Rural casualty crashes in NSW: A comparison of two major arterial roads and two main highways

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Abstract

This research considers the interaction between road geometry and driver behaviour and its impact on change of crash rates for day/night and different driving directions. An empirical location-specific approach is used to compare the results between two types of rural roads. The crash data is investigated for two major arterial roads (Kings Highway and Waterfall Way) and two main highways (Pacific and Princess Highways) in NSW. The results suggest that the risk of crashing is higher at night and during the day on arterial roads and varies according to travel direction. Driver gender, age and speed are all significantly different between day/night. Higher crash rates at night might be due to speed and fatigue, and more crashes during the day on arterial roads might because of the complexity of the interaction between road geometry and driver behaviour on sinuous sections of the road.

Background

There is widespread agreement that rural casualty crashes are a serious aspect of road safety (Elvik, 2008). It has been argued that they occur as a consequence of driver behaviour (e.g. speed and fatigue), road characteristics (e.g. segment length, horizontal and vertical curves, and lane and shoulder width), environmental features (e.g. time of the day and weather conditions), along with interactions between these issues (Alian, Baker, & Wood, 2015; Elvik, 2006; Shankar, Mannering, & Barfield, 1995; Yu & Abdel-Aty, 2014). Speed, visual field, road curvature, grade, and traffic volume are some of the variables that might increase both crash frequencies and rates, according to driver gender and age (Haynes, Jones, Kennedy, Harvey, & Jewell, 2007), but might have mixed effects on crash incidences depending on environmental conditions (Wang, Quddus, & Ison, 2013). Day/night driving (i.e. different illumination levels) (Fildes, Leening, & Corringan, 1989; Plainis, Murray, & Pallikaris, 2006) and eastbound/westbound or northbound/southbound driving (i.e. different effects of grade on speed in different travel directions) (Hassan, 2003) are two environmental variables that may have different effects on casualty crash rates.

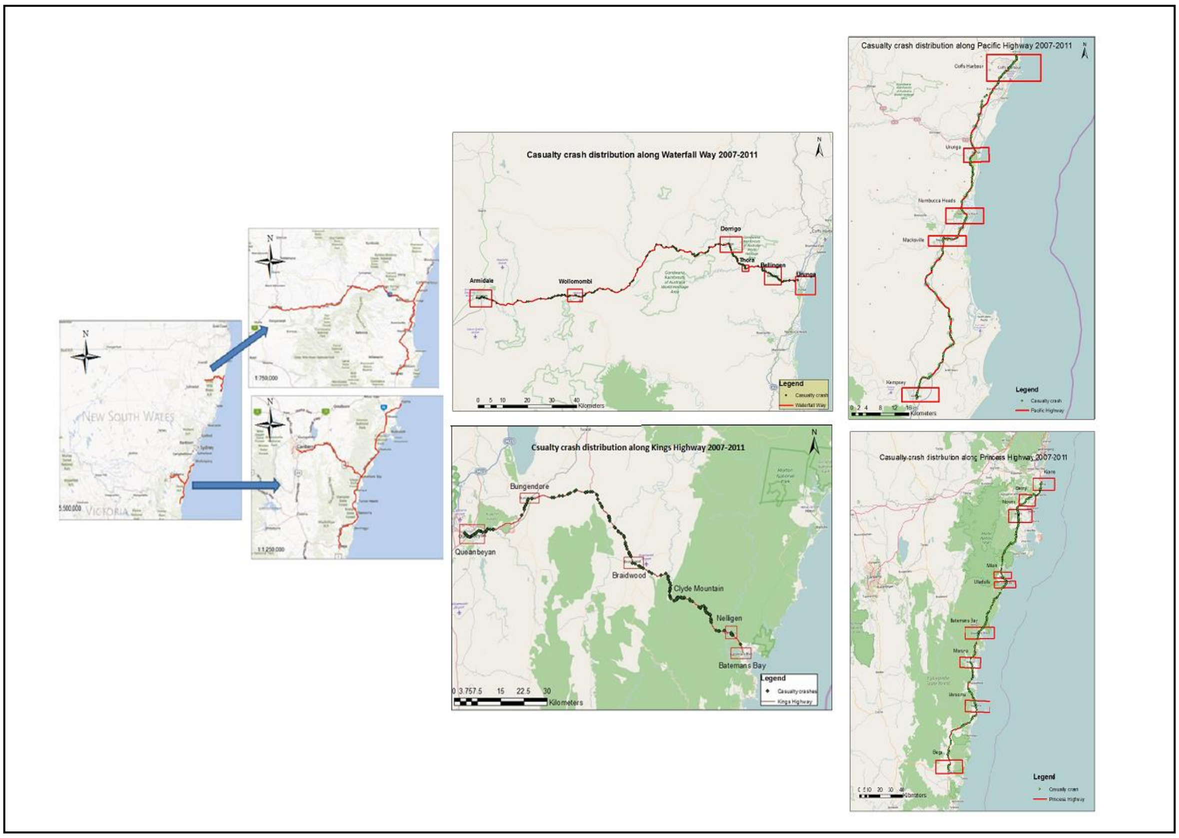
Apart from the role of road and environment, in about 80% of crashes driver errors or violations are the main causes of crashes (Rothengatter, 1997; Sabey & Taylor, 1980). Speeding, fatigue, driver inattention and violation, and drink driving are the main driver behavioural factors that contribute to crash occurances on rural roads in Australia (Siskind, Steinhardt, Sheehan, O'Connor, & Hanks, 2011). The contribution of driver behavioural factors to the risk, rate and distribution of casualty crashes might be different on different types of rural roads with changes of road characteristics and environmental features. Recently, the authors developed a location-specific approach to the study of road safety based on road segmentation using road centerline data. They considered the interaction between physical measures of road curvature (sinuosity index) and behavioural measures of road curvature (critical visual points) and its effect on changes in the rate and distribution of casualty crashes between day/night and eastbound/westbound travel on rural sections of the Kings Highway NSW. They concluded that casualty crashes are not significantly different on straights and curves at night, but the risk of having a crash is higher during the day on curvy sections of the road, traveling eastbound, because of the stronger effect of road geometry on driver visual cues (Alian et al., 2015).

