Risk Factors to Driver Fatalities in Single-Vehicle Crashes: Comparisons between Non-Motorcycle Drivers and Motorcyclists

Hsin-Li Chang[1] and Tsu-Hurng Yeh[2]

Abstract: Single-vehicle crash data for 2000 from Taiwan's Road Accident Investigation & Reporting System were employed to compare fatality risk factors between non-motorcycle drivers and motorcyclists. On average, motorcyclists had approximately a three times higher fatality risk than non-motorcycle drivers after adjusting for the driving mileage. Two respective logistic regression models for these two categories of drivers indicated that some common features, such as being male, a higher age, and crashes occurring between the hours of 2200 and 0600 revealed a greater likelihood of fatality. On the other hand, the risk discrepancies between these two drivers included the restraint-use effect, speeding, and impairment as the main crash cause, roadway class, and vehicle type. To reduce the high risk of fatality sustained by these two classes of drivers, enhancing the driver's seatbelt-use rate, the management of running speed, the rider's risk perceptions, and the road quality and facilities of the lowest roadway class are particularly recommended.

DOI: 10.1061/(ASCE)0733-947X(2006)132:3(227)

CE Database subject headings: Risk management; Fatalities; Traffic accidents; Taiwan.

Introduction

The injury severity for drivers in single-vehicle crashes has been widely studied for at least three reasons. First, single-vehicle crashes usually represent higher injury severity than multiple-vehicle crashes, so they naturally become the priority target for developing safety improvement strategies. Second, with no other vehicles involved, driver behavior or human factors that contribute to crash severity in single-vehicle crashes can be explored much more effectively. Third, focusing on the injury severity of drivers can simplify the research design by excluding the confounding effects of seating and other vehicles.

According to Taiwan's Road Accident Investigation and Reporting System (RAIRS) in 2000, single-vehicle crashes comprised 12.1% of total crashes, but accounted for 31.8% of total fatalities. In addition, driver fatalities accounted for 75.6% of all single-vehicle occupant fatalities. The high injury severity sustained by drivers of this kind of crash reveals that some specific and interesting risk factors are worth exploring.

Risk factors relating to the occurrence or injury severity of single-vehicle crashes have been raised by many studies. These include driver characteristics (e.g., age and gender), the main causes of crashes (e.g., alcohol use and speeding), roadway environment (e.g., weather, time of day, roadway type, and accident location), vehicle type, and crash type (Lawson 1985; Mckenna 1987; Bédard et al. 2003).

Driving behavior linked to single-vehicle crashes has also been a central issue in a few studies. Evans (1991) chose single-vehicle crashes to demonstrate the similarity between crash rates and crime rates because this kind of crash revealed much more the behavioral aspects of crash involvement. Lang et al. (1996) examined risk-taking behavior measured by demographic, psychosocial, and substance use factors to show that the high crash rate of adolescent drivers may be associated with this kind of behavior in single-vehicle and injury crashes. Bergdahl and Norris (2002) applied single-vehicle fatal crash data spanning 1982–1991 in the United States to analyze whether females tended to adopt similar behavior to males (the so-called "convergence hypothesis" in their study) over the study periods. They found that females' relatively increasing exposure to driving, but not risk-taking behavior adopted by females, was the main reason for the diminishing differences between male and female fatalities.

Most studies on single-vehicle crashes have focused on motor vehicles rather than on motorcycles. Shankar and Mannering (1996) employed a multinomial logit model to analyze the effect of environment, roadway, vehicle, riders' attributes, and their interactions on the injury severity of motorcycle riders involved in single-vehicle crashes. Harrison (1997) found that disqualified drivers and motorcyclists were over-represented in single-vehicle and hit-object crashes. On the other hand, specific single-vehicle crash types such as rollovers and run-off-roadway for motor vehicles, have received more attention in recent years. Farmer and Lund (2002) explored the likelihood of rollover occurrence in fatal and injury crashes between 1995 and 1998. They showed that light trucks were twice as likely as cars to experience rollovers, owing partly to physical differences after controlling for the driver and roadway environment factors. Lee and Mannering

[1]Professor, Dept. of Transportation Technology and Management, National Chiao-Tung Univ., 1001, Ta Hsueh Rd., Hsinchu, Taiwan 30050, ROC (corresponding author). E-mail: hlchang@cc.nctu.edu.tw

[2]Doctoral Student, Dept. of Transportation Technology and Management, National Chiao-Tung Univ., 1001, Ta Hsueh Rd., Hsinchu, Taiwan 30050, ROC. E-mail: yth@iot.gov.tw

Note. Discussion open until August 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on November 2, 2004; approved on June 10, 2005. This paper is part of the ***Journal of Transportation Engineering***, Vol. 132, No. 3, March 1, 2006. ©ASCE, ISSN 0733-947X/2006/3-227–236/$25.00.

(2002) combined road accidents data with abundant roadway geometric databases in Washington State to analyze the geometric factors that affect the occurrence and injury severity of run-off-roadway crashes.

Comparatively little research has been conducted on the motorcyclists' risk factors to single-vehicle crashes, possibly because of the low ownership rate of motorcycles in most western countries. Furthermore, little has been noted on the comparisons between these two kinds of drivers who are involved in a single-vehicle crash. This knowledge is especially valuable for those countries where motorcycles are heavily used. Understanding the differences in risk factors between these two kinds of drivers is helpful for constructing effective safety strategies towards specific high-risk drivers. Among various safety strategies, enhancing driver's risk perception seems especially important in reducing crash involvement and severity. Risk perception differences between car drivers and motorcyclists (Armsby et al. 1989), as well as novice and experienced drivers (Benda and Hoyos 1983; Finn and Bragg 1986), have been identified. Armsby et al. (1989) indicated that since motorcyclists were vulnerable to road-based hazards, they perceived features of the road environment better than car drivers. In addition, it has also been found that novice drivers did not perform as well on hazard perception tasks compared with more experienced drivers (Benda and Hoyos 1983; Finn and Bragg 1986).

Motorcycles in Taiwan play a very important role in daily transportation and traffic operation. More than 99% of motorcycles in Taiwan are less than 150 cubic centimeters (cc). Because of the advantages of high accessibility and low cost for this displacement, motorcycles are widely owned and used. According to Taiwan's Traffic Policy White Paper [Ministry of Transportation and Communications (MOTC 2002)] 11.4 million motorcycles were registered (that is, 1.7 motorcycles per household) and made up 67% of all motor vehicles in Taiwan at the end of 2000. Motorcycle use revealed different characteristics as compared with passenger cars. In the year 2000, the average running distance per day for a motorcyclist was 7.1 km and weighted average running distance for a non-motorcycle driver was 43.9 km (MOTC 2001a,b). In addition, the ridership rate for passenger cars was around 2.2 occupants per vehicle on average, while for motorcycles the rate was 1.3 occupants (MOTC 2003).

