Bambach and Grzebieta 1 FATALITY RISK MITIGATION FOR RURAL MOTORCYCLE COLLISIONS WITH TREES AND UTILITY POLES

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FATALITY RISK MITIGATION FOR RURAL MOTORCYCLE COLLISIONS WITH TREES AND UTILITY POLES

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ABSTRACT

Around 200 motorcycle fatalities result from rural roadway departures into trees or utility poles in the United States annually. A logistic regression model for calculating the fatality risk for motorcyclists colliding with fixed objects was previously developed by the authors. In this paper, the model is used to estimate the fatality risk of motorcyclists colliding with trees and utility poles following a departure from a rural roadway. Real-world data of fatal cases from 2000 to 2009 in the United Sates are collected, and a fatality risk analysis is performed to investigate the benefits that various road safety measures may have had in the reduction of the fatality risk in these cases. Safety measures include reducing speed, helmet use and the installation of barriers to protect the motorcyclists from impacting the trees or poles. The benefits are expressed in terms of the resulting reductions in fatality risk, calculated using the logistic regression model. The road safety measures are discussed in terms of their relative benefit to reducing the fatality risk of motorcyclists, in rural roadway departure collisions with trees and utility poles.

Keywords: Rural roadway departures, motorcycles, trees, utility poles, fatality risk

INTRODUCTION

In the United States, around 25% of the approximately 5,000 motorcyclist fatalities that occur annually result from a collision with a fixed object (*1*). This compares with 19% for passenger cars, 14% for light trucks, and 4% for large trucks, such that motorcycles are more likely to be involved in a fatal collision with a fixed object than are other vehicles (*1*). Around 25% of fatal motorcycle fixed object collisions involve trees, and 16% involve utility poles (*2*). Motorcyclist fatality rates for collisions with trees (15%) and poles (12%), have been found to be significantly more than those for roadside barriers (7%) and all fixed objects generally (7%) (*2*). Logistic regression models of fatality, conditional upon a fixed object motorcycle collision, have found that the odds of fatality for trees and poles are 3.6 and 1.9 times greater than for roadside barriers, respectively (*2*). Roadside barriers included steel guardrail and concrete traffic barriers. It is clear from these data that fixed object collisions, and particularly collisions with trees and poles, are a significant safety concern for motorcyclists. A range of factors have been identified as contributing to motorcycle crashes, their severity and the severity of the motorcyclists' injury(s): speed, age, time of year, experience, alcohol, illicit drug use, time of day, conspicuity, risk taking behaviour, roadside infrastructure and helmet use (*3-14*).

Analysis of the National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) from 2000 to 2009 (inclusive), indicates that 52% of the more than 11,500 fixed object motorcycle fatalities occurred on rural roadways. Since rural roadways have different functional and design issues compared to other types of roadways, this paper analyses motorcycle fatalities that occurred following a roadway departure on a rural roadway. Since trees and utility poles were identified as the most harmful fixed objects to motorcyclists (*2*), the analysis focuses on these objects, and ways in which fatality risk may be mitigated in collisions with these objects. Fatality risk mitigation techniques investigated are: changes to the roadside environment, including the installation of roadside barriers; rider behaviour/enforcement issues such as riding at the speed limit and wearing a helmet; and policy issues such as reducing the speed limit. The effectiveness of these techniques are quantified using the logistic regression models of fatality developed in (*2*), and expressed as reductions in the fatality risk. The techniques are discussed in terms of their relative benefit to reducing the fatality risk of motorcyclists, in rural roadway departure collisions with trees and utility poles.