Against this backdrop, the current study aims to apply the above approach to different types of rural roads (i.e. main arterial roads, and main highways), discuss similarities and differences, and generalise previous outcomes. It considers the interaction between road geometry and driver behaviour and its impact on segmental rates of change and distribution of casualty crashes between day/night and eastbound/westbound or southbound/northbound travel in four different study areas in NSW.

Study areas

The current paper explores two major arterial (overpass-mountain) roads, running from inland to the coast (Kings Highway [about 132 Km] and Waterfall Way [about 163 km]), and two sections of coastline highway (Princess Highway, from Kiama to Bega [about 304 km]; and Pacific Highway, from Coffs Harbor to Kempsey [about 116 km]) all of which were mainly two-way, undivided rural roads during the study period (2007-2011). Figure 1 illustrates the casualty crash distribution in the study areas. The study areas were selected because of high casualty crash rates during the study period and mixed geometry characteristics. Since 2011, the Roads and Maritime Services (RMS) introduced a number of road safety reviews, road upgrades, and some long-term plans on the selected routes. The particular focus of this paper is on similarities and differences, if any, between the selected routes in terms of casualty crash rates and distributions, driver behavioural factors and road geometry variables, according to day/night and different travelling directions.

Figure 1. Crash distribution in selected study areas (2007-2011)



Method[i]

In this research three sources of data were used including crash data and traffic count data (from RMS), and road centerline data (from NSW Lands Department); comprehensive road geometry data was not made available to the authors. The method followed Alian et al. (2015), which might be used in circumstances where detailed road geometry data is not available. It is a bottom-up, exploratory data analysis approach that considers the geographical location and time of casualty crashes. In summary, to measure road geometry variables, the road centerline was divided into *n* segments where the straight-line distance for each road segments was equal to 1 km. In each road segment the sinuosity index (ratio of actual road distance to straight-line distance) and grade (ratio of vertical change to horizontal change) were determined to capture key road geometry characteristics, and critical visual points (focal points, or the points in a curved segment where the visual information of the driver changes because of change in the direction) were measured to reflect key aspects of driver behavioural responses to road characteristics. The sinuosity index equals one for straight segments and increases according to increasing road curvature; grade reflects the differences between uphill and downhill travel; and critical visual points are measured by tangent lines to reflect differences between different types of road segments where sinuosity is equal, and to provide a proxy to changes in the visual information of drivers.

The method is an empirical, bottom-up approach that considers the nonlinear interaction between geometrical and behavioural measures of road curvature as a basis for further steps of the analysis. Urban areas were excluded (because of the built-up environment, and different speed limits). For the rural segments, associations between changes of sinuosity index and critical visual points were plotted and analysed using quadratic regression.

To explore the data, crash data was standardised per volume and length, and crash frequency, crash rate, driver age, gender, travel speed, and the frequency of crashes on straight and curved sections of the roads were compared for day/night travel and different travelling directions. To avoid the influence of assumptions concerning normal or random distributions, nonparametric statistical tests (chi-square and Mann-Whitney U tests) were used to test for significant differences between two groups of variables. The results were regarded as significant for p-values less than 0.05 (greater than 95% confidence).