Therefore the dissimilarity between these two vehicle types as to operational manner, the influence of driving roadway, environment, and vehicle protection design, as well as driver characteristics and driving behavior could result in different risks to drivers and motorcyclist fatality. To compare the overall fatality risks between these two kinds of drivers, the relative fatality risk was measured by an exposure-based (i.e., average running distance per day) method. Besides, two separate logistic regression models were constructed to explore the risk factors which expanded the likelihood of driver and motorcyclist fatalities in single-vehicle crashes, and to compare the differences in risk factors between these two kinds of drivers.

Since the distinction in risk factors between these two kinds of drivers has implications for safety strategies, the objective of this study was to uncover the risk factors to driver fatality, provided that a single-vehicle injury crash occurred. In addition, to understand the risk difference between these two kinds of drivers, this paper will place considerable emphasis on the comparison of risk factors contributing to non-motorcycle driver and motorcyclist fatalities, and also on possible explanations as to how and why they arise.

Table 1. Detailed Categories for Single-Vehicle Crashes in RAIRS

Main category	Subcategory
Rollover or spillover	—
Run-off-roadway	—
Hit traffic facilities	Barrier
	Traffic signal or signage pole
	Toll station
	Traffic island
	Nonfixed facility
Hit other objects	Bridge or building
	Tree or utility pole
	Parking vehicle
	Animal
	Construction work
	Others

Methods

Data

Crash data in the Taiwan police-reported accident database, RAIRS, were divided into three categories (A1, A2, and A3). The latest definitions of A1, A2, and A3 accidents, revised in 2000, are at least one person died within 24 h, at least one injury occurring, and only property damage occurring in the accident, respectively. The difference between the new and its previous definition is that in the previous version, A1 data could represent either the death of at least one person within 24 h of the accident, or at least one severe injury in the accident. RAIRS has been operating since 1985 but only A1 accident data have been fully recorded. A2 accident data were not formally recorded until 1998; A3 data, however, had not yet been incorporated into RAIRS by the end of 2002.

The classification of crash types in RAIRS is divided into four different categories (i.e., pedestrian and vehicle, vehicle and vehicle, single-vehicle, and vehicle and train). This study retrieved single-vehicle crashes recorded from A1 and A2 data of RAIRS for 2000 in order to analyze factors contributing to driver fatalities. According to the classifications of single-vehicle crashes, there are 13 detailed items recorded in the database (see Table 1).

The total number of crashes for 2000, 47,929, included 3,207 A1 crashes and 44,722 A2 crashes respectively, and among these, 5,785 were single-vehicle crashes (that is, 12.1% of the overall A1 and A2 crashes). Single-vehicle crashes did not appear especially prominent in Taiwan, but the severity of this kind of crash was significantly prominent (31.8% of total occupant fatalities). This phenomenon was similar to that of the United States. Evans (1991) indicated that in terms of accident severity, single-vehicle crashes became more prominent as compared with two-vehicle crashes and the occupant fatality percentage in single-vehicle crashes accounted for 44.7% of total vehicle occupant fatalities.

The 5,785 crashes can be further divided into non-motorcycle and motorcycle crashes. Since each single-vehicle crash involved only one driver, there would have been 3,140 motor vehicle drivers and 2,645 motorcyclists to be used as a data resource. Among the total fatalities in single-vehicle crashes, driver fatalities comprised 75.6% of all single-vehicle occupant fatalities, and motorcyclist fatalities accounted for 55.5% of overall single-vehicle driver fatalities.

J. Transp. Eng. 2006.132:227-236.

The dissimilarity between at least four-wheeled motor vehicles and motorcycles was mentioned earlier. A pooled model calibrating the likelihood of fatality for the two different kinds of drivers may cause part of the risk factors to be regressed to the mean. For example, since motorcycles are prohibited running onto freeways, a pooled model combining non-motorcycle drivers and motorcyclists may underestimate the fatality risk of non-motorcycle drivers on freeways after accommodating almost all accident-free samples of motorcyclists in this roadway class. To avoid the regression-to-mean effect caused by a pooled model, it is essential to build two separate models based on the likelihood of non-motorcycle driver and motorcyclist fatalities. The dependent variable concerned was "fatal" or "nonfatal" binary outcomes of a driver in a crash. Four risk factor categories—driver's characteristics, roadway environment, vehicle type, and single-vehicle crash type—selected as the explanatory variable categories for the two specific models, are illustrated as follows:

1. Drivers' characteristics: including gender, age, driver's qualification, seatbelt use (helmet use for motorcyclists), and the main cause of the accident;
2. The roadway environment: including time of a crash, roadway class, and roadway geometric pattern;
3. Vehicle type: classified into passenger car, light truck, large truck, and others for non-motorcycles; and divided into moped (i.e., equal or less than 50 cc) and light motorcycle (i.e., almost all ranged from over 50 to 150 cc) for motorcycles; and
4. Single-vehicle crash type: divided into rollover (spillover, which means falling down, for motorcyclists), run-off-roadway, hit barrier, hit tree or utility pole, and others.

Since the coding records in RAIRS are divided into many detailed items, most risk factors for this study were pooled in advance based on past studies, or on our own hypotheses, prior to running the models. For example, there are 48 candidate items in the raw data for the main cause of a crash, but only four concerned causes were chosen to make up the new classification. They were speeding, impaired driving (three items were combined here—drug use, alcohol use, and fatigue), negligent driving, and others. Similarly, 13 items from single-vehicle crash types, as mentioned above, were also recategorized into just five types: rollover (spillover for motorcyclists), run-off-roadway, hit barrier, hit tree or utility pole, and others. The variable of age was categorized by six groups (<20, 20–29, 30–39, 40–49, 50–59, and 60+) while computing the frequency table, but treated as a continuous variable when applying the regression model for the concise purpose. Except for the driver's age, all other variables in the regression models were categorical data.

Statistical Method

The logistic regression model was employed in this study to estimate the relative likelihood of fatalities for drivers and motorcyclists between specific levels of a risk factor. This regression model is widely used if the dependent variable is dichotomous in the regression equation. It is one form of statistical model called "generalized linear model" with a logit [also called "log odds," i.e., $\ln p/(1-p)$] link function. This model has many advantages over ordinary least-squares regression models while the dependent variable violates the assumptions of continuous or normal distribution, and conditional constant variances. Logistic regression allows one to predict a binary outcome from a set of explanatory variables that may be continuous, categorical, or a mixture of the two. The basic model form and statistical test method for logistic regression is introduced as follows (McCullagh and Nelder 1989).

