provided a comprehensive overview of traffic crash data in Serbia. Utilising network methods such as Network K-function and the Network Kernel Density Estimation, the authors were able to analyse the spatial patterns of crash locations within the network. The novelty of their work was the application of the Network Kernel Density Estimation which enabled the authors to identify actual cluster locations of crashes (see also (Atsuyuki Okabe & Sugihara Kokichi, 2012)). In addition, to, Cela *et al.,* (2013) found that road crashes were primarily explained by road conditions and time.

A methodological paper authored by Quddus et al. (2013) focused on, and contributed to the debate of the relationship between average speed, speed variation, and crash rates using spatial statistical models and GIS. The results found that speed was not associated with crash rates when controlling for other factors such as traffic volume, road geometry and number of lanes. Speed variation, however, was found to be statistically significant and positively associated with crash rates. It was for this reason that it was decided to include some of the suggested methods recommended by earlier studies. In particular, the analyses of hot spots employing the Kernel Density Estimation (KDE) model as applied to network datasets have been adopted in this study.

In a paper which investigated spatial patterns of single vehicle crashes in Western Australia, Charlotte Plug et al. (2011) reviewed traffic crashes over a nine year period (1999-2008) to identify possible reasons for crashes based on location and time in particular hot spot regions. Utilising both spatial and temporal hot spots illustrated by KDE and star graph methodologies, including a combination of the two - through the use of spatial-temporal (Comap) approaches, enabled the authors to show the changes of accidents patterns during a certain time period. Through a combination of pattern intersection analysis including known risk factors such as speed and fatigue, they were able to identify significant factors enabling a further understanding as to the reasons behind some of the patterns within the crash data.

5. Methodological approach

5.1 Study design

A retrospective analysis of articulated heavy vehicle road crashes in WA from 2001 to 2013 using a GIS approach was undertaken.

5.2 Segmental granularity

Traffic volume and road information provided to the research team was broken down into 1601 road segments, representing 495 roads in Western Australia. An indicator of travel exposure, Million Vehicle Kilometers Travelled (MVKT), was calculated for each segment of the road to identify the volume of both regular and articulated heavy vehicular traffic (Refer to Appendix I for sample calculation). Road segments vary in length and therefore tend to skew the results when vehicular traffic is included. In this study road segments were aggregated to total road distance and the data smoothed to account for the variation.

5.3 Data sources

Road crash data used in this study was obtained from the Integrated Road Information System Crash Database (IRIS) which is a collection of road crashes reported to WA Police and is maintained by Main Roads WA. The IRIS database contains detailed information on the characteristics of the vehicles involved in road crashes, crash circumstances, Police reported injury and road information related to the crash location.

The dataset represented 2,828 articulated road crash locations on non-state roads and 5,136 on state roads from 2001 to 2013. Additional information provided by the IRIS database included location, month, date, day, time, vehicle type, crash severity and type of crash.

A separate dataset supplied by Main Roads provided information pertaining to traffic volume for both individual road segments (1601) for 495 roads within Western Australia. Information from both datasets were utilised to generate normalised crash rates across the WA.

5.4 State roads versus local (non-state roads)

Most, if not all, of the accumulated traffic volume data that was provided was associated with WA State roads only. The separation of total data set into smaller datasets based on available traffic volume is an important distinction especially in relation to policy recommendations. In Western Australia, the majority of State road funding and maintenance of highways and main roads, with the exception of Commonwealth's funding contribution towards the National Land Transport road network, is the responsibility of State Government (Main Roads Act 1930) ("Guidelines for Determining and Assigning Responsibility for Roads in Western Australia. Policy for classification, proclamation and transfer of Western Australian Roads.," 2011). It was therefore reasonable to divide the dataset into state road crashes and non-state road crashes. Since volume of traffic was available with state road locations, it was also possible to account for the traffic and calculate the rate of crashes per state road; and was an important addition to the analysis undertaken in this study.

5.5 Vehicle class discrepancies

Data provided in the volume dataset only included vehicle classes 24, 25 & 26 and 3-12. The crash dataset only provided information for vehicle classes 24, 25 & 26. This can potentially lead to a bias from a volume perspective, as more vehicles are included in the volume dataset suggesting that reported ratios might be under-represented.

5.6 Metadata

It is crucial when working with multiple datasets that there is an understanding of the data that is provided so that correct inferences can be made between the two sets. The information pertaining to each dataset is typically provided as metadata and describes the content of each field. After consultation with Main Roads staff and a detailed evaluation of the files provided, it was found that there are inconsistencies between the datasets. Whenever uncertainty between fields was encountered, further information was sought and obtained from the data providers.

5.7 Survey period

One of the factors this study did not account for was the period or months of the year that the road volume and crash data was collected over the 10-year time frame. For the purpose of this research it has been assumed that the data collection was taken during at any time of the year accounting for all weather periods. Peak traffic periods such as national and state holidays were not treated differently to non-peak times of the year. To account for varying peak periods, traffic volume for both road segments and total road lengths were normalised by the use of the MVKT metric, which focuses on the average volume of traffic within a particular distance and multiplied by million vehicles travel and were instead the results therefore may not accurately reflect.

5.8 Spatial analysis and spatial-temporal procedures

In addition to understanding the patterns of articulated heavy vehicle crashes and changes over time, spatial-temporal analytical procedures were used. The GIS analysis was conducted using two software tools 1) ArcGIS Pro, and 2) ArcGIS 10.2. The aim was to identify whether there were any trends that could be identified throughout the 13 years of articulated heavy vehicle crashes. For example, in our study the Emerging Hot Spot Analysis tool was used to identify space-time hotspots (ESRI - ArcGIS Pro, 2014a). The tool identifies trends in the data over time and space. It takes as input a space-time NetCDF cube file created using the Create Space Time Cube tool. It then uses the Neighborhood Distance and Neighborhood Time Step parameter values to calculate the Getis-Ord Gi* statistic (Hot Spot Analysis) for each bin (see Figure 1) (ESRI Help of ArcGIS Pro, accessed December 2014 (ESRI - ArcGIS Pro, 2014a)). Once the space-time hot spot analysis is completed, each bin in the input NetCDF cube has an associated z-score, p-value, and hot spot bin classification added to it. That means a trend over time or space can be identified. Next, these hot and cold spot trends are evaluated using the Mann-Kendall trend test. With the resultant trend z-score and p-value for each location with data, and with the hot spot z-score and p-value for each bin, the Emerging Hot Spot Analysis tool categorises each study area location as appears in Table 1:

Table 1. Categories available in the emerging hotspot tool (ESRI - ArcGIS Pro, 2014b).

