Severity indices for motorcyclist collisions with roadside hazards and barriers

Bambach, M.R., Mitchell, R.J. & Grzebieta, R.H.

Transport and Road Safety (TARS) Research, University of New South Wales, Australia

Abstract

Roadside barriers are often deployed between road users and fixed hazards to protect users from injury. However, the Australian Roadside Design Guide (ARDG) does not consider motorcyclists in the risk-based decision process for the deployment of a barrier, since the severity indices for barriers and fixed hazards were developed for passenger vehicles. The provision of a safe road environment for all road users, including motorcyclists, is an objective of all road authorities, and is the basis of the Safe Systems approach. Therefore, there is a need to determine the risk of injury to motorcyclists from fixed objects and barriers, and to provide guidance to roadside designers. The aim of the present study is to develop severity indices for motorcyclists applicable to the ARDG. The study used a retrospective case series methodology, using linked police-reported road crash and hospital admission data in New South Wales, from 2001 to 2009. A total of 1,364 motorcyclists injured as a result of single-vehicle collisions with roadside barriers, trees, utility poles and other fixed roadside infrastructure were identified. Serious injury rates and logistic regression were used to develop severity indices and calculate relative risks of trees, posts, utility poles and roadside barriers to motorcyclists. It is shown that roadside barriers are generally safer for motorcyclists than the hazards that they shield. The methodology used for developing the severity indices was aligned with that used for passenger vehicles recently developed by other authors, such that a consistent approach may be proposed for the ARDG.

Introduction

Motorcyclist serious injuries and fatalities contribute significantly to road trauma in Australia. In 2007, Australian motorcyclists were 30 times more likely to be killed and 37 times more likely to be seriously injured than car occupants per distance travelled (Henley and Harrison 2009). Motorcycle usage rates have been increasing substantially in Australia, with an average annual increase in registrations of 7% between 1998 and 2007 (Johnston et al 2008). This rate of increase was around 2.5 times larger than that for registrations of passenger vehicles. The increase in motorcyclists on the roadways has, in part, led to an average annual increase in motorcyclist fatalities of 3% over this period, while all other road user fatalities decreased. By 2007, motorcyclist fatalities exceeded pedestrian fatalities, and were second in frequency only to passenger vehicle fatalities. Motorcycle deaths as a proportion of all road deaths increased from 10% to 15% over this period. These figures indicate that initiatives must be undertaken by motorcycling groups, road safety practitioners and road authorities in order to address motorcyclist safety and attempt to reduce the rising numbers of motorcyclist injuries and fatalities.

In a recent study of motorcyclist fatalities in Australia during the period 2001 to 2006 (inclusive), the high proportion of fatalities resulting from single-vehicle collisions with fixed objects in the roadside were highlighted (Bambach et al 2012a). As a proportion of fatalities where the crash mode was known (n=1,127), single-vehicle fixed-object collisions accounted for 441 fatalities (39%). Of these, the most frequently struck fixed objects were; trees (n=136), roadside barriers (n=73), posts (n=52), utility poles (n=43), culverts/drains (n=39), fences (n=36) and embankments (n=22).

These figures indicate that fixed hazards and infrastructure in the roadway environment pose a substantial risk to motorcyclists. The provision of a safe road environment for all road users, including motorcyclists, is an objective of all road authorities, and is the basis of the Safe Systems approach. However, currently the severity indices for barriers and fixed hazards in the Australian Roadside Design Guide (ARDG) do not consider motorcyclists, since they were developed for passenger vehicle occupants. Therefore, there is a need to quantify the risk of injury to motorcyclists from fixed objects and barriers, and to provide guidance to roadside designers.

In a recent study by the authors (Bambach et al 2013), linked police-reported road crash and hospital admission data in New South Wales identified 1,364 motorcyclists injured as a result of single-vehicle collisions with roadside barriers, trees, utility poles and other fixed roadside infrastructure. Serious injury rates and logistic regression were used to determine the *relative risk* of various fixed hazards compared with roadside barriers. Recently, a new approach to developing severity indices for Australian passenger vehicle occupants has been proposed by Austroads, which uses the *absolute risk* of serious injury using Fatality or Serious Injury (*FSI*) ratios (Jurewicz et al 2012). In addition to the use of absolute risk instead of relative risk, the procedure differs from that used previously by the present authors in the definition of what constitutes a 'seriously injured' road user. The aim of the present study is to develop severity indices for motorcyclists applicable to the ARDG and using a consistent methodology with that proposed for passenger vehicle occupants (i.e. the *FSI* ratio method). Comparisons are made with the severity indices developed for passenger vehicle occupants (Jurewicz et al 2012), the relative risk measures developed previously by the authors and methods using alternative measures of 'serious injury' (Bambach et al 2013).