The logistic regression model was developed previously by the authors (*2*), where the United States National Automotive Sampling System (NASS) General Estimates System (GES) was used to determine factors associated with fatality in single-vehicle, fixed object motorcycle crashes for the years from 2000 to 2009 (inclusive). The GES provides data about all types of crashes involving all types of vehicles, and is a probability sample that reflects the geography, roadway mileage, population, and traffic density in the US. Around 50,000 crashes are sampled each year, including those that result in a fatality or injury, and those involving property damage only. All human, vehicle and environmental variables were considered as parameters in the model. A dichotomous outcome of fatal (1) or not fatal (0) was used. Model parameters were included based on their significance levels, and parameter estimates were determined from the method of maximum likelihood. Model selection was based on Wald chi-square statistics, Akaike's information criterion (AIC) and likelihood ratio tests. The log-likelihood, Hosmer and Lemeshow goodness-of-fit test, and the area under the receiver operating characteristic curve (AUC), indicated that the selected model had good convergence, fit and predictive power (*2*). In the present paper the developed model is compared with data from the FARS database. These are real-world cases which present a real-world set of crash variables, for which a theoretical fatality risk is determined. The variables are then modified according to various fatality risk mitigation techniques, to determine the resulting reduction in fatality risk. In this way a general idea of the possible reductions in risk that can be achieved by such measures is determined.

METHODS

Data

The FARS database is a census of all crashes in the United States of motor vehicles travelling on a traffic way customarily open to the public, which resulted in the death of a motorist or a non-motorist within 30 days of the crash. The FARS database was queried for the years from 2000 to 2009 (inclusive), to determine all fatal motorcycle rural roadway departure collisions with trees and utility poles. These cases were identified in the database when they satisfied the following conditions: the roadway function class was defined as rural (rural arterial, rural collector, rural local road or street, or rural unknown); the vehicle body type was a motorcycle; the crash was a single-vehicle crash; and the most harmful event was a collision with a tree or utility pole. The cases were then reduced to those that contained known quantities for the variables required in the logistic regression model, including; travel speed, helmet use, motorcyclist age, speed limit (compared with travel speed to ascertain if the motorcyclist was speeding), motorcycle model year, lighting condition, location relative to an interchange, and roadway profile. The variable for the direction of the roadside departure could not be extracted from the FARS database. Since 68% of the fixed object motorcycle crashes in (*2*) involved departures to the right side of the roadway, this variable was set to 1 (right side departure) for all cases in the present analysis. Speed values were converted from miles/hr to km/hr, since these units were required for input into the logistic regression model.

Fatality Risk Analysis

The fatality risk (probability of fatality) for motorcycle fixed object collisions was determined from the multiple variable logistic regression model developed in (*2*) and discussed in the Introduction. The statistically significant explanatory variables, regression coefficients and significance values of the model are presented in Table 1.

It is noted that the following explanatory variables were found not to be significantly associated with a fatal outcome and were removed from the model (odds ratio, 95% confidence interval, p value): gender (1.766, 0.794-3.931, 0.164), roadway alignment (1.147, 0.642-2.049, 0.644), alcohol involvement (0.821, 0.44-1.531, 0.535), divided road location (1.810, 0.917-3.570, 0.087), surface condition (2.057, 0.671-6.303, 0.207), interstate highway location (0.461, 0.163-1.308, 0.146) and motorcycle defect (1.602, 0.735-3.492, 0.236).

The logistic regression function determining the probability of a fatal outcome is given by Equation 1.

$$P(fatal) = \frac{1}{1+e^{-z}} \qquad (1)$$

The logit (z) is given by Equation 2, and is the sum of the products of the regression coefficients (β_i) and the corresponding values of the explanatory variables (x_i), given in Table 1. The intercept is denoted β_0.

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_{15} x_{15} \qquad (2)$$

Typical to logistic regression, the magnitude of the variable estimates indicate the magnitude to which they affect the probability of fatality. Positive estimates indicate that the variable is associated with an increase in the probability of fatality, and negative a decrease. The exponent of the estimate provides the odds ratio for the variable, conditional upon the motorcyclist being involved in a single-vehicle rural collision with a tree or pole.