To identify and compare how associations between the rate of casualty crashes and the sinuosity index vary according to day/night travel and according to major arterial roads and main highways, routes with similar road geometry and crash rates were combined. The road segments for both arterial roads (Kings Highway and Waterfall Way) and main highways (Princess and Pacific Highways) were divided into three main groups: straight ($SI \leq 1.05$), curved ($1.05 < SI \leq 1.25$), and twisted ($SI > 1.25$) and the crash rates were compared. The nonparametric Kruskal-Wallis test was used to ascertain significance since it considers the equality of more than two population means.

To determine how associations between changes in road geometry variables and crash rates vary according to day/night travel and according to major arterial roads/main highways, the rural road centerlines were divided into equal sections where each section included five segments to reflect the NSW road advisory signs. The quadratic correlation coefficients between road geometry variables and crash rates for day/night were measured and significant results ($p < 0.05$) used for further analysis.

To illustrate and analyse the interplay between road geometry variables (both physical and behavioural) and casualty crashes rates and distributions, during both day and night travel, a responsiveness of curvature index was used. It considered the multiplying effect of the sinuosity index and critical visual points (horizontal change of road curvature) on the segmental change of crash rates on both overpass mountain (arterial) roads and coastline (main) highways for day/night driving conditions.

Finally, the speed- and fatigue-related crashes (sourced from crash database) were compared for day/night and for two different travel directions (eastbound/westbound or southbound/northbound) between the selected study areas.

Results

As discussed above, the urban areas are excluded from these results. For the remaining rural areas, to measure road geometry variables 121.66 km of the Kings Highway is divided into 115 segments; 157.47 km of the Waterfall Way is divided into 148 segments; 264.48 km of the Princes Highway is divided into 252 segments; and 94.90 km of the Pacific Highway is divided into 93 segments.

Associations between the sinuosity index and critical visual points are illustrated in Figure 2. In this figure, the X-axis represents the sinuosity index measure per segment and the Y-axis shows the critical visual point measure per segment. The results are compared between 263 rural segments on overpass mountain roads (Waterfall Way and Kings Highway) in the left graph and 345 rural segments on coastline highways (Princess and Pacific Highways) in the right graph. The graphs suggest that both sinuosity index and critical points measures are about two times greater on overpass mountain arterial roads than coastal highways. The R-squared and p-values suggest that for both types of roads R-squared values are greater for quadratic regression rather than linear regression (0.549 to 0.526 for arterial roads, and 0.189 to 0.169 for main highways). In addition, regression lines/curves suggest that quadratic regression better represents how critical visual points (driver behaviour) change in relation to the sinuosity index (road geometry).

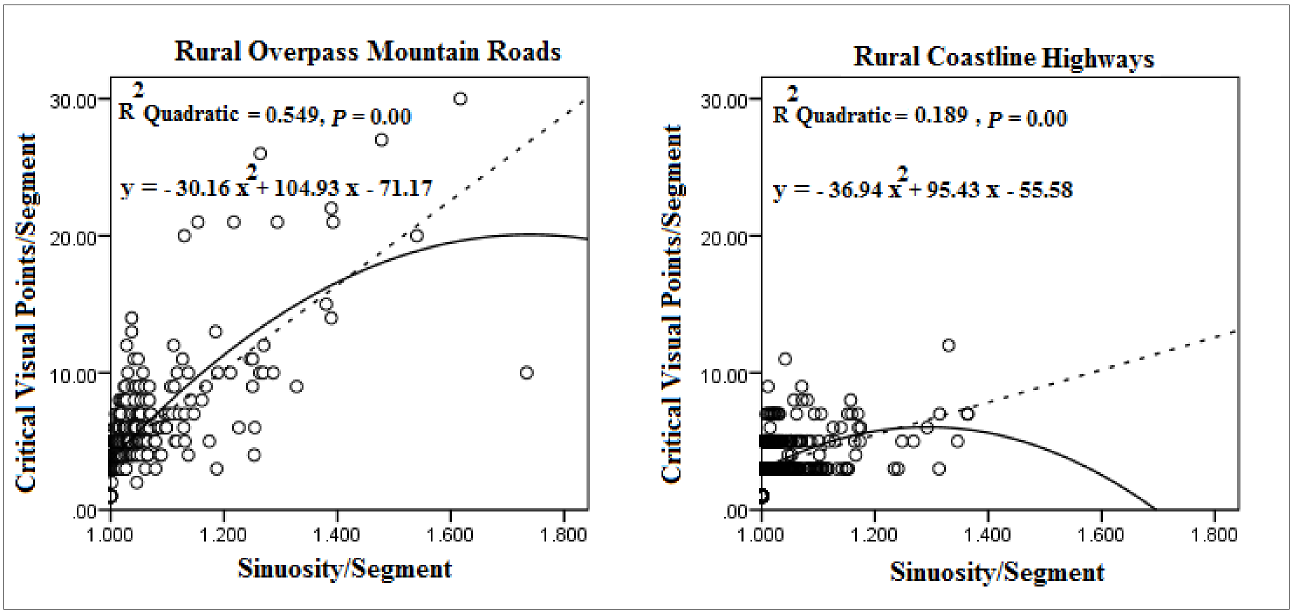
The results of further data exploration are summarised in Table 1. Some of the significant results are highlighted in bold. The crash data results indicate that for all study areas the risk of having a crash at night is greater than day-time. The results are statistically significant for Kings Highway, Waterfall Way and Princess Highway ($p < 0.05$), but not statistically significant for Pacific Highway. Crash frequencies and rates are higher travelling eastbound, during the day, on arterial roads (Kings Highway and Waterfall Way), but no significant difference was found on the main highways (Pacific and Princess Highway) for different travelling directions. For all study areas the mean driver age is higher during the day. In addition, the probability of a crash by male drivers is higher at night time, and the results are statistically significant. For most of the study areas the mean travel speed at night-time is higher than day-time. For arterial roads the risk of having a crash on both straight and curved sections is greater travelling eastbound during the day. The road data results suggest that the mean and standard deviation for the sinuosity index, the mean and standard deviation for critical visual points, the standard deviation of the ratio of negative gradient to positive gradient, and the ratio of curved segments ($SI > 1.05$) to straight segments ($SI \leq 1.05$) are all higher on arterial roads. The greatest variation in road geometry variables is found on Waterfall Way, followed by Kings Highway; the lowest variation is found on Pacific Highway. In summary, the risk of having a crash is higher on arterial overpass mountain roads than on coastline highways. The probability of having a crash is highest on Waterfall Way and lowest on the Pacific Highway.