Methods

Data collections

The Admitted Patient Data Collection (APDC) includes information on all inpatient admissions from all public and private hospitals, private day procedures, and public psychiatric hospitals in NSW. The APDC contains information on patient demographics, source of referral, diagnoses, external cause(s), separation type and clinical procedures. Diagnoses and external cause codes are classified using the International Classification of Diseases, 10th Revision, Australian Modification (ICD-10-AM) (National Centre for Classification in Health, 2006).

The CrashLink data collection contains information on all police-reported road traffic crashes where a person was unintentionally fatally or non-fatally injured, or at least one motor vehicle was towed away and the incident occurred on a public road in NSW. Information pertaining to the crash and conditions at the incident site, the traffic unit or vehicle, and the vehicle controller and any casualties resulting from the crash are recorded. Each individual is identified as being non-injured, injured or killed (died within 30 days). Data were extracted for motorcyclists involved in single-vehicle collisions with fixed objects that were injured or killed, and are termed 'motorcyclist casualties'. Data for motorcyclists that were non-injured were excluded, since these incidents are rarely reported to police and the group is thus difficult to identify and may suffer from selection bias. Data were extracted from both data collections from 1 January 2001 to 31 December 2009.

Data Linkage

The APDC was linked to CrashLink by the Centre for Health Record Linkage (CHeReL). The CHeReL uses identifying information (e.g. name, address, date of birth, gender) to create a person project number (PPN), for each unique person identified in the linkage process. The record linkage used probabilistic methods and was conducted using ChoiceMaker software (ChoiceMaker Technologies, 2012). A successful link with CrashLink was defined as when the PPN matched in both data collections, and the admission date in the APDC was on the same day or the next day as the crash date.

Fixed object identification

The following fixed objects in CrashLink were considered; guardrails (steel W-beam barriers), concrete barriers, wire rope (cable) barriers, culverts, embankments, posts, trees and utility poles. The culvert category also included drains; the embankment category also included cuttings, rocky outcrops and boulders; and the post category included guide posts, traffic signal poles and signposts.

CrashLink does not specify what type of barrier was struck by the motorcyclist, thus the barrier type (guardrail, concrete barrier or wire rope barrier) was identified using the street view feature in Google Earth using a methodology described in Bambach et al 2013. Only seven cases of collisions with wire rope barriers were identified. Since wire rope barriers are substantially more flexible than guardrails and concrete barriers, they might present a substantially different injury potential to motorcyclists, therefore they were not aggregated with these barriers. As an individual group the sample was too small from which to draw statistically significant conclusions, thus these crash records were discarded from the study population.

Severity indices (FSI ratios)

The severity indices were calculated according to the procedure outlined in Austroads (Jurewicz et al 2012) for passenger vehicle occupants and summarised herein. The procedure used data from VicRoads CrashStats and included single-vehicle run-off-road casualty crashes in 100km/h and 110km/h speed zones, where a passenger vehicle or light truck collided with a fixed object. Casualty crashes included any crash reported to police where at least one occupant was recorded as being injured by the police. Since a passenger vehicle casualty crash may also contain other occupants, who may or may not have been injured, the dataset contained more occupants than crashes and also contained non-injured occupants. Casualties were identified as ‘seriously injured’ if they were admitted to hospital, as reported by the police.

The severity indices (*FSI* ratios) were calculated from Equation 1;

$$FSI = \frac{\sum FSI_i}{\sum Persons_i}$$

where;
FSI = FSI ratio for roadside hazard i
$\sum FSI_i$ = Number of fatalities and serious injuries for hazard type i
$\sum Persons_i$ = Number of people involved in casualty crashes for hazard type i

Unlike the Victorian CrashStats, the NSW CrashLink does not identify if casualties were admitted to hospital. Therefore in the present study, motorcyclist casualties that were admitted to hospital were identified as those whose CrashLink record had a linked APDC hospital record, and were thereby designated as ‘seriously injured’. Motorcyclist crashes were considered for all speed zones, and then disaggregated into two speed zone groups; <100km/h and ≥100km/h.