TABLE 1 Logistic Regression Model

#	Variable	Variable description and value x_i	Estimate β_i	p
0	Intercept		-8.7657	<.0001
1	travel speed	Police estimate of pre-crash travel speed (km/h)	0.0495	<.0001
	type of fixed object	Relative to a barrier (0, 0, 0)		
2		Pole (1,0,0)	0.6356	0.0839
3		Tree (0,1,0)	1.2774	0.0002
4		Other (0,0,1)	-0.1590	0.5828
5	helmet use	Motorcycle helmet worn (1) or not (0)	-2.7616	<.0001
6	motorcyclist age > 57	Motorcyclist was aged above 57 yr (1) or not (0)	5.5574	<.0001
7	speed related	Crash was speed related (1) or not (0)	0.5297	0.0419
8	motorcycle model > 2000	Motorcycle model later than 2000 (1) or not (0)	0.5228	0.0236
9	lighting	Crash occurred in daylight (0) or not (1)	3.2916	<.0001
10	interchange location	Crash occurred at an interchange (1) or not (0)	1.2209	0.0205
11	roadway profile	Crash occurred on level roadway (0) or not (1)	0.6693	0.0048
12	roadside departure direction	Departure was to the right (1) or left (0)	1.3456	<.0001
13	travel speed x helmet use	Interaction of variables previously defined	0.0225	0.0028
14	travel speed x age > 57	Interaction of variables previously defined	-0.0670	<.0001
15	travel speed x lighting	Interaction of variables previously defined	-0.0312	<.0001

For each fatal motorcycle case derived from the FARS database, the values for the explanatory variables were input into Equations 1 and 2 to determine the fatality risk. The fatality risk was then calculated for various fatality risk mitigation techniques by changing the values for the explanatory variables accordingly. The techniques considered include:

1. Install a roadside safety barrier to protect motorcyclists from the tree or utility pole. For this technique the explanatory variables for the type of fixed object (β_2, β_3, β_4) were all set to zero (Table 1).
2. Travel speed not exceeding the speed limit. For motorcyclists whose travel speed exceeded the speed limit, the travel speed (β_1) was reduced to the speed limit value. This technique assumes that enforcement and/or education programs can change rider behaviour.
3. Helmet use. For motorcyclists who were not wearing a helmet, the helmet use variable (β_5) was set to 1. This technique assumes that enforcement, education programs and/or policy changes can change rider behaviour.
4. All of techniques 1, 2 and 3.
5. A reduced speed limit. The speed limit was reduced by 10%, 20% and 30%, and then technique 2 above was repeated for each value. This technique assumes that policy changes can change speed limits, and enforcement and/or education programs can change rider behaviour.

It is noted that the final three explanatory variables in Table 1 (β_{13}, β_{14}, β_{15}) are interaction variables that contain travel speed and another variable, thus changing the values for these variables also changes those for the interaction variables.

RESULTS

Data Results

From the FARS database it was determined that for the years from 2000 to 2009 (inclusive), there were: 11,681 fatal fixed object motorcycle crashes; 1,964 fatal single-vehicle rural motorcycle collisions with trees or poles; and 782 of these 1,964 cases contained known values for the required model variables. In most cases, the variable for travel speed was the unknown variable responsible for a case not being included in the final dataset. Descriptive statistics for the 782 cases are presented in Table 2.

TABLE 2 Descriptive Results for Fatal Motorcycle Single-Vehicle Rural Roadway Departure Collisions into Trees or Utility Poles (*n* = 782)

	Proportion of cases		Mean (km/hr)
tree collision	72%	travel speed rural arterial	93.9
pole collision	28%	travel speed rural collector	96.6
rural arterial (principle or minor)	19%	travel speed rural local	92.5
rural collector (major or minor)	40%	speed limit rural arterial	81.3
rural local (road or street)	39%	speed limit rural collector	77.2
rural unknown	2%	speed limit rural local	67.5
travelling in excess of 100km/hr	37%		
motorcyclist was wearing a helmet	55% *(61%)*[a]		
motorcyclist was more than 57 years old	8% *(7%)*[a]		
speed related	63% *(46%[a])*		
motorcycle was manufactured after 2000	49% *(53%)*[a]		
occurred in daylight	58% *(73%)*[a]		
occurred at an interchange area	1% *(2%)*[a]		
occurred on a level roadway	59% *(53%[a])*		