Figure 3 illustrates how increase in the sinuosity index affects casualty crash rates. The results are compared between three different groups of sinuosity index for day/night between 263 segments on major arterial roads and 345 segments on the main highways. In Figure 3, the X-axis shows the three different sinuosity index groups (straight, curved, and twisted), and the Y-axis illustrates mean crash rates standardised per 100000 moving vehicles and length of segments in each group. The results are compared between day in the left column and night in the right column, and major arterial roads in the first row and main highways in the second row. The graphs suggest that there is a slight increase in crash rates as the sinuosity index increases on main highways, but considerable increase in crash rates when the sinuosity index increases on major arterial roads. The results at night-time are not consistent for main highways and arterial roads. The nonparametric Kruskal-Wallis test results suggest that for both arterial roads and main highways the results are statistically significant for day-time (p-values are 0.000 and 0.020). In contrast, the results for night-time are not statistically significant for both arterial roads and main highways (p-values are 0.233 to 0.396).

Appendix 1 shows the quadratic correlation coefficients between the mean and standard deviation of the road geometry variables per 5 segments and casualty crash rates according to day/night for all the study areas. The quadratic R-squared values are significant for day crashes in relation to the mean sinuosity index, mean critical visual points, standard deviation for critical visual points, and mean grade for Kings Highway and Waterfall Way (major arterial roads). No significant results are found for the mean and standard deviation of road geometry variables at night-time for arterial roads (except for the mean grade on Waterfall Way, which might be random). On the main highways (Princes and Pacific Highway), no significant results are found between road geometry variables and day-time crashes. The results are significant for night-time crashes in relation to the standard deviation of critical visual points, mean grade and standard deviation of grade for Princess Highway; and for night-time crashes and the mean sinuosity for Pacific Highway. Further analysis of these results is required.