Results

Descriptive characteristics

The total number of police-reported motorcyclist casualties resulting from single-vehicle collisions with the identified types of fixed objects in NSW between 2001 and 2009 was 1,364. The numbers of casualty collisions involving the fixed objects considered were; 352 (25.8%) trees, 291 (21.3%)

guardrails, 247 (18.1%) embankments, 226 (16.6%) posts, 111 (8.1%) culverts, 95 (7.0%) utility poles and 42 (3.1%) concrete barriers.

The descriptive characteristics of crashes and casualties using various variables available in CrashLink, disaggregated by type of fixed object, are presented in Table 1. Seventy-one percent of motorcycle casualty collisions were speed-related; 78.9% occurred on a curve; 70.5% occurred in a speed zone of less than 100km/h; 90.5% of motorcyclists were male; the majority of casualty collisions involved helmeted motorcyclists and occurred on dry, sealed roadways, in the daytime and not on highways/freeways nor at intersections.

Of the total 1,364 motorcyclist casualties, 756 (55.4%) were admitted to hospital to treat their injuries (seriously injured) and 130 were fatally injured (9.5%) (Table 1). The fixed objects resulting in the lowest proportion of *FSI* casualties were embankments (54.3%) and concrete barriers (54.8%), while the highest were utility poles (73.7%) and trees (70.5%).

Severity indices (FSI ratios)

The severity indices for the two speed zone groups considered are tabulated in Table 2, including 95% confidence intervals (CI) calculated using standard statistical methods. Since the concrete barrier casualties were small in number (n=42), more meaningful results were obtained by aggregating the concrete barriers and guardrail barriers into a ‘Barrier’ category. The results indicate that in speed zones of less than 100km/h, roadside barriers had a severity indice of 0.636 (95% CI 0.536-0.736), while culverts had a slightly lower value (0.603, 95% CI 0.408-0.799), embankments had a lower value (0.524, 95% CI 0.413-0.635), posts had a slightly higher value (0.671, 95% CI 0.546-0.796), trees had a higher value (0.706, 95% CI 0.596-0.816) and utility poles had a higher value (0.733, 95% CI 0.554-0.913) than roadside barriers. The values for speed zones of 100km/h or more were quite similar, while all values except that for trees were slightly higher than those in speed zones of less than 100km/h. The results for utility poles in speed zones of 100km/h or more should be treated with caution due to the small case counts.

The severity indices for all casualties without disaggregating into the two speed zone groups are tabulated in Table 3. The results are quite similar to the disaggregated results, since the results for the two speed zone groups were quite similar. Roadside barriers had a severity indice of 0.637 (0.551-0.723), while culverts had a slightly lower value (0.631, 95% CI 0.481-0.780), embankments had a lower value (0.543, 95% CI 0.450-0.635), posts had a slightly higher value (0.673, 95% CI 0.565-0.780), trees had a higher value (0.705, 95% CI 0.617-0.793) and utility poles had a higher value (0.737, 95% CI 0.562-0.912) than roadside barriers. The 95% confidence intervals were quite wide for both aggregated and disaggregated results due to the relatively small case counts, while those for the aggregated results were slightly narrower.

The *FSI* values for the various fixed objects relative to those for roadside barriers are tabulated in Tables 2 and 3 (calculated by dividing the *FSI* for each fixed object by the value for barriers). Again the results for the aggregated and disaggregated cases are quite similar. The aggregated results indicate that, compared with roadside barrier collisions, culvert collisions were approximately the same severity (0.99), embankment collisions were lower severity (0.85), post collisions were slightly higher severity (1.06), tree collisions were higher severity (1.11) and utility pole collisions were higher severity (1.16). An example calculation of the benefit-cost-ratio of a roadside treatment for motorcyclists is presented in the Appendix.

Table 1. Descriptive characteristics of motorcyclist casualties resulting from single-vehicle collisions with fixed objects, NSW 2001-2009

