

When, where and why road crashes are likely on the Kings Highway NSW?

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Abstract

Rural road crashes are a major problem in regional Australia. The reasons for these crashes are a complex interplay between human behaviour, road characteristics and environmental factors. This paper will consider the contribution that road geometry makes to the incidence of crashes involving injuries or fatalities. This relationship will be explored specifically for the Kings Highway, a major arterial road connecting the ACT with coastal southern New South Wales, Australia. It introduces a new method of plotting crashes with road segmentation calculating sinuosity index, critical visual points, and road grade as three components of road geometry within a GIS context. The traffic flows are standardised relative to volume and the data is used to ascertain whether there is any correlation between the road geometry components and crash distributions between day and night driving. The results suggest that the likelihood of a crash is higher during the day on downhill curvy segments of the road. This is not the case for night driving where the incidence of crash is similar on both straight and curved roads segments because of the headlight effect and limited background visual field.

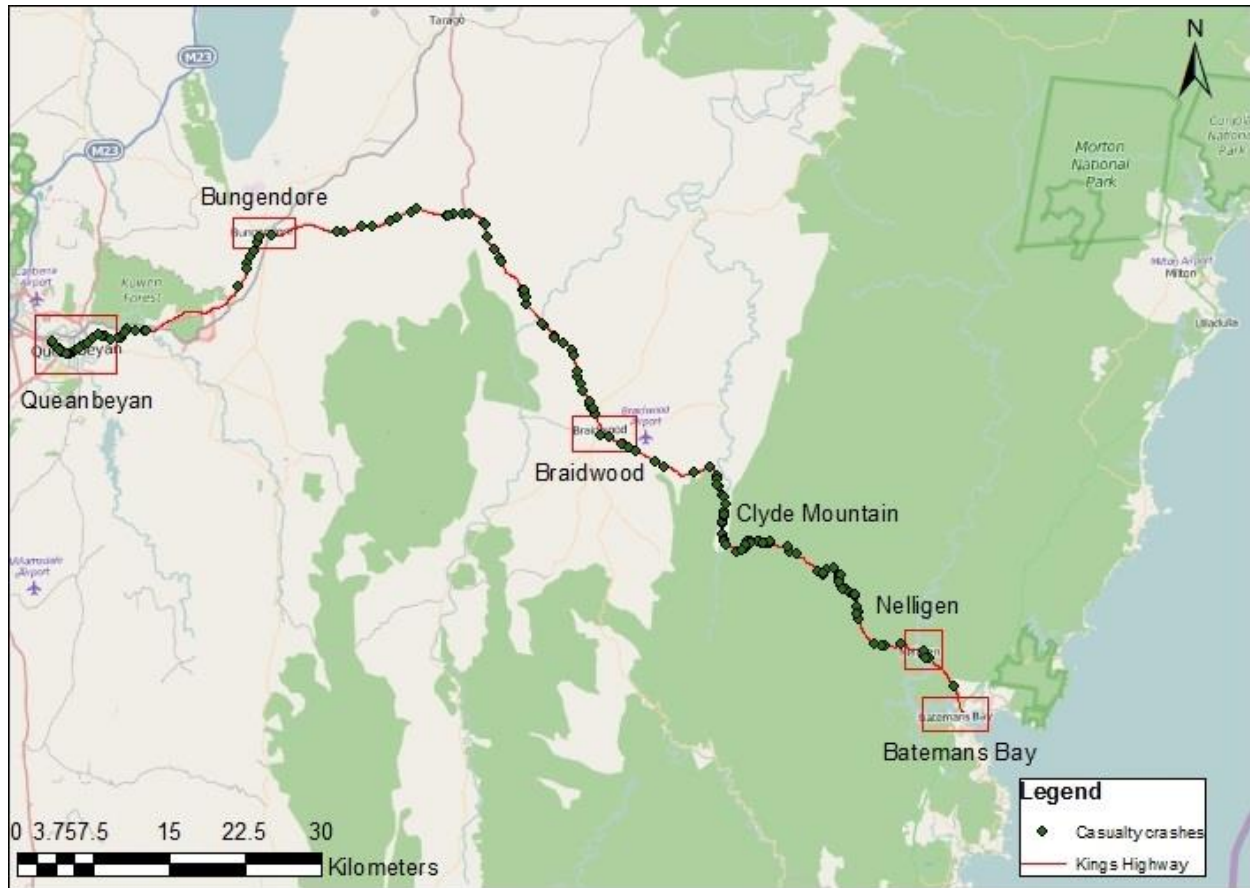
Introduction

Rural casualty crashes are a major safety problem in New South Wales (NSW), Australia (Austroads 2010a). Within the substantial literature that has sought to explore and theorise the factors contributing to road safety there is widespread agreement that human behaviour, road characteristics and the environment are the main factors that affect road safety (Shankar, Mannering et al. 1995; Elvik, Christensen et al. 2004; Wang, Quddus et al. 2013; Yu and Abdel-Aty 2014). Driver errors, in isolation or in combination with other factors, are involved in about 80% of crashes (Forkenbrock and Foster 1997). In addition to the significant contribution of driver behaviour, road geometry, traffic conditions and lighting conditions can also affect road safety (Sagberg 1999; Golob 2003). The mixed effect on road safety of some of these factors, especially traffic conditions, speed and geometry (Shankar, Mannering et al. 1995; Aarts and Van Schagen 2006; Jones, Haynes et al. 2012; Wang, Quddus et al. 2013) provides a key rationale for further research in this area.

Against this backdrop, the current paper will consider associations between key road geometry variables (sinuosity, critical visual points, and grade) and crash rates within different environmental conditions (day/night, eastbound/westbound), along Kings Highway, NSW. The overarching research question is: when, where and why are crashes likely on Kings Highway? The latter is a main rural road, around 132 km in length that connects Queanbeyan, on the border of the ACT, to Batemans Bay, a coastal town in NSW. The road provides residents of the ACT with their primary means of accessing a range of holiday, recreation and leisure destinations along the scenic south coast of NSW. Bungendore and Braidwood are the main towns along the road. In recent years, there has been a slight increase in casualty crash rates along Kings

Highway, resulting in a road safety review and ongoing upgrades (RMS 2013). Figure 1 illustrates the Kings Highway route and casualty crash locations from 2007 to 2011.

Figure 1. Crash distributions along Kings Highway, 2007-2011



Method