The dependent variable in logistic regression is dichotomous; that is, it is assumed to follow a Bernoulli distribution. Therefore it takes the value 1 with a probability p of an event occurred, and the value 0 with probability $1-p$ of an event not occurred. The form of the logistic regression equation is

$$\ln\{p(x)/[1-p(x)]\} = \alpha + \sum_{i=1}^{n} \beta_i x_i$$

where $p(x)$=probability of a driver fatality, which is a function of a set of risk factor vectors, x, in a single-vehicle crash; α=constant of the equation; and β_i=coefficient of the ith risk factor.

The coefficients of the logistic model can be obtained by using the maximum likelihood estimation (MLE) method. A Wald test is usually used to test the statistical significance of each coefficient, β_i, in the model. The squared of Z statistic yields a Wald statistic of asymptotic chi-square distribution with one degree of freedom, that is

$$\text{Wald} = [\hat{\beta}_i/\text{SE}(\hat{\beta}_i)]^2 \sim \chi_1^2$$

where $\hat{\beta}_i$=ith estimated coefficient; and $\text{SE}(\hat{\beta}_i)$=standard error of the ith estimated coefficient.

As for the overall test of the model, the likelihood-ratio test is widely used. This test employs the ratio of the maximized value of the likelihood function for the model with constant term only [$L(c)$, where c=constant term] over the model with a constant and estimated coefficient [$L(\hat{\beta})$, where $\hat{\beta}$=vector sum of constant term and $\hat{\beta}_i$]. The negative twice value of the log transformation of the likelihood ratio yields an asymptotic chi-squared distribution with degree of freedom n. That is

$$-2\log[L(c)/L(\hat{\beta})] = -2\lfloor\log[L(c)] - \log[L(\hat{\beta})]\rfloor \sim \chi_n^2$$

where $\log[L(c)]$ and $\log[L(\hat{\beta})]$=values of the log likelihood function at its maximum,respectively; and n=number of estimated coefficients for explanatory variables.

The goodness-of-fit measure, ρ^2, was also used in this study. It is defined as follows (Ben-Akiva and Lerman 1985):

$$\rho^2 = 1 - \log[L(\hat{\beta})]/\log[L(c)]$$

To interpret the model conveniently, logit [i.e., $\ln p/(1-p)$] can be converted easily into a statement about odds ratio (OR) of the dependent variable simply by using the exponential function. For example, if the x_i variable increases one unit while holding the remainder variables constant, the OR of these two levels for x_i will be $\exp(\hat{\beta}_i)$ and the 95% confidence interval (CI) for OR will be $\exp[\hat{\beta}_i \pm Z_{0.95} \cdot \text{SE}(\hat{\beta}_i)]$.

Results

Basic Information

According to the four risk factor categories assumed in this study, the frequency distributions of a cross-table between the specific risk factors and the dependent variable have been, respectively, demonstrated for drivers (see Table 2) and motorcyclists (see Table 3). It appears that the proportion of fatal injuries in

J. Transp. Eng. 2006.132:227-236.

Table 2. Frequencies of Risk Factors to Drivers

Risk factor	Degree of injury: Nonfatal	Fatal (percentage)	Total
Total	2,778	362 (11.5)	3,140
Gender			
Male	2,451	337 (12.1)	2,788
Female	327	25 (7.1)	352
Age			
<20	97	24 (19.8)	121
20–29	832	136 (14.0)	968
30–39	845	90 (9.6)	935
40–49	636	73 (10.3)	709
50–59	173	22 (11.3)	195
60+	195	17 (8.0)	212
Driver's qualification			
Disqualified	99	25 (20.2)	124
Qualified	2,679	337 (11.2)	3,016
Seatbelt use			
Not-wearing	2,320	327 (12.4)	2,647
Wearing	458	35 (7.1)	493
Main cause of accident			
Speeding	468	208 (30.8)	676
Impaired driving	570	40 (6.6)	610
Negligent driving	291	58 (16.6)	349
Others (43 items in RAIRS)	1,449	56 (3.7)	1,505
Time of crash			
22:00–06:00	1,263	194 (13.3)	1,457
Other time	1,515	168 (10.0)	1,683
Roadway class			
Freeway	340	31 (8.4)	371
Provincial road	474	117 (19.8)	591
County road	380	83 (17.9)	463
Urban road	1,332	75 (5.3)	1,407
Others (village and farm roads)	252	56 (18.2)	308
Roadway geometric pattern			
Intersection	459	44 (8.7)	503
Curved road	285	79 (21.7)	364
Straight road	1,806	213 (10.5)	2,019
Others (grade crossing, tunnel, bridge or elevated roads)	228	26 (10.2)	254
Vehicle type			
Passenger car	1,935	288 (13.0)	2,223
Light truck	474	60 (11.2)	534
Large truck	149	6 (3.9)	155
Others (buses and large trucks with trailers)	220	8 (3.5)	228
Crash type			
Rollover	206	11 (5.1)	217
Run-off-roadway	142	51 (26.4)	193
Hit barrier	371	52 (12.3)	423
Hit tree or utility pole	372	124 (25.0)	496
Others (nine items in RAIRS)	1,687	124 (6.8)	1,811

Table 3. Frequencies of Risk Factors to Motorcyclists

Risk factor	Degree of injury: Nonfatal	Fatal (percentage)	Total
Total	2,194	451 (17.1)	2,645
Gender			
Male	1,632	395 (19.5)	2,027
Female	562	56 (9.1)	618
Age			
<20	315	71 (18.4)	386
20–29	692	125 (15.3)	817
30–39	433	84 (16.2)	517
40–49	327	68 (17.2)	395
50–59	194	52 (21.1)	246
60+	233	51 (18.0)	284
Driver's qualification			
Disqualified	279	78 (21.8)	357
Qualified	1,915	373 (16.3)	2,288
Helmut use			
Not-wearing	468	186 (28.4)	654
Wearing	1,726	265 (13.3)	1,991
Main cause of accident			
Speeding	346	104 (23.1)	450
Impaired driving	512	57 (10.0)	569
Negligent driving	549	146 (21.0)	695
Others (43 items in RAIRS)	787	144 (15.5)	931
Time of crash			
22:00–06:00	722	181 (20.0)	903
Other time	1,472	270 (15.5)	1,742
Roadway class			
Freeway	2	0 (0.0)	2
Provincial road	248	80 (24.4)	328
County road	293	98 (25.1)	391
Urban road	1,380	150 (9.8)	1,530
Others (village and farm roads)	271	123 (31.2)	394
Roadway geometric pattern			
Intersection	464	52 (10.1)	516
Curved road	157	63 (28.6)	220
Straight road	1,343	301 (18.3)	1,644
Others (grade crossing, tunnel, bridge or elevated roads)	230	35 (13.2)	265
Motorcycle type			
Light motorcycle	1,467	347 (19.1)	1,814
Moped	727	104 (12.5)	831
Crash type			
Spillover	911	104 (10.2)	1,015
Run-off-roadway	75	53 (41.4)	128
Hit barrier	51	34 (40.0)	85
Hit tree or utility pole	132	98 (42.6)	230
Others (nine items in RAIRS)	1,025	162 (13.6)	1,187

J. Transp. Eng. 2006.132:227-236.

single-vehicle crashes for motorcyclists (17.1%) was higher than for drivers (11.5%); in addition, within the same level of a risk factor, except for age under 20 and speeding as the main cause of a crash, the fatality rate for motorcyclists was still higher. For the convenience of comparison, the frequencies and percentage of fatal injuries for drivers and motorcyclists within the same risk factor category are discussed together in the following sections.