	Guardrail		Concrete		Culvert		Embankment		Post		Tree		Utility pole		Total	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Speeding related	235	80.8	24	57.1	71	64.0	195	78.9	144	63.7	239	67.9	59	62.1	967	70.9
Not	56	19.2	18	42.9	40	36.0	52	21.1	82	36.3	113	32.1	36	37.9	397	29.1
BAC over 0.05	13	4.5	*	2.4	9	8.1	13	5.3	47	20.8	50	14.2	23	24.2	156	11.4
Not	278	95.5	41	97.6	102	91.9	234	94.7	179	79.2	302	85.8	72	75.8	1208	88.6
Curve location	267	91.8	32	76.2	88	79.3	227	91.9	151	66.8	261	74.1	50	52.6	1076	78.9
Not	24	8.2	10	23.8	23	20.7	20	8.1	75	33.2	91	25.9	45	47.4	288	21.1
Dry roadway	259	89.0	39	92.9	100	90.1	229	92.7	205	90.7	314	89.2	89	93.7	1235	90.5
Not	32	11.0	*	7.1	11	9.9	18	7.3	21	9.3	38	10.8	6	6.3	129	9.5
Helmet	267	91.8	39	92.9	94	84.7	232	93.9	197	87.2	290	82.4	77	81.1	1196	87.7
No helmet/unknown	24	8.2	*	7.1	17	15.3	15	6.1	29	12.8	62	17.6	18	18.9	168	12.3
Operator	279	95.9	39	92.9	102	91.9	232	93.9	205	90.7	325	92.3	89	93.7	1271	93.2
Pillion	12	4.1	*	7.1	9	8.1	15	6.1	21	9.3	27	7.7	6	6.3	93	6.8
Male	268	92.1	40	95.2	103	92.8	221	89.5	198	87.6	316	89.8	89	93.7	1235	90.5
Female	23	7.9	*	4.8	8	7.2	26	10.5	28	12.4	36	10.2	6	6.3	129	9.5
Intersection location	17	5.8	*	2.4	14	12.6	8	3.2	61	27.0	27	7.7	29	30.5	157	11.5
Not	274	94.2	41	97.6	97	87.4	239	96.8	165	73.0	325	92.3	66	69.5	1207	88.5
Speed zone <100km/h	208	71.5	39	92.9	63	56.8	166	67.2	167	73.9	228	64.8	90	94.7	961	70.5
Speed zone≥100km/h	83	28.5	3	7.1	48	43.2	81	32.8	59	26.1	124	35.2	5	5.3	403	29.5
Highway/freeway location	92	31.6	16	38.1	17	15.3	47	19.0	38	16.8	36	10.2	10	10.5	256	18.8
Not	199	68.4	26	61.9	94	84.7	200	81.0	188	83.2	316	89.8	85	89.5	1108	81.2
Sealed roadway	287	98.6	41	97.6	100	90.1	230	93.1	222	98.2	289	82.1	87	91.6	1256	92.1
Not	*	1.4	*	2.4	11	9.9	17	6.9	*	1.8	63	17.9	8	8.4	108	7.9
Occurred in daytime	243	83.5	26	61.9	95	85.6	218	88.3	141	62.4	264	75.0	54	56.8	1041	76.3
Not	48	16.5	16	38.1	16	14.4	29	11.7	85	37.6	88	25.0	41	43.2	323	23.7
Equipment failure	7	2.4	0	0.0	*	2.7	*	1.6	*	0.4	*	1.1	0	0.0	19	1.4
Not	284	97.6	42	100.0	108	97.3	243	98.4	225	99.6	348	98.9	95	100.0	1345	98.6
Fatigue related	56	19.2	13	31.0	30	27.0	51	20.6	48	21.2	86	24.4	7	7.4	291	21.3
Not	235	80.8	29	69.0	81	73.0	196	79.4	178	78.8	266	75.6	88	92.6	1073	78.7
Seriously injured[a]	167	57.4	19	45.2	54	48.6	118	47.8	134	59.3	210	59.7	54	56.8	756	55.4
Not	124	42.6	23	54.8	57	51.4	129	52.2	92	40.7	142	40.3	41	43.2	608	44.6
Fatally injured	22	7.6	*	9.5	16	14.4	16	6.5	18	8.0	38	10.8	16	16.8	130	9.5
Not	269	92.4	38	90.5	95	85.6	231	93.5	208	92.0	314	89.2	79	83.2	1234	90.5
FSI	189	64.9	23	54.8	70	63.1	134	54.3	152	67.3	248	70.5	70	73.7	886	65.0
Not	102	35.1	19	45.2	41	36.9	113	45.7	74	32.7	104	29.5	25	26.3	478	35.0

* data have been removed to prevent identification of cell sizes less than five

[a] Seriously injured = admitted to hospital, identified by a linked APDC hospital record

Table 2. Severity indices (FSI ratios) for motorcyclist collisions with fixed objects disaggregated into two speed zone groups, NSW 2001-2009