Pattern Name	Definition
No Pattern Detected	Does not fall into any of the hot or cold spot patterns defined below.
New Hot Spot	A location that is a statistically significant hot spot for the final time step and has never been a statistically significant hot spot before.
Consecutive Hot Spot	A location with a single uninterrupted run of statistically significant hot spot bins in the final time-step intervals. The location has never been a statistically significant hot spot prior to the final hot spot run and less than ninety percent of all bins are statistically significant hot spots.
Intensifying Hot Spot	A location that has been a statistically significant hot spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of high counts in each time step is increasing overall and that increase is statistically significant.
Persistent Hot Spot	A location that has been a statistically significant hot spot for ninety percent of the time-step intervals with no discernible trend indicating an increase or decrease in the intensity of clustering over time.
Diminishing Hot Spot	A location that has been a statistically significant hot spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering in each time step is decreasing overall and that decrease is statistically significant.
Sporadic Hot Spot	A location that is an on-again then off-again hot spot. Less than ninety percent of the time-step intervals have been statistically significant hot spots and none of the time-step intervals have been statistically significant cold spots.
Oscillating Hot Spot	A statistically significant hot spot for the final time-step interval that has a history of also being a statistically significant cold spot during a prior time step. Less than ninety percent of the time-step intervals have been statistically significant hot spots.
Historical Hot Spot	The most recent time period is not hot, but at least ninety percent of the time-step intervals have been statistically significant hot spots.
New Cold Spot	A location that is a statistically significant cold spot for the final time step and has never been a statistically significant cold spot before.
Consecutive Cold Spot	A location with a single uninterrupted run of statistically significant cold spot bins in the final time-step intervals. The location has never been a statistically significant cold spot prior to the final cold spot run and less than ninety percent of all bins are statistically significant cold spots.

Intensifying Cold Spot	A location that has been a statistically significant cold spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is increasing overall and that increase is statistically significant.
Persistent Cold Spot	A location that has been a statistically significant cold spot for ninety percent of the time-step intervals with no discernible trend, indicating an increase or decrease in the intensity of clustering of counts over time.
Diminishing Cold Spot	A location that has been a statistically significant cold spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of low counts in each time step is decreasing overall and that decrease is statistically significant.
Sporadic Cold Spot	A location that is an on-again then off-again cold spot. Less than ninety percent of the time-step intervals have been statistically significant cold spots and none of the time-step intervals have been statistically significant hot spots.
Oscillating Cold Spot	A statistically significant cold spot for the final time-step interval that has a history of also being a statistically significant hot spot during a prior time step. Less than ninety percent of the time-step intervals have been statistically significant cold spots.
Historical Cold Spot	The most recent time period is not cold, but at least ninety percent of the time-step intervals have been statistically significant cold spots.

To get a measure of the intensity of feature clustering, this tool uses a space-time implementation of the Getis-Ord Gi* statistic, which considers the count value for each bin within the context of the count values for neighbouring bins. A bin is considered a neighbour if its centroid falls within the Neighbourhood Distance and its time interval is within the Neighbourhood Time Step you specified (ESRI - ArcGIS Pro, 2014a). See also Figure 1. A particular drawback of the Getis-Ord hot spot analysis is that it requires aggregation of data, instead of using individual crash locations.

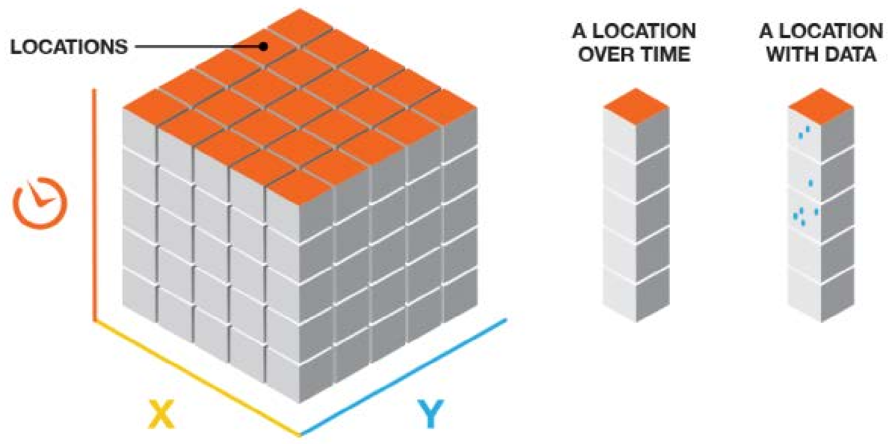

Figure 1. Emerging Hot Spot detection using Input Space Time Cube (ESRI - ArcGIS Pro, 2014a)

To address the different research questions (see Table 2), this study encompasses several spatial analysis procedures and methods. In general, spatial analysis methods can be classified in two categories:

5.9 Descriptive spatial analysis

Spatial analysis is associated with a basic examination that summarises existing spatial characteristics of particular measurements. For example, common techniques are: proximity analysis, density analysis, hotspot analysis, directional distribution analysis, group analysis, overlay analysis, spatial-temporal analysis (trends changes over time) and network analysis.

Our methodological spatial framework is presented in Table 2. Given a set of weighted features, identifies statistically significant hot spots and cold spots using the Getis-Ord Gi* statistic (Ord J.K. & A. Getis, 1995). This method was utilised to examine where articulated heavy vehicles' crashes were clustered. However, given the nature of this method, volume of traffic was not considered in the analysis, thus the results could be spatially skewed by the higher volume of traffic in a certain geographic areas (e.g., Perth metropolitan area).