Driver Characteristics

Male drivers and motorcyclists both had a higher percentage than their female counterparts of fatal injuries, and this gender difference for motorcyclists tended to be more substantial than drivers (10.4 versus 5%). Meanwhile, among the six levels of driver age, less than 20 years had the highest percentage of fatalities (19.8%) for drivers; however, aged 50–59 had the highest (21.1%) for motorcyclists. Disqualified drivers and motorcyclists (i.e., without a license or with license revoked or suspended) both had a higher percentage of fatality than their qualified counterparts. However, disqualified and qualified drivers revealed much prominent difference on fatality proportion than motorcyclists did (9 versus 5.5%).

The wearing of restraints, both for drivers and motorcyclists, revealed a smaller proportion of fatal injury as compared with the nonwearing of restraints. On the other hand, the restraint use rate for these two vehicle types recorded in single-vehicle crashes had obvious differences. As indicated by the crash data, only 15.7% of all drivers had ever used seatbelts. In contrast, 75.3% of motorcyclists wore helmets. This is the case that the mandatory regulation for motorcycle helmet use has been effective since June of 1997, whereas except for on expressways and freeways, mandatory seatbelt-use requirement for the front seat occupants was more recently implemented in 2001.

As for the main causes of driver crashes, speeding was the principal cause (30.8%) of fatal injuries. Negligent driving was the second. For motorcyclists, except that impaired driving had the lowest fatality ratio, there was a similar tendency but differences between each cause were not so apparent.

Roadway Environment

The occurrence time of a fatal crash tended to happen late at night and early in the morning for both drivers and motorcyclists (13.3 and 20.0%, respectively). For the classification of the class of roadway, since a motorcycle was not permitted to run onto freeways, no fatal crash occurred in this kind of road. Urban roads had the lowest fatality percentage both for drivers (5.3%) and motorcyclists (9.8%). However, except for freeways and urban roads, provincial, county, and other roads (i.e., the lowest roadway class such as village and farm roads) all had a higher fatality percentage for drivers and motorcyclists. In terms of geometric pattern of the roads, curved roads had an apparently higher fatality percentage for drivers (21.7%) and motorcyclists (28.6%). The intersections, however, had the lowest proportion of fatalities for both kinds of drivers.

Vehicle Type

The percentages of fatal driver injuries for passenger cars (13%) and light trucks (11.2%) were both higher compared with large trucks and other vehicles (i.e., buses and large trucks with trailers). For the motorcycle part, motorcyclists riding light motorcycles tended to have a higher proportion of fatalities (19.1%) than those driving mopeds (12.5%).

Single-Vehicle Crash Type

Rollover for drivers and spillover for motorcyclists both had the lowest fatality percentages among all crash type levels (5.1 and 10.2%). On the other hand, run-off-roadway, hit barrier, and hit tree or utility pole accidents had a relatively high fatality percentage for drivers (26.4, 12.3, and 25%), and an even higher percentage for motorcyclists (41.4, 40, and 42.6%).

Driver Fatality Risk Model

Relative Fatality Risk between Non-Motorcycle Drivers and Motorcyclists

The fatality percentages of single-vehicle injury crashes were 17.1% for motorcyclists and 11.5% for non-motorcycle drivers, respectively. It means that motorcyclists had a 48% higher fatality risk than non-motorcycle drivers once a single-vehicle injury crash occurred.

As mentioned in the previous section, the average running distances per day are 7.1 and 43.9 km for a motorcyclist and a non-motorcycle driver, respectively, in the year 2000. At the same time, the amount of motorcycles was about twofold as much as motor vehicles with four-wheels or over in Taiwan in the year 2000. Taking the running distance as the exposure to risk, we can find the motorcyclists had around 3.9 times of risk to be involved in a single-vehicle fatal accident as compared with the non-motorcycle drivers. Therefore motorcyclists revealed to have higher fatality risk of single-vehicle crash than non-motorcycle drivers for both nonexposure-based and exposure-based measurements. Moreover, this risk difference expanded while controlling for driving exposure.

Though motorcyclists had about three times higher fatality risk than non-motorcycle drivers after adjusting for the running exposure, this exposure was not able to be further divided into detailed exposure components for different factors and, as a result, some specific risk factors expanding the likelihood of driver fatality could not be determined. To overcome this difficulty, the logistic regression method was used.

To explore further the influence of different risk factors on the likelihood of driver fatality, this study separately employed two logistic regression models. Among all hypothetical risk factors, except for two variables—driver qualification and roadway geometric pattern—all the other factors indicated by the Wald test statistic were significant at the $\alpha = 0.05$ level. The description of the risk factors is shown in Table 4. The estimated results of logistic regression models for driver and motorcyclist fatality are demonstrated in Table 5. The findings of these two models are separately illustrated in the next two sections.

Fatality Risk Factors for Non-Motorcycle Drivers

3,011 effective observations were offered to calibrate the driver fatality model. The overall test for this model was highly significant (p value<0.001) and the goodness-of-fit measure, ρ^2, was 0.214. If factors were changed one at a time while controlling for the remainder of variables, the OR and its CI were able to be determined.

From the left part of Table 5, we can obtain the different risk factors, which could be divided into four categories, affecting the relative likelihood of fatality for a driver. The first category of risk factors associated with driver characteristics included gender, age, driver's qualification, seatbelt-use, and the main cause of a crash.