	<100km/h speed zones						≥100km/h speed zones					
	FSI cases	Total cases	FSI ratio	FSI CL_U	FSI CL_L	FSI/ $FSI_{barrier}$	FSI cases	Total cases	FSI ratio	FSI CL_U	FSI CL_L	FSI/ $FSI_{barrier}$
Barrier	157	247	0.636	0.736	0.536	1.00	55	86	0.640	0.811	0.468	1.00
Culvert	38	63	0.603	0.799	0.408	0.95	32	48	0.667	0.904	0.430	1.04
Embankment	87	166	0.524	0.635	0.413	0.82	47	81	0.580	0.749	0.412	0.91
Post	112	167	0.671	0.796	0.546	1.06	40	59	0.678	0.893	0.463	1.06
Tree	161	228	0.706	0.816	0.596	1.11	87	124	0.702	0.851	0.553	1.10
Utility pole	66	90	0.733	0.913	0.554	1.15	4	5	0.800	--	--	1.25

CL_U = upper 95% confidence limit, CL_L = lower 95% confidence limit

Table 3. Severity indices (FSI ratios) for all motorcyclist collisions with fixed objects, NSW 2001-2009

	FSI cases	Total cases	FSI ratio	FSI CL_U	FSI CL_L	FSI/ $FSI_{barrier}$
Barrier	212	333	0.637	0.723	0.551	1.00
Culvert	70	111	0.631	0.780	0.481	0.99
Embankment	134	247	0.543	0.635	0.450	0.85
Post	152	226	0.673	0.780	0.565	1.06
Tree	248	352	0.705	0.793	0.617	1.11
Utility pole	70	95	0.737	0.912	0.562	1.16

CL_U = upper 95% confidence limit, CL_L = lower 95% confidence limit

Comparison with other methodologies

As discussed in the introduction, severity indices have previously been calculated using relative injury risk using logistic regression, and absolute risk using an alternative definition of serious injury (Bambach et al 2013). The relative risk values determined using logistic regression were derived from the same dataset as the present study, and were calculated from the odds ratios for each fixed object for an outcome of a motorcyclist sustaining at least one serious injury, where the reference fixed object was 'Barriers'. The absolute risk of selected fixed objects was also determined from the same dataset, and was expressed as the number of serious injuries per 100 casualty collisions with each of the fixed objects. In both cases a serious injury was defined as an ICD-10 injury that has a mortality rate of at least 3.5%, in accordance with the International Classification of Diseases Injury Severity Score (ICISS) methodology. Further details are provided in Bambach et al (2013).

These approaches are compared with the present approach in Table 4. Also included in Table 4 are the severity indices for passenger vehicle occupants using the *FSI* methodology (Jurewicz et al 2012), where values were for speed zones of 100km/h or more, and the value for barriers was taken as an average of rigid and semi-rigid barriers for comparison with the present results. A plot of the absolute risk of selected fixed objects for sustaining at least one serious injury in different body regions is presented in Figure 1 (Bambach et al 2013).

Table 4: Comparison of the present results with those using different methodologies, and comparison of results for motorcyclists with those for passenger vehicle occupants

	Absolute risk (FSI)		Relative risk		
	Present study	Austroads[1]	Present study	SI per 100 casualty collisions[2]	Logistic regression[2]
Casualty type:	MC	PVO	MC	MC	MC
Barrier	0.63	0.36	1.00	1.00	1.00
Culvert	0.63	--	0.99	ns	ns
Embankment	0.54	0.41	0.85	ns	ns
Post	0.67	--	1.06	1.67	1.26 (1.05-1.46)
Tree	0.71	0.52	1.11	1.65	1.34 (1.16-1.51)
Utility pole	0.74	0.55	1.16	2.07	1.40 (1.12-1.65)

MC = motorcyclist, PVO = passenger vehicle occupant, SI = serious injuries, ns = not statistically significant
[1] Austroads (Jurewicz et al 2012), [2] Bambach et al (2013)

Discussion

This study has provided needed information to further inform the ARDG in relation to the risk of serious injury to motorcyclists resulting from collisions with various roadside hazards. The *FSI* ratio results indicate that trees, posts and utility poles resulted in greater numbers of seriously injured motorcyclists than roadside barriers, when the motorcyclist was involved in a single-vehicle casualty collision. These results are generally supported by other methodologies, including logistic regression analysis (Bambach et al 2013), where trees, posts and utility poles were statistically significantly more likely to result in one or more serious injuries than roadside barriers (Table 4). These fixed objects also substantially more frequently resulted in serious injuries to the head, spine, torso and extremities than barriers (Figure 1). These results are generally in agreement with those by Bambach et al (2011), who showed that the *fatality* risk of poles and trees was statistically significantly greater than that for barriers, by 1.89 and 3.59 times, respectively. Similarly, Daniello and Gabler (2011a) found that the *fatality* risk of poles and trees were 1.51 and 2.03 times that for guardrails. In both studies posts and utility poles were aggregated, and only data from the United States was used.