In the literature, the most common methods used for crash analysis are crash frequency and crash rate methods (Mannering and Bhat 2014); the particular approach that is employed will be dependent upon data availability and project aims and objectives (Yu, Liu et al. 2014). The data used for this study was 5 years of casualty crash and traffic count data sourced from the NSW Department of Roads and Maritime Services (2007-2011). While the quality of this data was generally very good, it did have the limitation of not identifying crash types. To analyse this data, crash frequencies and crash rates were determined, and associations with driver gender, age and speed were explored, including differences (if any) between day/night, and eastbound/westbound driving directions (Night was considered as extending from 6pm to 6am i.e. when headlights are generally used).

In terms of road geometry analysis, data limitations imposed certain constraints on the range of methods that could be considered for the current paper. Road centreline data was supplied by the NSW Lands Department. Comprehensive geometric data concerning Kings Highway was not

made available to the authors. As such, the methodology described below could be construed as a viable crash rate analysis method that might be employed when detailed road characteristic data is limited or unavailable.

Regardless of the particular methodology that is used, with respect to analysis of road characteristics segmentation is almost invariably used to extract certain road geometry variables, and to identify black spots. Within the literature, the length of road segments ranges from 500 m to 7 km (Miaou and Lum 1993; Ackaah and Salifu 2011; Mamčić and Sivilevičius 2013; Hosseinpour, Yahaya et al. 2014). For the purposes of this study, the road was divided into n circles and the diameter of each circle was 1 km. The latter corresponded to the straight-line distance for each road segment, entailing that the actual length of each road segment $k_n \geq 1$ km. Using this approach, the total road length (about 132 km from the last roundabout in Queanbeyan to the first roundabout in Batemans Bay) was divided into 124 segments.

Once a road has been segmented, the next task for any analysis of road characteristics is to determine key geometric characteristics, especially those relating to curvature. Within the literature, a wide range of curvature measurements have been used in the analysis of road crashes, including bend density (the number of bends per kilometre), detour ratio (the ratio of actual road distance to straight distance), straightness index (the proportion of road segments that are straight), cumulative angle (the cumulative angle turned per kilometre), mean angle (the mean angle turned per bend) (Haynes, Jones et al. 2007). It is widely agreed that use of a single measure will not suffice to capture enough of the significant geometric characteristics for a given road.

When data sources are limited, as in the current study, determining key characteristics of the road geometry can be challenging (Barker, Farmer et al.). To partly address these challenges, the current study focuses on three key components of road geometry that have not been widely used to date. These include: sinuosity index (actual road distance to straight-line distance) (Williams 1986; Jones, Haynes et al. 2012); critical visual points (focal points, or points in a bent segment where the visual information of the driver changes due to changes in direction) (Land and Lee 1994); and grade (ratio of vertical change to horizontal change) (Austroads 2015). These features are presented diagrammatically in Figure 2, and discussed further below, in turn.