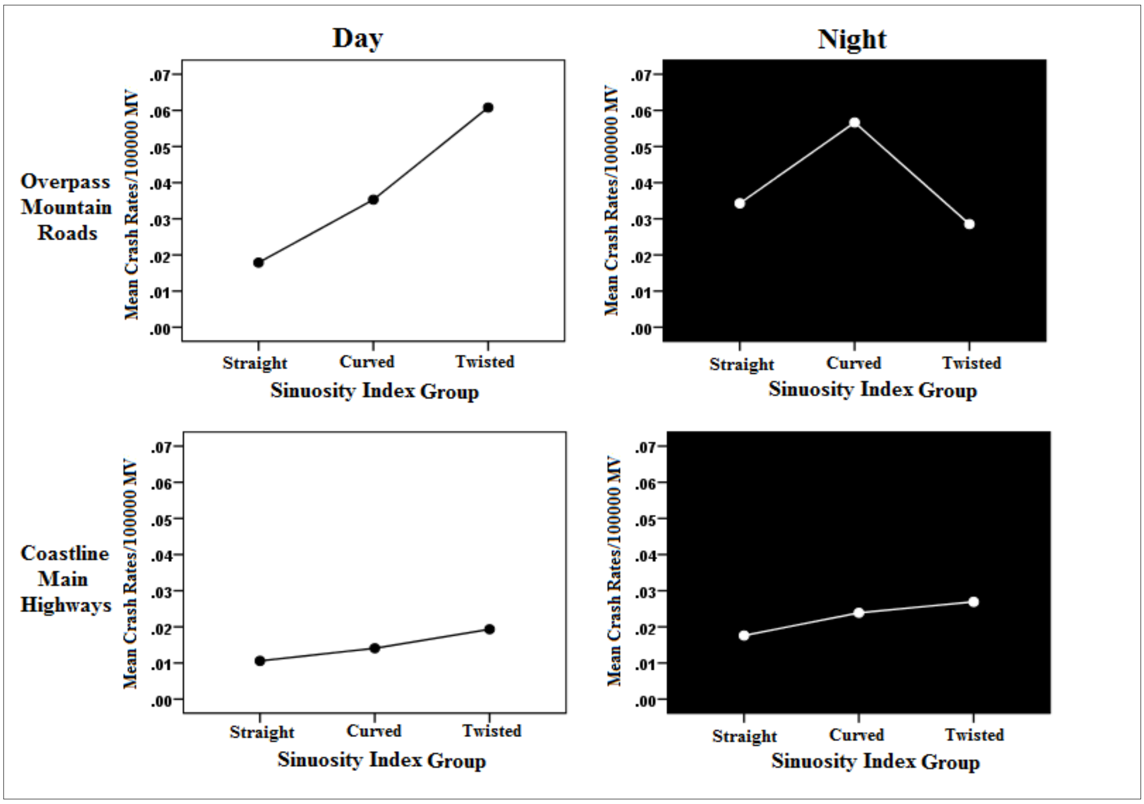
Figure 4 shows the regression analysis results between crash rates and responsiveness to curvature index for day/night driving on overpass mountain arterial roads and coastline highways, respectively. In Figure 3, the X-axis illustrates responsiveness to curvature index (calculated by multiplying the mean sinuosity index by the standard deviation of critical visual points per 5 segments), and the Y-axis illustrates crash rates standardised per 100000 moving vehicles per 5 segments. In this figure the first column shows the results for day-time and the second column shows the results for night-time. Finally, the first row illustrates the relationship on overpass mountain roads, and the second row graphs it for the main highways. The quadratic regression results suggest that *R*-squared values are significant for overpass mountain roads during day-time ($p < 0.05$), but no significant results are found for overpass mountain roads at night-time, or for the coastline highways for either day or night. The quadratic curves suggest that there is a limit to the impact of road curvature on casualty crash rates.

Figure 2. Quadratic regression between sinuosity index and critical visual points



As a further aid to analysis, Table 2 summaries the percentage of speed and fatigue related crashes (sourced from the crash database) between the study areas for day/night and different travel directions (eastbound/westbound and southbound/northbound). The results suggest that the percentage of speed-related crashes is higher on overpass mountain roads (major arterial roads) during the day and on coastline highways (main highways) at night-time. The results also suggest that the percentage of fatigue related crashes for both day and night is higher on the main highways. Except for the significant difference between fatigue-related crashes on Waterfall Way between eastbound and westbound travel at night there are no significant changes between different travelling directions. The comparison between day/night suggests that fatigue-related crashes at night in all the study areas are about two times more than day-time.

Figure 3. Distribution of crash rates for different types of sinuosity for day/night and arterial roads/main highways



Discussion

In this research an empirical approach is used to identify how road curvature might affect the risk and geographical distribution of having a crash according to day/night and different travelling directions (i.e. eastbound/westbound or southbound/northbound). Road centreline data is used to measure road geometry characteristics and the interaction between geometrical and behavioural components of road curvature (sinuosity index and critical visual points) is used for further steps of the analysis. The method is applied to four rural roads: two overpass mountain roads (Kings Highway and Waterfall Way), and two coastline Highways to validate and expand previous findings (Alian et al., 2015). The findings in this research might be used as the preliminary basis for further crash analysis and road safety studies.

The regression analysis between the geometrical measure (sinuosity index) and the behavioural aspects (critical visual points) of road curvature suggest that quadratic regression might better represent the interaction and nonlinear associations between road and driver behaviour than a linear one. As the regression curves show there is a saturation to the impact of sinuosity on driver visual cues. The stronger *R*-squared values for overpass-mountain roads might be due to higher rates of change of both geometrical and behavioural proxies of road curvature in comparison with the less sinuous coastline highways. Range, average, and variation of road geometry variables are all greater on Waterfall Way and Kings Highway in comparison with Princess and Pacific Highways.