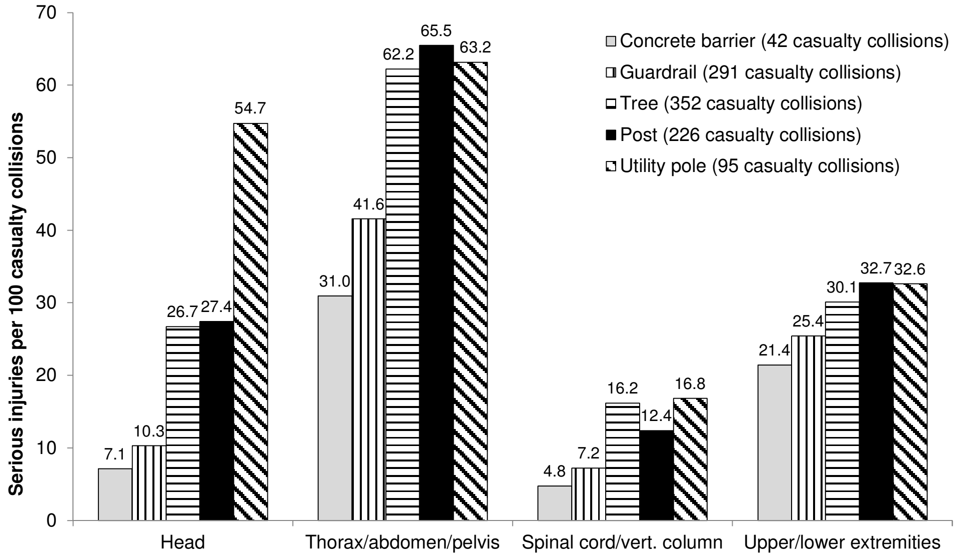

Figure 1: Number of serious injuries per 100 casualty collisions (serious injury is an ICD-10 injury code with mortality ≥3.5%) from single-vehicle motorcyclist casualty collisions with fixed objects, NSW 2001-2009 (Bambach et al 2013)

The magnitude of the serious injury potential of the fixed objects considered compared with barriers was substantially more pronounced in the Bambach et al (2013) study (Table 4) than in the present study, while the same dataset was used for both. This is due to the use of a different definition of serious injury than that used in the present study, where serious injury was defined as admission to hospital *and* at least one injury with a mortality rate greater than 3.5%. This outcome was considered in the logistic regression analysis, and other crash variables were considered as possible confounders. The results in Figure 1 also use this definition of serious injury, and the total number of serious injuries sustained was considered. These results indicate that while the different methods are generally in agreement with regards to the fixed objects considered providing greater injury potential to motorcyclists than barriers, the definition of serious injury has a substantial effect on the magnitude of the relative risk values obtained. When a more severe injury outcome is considered, the difference in the risk between trees/posts/utility poles and barriers is more pronounced.

While the concrete barrier collisions and guardrail collisions were aggregated in the *FSI* analysis due to the small case counts for concrete barriers, the *FSI* value for guardrail (0.649) was greater than that for concrete (0.548) (Table 1). This indicates that, within the limitation of the small case counts, the serious injury risk of guardrails to motorcyclists is greater than that for concrete barriers. Similar results were found in the study by Daniello and Gabler (2011a), where the *fatality* risk of concrete barriers compared to guardrails was 0.57. Daniello and Gabler (2011b) also found that the odds of *severe* injury (incapacitating injury or fatality) of concrete barriers relative to guardrail was 0.86.