5.10 Million vehicle kilometers travelled (MVKT)

To address this spatial issue, traffic volume was normalized for each road using the MVKT calculation. When analysing crash rates it is important to utilise a normalised denominator, which is routinely calculated with a traffic component embedded in the equation; for example crashes per million vehicle kilometers travelled (MVKT). Taking the provided Annualised Average Daily Traffic (AADT), which represents the daily volume of vehicular traffic of a particular road segment, enabled our analysis to account for road volume from a normalised perspective allowing the results to be comparable with previous studies. Crashes per million vehicle kilometers travelled over a 5-year period were calculated for each segment of the total road length as shown below. Crashes/MVKT = Crashes per year / (segment length (km) x AADT x 365 days x 5 year / million). This approach however was found to be inappropriate as the MVKT unit makes the assumption that crash rate has a linear relationship with crashes; i.e. as traffic increases on a road segment the crashes will also increase. Limitations with regards to geocoding crashes to roads instead of segments also provided a challenge that needed to be overcome and it was clear that working with the aggregated total road lengths as opposed to the more granular road segments would alleviate both of these issues. To that end, we instead used the following method to calculate crash rate: Crash/MVKT = Crashes per year / (sum of all road segment lengths (km) for a particular road) x AADT x 365 days x 5 year / million). This information was then joined into the state road layer. Next, number of crashes per road was spatially aggregated and this measure was divided by the MVKT, which yielded the rate of articulated heavy vehicle crashes, see also Figures 6-7. It is important to note, that traffic volume dataset was available for state roads only.

5.11 Kernel density estimation (KDE)

To assist in identifying spatial patterns of articulated Heavy Vehicle Incidents (HVI), the commonly used Kernel Density Estimation (KDE) for network was utilised. The model is based on a non-parametric estimation of density, or amount of crashes in a given area, of a random variable (articulated heavy vehicle crashes). This creates a representational field of articulated heavy vehicle crashes - the density of articulated heavy vehicle crashes in each area or pixel and is calculated by counting the number of crashes in a defined kernel (or region), circumferential to an individual pixel. Subsequent smoothing occurs through the interpolation of adjacent regions allowing for continuity of inferences about the population within a finite data set. Results obtained from this model identify regions of increased crash intensity represented by darker colours within the surface map (Sabel, Kingham, Nicholson, & Bartie, 2005) and (Zhixiao Xiea & Jun Yan, 2013). The KDE model is preferred over other classical statistical clustering methods as it accounts for the network rather than broad surface as well as taking into consideration the uncertainty of the exact location of the traffic crash. Adjusting this uncertainty is attributable to spreading the risk of correctly allocating the location of the crash (Anderson, 2009) .

Table 2. Spatial Intelligence Framework

Research Topic	Sub Questions	Measures	Spatial Analysis	Temporal Data
Articulated Heavy vehicles crashes	Where are the hotspots of heavy vehicles crashes (across state and non state roads)? What are the trends in time and space of heavy vehicles crashes (spatial-temporal patterns)?	Crash locations (State and non state locations)	Hotspots analysis tool (using ESRI ArcGIS 10.2) Kernel Density Estimation for Network (using SANET) Emerging hotspots (spatial-temporal modelling using ArcGIS Pro 1.0)	Yes
Articulated Heavy vehicles crash rates	Which state roads have the highest crashes	MVKT measures for state roads	Spatial join and cluster analysis	No

In summary, the spatial analysis procedures were useful in identifying spatial and temporal patterns in the articulated heavy vehicles dataset.

6. Results

The map in Figure 2 presents time trends of time and space (state roads crashes and non-roads). Since, most of the crashes occurred in the vicinity of Perth metropolitan area, the time space analysis was undertaken on that area, in order to understand the spatial distribution and variation of articulated heavy vehicle crashes. The consecutive hotspots stand (represented as dashed orange in Figure 2) for a location with a single uninterrupted run of statistically significant hot spot bins in the final time-step intervals. The location has never been a statistically significant hot spot prior to the final hot spot run and less than ninety percent of all bins are statistically significant hot spots. These hot spots are important to identify recent trends in heavy vehicle crashes. This reflects a location that has been a statistically significant hot spot for ninety percent of the time-step intervals with no discernible trend indicating an increase or decrease in the intensity of clustering over the study period. Thus, it could certainly be an area of focus in terms of road safety or intervention by authorities. Appendix II, presents the list of the roads, which are completely or partially within these hotspots. Figure 2, shows the results of the hot spots analysis in the state level, however since it was expected to be clustered in Perth metropolitan area due to higher volume of traffic, it was essential to run analysis also in the vicinity of the Perth Metropolitan area to identify the spatial distribution as appears in Figure 2.