J. Transp. Eng. 2006.132:227-236.

Table 4. Description of Explanatory Variables in Two Models

Variable type	Variable title	Variable description	
		Driver fatality model	Motorcyclist fatality model
Driver characteristics	Male	Gender (male=1)	Gender (male=1)
	Age	Age of driver (year)	Age of driver (year)
	Qualification	Driver qualification (disqualified=1)	Driver qualification (disqualified=1)
	No seatbelt	No seatbelt usage (yes=1)	—
	No helmet	—	No helmet usage (yes=1)
	Accident main cause		
	Speeding	Speeding (yes=1)	Speeding (yes=1)
	Impaired	Impaired driving (yes=1)	Impaired driving (yes=1)
	Negligent	Negligent driving (yes=1)	Negligent driving (yes=1)
Roadway environment	Time	Time of a crash (22:00–06:00=1)	Time of a crash (22:00–06:00=1)
	Roadway class		
	Freeway	Freeway (yes=1)	Freeway (yes=1)
	Provincial	Provincial road (yes=1)	Provincial road (yes=1)
	County	County road (yes=1)	County road (yes=1)
	Urban	Urban road (yes=1)	Urban road (yes=1)
	Road geometric pattern		
	Intersection	Intersection (yes=1)	Intersection (yes=1)
	Curved road	Curved road (yes=1)	Curved road (yes=1)
	Straight road	Straight road (yes=1)	Straight road (yes=1)
Vehicle type	For motor vehicles		
	Passenger car	Passenger car (yes=1)	—
	Light truck	Light truck (yes=1)	—
	Large truck	Large truck (yes=1)	—
	For motorcycles		Motorcycle type
	Motorcycle type	—	(light motorcycle=1; moped=0)
Single vehicle crash type	For motor vehicles		
	Rollover	Rollover (yes=1)	—
	Run-off-road	Run off-roadway (yes=1)	—
	Hit barrier	Hit barrier (yes=1)	—
	Hit tree or pole	Hit tree or utility pole (yes=1)	—
	For motorcycles		
	Spillover	—	Spillover (yes=1)
	Run-off-road	—	Run off-roadway (yes=1)
	Hit barrier	—	Hit barrier (yes=1)
	Hit tree or pole	—	Hit tree or utility pole (yes=1)

The relative fatality risk for a male driver was 1.79 times that for a female driver. That means a male driver was placed 79% higher in the odds of fatalities than a female once a single-vehicle crash occurred. The fatality risk also rose with the increase in a driver's age, which was N years of age difference for $\exp(0.019 \cdot N)$ times. Consequently, drivers aged 80, 60, and 40 had 3.1, 2.1, and 1.5 times OR of fatal injury, as compared with those aged 20 correspondingly. Disqualified drivers had a slightly higher fatal risk compared with qualified ones, but the CI of OR showed no difference between these two groups. Drivers' seatbelt use had a significant influence on the possibility of fatality; that is, the nonwearing of a seatbelt in a single-vehicle crash had 3.29 times the risk of fatality as compared with the wearing of a seatbelt. Among the main causes of a crash, speeding had the dominant effect over any other causes contributing to a fatal crash (OR=7.5); negligent driving also had a high effect (OR=3.4); impaired driving had a slightly raised OR, but the OR in this case had no statistical difference compared with the reference group.

The second category of factors was the time of a crash and the class of roadway. These were both significant roadway and environment factors affecting driver fatalities. Fatalities were higher late at night and in the early hours of the morning (OR=1.6). Roadway class was also a significant factor contributing to the risk of fatality. It seems that the higher the roadway class, the greater the likelihood of a fatal injury. Among all roadway class categories, urban roads were significant in having the lowest fatal possibility of driver fatality. Roadway class as discussed here is administrative classification, but basically a higher rank in the roadway class level has a higher speed limit. On the other hand, although curved roads had a slightly higher likelihood of causing fatalities to drivers, the variable for road geometric pattern was not statistically significant.

The third category of factor was vehicle type. Passenger cars (OR=3.5) and light trucks (OR=3.7) similarly had obviously higher fatality risk for drivers than did the reference vehicle group (i.e., buses and large trucks with trailers). The OR of large trucks,

J. Transp. Eng. 2006.132:227-236.

Table 5. Model Results for Driver and Motorcyclist Fatality

	Driver fatality model				Motorcyclist fatality model			
Explanatory variables	$\hat{\beta}_i$	SE($\hat{\beta}_i$)	p value	OR (95%CI)	$\hat{\beta}_i$	SE($\hat{\beta}_i$)	p value	OR (95%CI)
Male	0.583	0.236	0.013	1.79 (1.13,2.85)	0.640	0.166	0.000	1.90 (1.37,2.63)
Age	0.019	0.006	0.001	1.02 (1.01,1.03)	0.013	0.004	0.000	1.01 (1.01,1.02)
Qualification	0.224	0.262	0.392	1.25 (0.75,2.09)	0.207	0.161	0.199	1.23 (0.90,1.69)
No seatbelt	1.191	0.270	0.000	3.29 (1.94,5.58)	—	—	—	—
No helmet	—	—	—	—	0.610	0.123	0.000	1.84 (1.45,2.34)
Accident main cause								
Speeding	2.008	0.186	0.000	7.45 (5.18,10.73)	0.221	0.165	0.180	1.25 (0.90,1.72)
Impaired	0.171	0.229	0.456	1.19(0.76,1.86)	−0.898	0.181	0.000	0.41 (0.29,0.58)
Negligent	1.211	0.216	0.000	3.36 (2.20,5.12)	−0.178	0.149	0.232	0.84 (0.62,1.12)
Time	0.487	0.133	0.000	1.63 (1.25,2.11)	0.563	0.125	0.000	1.76 (1.37,2.24)
Roadway class								
Freeway	0.649	0.367	0.077	1.91 (0.93,3.93)	−5.218	9.424	0.580	0.01 (0, 570000)
Provincial	0.117	0.207	0.573	1.12 (0.75,1.69)	−0.132	0.186	0.478	0.88 (0.61,1.26)
County	−0.019	0.217	0.932	0.98 (0.64,1.50)	−0.292	0.178	0.100	0.75 (0.53,1.06)
Urban	−0.840	0.216	0.000	0.43 (0.28,0.66)	−0.908	0.161	0.000	0.40 (0.29,0.55)
Road geometric pattern								
Intersection	−0.099	0.292	0.734	0.91 (0.51,1.61)	−0.079	0.253	0.755	0.92 (0.56,1.52)
Curved road	0.221	0.277	0.426	1.25 (0.72,2.15)	0.469	0.262	0.074	1.60 (0.96,2.67)
Straight road	0.021	0.249	0.932	1.02 (0.63,1.67)	0.304	0.212	0.151	1.36 (0.90,2.05)
Motor vehicle type								
Passenger	1.256	0.391	0.001	3.51 (1.63,7.56)	—	—	—	—
Light truck	1.318	0.412	0.001	3.74 (1.67,8.37)	—	—	—	—
Large truck	0.292	0.571	0.608	1.34 (0.44,4.10)	—	—	—	—
Motorcycle type	—	—	—	—	0.326	0.135	0.016	1.39 (1.06,1.81)
Motor vehicle crash type								
Rollover	−0.418	0.343	0.223	0.66 (0.34,1.29)	—	—	—	—
Run-off-road	0.738	0.213	0.001	2.09 (1.38,3.18)	—	—	—	—
Hit barrier	0.592	0.233	0.011	1.81 (1.15,2.85)	—	—	—	—
Hit tree or pole	0.820	0.160	0.000	2.27 (1.66,3.10)	—	—	—	—
Motorcycle crash type								
Spillover	—	—	—	—	−0.374	0.142	0.009	0.69 (0.52,0.91)
Run-off-road	—	—	—	—	0.853	0.221	0.000	2.35 (1.52,3.62)
Hit barrier	—	—	—	—	1.230	0.259	0.000	3.42 (2.06,5.68)
Hit tree or pole	—	—	—	—	1.214	0.175	0.000	3.37 (2.39,4.74)
Constant	−6.748	0.680	0.000	—	−2.905	0.334	0.000	—
Number of observations			3,011				2,578	
$-2\log[L(c)]$			2,212				2,391	
$-2\log[L(\beta)]$			1,742				1,996	
Degree of freedom			22				20	
Overall test (p value)			<0.001				<0.001	
ρ^2			0.214				0.165	

