Fatality Rates for Motorcyclists and Car Occupants: A Decomposition into Fatality Risk and Accident Risk

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I. INTRODUCTION

In safety studies, the number of injuries, injury risk (such as fatality risk) and exposure can be used as measures to define road safety problems [1]. Road fatalities per billion vehicle-kilometers (fatalities/10⁹ km) is a common metric, used (for example) in [2], where a significant difference can be observed between car occupants and motorcyclists. In Germany the figure for car occupants (3.3) is much lower than that for motorcyclists (59.5).

To understand this difference, fatality risk curves for car occupants and motorcyclists can help. Even though several studies have used these fatality risk curves, each study used different filters and variables for modelling, so the different curves are not comparable. For example, [3] build fatality risk curves for motorcyclists against different opponents, using relative speed and other variables (impact side, pre-crash stability, etc.). In another paper, delta velocity (DV) has been selected to evaluate the fatality risk of car drivers in frontal impacts with other cars [4]. Relative speed was favoured in this study as measure of crash severity as it is easily comprehensible and can be associated with speed limits.

This paper aims to explain the difference in fatalities/10⁹ km between motorcyclists and car occupants by decomposing it into fatality risk and accident risk and using fatality risk curves against the relative speed for quantitative analysis.

II. METHODS

Dataset

This paper used the German In-Depth Accident Study (GIDAS) dataset from the years 1999-2018. However, because of the imperfect sampling process, severe and fatal accidents are overrepresented [5]. Thus, the Destatis (German Federal Statistical Office) report (2018), which covers all police-reported traffic accidents across Germany, was applied for weighting. Occupants of M1 vehicles (passenger cars) and riders of L4e and L3e vehicles (motorcycles) were selected. For the normalised weighting factors, L4e and L3e were calculated together, while only L3e was used in the modelling of fatality risks (similar to [3]).

In order to have comparable results, consistent filtering was implemented and the same variables were chosen for both car occupants and motorcyclists. First, the accident events causing the worst injuries (the most serious injuries) were considered. These events were further classified as car-involved or motorcycle-involved. For carinvolved accidents, side swipe and rollover were excluded since these characteristics tend to mitigate or aggravate the consequences. Similarly, side swipe and run-over were disregarded for motorcycle-involved accidents.

The data were filtered to select only motorcyclists and car occupants who used safety protection equipment (helmets and seat belts, respectively). Further, the data were split into a training set (80%) and a test set (20%). The training set was used to train the model and the test set revealed its true performance.

Accident risk, exposure and fatality risk

According to [6], accident risk, exposure, and injury risk (which is fatality risk in this paper) can be plotted in three-dimensional space as in Figure 1. The volume indicates the number of people injured or killed in the traffic accident. This relationship can also be captured by the following equation:

$$\mathbf{I} = \mathbf{E} * \frac{A}{E} * \frac{I}{A}$$

where I is the number of people injured or killed in the traffic accidents, A is the number of people involved in the accidents, E stands for exposure, $\frac{A}{E}$ is the accident risk and $\frac{I}{A}$ is the injury risk. Notice that since Destatis does

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not record all non-injury accidents, uninjured car occupants and motorcyclists were excluded from the modelling of fatality risk curves.



Fig. 1. The safety problem defined as the product of accident risk, injury risk and exposure.

Logistic Regression

Logistic regression was used to model the relation between age, relative speed and single event (which indicates whether the participant experienced multiple crashes in the accident) and fatality, both for car occupants and motorcyclists. The general mathematical expression is as follows:

$$P = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n)}}$$

where $x_1, x_2 \dots x_n$ are predictors. $\beta_0, \beta_1, \beta_2 \dots \beta_n$ are coefficients and P is the probability that the target event is present [7]. If the P and coefficients are given, it is easy to calculate one predictor with other predictors fixed. In addition, the confidence interval (CI) is applied to compute the range of values within which the true value is likely to fall given a specified level of confidence [8].

In order to evaluate model performance, the area under the curve (AUC) of the receiver-operating characteristic (ROC) curve was calculated. The AUC is good for distinguishing between models: the higher the AUC, the better the model. A random classifier can achieve an AUC of 0.5, so this value serves as a baseline to tell whether the model has good class separation capability [9].

In this paper, since the fatalities per billion km (I/E), which is the product of accident risk (A/E) and fatality risk (I/A), was known in advance, it is easy to calculate the accident risk (A/E) once the fatality risk (I/A) is obtained from the national statistics. Furthermore, to distinguish fatality risks at different relative speeds, the logistic regression models associated with relative speed and other variables (age and single event) for car occupants and motorcyclists respectively were built.