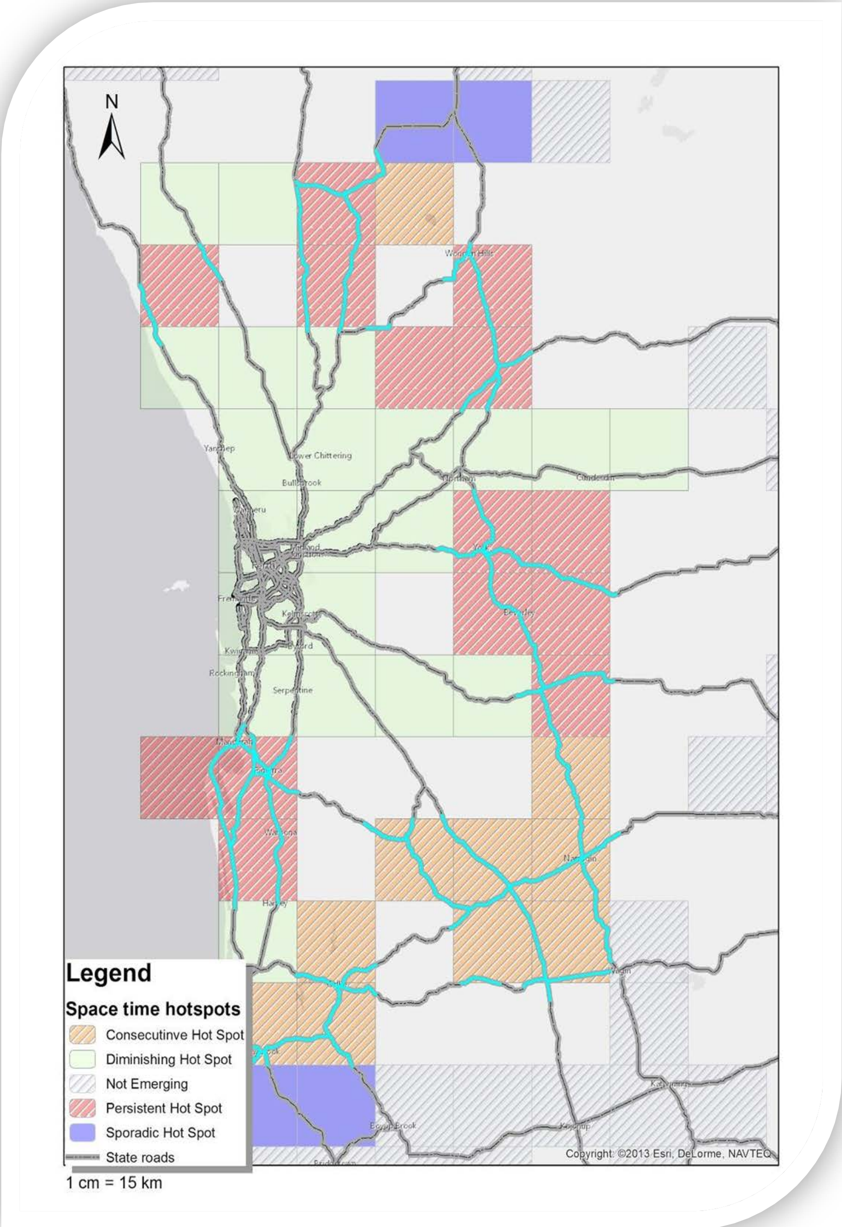

Figure 2. Space time Hot Spots of articulated heavy vehicle crashes in the vicinity of the Perth metropolitan area: 2001-2013

Figure 3 presents time trends of time and space within Perth metropolitan area only, in an attempt to understand the variation within the metropolitan boundaries (represented by the red coloured polygon). The persistent hotspots (represented as brown filled-in in Figure 3) denotes a location that has been a statistically significant hot spot for ninety percent of the time-step intervals with no discernible trend indicating an increase or decrease in the intensity of clustering over time. The two cells highlighted in blue are of particular interest as they were found to be as intensifying hotspots which reflects on a location that has been a statistically significant hot spot for ninety percent of the time-step intervals, including the final time step. In addition, the intensity of clustering of high counts in each time step is increasing overall and that increase is statistically significant. Thus, these two areas near Spearwood in the south and Beechboro in the north should be monitored with more attention. The red 3D bins in Figure 3 displays whether the cell representing the area of (5Km square) over the 13 years of data has been significant in term of hot spots (red) or cold spots (blue) or not significant (grey colour)

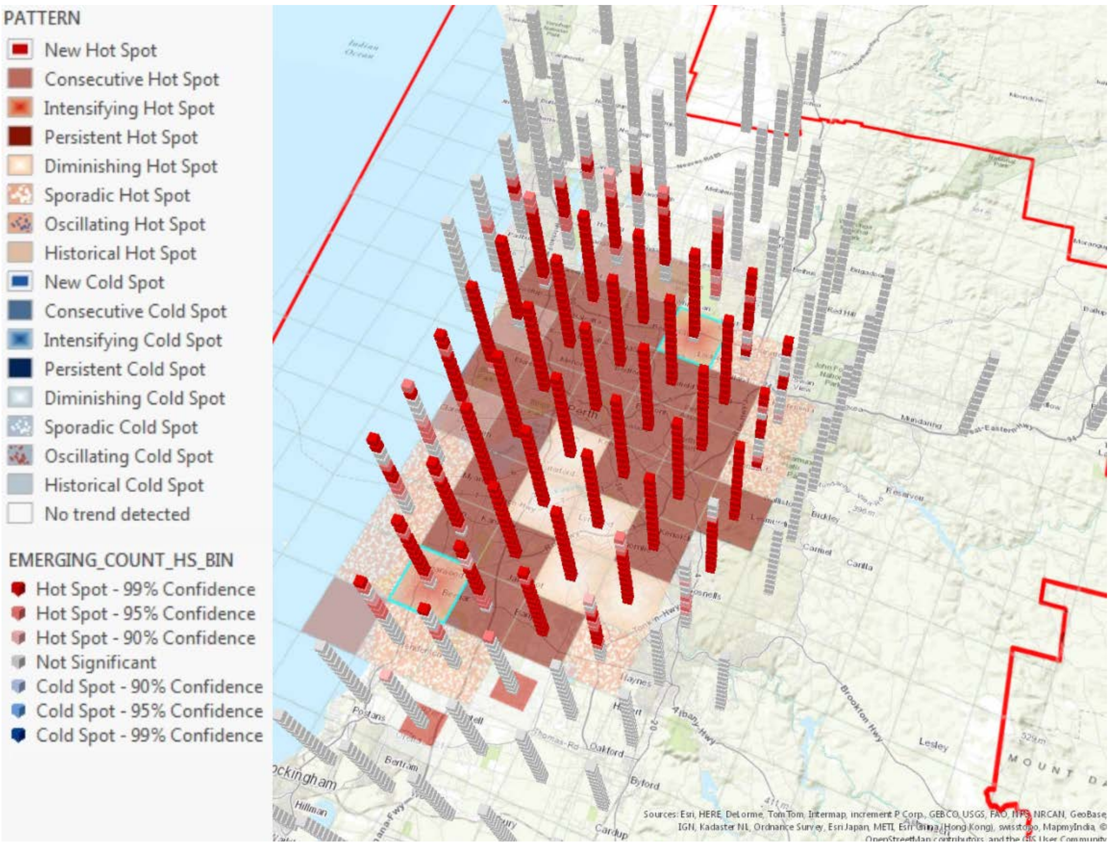

Figure 3. Space time Hot Spots of articulated heavy vehicle crashes in the Perth metropolitan area only: 2001-2013

It was hypothesized that to gain a better understanding of the articulated heavy vehicle crashes and to account for the volume of traffic, additional analyses were conducted to yield the rates of state roads articulated heavy vehicle hot spots. Figures 4-6 show the overall distribution of articulated heavy vehicle crash rates (based on the MVKT measure) on the state roads. Figure 4 shows the overall state road's articulated heavy vehicle crash rates. Figure 5 illustrates the rate of articulated heavy vehicles crashes in the Perth metropolitan area, some higher crash rates (orange and red colours) could be observed not far from Fremantle port and Perth airport and industrial zone.

