The Kinematical Features of Motorcycles in Congested Urban Networks

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Abstract

The aim of this paper is to compare the kinematical features of motorcycles with those of passenger cars in urban traffic. The hypothesis that motorcycles' capability of swerving in urban traffic contributes to their seemingly assertive behaviour is examined. Data for this study were collected in afternoon peak hours at Central London using video camcorders. The information on the trajectories of 2,109 vehicles (including 477 motorcycles and 1,293 passenger cars) was extracted from the video images and the observable kinematical features were analysed. In addition, a model describing the longitudinal following behaviour of motorcycles was adopted to analyse the impacts of motorcycles' swerving behaviour. The Bayesian analysis and Markov Chain Monte Carlo numerical methods were employed for assisting with the model calibration and parameter estimation. The observable kinematical features show that in comparison with passenger cars, motorcycles have shorter safety gaps, higher speeds and more severe acceleration and deceleration rates. However, the data also support the hypothesis that motorcyclists have maintained a considerable safety margin as they have the ability of swerving away to avoid a collision.

Keywords: Motorcycle safety, Motorcyclist behavior, Bayesian analysis, MCMC

1 Introduction

The difference in mechanical structure between motorcycles and passenger cars leads to their different behavioural patterns on roads. Motorcycles have narrower widths and smaller sizes. Also, motorcyclists, as compared to passenger car drivers, enjoy a wider field of view and a more intuitive steering method. All this contributes to their agile manoeuvrability when moving in traffic and could also contribute to some of their idiosyncratic behaviour patterns.

It is commonly observed that motorcycles do not make a conventional lane-based progression, particularly in heavy traffic in urban networks. Branston (1977) reported that motorcycles are able to travel alongside other vehicles in the same lane. Robertson (2002) categorised motorcycles' characteristic movements behind stop lines as: going to the head of queues, filtering, wriggling, lane changing, inaction and balking. Later on, the oblique following behaviour was recognised in his follow-up study (Robertson, 2003). Lee (2008) went further to analyse the differences between motorcycles and cars in respect of sizes, weights, turning radii, drivers' field of views and steering methods and observed that motorcycles would travel according to dynamic virtual lanes and would maintain shorter safety gaps when aligning to the edge of the preceding vehicles. These characteristic movements would add heterogeneity to the traffic and thus could increase road accidents. However, the behavioural differences between motorcycles and passenger cars have not yet been investigated systematically, nor have the reasons causing these differences been studied.

The aim of this study is to measure the kinematic features of motorcycles and passenger cars. In addition, a hypothesis is suggested to explain the causes of the behavioural differences. The key challenge of this context is to measure the erratic trajectories of motorcycles in heavy traffic and to describe their interaction with other vehicles. The video recording method is employed to collect data as this method is able to collect the trajectory data of a large number vehicle simultaneously. The mathematical model describing the longitudinal following distance of motorcycles in Lee et al. (2009) is adopted to describe the interaction between motorcycles and other vehicles and to explain the behavioural differences.

This paper is organised as follows: Section 2 reviews the studies about the kinematical parameters of motorcycles and passenger cars; Section 3 describes the data collection method; Section 4 reports the observable kinematical features; Section 5 suggests a hypothesis to explain the behavioural differences between motorcycles and passenger cars and Section 6 concludes the findings of this study.

2 Literature review

Research into motorcycling safety impinges a wide range of fields. This section reviews the studies focusing on the comparisons of kinematical characteristics between motorcycles and passenger cars, in terms of braking decelerations, speeds, safety gaps and reaction times.

The physical mechanism of applying brakes to a motorcycle is complicated. A motorcyclist needs highly developed manoeuvring skill to achieve the maximum braking deceleration of the motorcycle. Ecker et al. (2001) found in an experiment that common motorcyclists could only achieve an average braking deceleration of around -6.19 m/sec^2, which is only 56% of the maximum deceleration capability of the machine (around -11 m/sec^2, Biokinetics and Associates Ltd, 2003). Vavryn and Winkelbauer (2004) also reported similar results (-6.6 m/sec^2) in their tests. However, the value varied slightly with the factors such as familiarity with the vehicle, training of riders, condition of the road surface and types of braking systems. Regarding passenger cars, the mechanical maximum braking capability is around -10 m/sec^2 (quoted in Ecker et al., 2001). The major difference in the braking behaviour of these vehicle types is that there is a psychological and technical hurdle for motorcyclists to achieve the maximum braking, whereas car drivers usually can achieve the maximum braking if necessary.