It is noted that in comparison to the *FSI* values derived for passenger vehicle occupants (Table 4), the values for motorcyclists are substantially higher. This indicates that fixed objects generally provide a greater serious injury risk to motorcyclists than passenger vehicle occupants. This is likely a result of the fact that motorcyclists are unprotected by a vehicle structure, and therefore more susceptible to injury in a collision with a fixed object. Interestingly, the difference between the *FSI* values for passenger vehicle occupants and motorcyclists is quite different for trees/utility poles and roadside barriers. For trees/utility poles, the motorcyclist values are around 35% higher than those for passenger vehicles, while for barriers the value is 75% higher. This is likely due to the fact that roadside barriers are very effective in reducing injury potential for passenger vehicle occupants, for which purpose barriers are specifically designed, while less so for motorcyclists. In order to further improve motorcyclist safety, it is recommended that efforts to improve barrier design for motorcyclist collisions continue. Barrier crash test performance standards specifically addressing motorcyclist safety, such as those developed in Europe (prEN 1317-8 2010, UNE 135900-1,2 2008), might assist this process, as discussed by the authors in previous studies (Bambach et al 2012b, Grzebieta et al 2013). In the future it may also be possible to determine severity indices for 'motorcycling friendly' barriers or barrier modifications designed to reduce the injury risk for motorcyclist collisions, and thereby provide specific advice to roadside designers for such applications.

It is also noted that the serious injury risk of embankments to motorcyclists was found to be lower than that for barriers, while the converse was true for passenger vehicle occupants (Table 4). This might be related to the fact that embankments pose a substantial rollover risk to passenger vehicles, which typically results in a higher serious injury risk to the occupants than striking a barrier. Vehicle rollover is clearly not relevant to a motorcycle, and the embankment might provide an opportunity for the motorcyclist to tumble and/or slide to rest without sustaining serious injury.

The relative risks of trees, posts and utility poles compared with barriers determined in the present study (and the other studies discussed), indicate that roadside barriers provide a significant reduction in serious injury risk for motorcyclists, and thus a significant protective effect compared with these roadside hazards. This finding supports the deployment of barriers between motorcyclists and fixed roadside hazards, in the road network generally and particularly on popular motorcycling routes. Considering the substantial difference between the *FSI* values for passenger vehicle occupants and motorcyclists, it is recommended that motorcyclist-specific values are provided to roadside designers. This is especially true for roadways that form popular motorcycling routes. In the case that the ARDG adopts the *FSI* approach for the severity indices for roadway design (for example in the risk-based decision process for the deployment of a roadside barrier), it is recommended that the *FSI* values determined in the present study (column 1 in Table 4) be prescribed for motorcyclists.

Limitations

There are a number of limitations of the study that should be noted. It is well known that not all crashes are reported to police. In order to determine the linkage rate of CrashLink records to APDC records (ie the police reporting rate), motorcycle road traffic collisions with fixed or stationary objects were identified in the APDC using the ICD-10 external cause codes V27.4, V27.5 and V27.9. While the APDC does not differentiate between different types of fixed objects, the overall linkage rate of police-reported motorcyclists to motorcyclists admitted to hospital as a result of fixed object collisions was 53.6%. This indicates that the police-reported motorcyclist collisions used in the present study are a sample of all such crashes that required hospital treatment over the period considered, and may not be representative of all crashes in NSW. The exclusion of non-injured motorcyclists results in the risk estimates being relative to casualty crashes rather than all crashes. There were only 67 single-vehicle fixed object non-injury cases in CrashLink, which indicates that such crashes are very rarely reported to police and may suffer from selection bias. The 95% confidence intervals for the *FSI* ratios were typically quite wide, due to the limited case counts. Adding further data over time might improve the reliability of the *FSI* results.

Other limitations included: some of the data variables used relied on the varying and uncertain skills of police officers that attended the scene. There may be discrepancies between the manner in which different police jurisdictions record different particulars of a crash. The designation of injured (casualty) in the police-reported crash data is subjective and not clearly defined, and is based on the discretion of the reporting police officer. The probabilistic linkage method is not without possible linkage errors, however false positives and false negatives were estimated to be 0.4% and 0.5%, respectively.

Conclusions

In Australia, more than one third of motorcyclist fatalities result from a collision with a fixed object in the roadway environment. This study has determined that roadside barriers provide a significant reduction in the risk of motorcyclist serious injury and fatality compared with various roadside hazards. This finding supports the deployment of barriers to protect motorcyclists from fixed roadside hazards such as trees, posts and utility poles. Severity indices have been derived in order to facilitate the risk-based design process for the deployment of a roadside barrier in the Australian Roadside Design Guide, specific to motorcyclists. The values have been shown to be substantially different to values derived for passenger vehicle occupants, which supports the use of motorcycle-specific values, particularly on popular motorcycling routes. Motorcycle-specific roadside design procedures will assist road designers in improving the safety of the roadway environment for motorcyclists, and ultimately will help reduce the rising motorcyclist trauma burden.