Note: OR was calculated by changing one unit of one variable at a time while controlling for the other variables [i.e., $\exp(\beta)$]. For example, one year increase of age for non-motorcycle drivers raised the fatality risk to be 1.02 [$=\exp(0.019\times 1)$] times.

however, was slightly higher than the reference group but not statistically significant. It appears that because of differences between vehicle weights, drivers riding smaller vehicles may sustain relatively severe injuries when a single-vehicle crash occurs.

The last category of risk factor, crash type of a single-vehicle, showed that run-off-roadway and hit barrier, tree, or utility pole had around twofold OR to the reference crash type. But beyond expectations, rollover had the lowest OR (0.7) than any other crash type, even though it is not statistically significant at the $\alpha=0.05$ level.

Fatality Risk Factors for Motorcyclists

The overall test for the motorcyclist fatality model, which was estimated by 2,578 effective observations, was also highly significant (p value<0.001) and ρ^2 was 0.165 (see the right part of Table 5). In comparison with the previous model, both models had many similar risk factors and some factor levels even had close OR; however, there were also lots of differences between them.

With respect to similarity, gender, age, driver's qualification, restraint use, time of crash, roadway geometric pattern, and crash

J. Transp. Eng. 2006.132:227-236.

type had a consistent propensity that influenced the fatality risk in both models. Furthermore, males (OR=1.9), increasing age [N years of age difference for $\exp(0.013 \cdot N)$ times OR], disqualified drivers (OR=1.2), and the occurrence of a crash between 10 p.m. and 6 a.m. (OR=1.8) in the motorcyclist fatality model had a very close OR to the driver fatality model. Helmet-use for motorcyclists in reducing the probability of crash death was not so significant as compared with seatbelt-use for drivers (84 versus 229% reducing effect). Hitting a barrier, tree, or utility pole seems relatively to have more severe outcomes for motorcyclists.

On the other hand, it seems that risk factors—including the main cause of a crash, roadway class, and vehicle type—showed much more differentiation between these two models. In terms of main causes of a crash for motorcyclists, the OR for speeding was slightly higher but not statistically significant. Impaired driving for motorcyclists even demonstrated the lowest fatal risk (OR=0.4) and was around one-third the likelihood of fatality of the most dangerous cause, speeding (OR=1.3). As for roadway class, since motorcycles cannot drive on the freeways in Taiwan, there should be no fatality risk in this kind of road. The extremely low OR for this level may represent a few cases of violation of the law on freeways. Similar to motor vehicle drivers, motorcyclists on urban roads had the smallest risk of fatality; however, the lowest roadway class level (i.e., village and farm roads) had an even higher risk than provincial and county roads (OR=1/0.88 and 1/0.75). It seems that there are some specific reasons for the high fatality risk in this lowest roadway class. Without the higher protection effect offered by the weight of vehicles, light motorcycles contributed more significantly to motorcyclist fatalities than did mopeds (OR=1.4).

Discussion

This research aimed to explore risk factors that led to driver and motorcyclist fatalities, and to compare the differences in risk between these two kinds of drivers in single-vehicle crashes. Research has shown that accident risk was not linearly related to exposure possibly because high-mileage drivers had superior experience or collected their miles on safer highways, thus leading to a lower accident risk per mile driven (Maycock 1985; Janke 1991). However, since no disaggregate running exposure for each individual driver could be collected, a linear relationship between driver fatalities and running exposure was assumed in this study. On average, motorcyclists had a 48% higher risk of fatality than non-motorcycle drivers and this difference rose by 290% following the inclusion of running exposure.

Two separate logistic regression models were applied to identify the specific risk factors that expanded the likelihood of non-motorcycle driver and motorcyclist fatality in conditions where a single-vehicle injury crash had occurred. For comparison purposes, the similarities and discrepancies in fatality risk factors between these two kinds of drivers are discussed as follows.

Similarities in Risk Factors

The findings showed that, within each logistic regression model, some common factors contributing to these two different drivers had very close odds ratios. Males, increasing age, disqualification, crashes occurring from 10 p.m. to 6 a.m., and occurrence of accidents at curved roads all signified higher likelihoods of fatality for both kinds of drivers. Urban roads, however, were less likely to generate a fatal crash for both kinds of single-vehicle crashes.

Compared with previous research (Evans 1991; Bédard et al. 2003), the driver's age, seatbelt use, the main cause of a crash, the time of a crash, and vehicle weight as risk factors for non-motorcycle drivers seem to have consistent patterns. On the other hand, gender for both models and rollover for the non-motorcycle driver model appears to result in different outcomes (Evans 1991; Kockelman and Kweon 2002; Bédard et al. 2003). Male drivers had 79% higher odds of a fatality than females in this research, but in a previous study females had a 54% higher risk than males (Bédard et al. 2003); male motorcyclists had a 90% higher risk in this study versus another previous research which showed that female motorcyclists had a higher risk (Evans 1991). Evans (1991) thought that the differences in fatality risk between genders was owing mostly to differing susceptibility to fatal trauma. If this is true, this study has revealed that in Taiwan male drivers and motorcyclists had weaker susceptibility than female drivers and motorcyclists to fatal trauma. However, the racial factor between countries appears to be doubtful. Another possible reason may be that behavior factors from the accident database were not effectively taken into account. Consequently, males with a higher fatality risk in a single-vehicle crash may in fact partly be linked to high risk-taking behavior, such as driving faster, as shown by this group.