With regard to the speeds of motorcycles, Hsu et al. (2003) reviewed some local literature and summarised that the speeds of motorcycles in free flow are usually lower than the speeds of cars, but motorcycles have a higher speed in narrow streets. In addition, motorcycles enjoy a burst at the beginning of green at a signalised intersection, but their acceleration would be lower than that of cars when speeds are above 40 km/hr. The results from the laboratory experiments and roadside observations of Horswill and Helman (2003) indicated that motorcyclists like to choose higher speeds. However, statistics in the U.K. show that motorcycle speeds are about the same as car speeds (Department for Transport, 2005).

A few studies have described the following distances of motorcycles. According to Wigan (2000), Branston (1977) has measured the headway of motorcycles on motorways and found it is 0.6 to 0.9 times shorter than that of cars, although Branston did not publish the results formally. Horswill and Helman (2003) found that motorcycles are likely to pull into smaller gaps but do not have closer following distances than car drivers in free flow. Minh et al. (2005) measured the time headway of motorcycles, finding that 50% of the headways are around 0.5 to 1.0 sec, which is only half of the headways of passenger cars.

Green (2000) reviewed the studies of reaction time of car drivers and concluded that when fully aware, it is around 0.70 to 0.75 seconds and 1.25 to 1.5 seconds in unexpected situations. Tang (2003) surveyed the reaction time of motorcycles as he studied the effects of flash brake lamps, finding that the reaction time of motorcycles under fully aware or unexpected conditions is 0.7 to 0.9 seconds. In addition, Hsu et al. (2003) observed that motorcycles have a shorter reaction time at the start of the green time.

From the above studies, it is found that in comparison with car drivers, the motorcyclists have comparatively lower braking ability, and are more likely to have higher speeds and shorter safety gaps in urban networks. However, there is a need to understand the behavioural differences using empirical data collected in heavy urban networks. In addition, no studies have looked into the causes of these differences. These are the gaps to be filled in for understanding the behaviour of motorcycles inside the traffic system.

3 Data

The data for this study were collected from a section near a signalised pedestrian crossing at afternoon peak hours at Victoria Embankment in Central London. At this site the characteristic behaviour patterns of motorcycles and the interactions between vehicles could be observed when queues built up and discharged due to the traffic signal. Since this was a pedestrian junction without any side roads, after passing the signal, vehicles kept moving straight without turning behaviour.

The video recording method was employed and vehicular trajectory data were extracted from the video images. To reduce the errors and inaccuracy caused by image occlusion, a trajectory extracting system (Lee et al., 2008) was developed to assist with the data collection. Instead of using auto image recognition, this system employed a semi-automatic approach. To ensure accuracy, the locations of vehicles at every time step were recognised and pointed out by human eyes. Then, the system converted the coordinates, recorded the data and calculated the kinematical parameters automatically.

By using this approach, highly detailed and accurate data with a wide range of traffic parameters were generated. The database contained the data of vehicles of 2,109 vehicles (including 477 motorcycles) and a total of 42,711 records of their trajectories (recorded by every second).

Table 1: Numbers of vehicles surveyed

Mode	Motorcycle	Bicycle	Passenger car	Van	Heavy vehicle
Number	477	221	1,293	71	47

4 The kinematical characteristics

In this section, the measurements of the kinematical characteristics of motorcycles and passenger cars, such as the safety gaps, the speeds and the acceleration and deceleration rates are reported.

4.1 Safety gaps

The safety gap here is defined as the longitudinal gap between the front edge of a following vehicle and the rear edge of its preceding vehicle. It should be noted that by this definition, a vehicle in free flow status will have an extremely long safety gap to its preceding vehicle. This will affect the data analysis in this section later on.

The following distances that a motorcycle follows a passenger car, and a passenger car follows another passenger car are measured. From the database it is found motorcyclists maintained different following distances when following in different lateral areas behind the preceding cars. Therefore, the headways of motorcycles were analysed by dividing into two categories: following in the right and left half areas behind the preceding cars (see Figure 4). A total of 2,492 observations of following distances for passenger cars, 426 observations for motorcycles following in the left half and 375 observations for motorcycles following in the right half were selected. Their statistics are listed in Table 2 and the histograms are drawn in Figure 1.

Table 2. The statistics of the following distances

Vehicle type	Observation	Mean	Std. Dev	Median	Mode*	K-S test for lognormal dist.
Passenger car	2,492	12.43	9.40	9.56	5.41	0.67
Motorcycle (left)	426	17.57	14.36	13.42	5.16	0.32
Motorcycle (right)	375	15.56	13.84	11.31	3.87	0.10

* Mode is calculated based on the assumption of lognormal distribution.