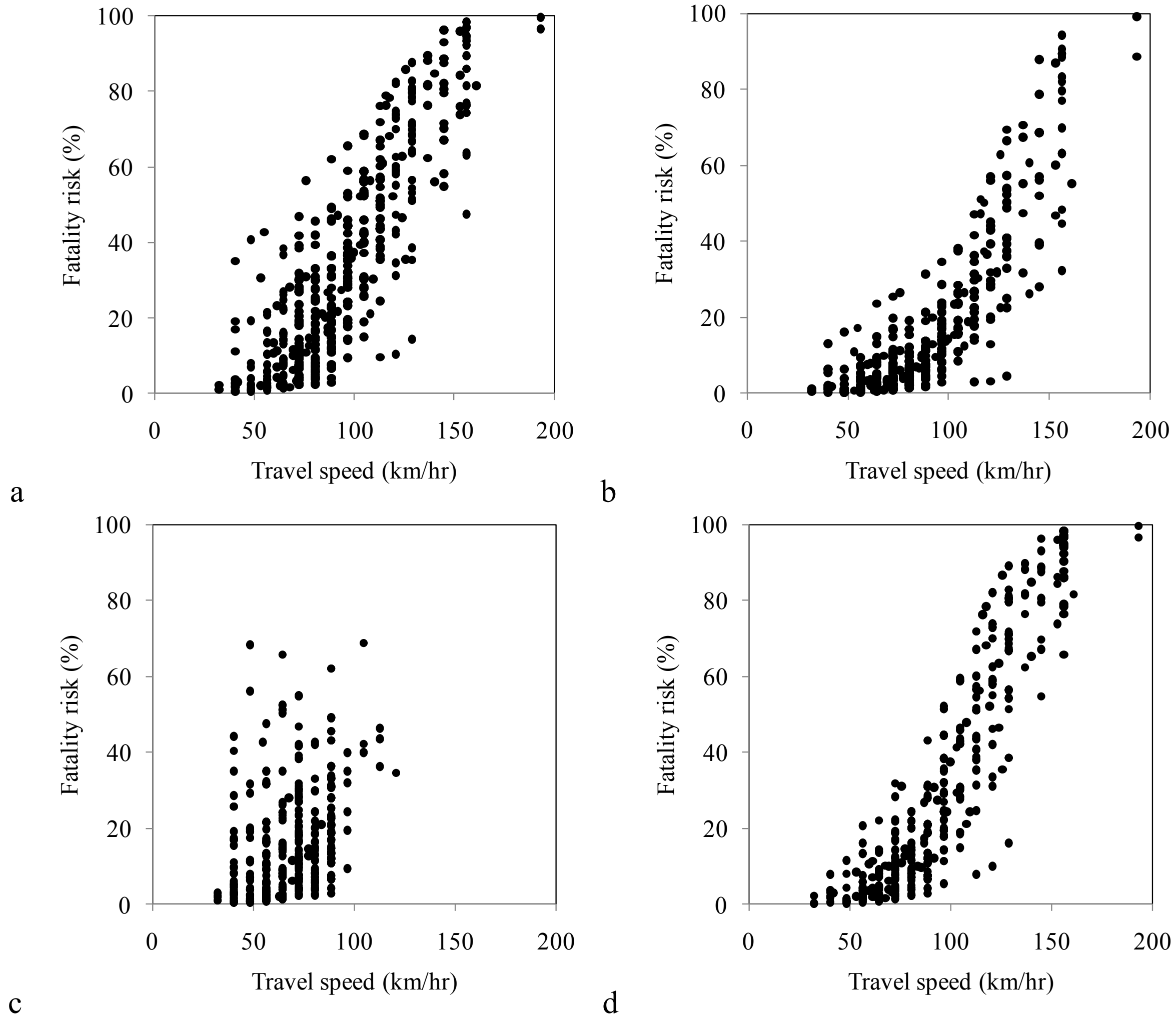
[a] comparison with corresponding nationally representative results from single-vehicle motorcycle fixed object collisions (*n* = 29,305) (*2*)

Fatality Risk Results

Summary results of the fatality risk analyses are presented as reductions in the fatality risk resulting from the various road safety measures investigated, compared with the original fatality risk (%). The reductions were calculated for each of the 782 cases, and group means are presented in Table 3.