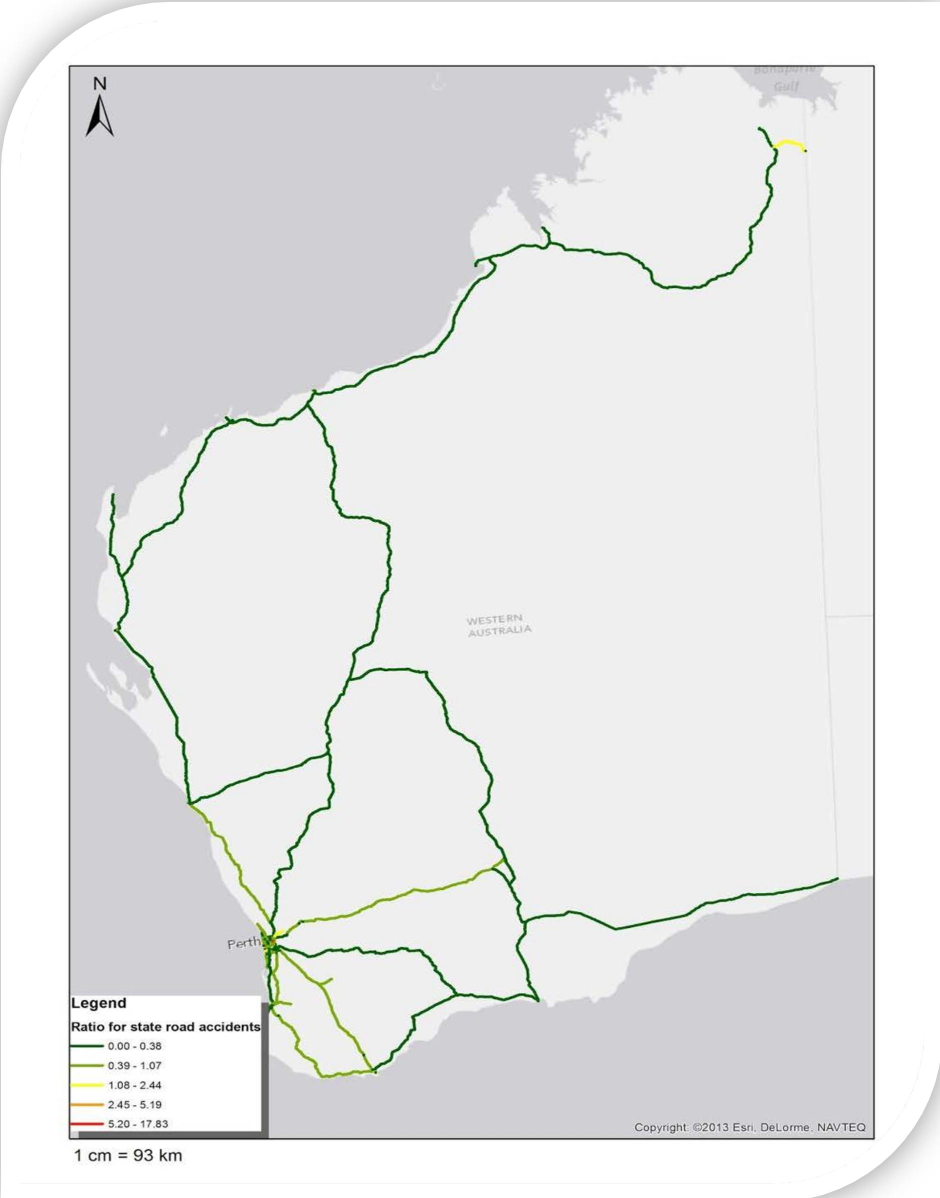

Figure 4. Articulated Heavy vehicle State road crash rates across Western Australia: 2001-2013