The results of data exploration confirm the previous findings in the literature. Higher crash rates at night might be due to a constrained visual field, speed, fatigue, and voluntary risk-taking of young male drivers (Konstantopoulos, Chapman, & Crundall, 2010). It might also happen because of the higher use of alcohol at night driving on rural roads (Siskind et al., 2011). The results for day-time, eastbound travel on arterial roads may be the result of the stronger effect of road geometry on curves, down the hill at day-time (Jurewicza, Chaub, Mihailidisb, & Buic, 2014). Finally, higher crash clusters on curves on arterial overpass mountain roads may be due to the important role that road geometry and environmental conditions play in affecting crash rates and distributions on twisty and mountainous sections of road.

Different crash rates between sinuosity groups for day/night and arterial roads/main highways suggest that road geometry might have different effects on casualty crash distributions and rates according to different environmental conditions and road type. The quick and continuous increase of crash rates from straight to curved and twisted road segments for day-time on arterial roads might be associated with the greater proportion of twisted and curved segments when compared with main highways. The results suggest that road geometry has a stronger effect on crash rates and distributions during the day, probably because more continuous and complex visual cues are provided than at night-time, where the background visual field is absent.

The quadratic correlation coefficients between road geometry variables (mean and standard deviation of sinuosity index, mean and standard deviation of critical visual points, mean and standard deviation of grade) and crash rates per 5 segments for day/night indicate that on arterial roads *R*-squared values are significant between mean road geometry variables and standard deviation of critical visual points and day-time crashes for both Kings Highways and Waterfall Way. No significant and consistent outcomes are found between mean and standard deviation of road geometry variables and night-time crashes on arterial roads, and mean and standard deviation of road geometry variables and day and night-time crashes on main highways. The results confirm the strong effect of road geometry on driver behaviour and crash rates on arterial roads for day-time.

The regression analysis between the responsiveness to curvature index and crash rates support the preceding discussion. As the sinuosity index and standard deviation of driver visual cues increases the crash rates will increase to a certain point and then will decrease for day-time. The results suggest that road curvature has a mixed effect on road safety. At the scale that we examined, the effect of segmental change of road curvature on crash rates, there is no significant change for night-time driving on both arterial and main highways, and for day-time driving on main highways. It suggests that crashes are randomly distributed at night and on quite straight highways.

Finally, a review of speed and fatigue related crashes indicates that the percentage of fatigue related crashes at night are about two times more than day-time. This suggests that fatigue (e.g. driving for a long time or lack of sleep) might be the main cause of higher crash risks at night, especially on main, straight highways with fairly monotonous driving environments (Sagberg, 1999; Ting, Hwang, Doong, & Jeng, 2008). The results also suggest that the percentage of speed related crashes during the day are higher on arterial roads because of the stronger effect of road geometry on driver behaviour (speeding and limited visual cues).

In summary the results suggest that the distribution of crashes on overpass mountain arterial roads is significantly different between day/night and eastbound/westbound, but this is not the case for main highways. The crashes are randomly distributed at night on both types of roads and during the day on main highways, but clusters have been found during the day on overpass mountain roads. The results suggest that during the day on bendy and hilly sections of the road the complex interplay between road curvature, driver visual cues, and background visual field might be the cause of crash clusters; that is not the case for night driving because of the absence of background information and the effect of headlights. The results also suggest that both road geometry and environment might have a positive effect on speeding on curves driving downhill, which might be the cause of runoff road crashes. The method might be used if detailed road geometry data is not available, but as a limitation, it cannot quantify the associations between segmental change of road geometry variables and crash rates at night and on almost straight road segments because crashes are randomly distributed.

The outcomes recommend to national authorities that different policies might be used for road safety public policies between day and night driving on arterial and main highways. Various speed limits, different advisory signs and accelerated upgrades might be required between these two types of roads.

Some of the limitations of this research are: not considering the effect of drug and alcohol, the role of some other road factors such as lane and shoulder width, the effect of animals, type of crash and vehicle, and the role of weather conditions due to data limitations. Further research might be used to expand and generalise the results. It should be noted that the results and discussions of this paper are preliminary outcomes of the research, and analysis is ongoing. In addition, some upgrades have been done in the selected study areas by authorities after the study period, and where data is available, it might be valuable to compare the results in future studies.

Conclusions

In this research an empirical approach compares the change of casualty crash rates between major arterial roads and main highways in NSW. It considers the interaction between road curvature (sinuosity) and driver visual cues (critical visual points) and its effect on the rate and distribution of casualty crashes for day/night driving and eastbound/westbound or southbound/northbound travels.

The results suggest that the risk of crashes is higher at night and on arterial roads during the day and only varies according to travel direction on arterial roads, but not main highways. High crash rates at night might be because of fatigue, speed, or the use of alcohol, and crash clusters during the day on arterial roads might be because of the complexity of the interaction between geometrical and behavioural measures of road curvature.

In summary both the rate and distribution of casualty crashes varies between straight/curves according to lighting conditions, travel directions and type of road. The outcomes of this research suggest that national authorities might use different safety policies for day/night and arterial roads/main highways.