TABLE 3 Reduction of Fatality Risk Results (*n* = 782)

	Reduction of fatality risk (%)			
Treatment	Mean	Standard deviation	Mean when travel speed <100km/hr	Mean when travel speed >100km/hr
a. Barrier	15.0	9.6	11.1	21.8
b. Speed not exceeding speed limit	29.9	16.3	10.8	44.1
c. Helmet use	10.6	6.7	11.9	6.1
d. All of a,b,c	31.7	26.2	16.1	58.7
e. 10% reduced speed limit	21.1	25.4	6.3	46.7
f. 20% reduced speed limit	23.3	26.4	8.0	49.9
g. 30% reduced speed limit	25.0	27.2	9.2	52.4



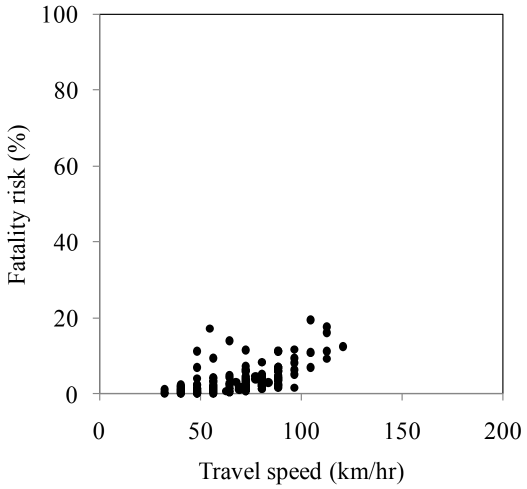


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FIGURE 1 Motorcyclist fatality risk profiles, conditional upon a rural roadway departure into a tree or utility pole, for road safety measures; a) None, b) Install a barrier, c) Speed not exceeding the speed limit, d) Helmet use, e) All measures (b, c and d).

Fatality risk profiles are presented for the various road safety measures investigated in Figure 1. In this figure, the fatality risk determined from the logistic regression model for each case is plotted against the travel speed. For the cases considering the fatality risk for a reduced travel speed (Figures 1c and 1e), the reduced travel speed is plotted. The numbers of cases falling within each decile of fatality risk are presented in Figure 2, for the various road safety measures investigated.