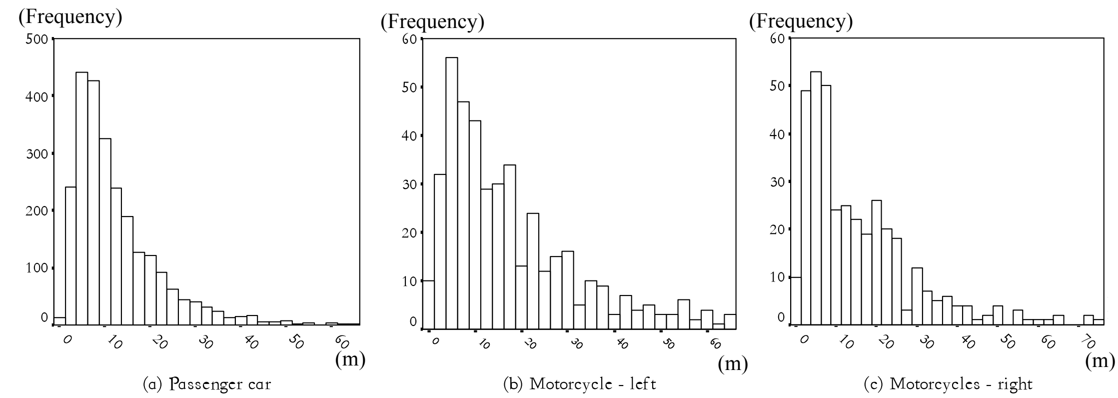


Figure 1. The following distances of passenger cars and motorcycles

Some basic statistical tests are conducted for these data. First, the distribution of the following distances are tested and found to be lognormally distributed (Kolmogorov-Smirnov goodness-of-fit test, as in Table 2). Secondly, the samples in these three groups are found not coming from the same population (Mann-Whitney test. Car vs. motorcycle-left, p=0.00; car vs. motorcycle-right, p=0.02; motorcycle-left vs. motorcycle-right, p=0.02).

In addition, it is interesting to find that motorcycles have larger means and medians but smaller modes. This is linked to the long tails of motorcycles' distribution curves (See figure 1). Such long tails are caused by the burst of the motorcycles at the beginning of green (Hsu et al., 2003) at the signalised junction upstream. When leaving the junction, they are in free flow status and have no preceding vehicles. The distances to the rear of the queue at the next junction are then counted as their safety gaps, which form the long tails their distribution curves. Since the mean and the median are affected by these extreme values seriously, the mode could be the best statistic to represent the safety gaps of motorcycles given that the safety gap in heavy traffic is of interest to this study. This point is also supported by the large standard deviations of motorcycles.

Based on the above analyses, three conclusions can be drawn: a) The following distances of motorcycles and passenger cars were lognormally distributed; b) The safety gaps of motorcycles were smaller than those of cars; c) The following distances of motorcycles had a larger variance and d) the mode was the better statistic to represent the safety gaps.

4.2 Speeds

For urban traffic in peak hours, a higher driving speed reflects a freer driving condition. To investigate the difference of speeds between the two vehicle types, 10,298 observations of speeds for passenger cars and 2,989 observations for motorcycles were selected. Their statistics are listed in Table 3 and the histograms are drawn in Figure 2, on which normal curves are superimposed.

Table 3. The statistics of the speeds

Vehicle type	Observation	Mean	Std. Dev	Skewness	Kurtosis	K-S test for normality
Passenger car	10,298	24.89	12.50	0.09	-0.51	0.00
Motorcycle	2,989	36.25	13.64	-0.16	-0.19	0.08