The sinuosity index is measured using equation 1; critical visual points are measured by tangent lines. They involve some sort of threshold for angular change in direction of field of view at a particular point; and grade (gradient) of the straight line is measured using Equation 2.

$$SI = \frac{\widehat{AB}}{\overline{AB}} \quad (1)$$

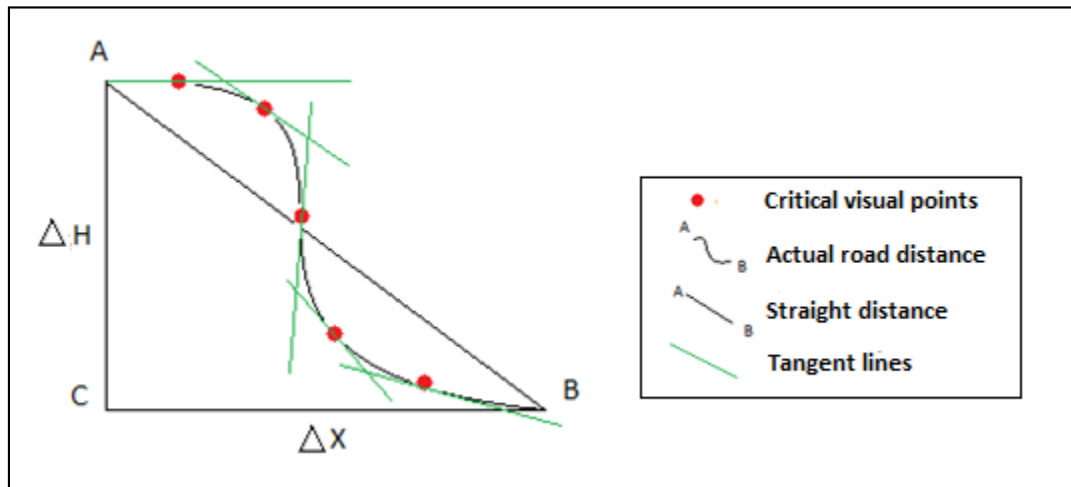
In Equation 1, SI is sinuosity index, \widehat{AB} is actual road (path) length, and \overline{AB} is shortest road (path) length.

$$G = \frac{\Delta H}{\Delta X} \quad (2)$$

In Equation 2 G is gradient, ΔH is change of height, and ΔX is change of distance

The sinuosity index provides a physical measurement of road curvature. Where $SI = 1$, the road

Figure 2. Sinuosity Index Critical Visual Points and Grade of the straight line



segment is straight; where $SI > 1$, the road segment is curved; as the index increases, so too does the curvature of the road segment. The sinuosity index is a relatively straightforward indicator of curvature that might be usefully employed when detailed geometric data is limited. However, the index does have its limitations in so far as it is easy to imagine one long, moderate curve having greater sinuosity than a series of shorter, sharper curves. Thus, it is essential to supplement the sinuosity index with data concerning critical visual points so as to differentiate between different types of curves. Consider, for example, two road segments where the respective sinuosity indices are identical, but one has three critical visual points, the other seven. The road segment with seven critical visual points will have sharper and more frequent curves, than the segment with three critical visual points. The critical visual points measure has the additional feature of embedding a key aspect of driver behaviour in the crash analysis since critical visual points relate to the visual field of drivers. Finally, it is essential to consider grades because crash rates are different between uphill and downhill sections of road (Jurewicz, Chaub et al. 2014).

In order to examine associations between crash data and road geometry, the frequency of crashes was plotted along Kings Highway. Urban areas were excluded because they have a built-up environment, along with different road geometry features, speed limits and environmental conditions; the distinction between rural and urban roads is recognised by NSW speed zoning guidelines (RTA 2011). The results were compared between day/night (daylight and darkness) and eastbound/westbound travelling directions. The crash data were then standardised per traffic per length of segment, results were compared at an aggregated level, and clusters identified for further analysis. Correlation matrix and regression methods were used to evaluate relationships between road geometry factors and crash rates in different lighting conditions and travelling directions. Where significant correlations were identified, a geometric index was developed which might form the basis for further research and analysis.

Results

Table 1 summarises crash data results, with significant outcomes highlighted in bold. In general,

Crash numbers vary by gender according to whether the travel is day/night or eastbound/westbound. There is a significant difference in the male/female ratio and younger/older drivers when comparing travel during the day and travel during the night. Young and Male drivers are far more likely to have a crash during the night than females. Number of Male to Female drivers is different travelling eastbound and westbound; specifically the ratio of number of male/female crashes travelling eastbound is more than twice travelling westbound. Nonparametric testing shows that the results are significant ($p < 0.05$).

Figure 3 illustrates the relationship between sinuosity and critical points. The best fit for the relationship is via a quadratic regression rather than a linear analysis ($R^2 = 0.65$ and 0.58 , respectively). This suggests that there is a ceiling to the impact of sinuosity on the number of critical visual points.