Acknowledgements

The authors wish to thank the NSW Ministry of Health for providing access to information in the NSW Admitted Patients Data Collection, the Centre for Health Record Linkage for conducting the record linkage, particularly Katie Irvine and Michael Smith, and the Centre for Road Safety at Transport for NSW for providing access to CrashLink, particularly Margaret Prendergast, Bill Pink, Stewart Hay, Andrew Graham and Phil Sparkes. Part funding for this study was also provided by the Centre for Road Safety at Transport for NSW, Main Roads Western Australia, New Zealand Transport Agency and the Australian Automobile Association (AAA). Their contribution is gratefully acknowledged.

References

Bambach, M.R, Grzebieta, R., Olivier, J., McIntosh, A.S., 2011. Fatality risk for motorcyclists in fixed object collisions. Journal of Transportation Safety and Security, 3:1-14.

Bambach M.R., Grzebieta R.H., Tebecis R. and Friswell R., 2012a. Crash characteristics and causal factors of motorcycle fatalities in Australia. Australasian Road Safety Research, Policing and Education Conference, Wellington, New Zealand.

Bambach M.R, Grzebieta R. and McIntosh A.S., 2012b. Injury typology in fatal motorcycle collisions with roadside barriers in Australia and New Zealand. Accident Analysis & Prevention, 49:253-260.

Bambach M.R., Mitchell R. and Grzebieta R., 2013. The protective effect of roadside barriers for motorcyclists. Traffic Injury Prevention, In press, online.

Choicemaker Technologies, 2012. Open Source Choicemaker Technology: http://oscmt.sourceforge.net/. [retrieved 18/4/2012].

Daniello, A., Gabler, H.C., 2011a. Fatality Risk in Motorcycle Collisions with Roadside Objects in the United States, Accident Analysis and Prevention, v.43, pp. 1167–1170.

Daniello, A., Gabler, H.C., 2011b. Effect of Barrier Type on Injury Severity in Motorcycle to Barrier Collisions in North Carolina, Texas, and New Jersey, Transportation Research Record: Journal of the Transportation Research Board, No. 2262, Transportation Research Board of the National Academies, pp. 144–151.

Grzebieta, R.H., Bambach, M.R. and McIntosh, A.S., 2013. Motorcycle impacts into roadside barriers: Is the European crash test standard comprehensive enough?. Paper 5373, 2013 Annual Meeting of the Transportation Research Board, Washington DC, USA.

Henley G. and Harrison J.E., 2009. Serious injury due to land transport accidents, Australia, 2006–07. AIHW Injury Research and Statistics Series No. 53. Australian Institute of Health and Welfare Canberra, 2009.

Johnston P., Brooks C., Savage H, 2008. Fatal and serious road crashes involving motorcyclists. Research and Analysis Report, Road Safety Monograph 20. Department of Infrastructure, Transport, Regional Development and Local Government, Australia.

Jurewicz, C, Lim, A., McLean, J. and Phillips, C., 2012. Improving Roadside Safety: Stage 3: interim report, Austroads, Sydney, NSW.

National Centre for Classification in Health. ICD-10-AM, 2006., Fifth edition, Sydney: National Centre for Classification in Health.

prEN 1317-8, 2010. Road restraint systems - Part 8 : Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers, Revised draft, 04/03/2010.

UNE 135900-1,2 2008. Spanish Standard: Performance evaluation of motorcyclist protection systems in safety barriers and bridge parapets, Parts 1 and 2.

VicRoads (2010). "VicRoads road design note – Roadside utility poles". RDN 06-03, July 2010.

Appendix

This appendix presents an example for calculating the benefit-cost-ratio (BCR) of a roadside treatment using the severity indices derived in this study for motorcyclists. The case study is based on that given in Appendix E of VicRoads (2010), for which a BCR for passenger vehicles of 7.1 was determined. The case study considers a utility pole located 1m from the edge of a straight undivided roadway with speed limit 80km/h, daily traffic volume of 15,000 and 2 casualty collisions per 5 years. The cost of treatment is $60,000 for the installation of a roadside barrier with a life of 20 years. For motorcyclists the crash reduction factor from Table 3 is determined as 0.138 (i.e. 1 – (1/1.16)). This results in a BCR of 2.0 for motorcyclists. This indicates that the BCR for motorcyclists is less than that for passenger vehicles, since roadside barriers are less effective in reducing the injury potential to motorcyclists than for passenger vehicle occupants (see the Discussion). This was reflected in the present analysis by the difference in the crash reduction factor, which was 0.5 for passenger vehicles and 0.138 for motorcyclists.