Kockelman and Kweon (2002), who applied accident data ranging from no injury to fatal injury, showed that rollover was the most serious single-vehicle crash type in their study. In this study, on the other hand, rollover had a lower fatality risk than any other crash type. One possible reason for this different outcome may come from the range difference of injury data. In our study, at least one occupant injury was included in the samples, so the driver fatality risk was based on more severe crashes. Since the OR of rollover was not statistically significant, the real effect remains to be validated by more samples.

Discrepancies in Risk Factors

Except for the similar pattern discussed above, there were many discrepancies in risk factors between these two kinds of drivers, including restraint-use effect, the main cause of a crash, roadway class, and vehicle type.

Restraint-Use Effect

Seatbelt-use and helmet-use both had a positive effect in reducing driver fatalities. However, using a seatbelt brought a 229% reduction in the odds of a fatality compared with helmet-use bringing only an 84% decrease. This difference may illustrate the fragile structure and limited protection characteristics offered by a motorcycle. The mandatory helmet-use regulation in Taiwan for motorcycle occupants and seatbelt-use for front-seat occupants on all roads became effective, respectively, on June 1, 1997 and September 1, 2001. In this study, 84.3% of drivers were recorded as not wearing seatbelts, while only 14.7% of motorcyclists were recorded in 2000 as not wearing helmets. It seems that intervention may promote the restraint-use rate. Therefore the seatbelt usage rate and overall reducing effect of driver fatalities after intervention will be worth studying in the future.

Main Cause of a Crash

Speeding and negligent driving were both the main causes for the increase in non-motorcycle driver fatality likelihood but not for motorcyclists. Speeding for drivers showed a 645% increase in

J. Transp. Eng. 2006.132:227-236.

the odds of fatality, compared with motorcyclists showing only a 25% increase (not significant at $\alpha=0.05$). Since the real running speed was not reported by the police, it is likely that the driving roads and vehicle performance differences between these two vehicle types may cause non-motorcycle drivers to have higher average crash speed and thus more fatality risk in a crash than did motorcyclists.

On the other hand, impaired driving for drivers brought about no obviously high fatality risk; and for motorcyclists this demonstrated the lowest risk (OR=0.4). The likelihood of motorcyclist fatality from impaired driving was over two-thirds less in the odds than that from speeding. This low risk of fatality by impairment reveals one possibility that since motorcycles are operated by two hands, the consequent lessened stability of this kind of vehicle makes it easy for an impaired motorcyclist to be injured before a fatal crash happens. Nevertheless, it is by no means that impaired motorcyclists are much safer simply because they did not suffer fatal injury. Thus more research should be conducted on why impaired motorcyclists had lower fatality risk.

In addition, the limitation of data quality should also be particularly noteworthy. Because the main cause of a crash has to be judged by the police on the scene, it should be taken into consideration whether some specific causes may be over or under-reported by the police-reported system.

Roadway Class

This study basically showed that the higher class the roadway, the more likely the non-motorcycle drivers were to sustain fatal injuries in a single-vehicle crash. It appears to be reasonable that a higher road class usually has a faster average running speed. In contrast, the highest fatality risk for motorcyclists occurred in the lowest class of roadways such as village and farm roads. One possible reason for motorcyclists being overexposed to fatal injuries in the lowest roadway class is that these roads in Taiwan are usually lacking in adequate illumination, maintenance, and traffic regulation facilities. Therefore, along with limited protection for motorcycles, the poor management of these roads may raise the risk of fatalities for motorcyclists.

Vehicle Type

In this study, vehicle weight tended to have a positive effect in reducing fatal injuries for drivers. In contrast, light motorcycles had a higher risk than mopeds. Similar to previous research on single-vehicle crash (Evans 1991), a heavier motor vehicle revealed a lesser propensity to result in a fatal single-vehicle crash, so vehicle weights could offer drivers more protection. Light truck drivers had the highest fatality risk (OR=3.7) and passenger car drivers the second (OR=3.5). The highest fatal risk for light truck drivers may be associated with the vehicle design factor. That is, a large proportion of light trucks in Taiwan have limited space in front of the driver's cab, which possibly raises the fatality risk for their drivers. As for motorcycles, light motorcycles inversely were 37% higher than mopeds in the odds of a motorcyclist fatality. It is likely that compared with the weights of fixed objects, vehicle weights of motorcycles are relatively small and have no obvious protection effect in a single-vehicle crash. This may suggest that, because light motorcycles can drive faster but have no prominent protective advantages over mopeds, a behavioral reason could be supported over a vehicle weight reason when exploring motorcyclist fatalities.

Safety Implications

First, seatbelt-use brought around a threefold reduction in driver fatality likelihood compared with helmet-use, but the use rate of a seatbelt in single-vehicle crashes was lower than 16% in 2000. This low use rate may partly have been because the mandatory seatbelt-use law had not been enacted that year. However, even though the mandatory law was introduced in September 2001, as compared with the easy detection of helmet wearing, the relative difficulty in perceiving whether automobile front-seat occupants obey the law means drivers are still quite likely not to wear their seatbelts. Therefore, to decline the severity of injury sustained by automobile drivers in single-vehicle crashes, enhancing the restraint-use rate by means of enforcement intervention and safety promotion should be especially raised.

Second, speeding in single-vehicle crashes was the dominant factor contributing to fatality likelihood for both kinds of drivers, especially non-motorcycle drivers. Speeding, provided that it fits into certain categories of single-vehicle crashes such as run-off-road, hit roadside barriers, trees, or utility poles, would further raise the likelihood of being a fatal injury to drivers. Research has indicated that the likelihood of fatality for a car driver in a crash increased with the change in speed at the moment of impact (O'Day and Flora 1982; Joksch 1993). Thus it is recommended that the government should effectively manage the running speed via traffic engineering measures, law enforcement, and even speed cameras.

Third, contrary to our expectatation, motorcyclist fatality risk was over-represented in the lowest roadway class (i.e., village and farm roads). Because village and farm roads in Taiwan are relatively poorly maintained, including lack of adequate illumination, traffic signs, and markings compared with higher classes of roads, riding motorcycles on these kinds of roads appears to be more dangerous once a single-vehicle crash occurs. Thus the important considerations here are improving road quality and safety facilities in the lowest class of roads.

Finally, since motorcycles have the disadvantages of a fragile structure, limited protection, and instability, enhancing motorcyclist risk perception via a licensure system appears crucial to reducing the accident involvement and severity for motorcycle riders. However, risk perception for Taiwan's motorcyclists is far from sufficient because of the current weak licensure system concerning driver training and education. The easy operational characteristics of lower displacement motorcycles, coupled with a government-administered riding test that does not require previous safety education and practical training, may well have caused learners to imagine, erroneously, that no particular training or education is needed for riding a motorcycle. This led to the phenomenon that the rider's skills and perception of risks are almost all inadequately acquired by self-learning and a trial-and-error process. As a result, improving motorcyclist risk perception through the licensure system should be emphasized.