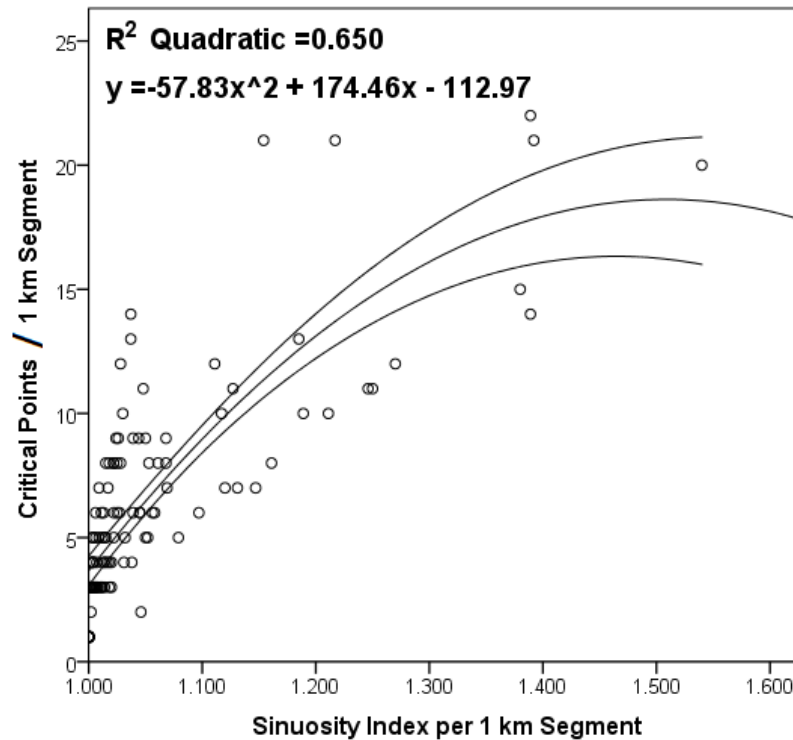
Figure 4 depicts the distribution of crash frequencies along Kings Highway, divided into 124. The X-axis summarises road centreline data measured by the methodology described above (critical visual points changes for $\overline{AB} = 1$, and $1 \leq SI \leq 1.5$), and the Y-axis illustrates sinuosity changes ($1 \leq SI \leq 1.5$). Crash frequency distribution is compared from Queanbeyan to Batemans Bay (above the X-axis) and Batemans Bay to Queanbeyan (below the X-axis), and between day and night.

Excluding the obvious differences in crash frequencies between day and night (due to greater volumes of traffic), the most noteworthy features of the diagram are clusters during the day travelling eastbound between segments 90-110 in the Clyde Mountain area (the road section with maximum sinuosity and critical points). At night time, there are no clusters; crash frequencies at night do not seem to vary according to straightness or sinuosity. When crash rates are standardised per traffic per length and compared in aggregate, Mann Whitney nonparametric test results suggest that daytime eastbound crashes are significantly different between straight sections and curves ($p < 0.05$); this is not the case for night crashes.

Figure 5 is a correlation matrix that summarises correlations between crashes and means for the road geometry factors, during the day and night. The results are presented at an aggregate level, where the total number of road segments is combined to form 24 sections, each section incorporating 5 segments. The aggregation of the segments into 24 x 5 km sections is intended to reflect road safety signage practices (whereby advisory signs refer to 5 km stretches of road). Significant quadratic correlations are highlighted in thick boxes. The results suggest that there is a correlation between eastbound daytime crashes and mean sinuosity, mean critical visual points, mean positive gradient (uphill) and mean negative gradient (downhill).

Figure 6 summarises relationships between crash rates and road geometry factors along Kings Highway is illustrated. In this figure, a geometrical index is used to examine a range of scenarios (day/night and eastbound/westbound) to take into account any impacts of gradient on the distribution of crash rates. The geometrical index is a multiplicative index, resulting from mean sinuosity \times mean gradient. The highest index corresponds to eastbound travel during the day, and to Section 19 which encompasses the beginning segments of the Clyde Mountain area (segments 19-22). The quadratic regression analysis results suggest an improvement in R^2 value from 0.35 to 0.75 by multiplying sinuosity index by gradient.

Figure 3. Sinuosity Index and Critical Points Regression



Discussion

In this research a simple and new methodology is used to identify the differences between crash rate distribution in different road geometry and environmental conditions. The method may be most fruitfully employed when detailed road geometry data is unavailable. Sinuosity, critical visual points and gradient are the three main variables used to summarise associations between road characteristics and the distribution of crashes (frequency and rate), for day/night and eastbound/westbound travel. The visualisation and segmentation method in this research is useful for summarising crash data and road geometry factors, and suggests some early interpretations that might be explored through further research and analysis.