Acknowledgement

We need to acknowledge The NSW Road and Maritime Services for providing crash and traffic data, and The Departments of Lands for providing road centreline data. It was not possible to do this research without their support.

Figure 4. Quadratic regression between responsiveness to curvature index and crash rates

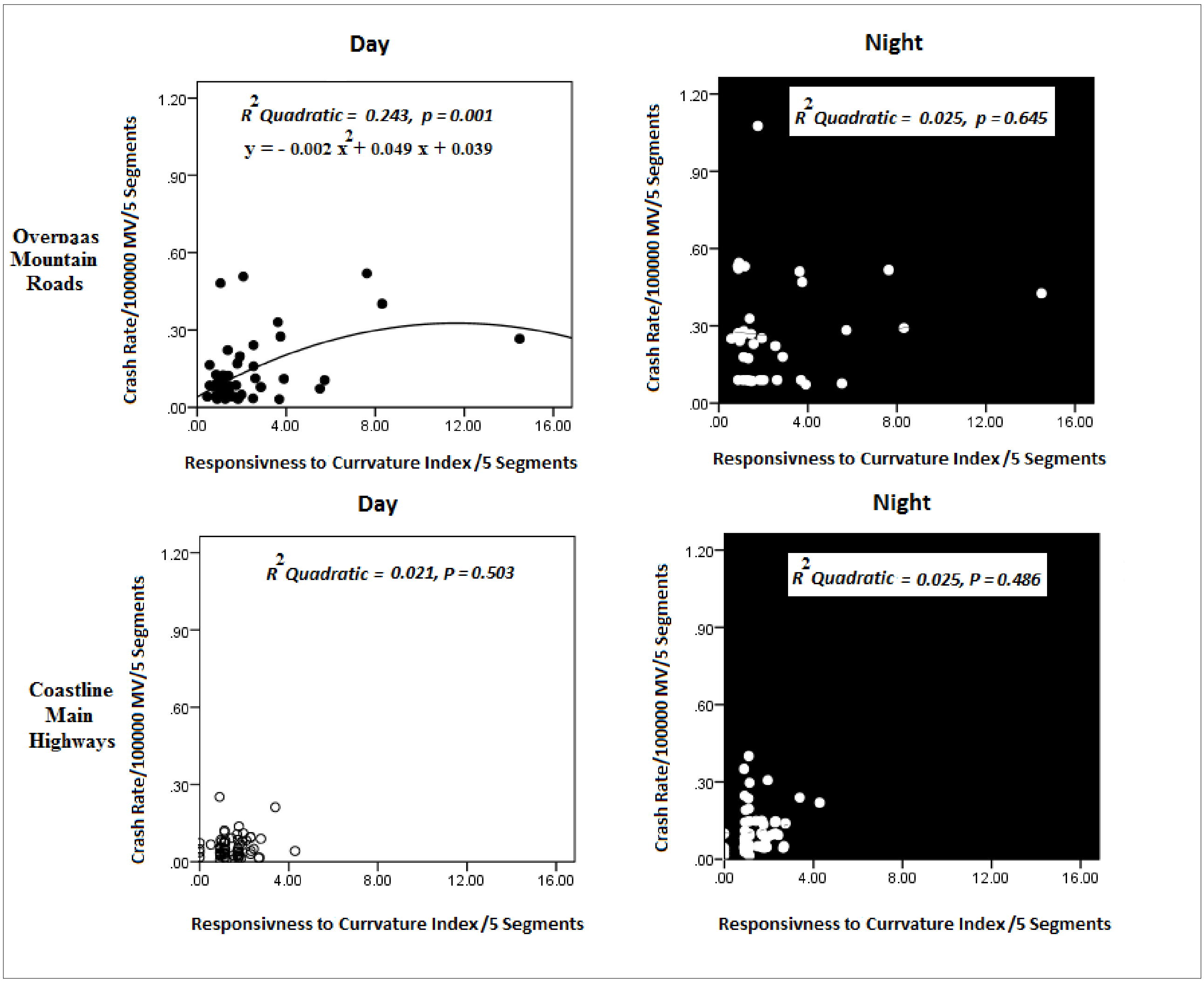


Table1. Summary of crash data, social economic and road geometry variables 2007-2011