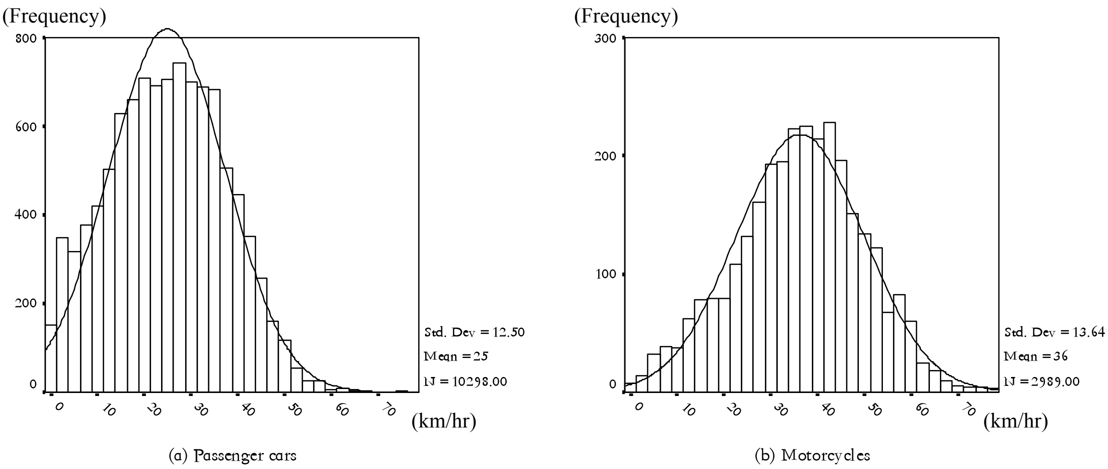


Figure 2. The histograms of the speeds

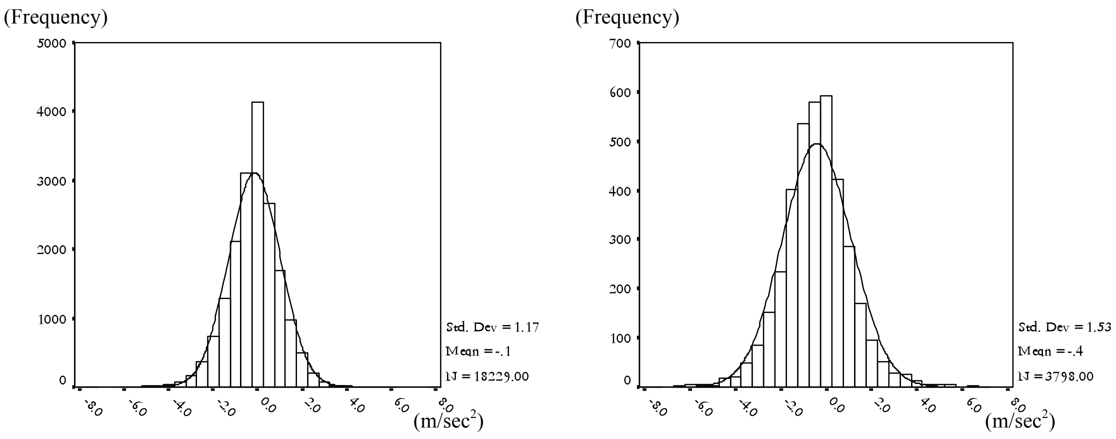
The speeds of motorcycles followed normal distribution (Kolmogorov-Smirnov test, p=0.08), but that of passenger cars did not (Kolmogorov-Smirnov test, p=0.00). Minh (2005) has also reported the observations that the speeds of motorcycles in the uncongested flow were normally distributed. Given that a steady flow will lead to normally distributed driving speeds, the result here implies that despite in the same traffic flow, motorcyclists were in a comparatively freer driving condition than car drivers were, particularly the ability to filter through the queue behind the stop line. The statistics of average speeds also support this point as the average speed of motorcycles, 36 km/hr, is significantly larger than passenger cars, 25 km/hr (Mann-Whitney test, p=0.00). In addition, the standard deviation of motorcycles is also larger than that of passenger cars, showing that motorcyclists have more chance and are willing to travel with a higher speed. These differences in speeds show that in the field data, the agility of the motorcycles gave them more choices on speeds.

4.3 Acceleration and deceleration rates

The acceleration and deceleration represent the change of speeds. Usually a great acceleration or deceleration rate is linked to the assertive driving behaviour or an unconstrained driving environment. The statistics of the acceleration and deceleration rates, based on 18,229 observations of passenger cars and 3,798 observations of motorcycles, are listed in Table 4. The histograms are shown in Figure 3, on which curves of normal distribution are superimposed.