The main findings are that the rate of crashes is more at night; and on curves during the day, travelling eastbound, downhill. No significant difference has been found between crash rates on straight sections and curves at night. The high crash rates at night may be due to speed (Fildes, Leening et al. 1989), lack of visual field (Plainis, Murray et al. 2006), voluntary risk taking of the driver (Konstantopoulos, Chapman et al. 2010) and driver age and experience (Underwood, Chapman et al. 2002). The results for daytime, eastbound, downhill travel suggests that road geometry has a stronger influence on crash rates on curves (Jurewicza, Chaub et al. 2014), in combination with the road environment and driver behaviour. The absence of a significant difference between crash rates on straights and curves at night, may be linked to a constrained visual field due to headlights (Aarts and Van Schagen 2006) and/or limited visual cues in the visual field (Fildes, Leening et al. 1989; Baker 1999; Plainis, Murray et al. 2006;

Konstantopoulos, Chapman et al. 2010). In summary, while curvature can increase crash risk, decreased visual field due to the darkness has a greater effect, producing more random crashes at night, and more clustered crashes on curves during the day.

As crash rates or clusters increase in a specific road segment, road safety might decrease and actions such as road upgrades, changing speed limits and/or additional police enforcement might be required. However, the findings reported here indicate that crash rates vary significantly, not only according to different road geometries, but also in different environmental conditions. This suggests that further consideration might be given to greater utilisation of variable speed limits.

Crash numbers for males and females differ significantly between day/night and eastbound/westbound travel. The results are statistically significant. This may be due to psychological and physiological differences between male and female drivers as discussed in previous studies. Young male drivers are more responsible for night and loss of control crashes because of speeding, risk taking, and the way they use roads (Clarke, Ward et al. 2006). Different crash numbers for males and females travelling eastbound and westbound might be due to differences between male and female driving skills (Laapotti and Keskinen 1998). Some further research is required in this area.

In conclusion apart from the significant effect of road characteristics on road safety, it is necessary to evaluate and consider the role of environmental conditions and driver behaviour, and the interaction between these three in any road safety analysis because crash rates are significantly different in geographical locations with similar road characteristics but different environmental conditions.

Some of the limitations of this research are: not considering the effect of some of road characteristics (e.g. lane and shoulder width, and overtaking zones), additional factors such as animals and alcohol, and type of crashes (e.g. run-off, rear end, or turning) because of the data limitation. In addition; Further research and some simulation studies are required to investigate the differences between male and female drivers and speed in day/night and eastbound/westbound.

More in-depth analysis of crash data, use a regression method to link all the variables, and implementing the method to new study areas are some of the future work that are required for validating of the results.

Acknowledgment

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Table 1. Data Exploration: Kings Highway, 2007-2011

		Crash Freq.		Crash Rate	Driver Age (yrs.)		Driver Gender			T. Speed (Km/h)	
		N	%	/100000 MV	Mean	SD	M	F	M/F	Mean	SD
Total (24h.)		180	100.00	2.45	40	18	106	73	1.45	78.51	23.65
Day (12h.)		144	80.00	2.31	42	19	80	64	1.25	76.84	22.32
Night (12h.)		36	20.00	3.25	33	16	26	9	2.88	85.83	28.03
East	Total (24h.)	115	63.90	3.13	40	18	75	39	1.92	75.91	24.90
	Day (12h.)	93	51.67	3.02	42	18	60	33	1.82	74.44	23.65
	Night (12h.)	22	12.23	3.68	31	12	15	6	2.5	83.93	30.60
West	Total (24h.)	65	36.10	1.77	40	20	31	34	0.91	82.80	20.93
	Day (12h.)	51	28.33	2.74	41	19	20	31	0.64	81.22	19.16
	Night (12h.)	14	7.77	1.77	36	20	11	3	3.66	87.86	26.00

Figure 4. Crash Frequency distribution through Kings Highway: A comparison between Day and Night