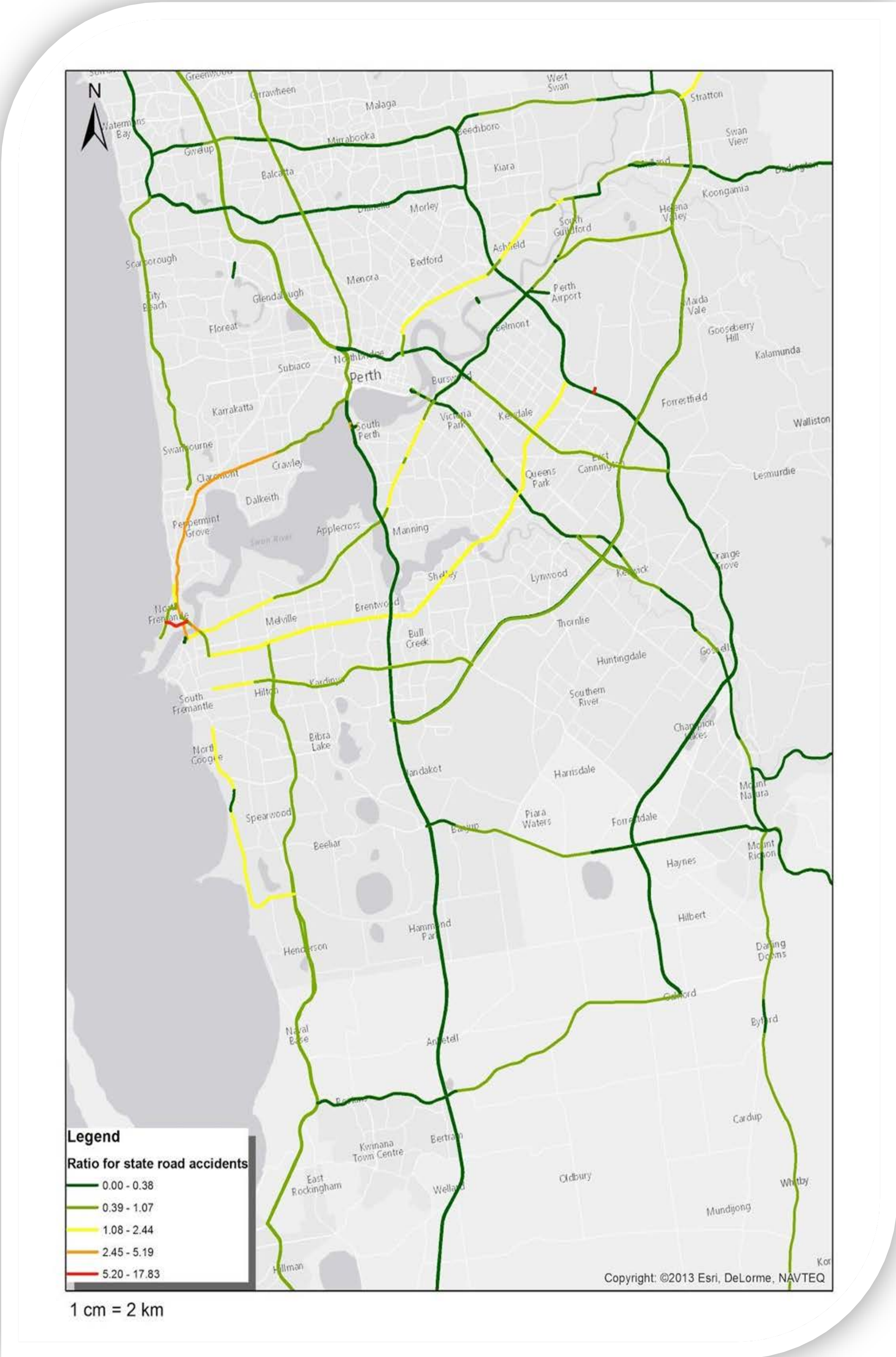

Figure 5. Articulated Heavy vehicle State road crash rates in the Perth metropolitan area: 2001 -2013.

Figure 6 shows the 10 highest state road rates in terms of articulated heavy vehicles crashes around Perth metropolitan area. Conversely, compared with the previous results, these findings accounted for the traffic volume and therefore are more reliable than the previous hotspots maps, which did not account for the volume of traffic.

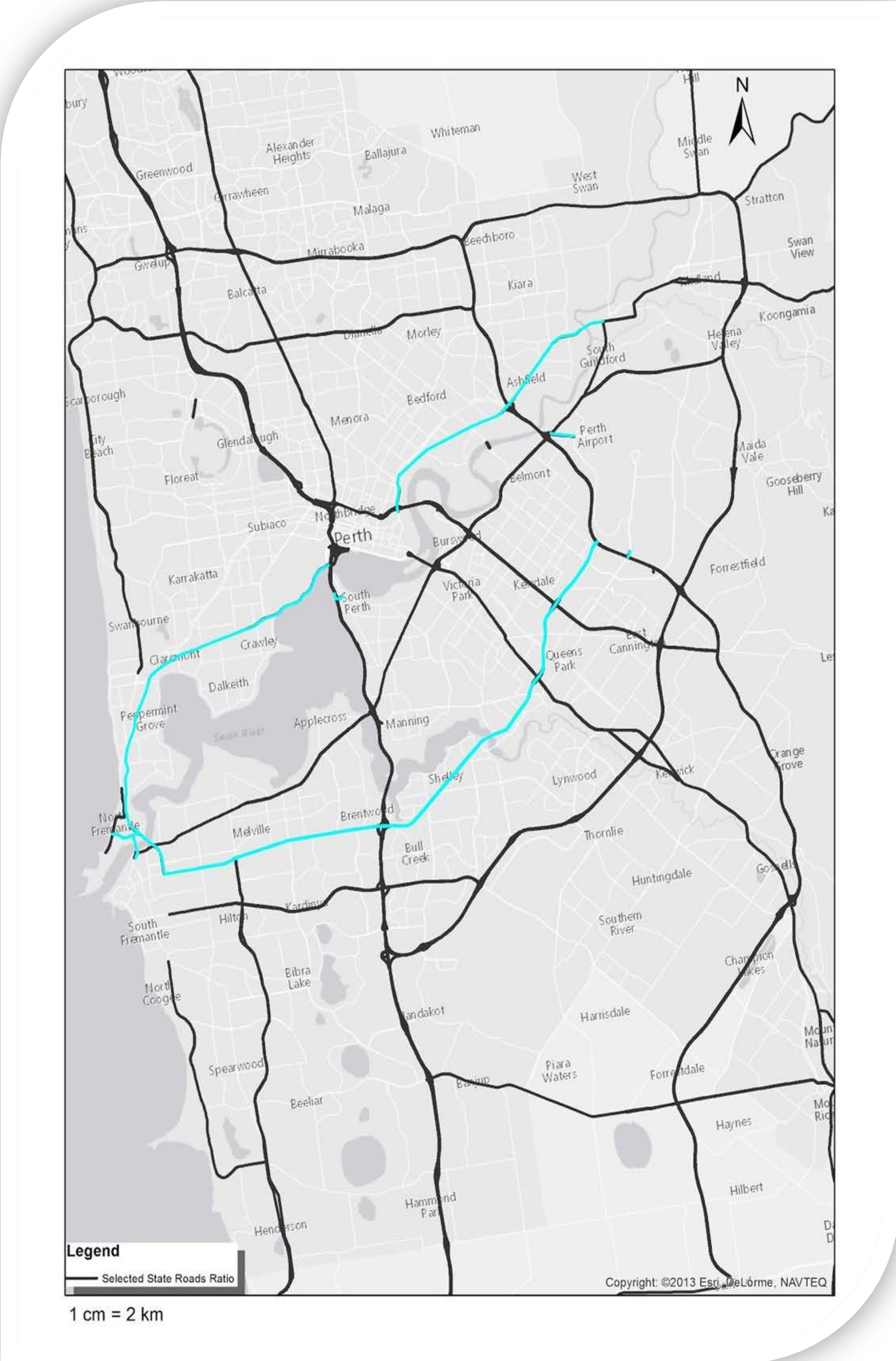

Figure 6. The ten highest state road crash rates (represented by blue colour) for articulated heavy vehicles in the Perth metropolitan area.