Conclusions

The dissimilar characteristics of operational manners, driving roadways, and vehicle protection effects between at least four-wheeled motor vehicles and motorcycles, imply that different risk factor combinations contributing to driver fatality may exist. Knowledge of the differences in the fatal risk factors between these two types of drivers is especially important for countries

J. Transp. Eng. 2006.132:227-236.

with large numbers of motorcycles, so that useful safety strategies can be developed for distinct types of drivers.

On average, motorcyclists had a 48% higher risk of fatality than non-motorcycle drivers without consideration of the exposure and the risk difference rose to 290% after the inclusion of running exposure in single-vehicle crashes. To further understand which risk factors expanded the likelihood of driver fatality, a logistic regression model was used. The findings in this study demonstrated that some common features such as being male, increasing age, crashes occurring from 10 p.m. to 6 a.m., and crashes occurring on curved roads revealed a higher likelihood of fatality for both kinds of drivers. In addition, urban roads were less likely to be the locations of fatal injuries for both kinds of drivers. These results are, for the most part, consistent with previous research, except for the gender and rollover risk factors.

On the other hand, the discrepancies between these two kinds of drivers included the effect of restraint use, the main cause of a crash, roadway class, and vehicle type factors. Seatbelt use had an almost threefold fatality reducing effect as compared to helmet-use. For non-motorcycle drivers, speeding had the most dominant effect on driver fatality of all the possible causes; however, impaired driving for motorcyclists revealed the lowest fatality risk. The findings also showed that higher-classed roadways posed greater fatality risks for non-motorcycle drivers; in contrast, the lowest class of road was the most dangerous for motorcyclists. In addition, vehicle weights appear to negatively correlate with the likelihood of fatal injuries sustained by drivers; however, fatality risks were higher with light motorcycles than with mopeds.

Some possible explanations for these differences include a fragile vehicle structure, limited protection characteristics, unstable operational manner of motorcycles, higher risk-taking behavior of light motorcycle riders, and poor management of the lowest class of roadway. The higher fatality risk for non-motorcycle drivers and motorcyclists under certain circumstances revealed that some improvements such as enhancing the seatbelt-use rate, managing running speed, increasing the risk perceptions of motorcycle riding, and upgrading the maintenance of specific classes of roadways may need to be proposed. Meanwhile, studies should continue in order to validate the accuracy of these speculations. Evaluation of property damage only and the use of multiyear accident data, if available, is suggested in order to aid future research and to enhance the models' precision.

References

Armsby, P., Boyle, A. J., and Wright, C. C. (1989). "Methods for assessing drivers' perception of specific hazards on the road." *Accid. Anal Prev.*, 21, 45–60.

Bédard, M., Guyatt, G. H., Stones, M. J., and Hirdes, J. P. (2003). "The independent contribution of driver, crash, and vehicle characteristics to driver fatalities." *Accid. Anal Prev.*, 34, 717–727.

Ben-Akiva, M., and Lerman, S. R. (1985). *Discrete choice analysis: Theory and application to travel demand*, MIT, Cambridge, Mass.

Benda, H. V., and Hoyos, C. G. (1983). "Estimating hazards in traffic situations." *Accid. Anal Prev.*, 15, 1–9.

Bergdahl, J., and Norris, M. R. (2002). "Sex differences in single vehicle fatal crashes: A research note." *Soc. Sci. J.*, 39, 287–293.

Evans, L. (1991). *Traffic safety and the driver*, Van Nostrand Reinhold, New York.

Farmer, C. M., and Lund, A. K. (2002). "Rollover risk of cars and light trucks after accounting for driver and environmental factors." *Accid. Anal Prev.*, 34, 163–173.

Finn, P., and Bragg, B. W. E. (1986). "Perception of risk of an accident by younger and older drivers." *Accid. Anal Prev.*, 18, 289–298.

Harrison, W. A. (1997). "An exploratory investigation of the crash involvement of disqualified drivers and motorcyclists." *J. Safety Res.*, 28, 213–219.

Janke, M. K. (1991). "Accidents, mileage, and the exaggeration of risk." *Accid. Anal Prev.*, 23, 183–188.

Joksch, H. C. (1993). "Velocity change and fatality risk in a crash—A rule of thumb." *Accid. Anal Prev.*, 25, 103–104.

Kockelman, K. M., and Kweon, Y. J. (2002). "Driver injury severity: An application of ordered probit models." *Accid. Anal Prev.*, 34, 313–321.

Lang, S. W., Waller, P. F., and Shope, J. T. (1996). "Adolescent driving: Characteristics associated with single-vehicle and injury crashes." *J. Safety Res.*, 27, 241–257.

Lawson, S. D. (1985). "Single-vehicle collisions with roadside objects: The problem and its need of treatment." *Traffic Eng. Control*, 26, 489–494.

Lee, J., and Mannering, F. (2002). "Impact of roadside features on the frequency and severity of run-off-roadway accidents: An empirical analysis." *Accid. Anal Prev.*, 34, 149–161.

Maycock, G. (1985). "Accident liability and human factors—Researching the relationship." *Traffic Eng. Control*, 26, 330–335.

McCullagh, P., and Nelder, J. A. (1989). *Generalized linear models*, 2nd Ed., Chapman and Hall, New York.

Mckenna, F. P. (1987). "Behavioral aspects of single-vehicle accidents." *Traffic Eng. Control*, 28, 233–236.

Ministry of Transportation and Communications (MOTC). (2001a). *Survey report on the usage of Taiwan's motorcycles*, Ministry of Transportation and Communications.

Ministry of Transportation and Communications (MOTC). (2001b). *The amendment of fuel consumption fee for motor vehicles*, Ministry of Transportation and Communications.

Ministry of Transportation and Communications (MOTC). (2002). *Taiwan's traffic policy white paper*, Ministry of Transportation and Communications.

Ministry of Transportation and Communications (MOTC). (2003). *Abstract report on the usage of Taiwan's passenger cars and motorcycles*, Ministry of Transportation and Communications, ⟨http://www.motc.gov.tw/⟩ (July 2, 2005).

O'Day, J., and Flora, J. (1982). "Alternative measures of restraint system effectiveness: Interaction with crash severity factors." *SAE Technical Paper 820798*, Society of Automotive Engineers, Warrendale, Pa.

Shankar, V., and Mannering, F. (1996). "An exploratory multinomial logit analysis of single-vehicle accident severity." *J. Safety Res.*, 27, 183–194.

J. Transp. Eng. 2006.132:227-236.