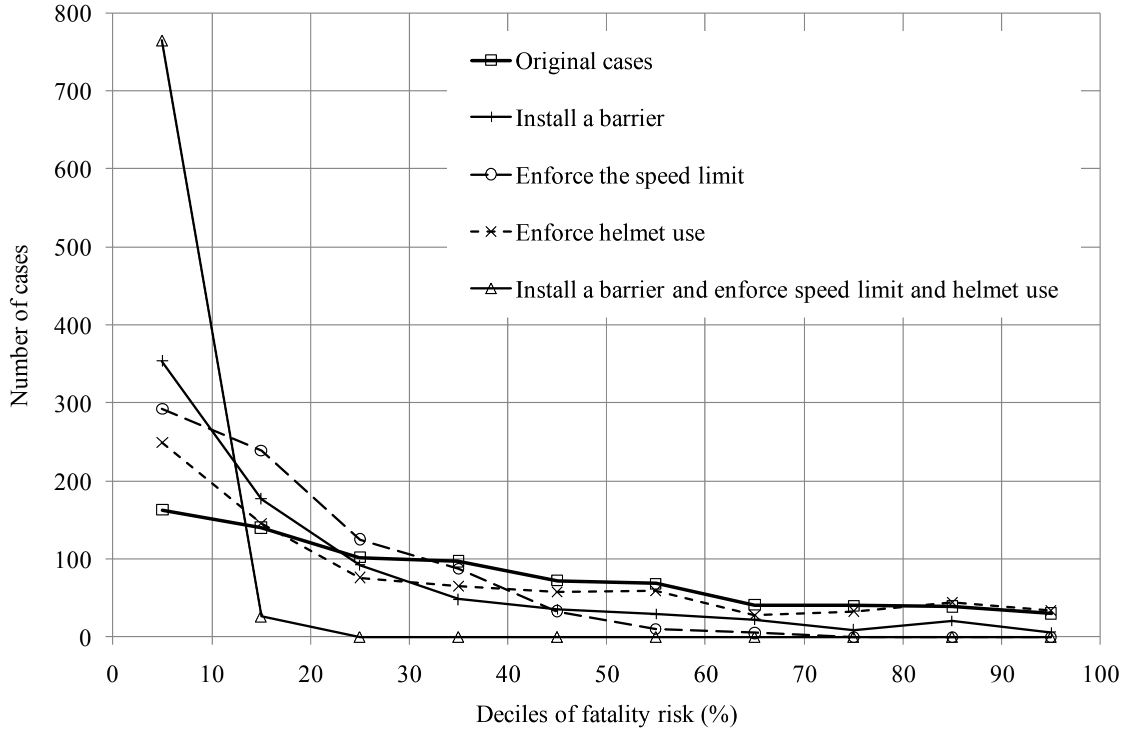

FIGURE 2 Number of cases within each decile of fatality risk.

DISCUSSION

The descriptive statistics presented in Table 2 show that the majority of fatal motorcycle tree and pole collisions on rural roads occur with trees. Most fatalities occurred on rural collector and rural local roads, with approximately equal numbers on each. Of the human, vehicle and environmental variables considered, in most cases the proportions were similar to the nationally representative values for all motorcycle fixed object collisions (*2*). A notable exception was the higher value for speed related crashes in the present study, where 63% were found to be travelling in excess of the speed limit. While the mean speed limit on rural local roads was around 14km/hr lower than that on rural arterial roads, the mean travel speeds were nearly the same. More than one third of the motorcyclists were travelling at high speed (in excess of 100km/hr).

The fatality risk analysis results presented in Table 3 and Figure 1 indicate that all the road safety measures investigated reduce the fatality risk of motorcyclists, in rural roadway departure collisions with trees and utility poles. Installing a barrier to protect motorcyclists from the tree or pole decreases the fatality risk for the entire group of 782 cases on average by 15.0%. The benefit of installing barriers is more pronounced in the group travelling at more than 100km/hr, where the reduction in fatality risk is nearly two times that for those travelling less than 100km/hr.

The effect of reducing the travel speed of speeding motorcyclists to the speed limit reduces the fatality risk on average by 29.9%, for the group of motorcyclists that were speeding. It is noted that 37% of the group were not speeding, and if they are also included the average is 18.2%. The reduction in fatality risk is 44.1% for the group travelling in excess of 100km/hr, which indicates that the effect of reducing travel speed is more pronounced for motorcyclists travelling at higher speeds. The result that higher travel speeds are associated with higher injury risk for motorcyclists has been noted by a number of authors (*9,10,12-14*)

Helmet use reduces the fatality risk on average by 10.6%, for the group of motorcyclists that were not wearing a helmet. If the 55% of motorcyclists who were already wearing a helmet are included, the average is 4%. The reduction in fatality risk is slightly lower for the group travelling in excess of 100km/hr, due to the interaction variable of travel speed and helmet use (variable 13 in Table 1). This interaction variable results in the benefit of helmet use becoming less pronounced at higher speeds, thus the reductions in fatality risk by enforcing helmet use become less also. A number of authors have noted reductions in motorcyclist injury risk with the use of helmets (*9-14*).

The effect of all three road safety measures, installing barriers and enforcing both the speed limit and helmet use, decreases the fatality risk on average by 31.7%. For the group of motorcyclists travelling in excess of 100km/hr, the average reduction is 58.7%. The effect of reduced speed limits provides modest reductions in fatality risk, where each 10% reduction in speed reduces the average fatality risk by around 2%.