In addition to evaluating the crash data, a density analysis over the network (i.e., roads) was conducted adopting the method developed by Atsuyuki and Kokichi (2012). This additional analysis acted as a validation confirming the existing hot spots. The red lines represent areas of concentrated crashes. Two particular areas have been identified (adjacent to Fremantle port and the industrial area near the airport). These patterns are also consistent with the findings that were presented in Figure 5 and 6.

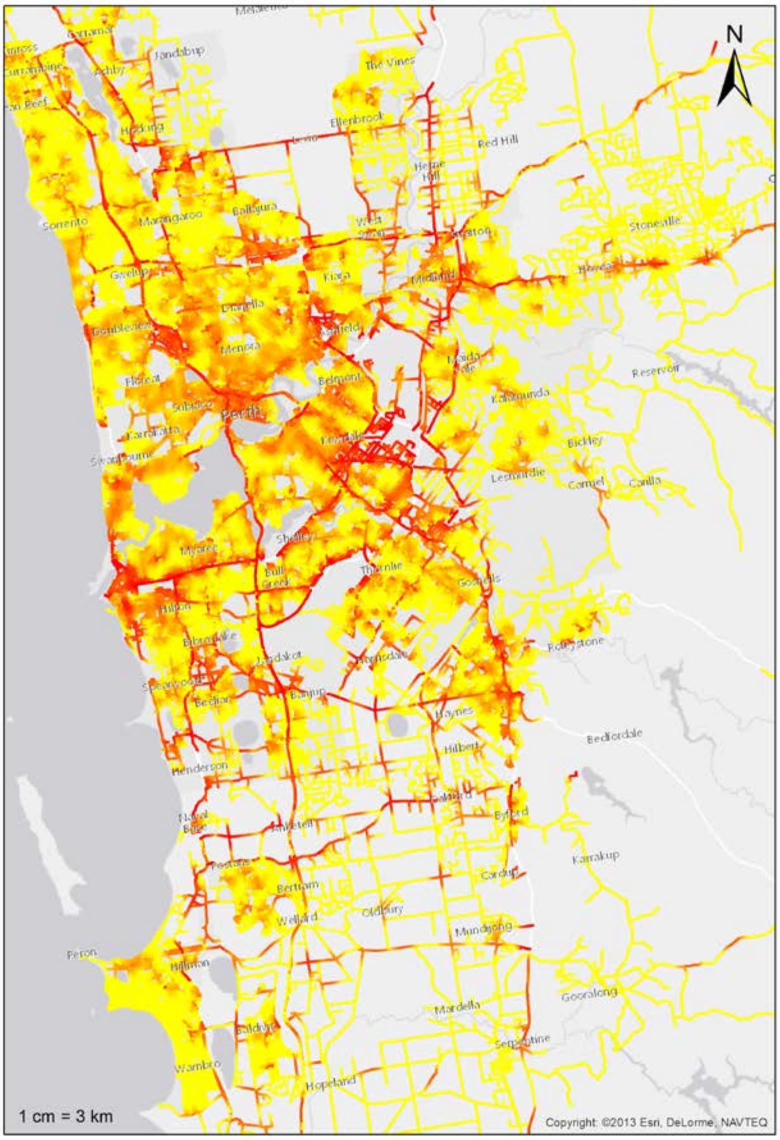

Figure 7. Kernel density estimation surface of articulated heavy vehicle crashes (within the Perth metropolitan area): 2001-2013

7. Discussion and conclusions

This report provides an overview on spatial trends and spatial-temporal patterns of articulated heavy vehicle crashes occurring on WA roads between January 1, 2001 and December 31, 2013. Based on the hotspot analysis, the results found that the majority of articulated heavy vehicle crashes were in the vicinity or within the Perth metropolitan area. This initial analysis however did not account for traffic volumes and therefore additional analysis were conducted, which included a ratio analysis incorporated the traffic volume. Based on the spatial-temporal analysis (See Figure 2 and 3), consistency in articulated heavy vehicles crashes during the years was observed in several areas such as: Mandurah, Waroona to Harvey, York and Baverley, and in the north area, Wongan Hills and Moora. Other areas found to be spatially significant (i.e., consecutive hot spots) in recent years (2012-2013) included Collie, Donnybrook, Narrogin and Wagin (see Figure 3). As noted earlier, to account for the traffic volumes, spatial analysis was conducted using the MVKT measure, findings revealed that most of the roads with the highest roads articulated heavy vehicle crashes were within the Perth metropolitan areas. These findings revealed certain roads were at significant risk; for example, roads lead to Fremantle Port (e.g. Leach Hwy & Stirling Hwy), Gilford Rd that leads to Midland, the road that leads to the domestic airport terminal (e.g., Brearley Ave) and the road that leads into the airport industrial zone (e.g., Horrie Miller Drive) and the entry to the Kwinana Fwy from Como or Mill Point Rd. Also, within the Perth metropolitan areas, two areas were identified as intensifying hotspots over time and should be monitored: near Spearwood in the south and Beechboro in the north.

7.1 Limitations

Although all efforts and precautionary measures were considered and taken during the analysis, it is important to bring to light some of the limitations in the report that may have an unintended impact on the findings and must be considered. The report did not address the question of "why" a crash occurred. The spatial patterns identified do not provide any indicators around the reasons for crashes being observed in specific locations and may need to be considered as a possible avenue for future research. Some of the hotspots analysis procedures did not account for the traffic volumes and this limitation was partially addressed by using the MVKT measure and the crash rates analysis method, which was subsequently applied. The study could also gain more by addressing more fine-grained spatial research questions, for example specific characteristics associated with articulated heavy vehicle crashes. Also, road conditions including weather, road and shoulder surfaces, road gradients and time of day in which crash occurred were not considered as part of this study. Despite these limitations, the study provided an important contribution, as this is one of the first studies to adopt a spatial analytical approach in investigating areas of high concentration of articulated heavy vehicle crashes in Western Australia.