III. INITIAL FINDINGS

	TABLE I					
	WEIGHTING FROM GIDAS TO NATIONAL DATA (DESTATIS)					
	Driver and passenger	National (1	999-2018)	GIDAS		Weighting
	of	Freq.	Prop.	Freq.	Prop.	
Slight	Car	4169213	84.7%	18585	77.7%	1.09
	Motorcycle	440267	66.1%	2022	58.2%	1.14
Severe	Car	703955	14.3%	4919	20.6%	0.69
	Motorcycle	211401	31.7%	1344	38.7%	0.82
Fatal	Car	51484	1.0%	413	1.7%	0.59
	Motorcycle	14849	2.2%	110	3.2%	0.69

Normalised weighting factors, calculated (Table I) to compensate for sampling bias, range from 0.59 to 1.14, indicating a slight bias towards higher injury severities, as expected.

To draw the fatality risk curves, the age was set to 25 and the single event indicator was determined to be true. As a result, the relative speed was the changing variable. Overall, it is obvious that the fatality risks for motorcyclists and car occupants were low (see Fig. 2). In particular, much flatter curve for car occupants stayed close to the horizontal axis. (Note that, if the car occupant model were to use DV, the results would be similar to

those in other research [4].) Meanwhile, as the relative speed increased, the gap between motorcyclists and car occupants widened. Table II gives the details of the two models: even though the coefficient of relative speed of motorcyclists was a little bit smaller than that of car occupants, the growth rate of fatality probability for the motorcyclists was higher, so the gap becomes larger at higher relative speeds. Both coefficients of single event indicators were negative meaning that if motorcyclists or car occupants were subject to a single event, they had less risk of fatality because negative values decreased the log-odds. Conversely, fatality probability increased with age for both models.

As for model performances, the AUC values were higher than 0.8 in both the training and test sets for car occupants. According to [10], this model can thus be regarded as excellent. In contrast, an AUC value of 0.799 in the test set for the motorcyclist model shows that it is acceptable.



Fig. 2. Fatality risks of motorcyclists and car occupants.

TABLE II
RESULTS FROM LOGISTIC REGRESSION AND AUC

Estimated coefficient	Intercept	Age	Relative speed	Single event	Train AUC	Test AUC	
				(True)			
Motorcyclists	-4.829	0.005	0.030	-1.091	0.841	0.799	
Car occupants	-6.852	0.010	0.031	-0.617	0.826	0.878	
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From the data in Table III, it is easy to calculate the approximate proportions of fatality risk for motorcyclists (2.308%:708/30680) and car occupants (0.914%:1986/217238) separately. Based on the given fatalities/10⁹ km data and the equation in 2.3, accident risks were 2,578 motorcyclists /10⁹ km and 361 car occupants /10⁹ km.

Through logistic regression, relative speeds were obtained (motorcyclists: 67 km/h, car occupants: 82 km/h) using the calculated fatality risks (2.308% and 0.914%) and predetermined predictors (age and single event indicator) as input. Since these fatality risks derive from national data, they indicate, not individual cases, but the average risks of each group. Therefore, 67 km/h and 82 km/h are the representative relative speeds of motorcyclists and car occupants, respectively.

TABLE III						
INJURY DETAILS ON THE PERSONAL LEVEL FROM DESTATIS						
2011	2011 Driver and passenger of					
Injury level	Motorcycle	Car				
Fatal	708	1986				
Severe	9889	29428				
Slight	20083	185824				
Total	30680	217238				

IV. DISCUSSION

To summarise, the fatalities/10⁹ km of motorcyclists was much higher than that of car occupants because motorcyclist fatality risk and accident risk were higher. To further associate the fatality risks with relative speed, fatality risk curves are presented (Fig. 2).

Relative speed was used in this study. Similarly, [11] use relative speed for passenger cars and motorcycles, and [3] also finds relative speed to be best for motorcycles. According to ISO, either DV or relative speed can be used, even though DV is preferred.

If the relative speed is reduced when the collision happens, the fatality risk also declines. For instance, if the representative relative speed for motorcyclists drops to 40 km/h the corresponding fatality probability drops to 1.017%. At the current accident risk level, the fatalities/10⁹ km would be 26.2, which is a dramatic drop (56%) from the original figure (59.5).

Finally, lowering fatality risk and/or accident risk could be effective for reducing the fatalities/10⁹ km of motorcyclists. To address their accident risk, active safety solutions could be considered, such as advanced driver assistance and monitoring empowered with speed warnings, detectors preventing drunk driving, and advanced displays [12]. Further, preventative action can be taken by improving infrastructure design when it is known under which conditions motorcycles are more likely to be exposed to an accident [13]. In the models, it was assumed that both car occupants and motorcyclists were wearing protective equipment, but additional countermeasures may be possible to further reduce the motorcyclist fatality risk. For example, a belted safety jacket has been proposed by [14] and there could be an airbag solution for motorcyclists [15].

This study has several limitations. A limited number of variables were used to establish the models; there could be models with higher AUC values. However, those models may sacrifice consistency and comparability. Additionally, since the data used in this paper was collected in Germany, the models may not be applicable to other countries. Furthermore, fatalities/10⁹ km could change as relative speed changes, a possibility which has not been covered in this paper.

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