The plots of fatality risk profiles in Figure 1 generally support the conclusions drawn from Table 3. Of particular note is the reduction in fatality risk to less than 70% for the entire group from travelling at the speed limit (Figure 1c). Similarly, the reduction to less than 20% for the entire group from all three safety measures (Figure 1e). These conclusions are similarly supported by the plots of the number of cases falling within each decile of risk in Figure 3.

As one might expect, the most influential method for reducing the fatality risk associated with rural roadway departure motorcycle collisions with trees and poles, is reducing travel speed. This is evident both in the mean reductions in fatality risk, and the net reductions in fatality risk. That is, while barriers and helmet use reduce the fatality risk, if the motorcyclist is travelling at high speed the fatality risk will remain high. Reducing riding speeds to the speed limit provide significant net reductions in fatality risk, and if barriers and helmets are additionally employed, the fatality risk of trees and poles to motorcyclists on the rural road network can be minimised to 20%.

There are clearly significant behaviour, education, enforcement and policy issues associated with implementing the hypothetical road safety measures considered herein. The question of how to slow road users down is an ongoing issue in road safety, and it is hoped that studies such as the present one can help to educate road users on the benefits of not exceeding speed limits. Police enforcement to maintain speeds within posted limits would also be part of the solution. The same issues apply to helmet use, where there are also significant policy issues in the United States regarding mandatory helmet use. The installation of barriers has the advantage that it does not rely on road user behaviour to be effective, however has significant cost implications, particularly on the extensive rural road networks. The modest effect on fatality risk of reducing speed limits does not support policy action in this area, and suggests that efforts should concentrate on the three issues of speeding, helmet use and barrier protection.

The limitations of the study should be noted. Firstly, there are a number of limitations related to the logistic regression model that was based on the GES data. The GES data is a probability sample, not a census. There are errors involved in the weighting values used in the statistical analysis; however, comparison with an unweighted model indicated the conclusions were not significantly affected (*2*). The GES sample was taken from police reported crashes; however, not all crashes that occur are reported to police. Travel speeds were determined by the police investigators, and involve inherent inaccuracies. There may be discrepancies between the manner in which different police jurisdictions record different particulars of a crash. There may be additional variables that are associated with fatality, that were not available in the GES data. The statistical method used determines associations with fatality; however, this does not conclusively imply causality. Secondly, there are number of limitations related to the comparison of the model with the FARS data in the present paper. As with the GES data, in FARS the travel speed estimations rely on the varying and uncertain skills of attending police officers. The calculations of fatality risk in the present paper, and therefore the risk reductions, are entirely theoretical and rely on the accuracy of the logistic regression model, which has a number of limitations as outlined above. The theoretical risk reductions might be validated in a real-world setting by before-and-after studies of fatality rates at tree/pole installations, where speed limits have been reduced or barrier protection has been employed. Such studies might confirm the model and provide insight as to how the model might be improved. Other factors could also be included in the model in the future. For example, removing trees/poles was not investigated since it could not be determined what hazards lay behind, thus the risk after removal could not be determined. However, if such information was known it could be included in the model to assess the resulting risk reduction. It should finally be noted that the safety measures investigated would be impossible to achieve in 100% of cases as has been assumed. Rather, the potential risk reductions have been presented to indicate what could be achieved in a hypothetical ideal situation.

CONCLUSIONS

The benefits of various road safety measures in reducing the fatality risk of motorcyclists in rural roadway departure collisions with trees and utility poles, have been demonstrated. The most effective measure for reducing fatality risk was reducing travel speeds to the posted speed limits. Were motorcyclists to travel at the speed limit, the fatality risk would reduce by 30% on average, and up to 44% for those who were travelling at high speed. Helmet use and installing barriers were also found to provide reductions in fatality risk, by 11% and 15% respectively. If all three safety measures could be achieved, the fatality risk of trees and poles to motorcyclists on the rural road network could be minimised to less than 20%. In this case, many of these 200 fatalities that occur annually could be avoided.

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