7.2 Strength of the study

This study is one of the first attempts to comprehensively use spatial analysis approach in understanding issues of articulated heavy vehicles crashes in Western Australia. Using spatial modeling and spatial-temporal analysis methods assisted in identifying emerging hotspots and roads, which should garner more attention. This, in turn, is likely to provide important insights to policy and decision-makers for improving road safety for articulated heavy vehicle drivers.

8. Recommendations

The following recommendations can be drawn from the findings of this study:

1. Include more in-depth detailed information on vehicle characteristics such as identified reason of the accident, while running the spatial analysis procedures; this will lead to more fine-grained results in future studies;
2. Investigate the reasons for the spatial patterns of the articulated heavy vehicle crashes. This in turn, may provide a crucial evidence to policy-makers in leading future safety interventions;
3. The roads identified as consistently and emerging hotspots should be given more monitoring or attention by authorities. WA road authorities

should continue to focus on the improvement of rural and semi-urban roads and prevention of articulated heavy vehicle crashes in these identified areas;

4. Continued monitoring of spatial trends for articulated heavy vehicle crashes in Western Australia; and
5. Provide the offices of Main Roads with spatial analysis data, adding to the continual improvement of its GIS dataset including spatio temporal aspects.

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10. Appendix I

Sample MVKT Calculation

- Crash Rate = No of crashes (09-13)/MVKT (Million Vehicle Kilometre Travelled)
- MVKT = AADT(Annual Average Daily Traffic)*Length*365*5/1,000,000
- Weighted AADT is calculated by (AADT*Length)/Total Length.

MVKT is derived using Weighted AADT. Please refer to spread sheet for example calculation.

2009-2013 Crash Rate on Kwinana Fwy SLK 0 to 10

Cway	Slk_From	Slk_To	True_From	True_To	AADT	Length*AADT	Length	Weighted AADT	MVKT	No Crashes (2009-13)	Crash Rate per MVKT (2009-2013)
L	0	1.18	0	1.18	89873	106050.14	1.18	125145.132	2283.899	2222	0.97
R	0	0.59	0	0.59	84923	50104.57	0				
R	0.59	1.08	0.59	1.08	81306	39839.94	0				
R	1.08	5.35	1.08	5.35	64883	277050.41	0				
L	1.18	1.41	1.18	1.41	65567	15080.41	0.23				
L	1.41	2.98	1.41	2.98	68193	107063.01	1.57				
L	2.98	5.2	2.98	5.2	63787	141607.14	2.22				
L	5.2	5.65	5.2	5.65	49696	22363.2	0.45				
R	5.35	5.75	5.35	5.75	51453	20581.2	0				
L	5.65	6.25	5.65	6.25	47046	28227.6	0.6				
R	5.75	6.21	5.75	6.21	42114	19372.44	0				
R	6.21	9.05	6.21	9.05	55443	157458.12	0				
L	6.25	8.96	6.25	8.96	61715	167247.65	2.71				
L	8.96	9.47	8.96	9.47	58101	29631.51	0.51				
R	9.05	9.41	9.05	9.41	57002	20520.72	0				
R	9.41	9.98	9.41	9.98	40705	23201.85	0				
L	9.47	9.83	9.47	9.83	48973	17630.28	0.36				
L	9.83	10	9.83	10	45305	7701.85	0.17				
R	9.98	10	9.98	10	35964	719.28	0				
						1251451.32	10				

11. Appendix II

A listing of all of the roads within the identified hot spots based on the spatio temporal analysis (see Figure 3)

Albany Hwy
Melville Mandurah Hwy
Brand Hwy
Great Northern Hwy
South Western Hwy
Kwinana Fwy
Bussell Hwy
Coalfields Hwy
Brookton Hwy
Williams Narrogin Hwy
Forrest Hwy
Bunbury Outer Ring Rd
Willinge Dr
Willinge Dr Acceleration Lane Onto Bunbury Outer Ring Rd
Bindoon Moora
Bannister Marradong
Vasse
Chidlow York
Donnybrook Kojonup
Goomalling Merredin
Pinjarra
Midlands

Northam Cranbrook
Northam Pithara
Collie Lake King
Narrogin Kondinin
York Merredin
Goodwood
Indian Ocean Dr
Collie Mumballup
Boyanup Picton
Pinjarra Williams
Wongan Hills Calingiri
Goomalling Toodyay
Boyanup Capel
Collie Williams
Greenlands Rd
Lakelands Lake Clifton
Sues Rd
Causeway Rd Rty
Robertson Dr Rty
Strelly St Rty
Greenlands Rd Rty
Mandjoogoordap Dr Rty

Picton Rty
Bunbury Outer Ring Rd Willinge Dr Rty
Bunbury Outer Ring Rd South West Hwy Rty
Pioneer Dr Rty
Lake Clifton Rty
Robertson Dr (Southbound) to Bussell Hwy (Southbound)
Kwinana Fwy (Southbound) off to Pinjarra Rd
Pinjarra Rd on to Kwinana Fwy/Forrest Hwy (Southbound)
Kwinana Fwy/Forrest Hwy (Northbound) off to Pinjarra Rd
Pinjarra Rd on to Kwinana Fwy (Northbound)
Greenlands Rd on to Forrest Hwy (Northbound)
Old Coast Rd Slip From/To Forrest Hwy (Sth Bnd)
Mandurah Rd (Nth Bnd) Slip At Mandjoogoordap Dr Rty

Mandurah Rd (Sth Bnd) to
Mandjoogoordap Dr (Nth Bnd)
Boyanup Picton Slip Rd to South West Hwy
West Bnd
Bussell Hwy Slip to Sues Rd
Albany Hwy to Collie-Lake King Slip Rd
Great Northern Hwy Nth Bnd Slip to Mid