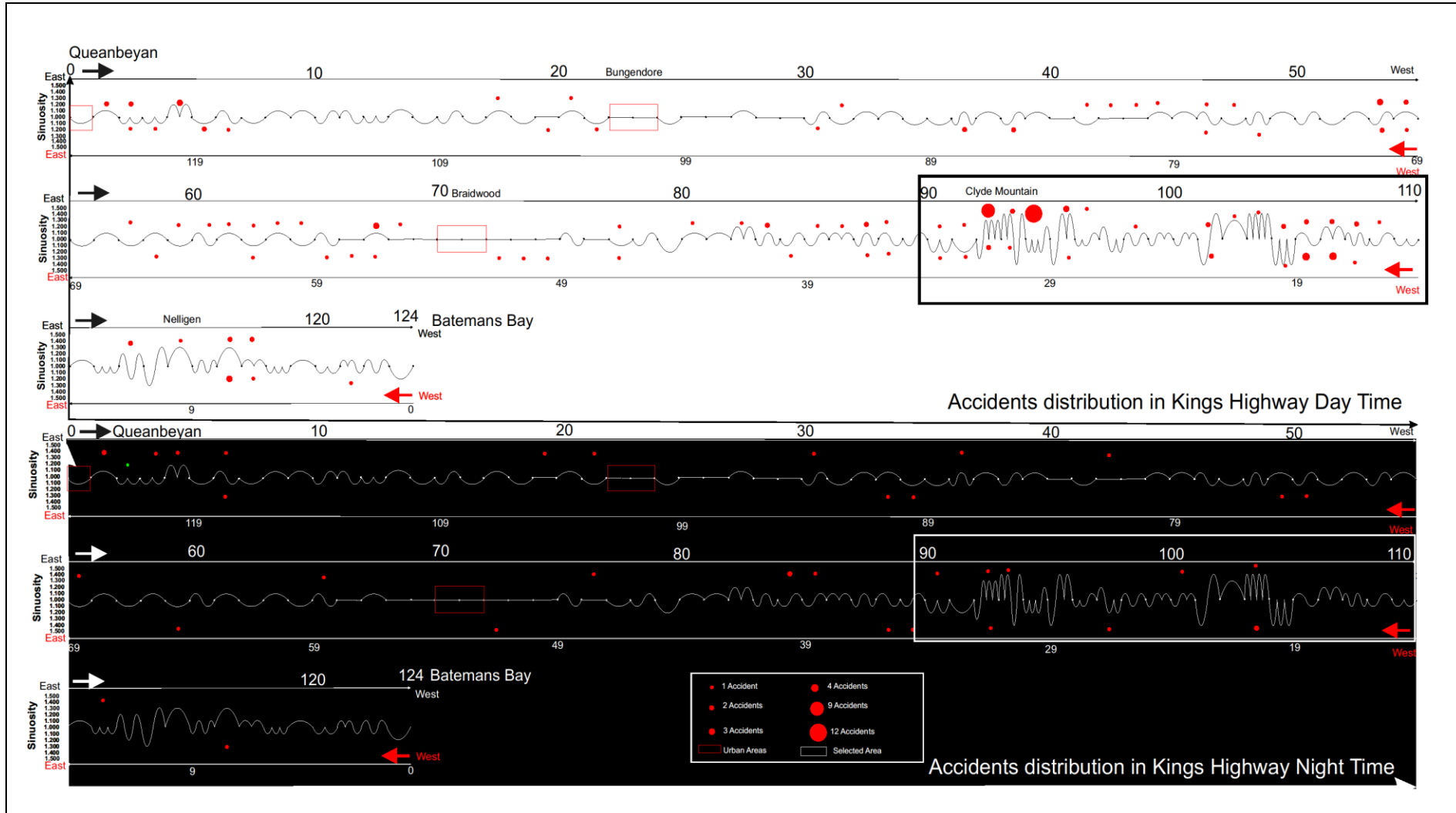


Figure 5. Correlation Matrix between Crash Rate and Road Geometry Factors: Day and Night Comparison