		Crash data															**Road data**					
		% Crash freq.			**Crash rate /100,000 (MV)/ (Km)**			**Mean driver age (yrs.)**			**Driver gender crash freq. (M/F)**			**Mean travel speed (Km/h)**			**Mean sinuosity index**	**SD sinuosity index**	**Mean critical visual points**	**SD critical visual points**	**SD N/P gradient**	**% Straight /curves**
		Total	**Day**	**Night**	**Total**	**Day**	**Night**	**Total**	**Day**	**Night**	**Total**	**Day**	**Night**	**Total**	**Day**	**Night**						
Kings Highway	**Total**	100	**80**	**20**	0.020	**0.019**	**0.027**	37	**41**	**33**	1.45	**1.25**	**2.88**	82	*77*	*86*	1.058	0.098	6.33	4.60	-	2.85
	East (Q-BB)	**64**	**52**	12	**0.026**	**0.024**	0.030	36	42	31	2.16	**1.82**	2.5	79	74	84					1.77	
	West (BB-Q)	**36**	**28**	8	**0.014**	**0.013**	0.020	38	41	36	2.86	**0.64**	**3.66**	84	81	88					0.56	
Waterfall Way	**Total**	100	**82**	**18**	0.033	**0.032**	**0.046**	37	40	34	1.47	1.35	2.25	82	*82*	*81*	1.064	0.102	5.72	4.15	-	1.94
	East (A-U)	**55**	**47**	8	**0.037**	**0.036**	0.044	36	39	33	1.52	1.36	3	83	80	**87**					1.65	
	West (U-A)	**45**	**35**	10	**0.029**	**0.026**	0.047	39	42	36	1.42	1.33	1.80	80	84	**76**					0.61	
Princess Highway	**Total**	100	**77**	**33**	0.014	**0.013**	**0.023**	41	**46**	**36**	2.09	1.72	2.47	83	*81*	*85*	1.050	0.073	3.91	1.95	-	2.45
	South (K-B)	50	39	11	0.014	0.013	0.020	42	47	37	2.22	1.87	2.56	83	82	85					1.12	
	North (B-K)	50	38	12	0.014	0.012	0.022	40	45	36	1.97	1.57	2.38	83	80	86					0.09	
Pacific Highway	**Total**	100	67	33	0.010	0.009	0.011	40	**44**	**36**	3.22	2.26	4.18	85	*83*	*87*	1.020	0.030	2.76	1.14	-	6.14
	South (C-K)	49	32	17	0.010	0.010	0.013	42	47	38	4.13	**1.87**	**6.40**	86	86	87					0.07	
	North (K-C)	51	35	16	0.009	0.009	0.010	37	41	34	2.94	2.65	3.23	83	80	87					1.33	

Note. MV: Moving Vehicles, M/F: Male/Female, SD: Standard Deviation, N/P: Negative/Positive. The main significant results are highlighted in bold ($p < 0.05$)

Table2. Summary of crash data, road geometry and social economic variables 2007-2011

		% Speed or fatigue related crashes							
		Day				Night			
		Speed	No /unknown	Fatigue	No /unknown	Speed	No /unknown	Fatigue	No /unknown
Kings Highway	**East (Q-BB)**	56	44	11	89	41	59	23	77
	West (BB-Q)	57	43	10	90	36	64	21	79
Waterfall Way	**East (A-U)**	52	48	8	92	42	58	17	83
	West (U-A)	59	41	14	86	36	64	7	93
Princess Highway	**South (K-B)**	41	59	13	87	42	58	26	74
	North (B-K)	39	61	13	87	39	61	18	82
Pacific Highway	**South (C-K)**	23	77	17	83	43	57	27	73
	North (K-C)	25	75	21	79	47	53	35	65

Appendix 1. Quadratic correlation coefficients between crash rates and road geometry variables day/night

		Mean SI	Deviation SI	Mean CVP	Deviation CVP	Mean Grade	Deviation Grade
Kings Highway	Day Crashes	**0.291** **0.044**	0.199 0.121	**0.468** **0.003**	**0.512** **0.001**	**0.637** **0.000**	0.152 0.210
	Night Crashes	0.185 0.176	0.042 0.693	0.158 0.232	0.206 0.141	0.164 0.219	0.084 0.474
Waterfall Way	Day Crashes	**0.364** **0.004**	**0.225** **0.041**	**0.491** **0.000**	**0.380** **0.003**	**0.279** **0.017**	0.132 0.170
	Night Crashes	0.133 0.343	0.080 0.534	0.119 0.388	0.046 0.701	**0.580** **0.001**	0.311 0.061
Princess Highway	Day Crashes	0.046 0.327	0.038 0.391	0.000 0.991	0.009 0.807	0.078 0.141	0.034 0.438
	Night Crashes	0.025 0.609	0.054 0.340	0.028 0.578	**0.178** **0.022**	**0.215** **0.009**	**0.205** **0.012**
Pacific Highway	Day Crashes	0.061 0.325	0.005 0.966	0.301 0.068	0.009 0.807	0.046 0.700	0.099 0.459
	Night Crashes	**0.241** **0.039**	0.042 0.724	0.296 0.072	0.037 0.752	0.047 0.697	0.038 0.750

The first value in each box is R-squared and the second value is p-value. The results sre significant for ($p < 0.05$)

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[i] A more detailed description of the methodology is provided in Alian et al (in press).