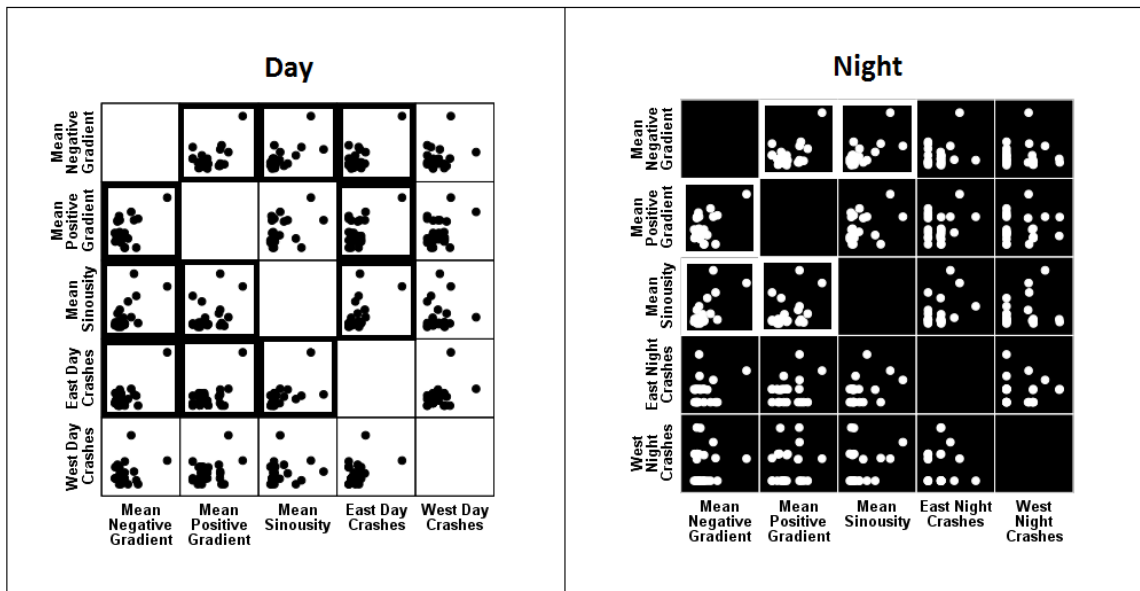
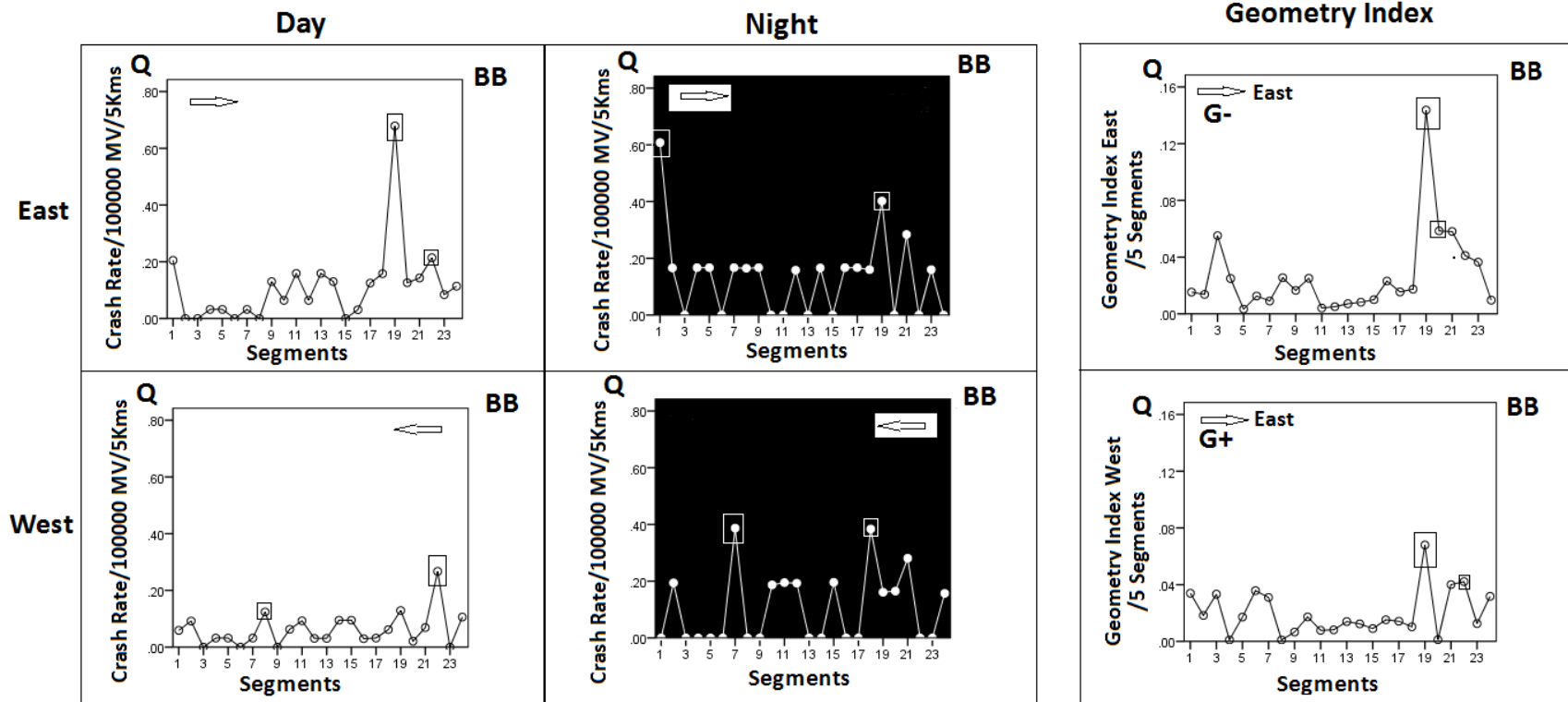


Figure 6. Summary of Crash Rate and Geometry Index distribution in Kings Highway



References

- Aarts, L. and I. Van Schagen (2006). "Driving speed and the risk of road crashes: A review." *Accident Analysis & Prevention* 38(2): 215-224.
- Ackaah, W. and M. Salifu (2011). "Crash prediction model for two-lane rural highways in the Ashanti region of Ghana." *IATSS Research* 35(1): 34-40.
- Austroroads (2010a). Rural run-off road crashes. Road Safety Engineering Assessment.
- Austroroads (2015). Road Geometry Study for Improved Rural Safety, Austroroads Ltd.
- Baker, R. G. V. (1999). "On the quantum mechanics of optic flow and its application to driving in uncertain environments." *Transportation Research Part F* 2: 27-53.
- Barker, J., S. Farmer, et al. "The development of accident-remedial intervention levels for rural roads, 1999." TRL Report 425.
- Clarke, D. D., P. Ward, et al. (2006). "Young driver accidents in the UK: The influence of age, experience, and time of day." *Accident Analysis & Prevention* 38(5): 871-878.
- Elvik, R., P. Christensen, et al. (2004). "Speed and Road Accidents: an Evaluation of the Power Model."
- Fildes, B. N., A. C. Leening, et al. (1989). Speed perception 2: Driver's judgments on safety and travel speed on rural curved roads at night, Federal Office of Road Safety.
- Forkenbrock, D. J. and N. S. J. Foster (1997). "Accident cost saving and highway attributes." *Transportation* 24(1): 79-100.
- Golob, T. F. (2003). "Structural equation modeling for travel behavior research." *Transportation Research* 37B: 1-15.
- Haynes, R., A. Jones, et al. (2007). "District variations in road curvature in England and Wales and their association with road-traffic crashes." *Environment and Planning A* 39(5): 1222.
- Hosseinpour, M., A. S. Yahaya, et al. (2014). "Exploring the effects of roadway characteristics on the frequency and severity of head-on crashes: Case studies from Malaysian Federal Roads." *Accident Analysis & Prevention* 62(0): 209-222.
- Jones, A. P., R. Haynes, et al. (2012). "Road traffic crashes and the protective effect of road curvature over small areas." *Health & place*.
- Jones, A. P., R. Haynes, et al. (2012). "Road traffic crashes and the protective effect of road curvature over small areas." *Health & place* 18(2): 315-320.

- Jurewicza, C., T. Chaub, et al. (2014). From Research to Practice—Development of Rural Mass Curve Treatment Program. Proceedings of the 2014 Australasian Road Safety Research, Policing & Education Conference, ACRS.
- Konstantopoulos, P., P. Chapman, et al. (2010). "Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving." *Accident Analysis & Prevention* 42(3): 827-834.
- Laapotti, S. and E. Keskinen (1998). "Differences in fatal loss-of-control accidents between young male and female drivers." *Accident Analysis & Prevention* 30(4): 435-442.
- Land, M. F. and D. N. Lee (1994). "Where we look when we steer." *Nature* 369(6483): 742-744.
- Mamčič, S. and H. Sivilevičius (2013). "The analysis of traffic accidents on Lithuanian regional gravel roads." *Transport* 28(1): 108-115.
- Mannering, F. L. and C. R. Bhat (2014). "Analytic methods in accident research: Methodological frontier and future directions." *Analytic Methods in Accident Research* 1(0): 1-22.
- Miaou, S. P. and H. Lum (1993). "Modeling vehicle accidents and highway geometric design relationships." *Accident Analysis & Prevention* 25(6): 689-709.
- Plainis, S., I. Murray, et al. (2006). "Road traffic casualties: understanding the night-time death toll." *Injury Prevention* 12(2): 125-138.
- Plainis, S., I. J. Murray, et al. (2006). "Road traffic casualties: understanding the night-time death toll." *Inj Prev* 12(2): 125-128.
- RMS (2013). Kings Highway Route Safety Review. Transport for NSW.
- RTA (2011). NSW speed zoning guidelines. T. R. T. Authority, NSW Centre for Road Safety. 4.
- Sagberg, F. (1999). "Road accidents caused by drivers falling asleep." *Accident Analysis & Prevention*.
- Shankar, V., F. Mannering, et al. (1995). "Effect of roadway geometrics and environmental factors on rural freeway accident frequencies." *Accident Analysis & Prevention* 27(3): 371-389.
- Underwood, G., P. Chapman, et al. (2002). "Visual search while driving: skill and awareness during inspection of the scene." *Transportation Research Part F: Traffic Psychology and Behaviour* 5(2): 87-97.

- Wang, C., M. A. Quddus, et al. (2013). "The effect of traffic and road characteristics on road safety: A review and future research direction." *Safety Science* 57(0): 264-275.
- Williams, G. P. (1986). "River meanders and channel size." *Journal of Hydrology* 88(1): 147-164.
- Yu, H., P. Liu, et al. (2014). "Comparative analysis of the spatial analysis methods for hotspot identification." *Accident Analysis & Prevention* 66(0): 80-88.
- Yu, R. and M. Abdel-Aty (2014). "Using hierarchical Bayesian binary probit models to analyze crash injury severity on high speed facilities with real-time traffic data." *Accident Analysis & Prevention* 62(0): 161-167.