Table 4. The statistics of the acceleration and deceleration rates

Vehicle type	Observation	Mean	Std. Dev	Skewness	Kurtosis	K-S test for normality
Passenger car	18,229	-0.14	1.17	-0.11	3.94	0.00
Motorcycle	3,798	-0.41	1.53	0.42	5.80	0.00



(a) Passenger car (b) Motorcycle

Figure 3. The histograms of the acceleration and deceleration rates

The frequency distributions of both passenger cars and motorcycles present slightly skewed and high-kurtosis curves with means close to 0 m/sec^2. Further tests show that both curves are not normally distributed (Kolmogorov-Smirnov test, p=0.00 for both) and these two samples are from different distributions (Mann-Whitney test, p=0.00). The standard deviations in Table 4 show that the motorcyclists accelerated and decelerated more sharply than car drivers did. This could be linked to their high their small size, agile manoeuvrability and intuitive steering method. However, the decelerations measured are fairly modest as the maximum braking deceleration of general motorcyclists is around -6.5 m/sec^2 (Ecker et al., 2001; Vavryn and Winkelbauer, 2004).

5 The assertiveness of motorcyclists

In the previous section, the observable kinematical features of traffic are analysed, indicating that motorcycles seem to behave more assertively as they have smaller safety gaps, higher speeds and sharper accelerations and decelerations. This seems contradictory to the fact that motorcyclists are thought to be vulnerable to road accidents. This raises an issue that why motorcyclists behave more assertively, rather than cautiously?

The model proposed in Lee et al. (2009) for describing the longitudinal following behaviour of motorcycles could be able to provide an explanation. The model assumed that by aligning to the lateral edge of the preceding vehicle, a motorcycle is able to maintain a smaller safety gap as it can easily swerve away to avoid a possible collision once the leading vehicle brakes suddenly, as illustrated in Figure 4. In heavy urban traffic, vehicles move at the speeds of around 40 km/hr. This range of speeds enables motorcyclists to make lateral movements safely. Hence, the potential for swerving is linked to the assertive behaviour.

This section presents the derivation of the model equations and the calibration of the model. The implications of this model are also discussed.

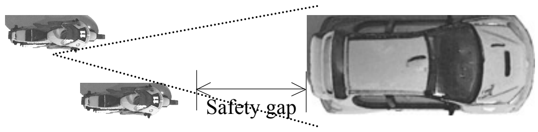


Figure 4. The safety gap of motorcycles

5.1 The model

Figure 5 shows the quantitative space-time trajectories of the braking manoeuvres of a leading passenger car and a following motorcycle. There are two strategies that a motorcyclist is likely to adopt in order to avoid a collision. When the motorcyclist decides not to swerve away, the safety gap should enable the motorcycle to stop safely (Figure 5c). Alternatively, the motorcyclist can use the safety gap to swerve away (Figure 5d).

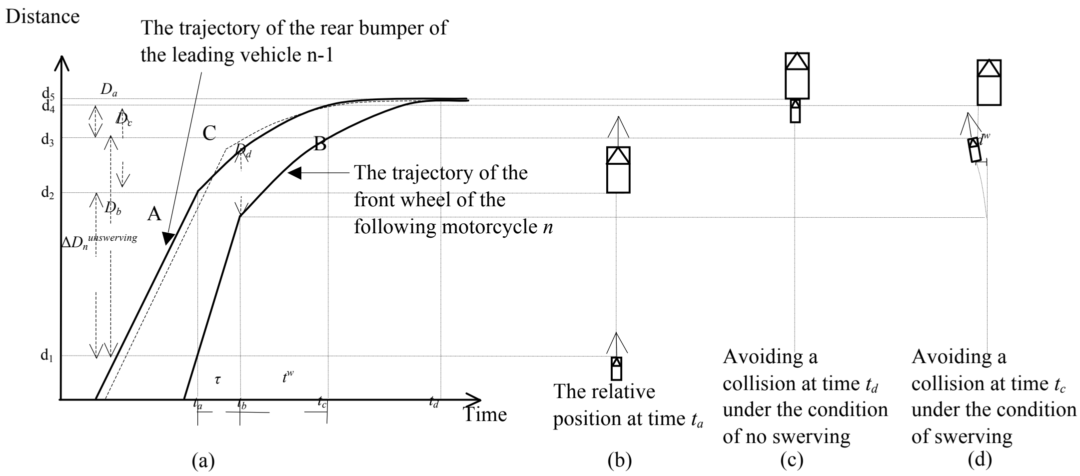


Figure 5 The space-time trajectories showing the safety gap of a motorcycle.

Curve A in Figure 5a is the trajectory of the rear edge of the car and curve B is the trajectory of the front edge of the motorcycle. The vertical distance between these two curves represents the safety gap between these two vehicles. Under the unswerving condition, as shown in Figures 5a, 5b and 5c, the motorcyclist senses the leading vehicle decelerating at time t_a and needs to stop in time (before time t_d) to avoid a collision. The safety gap that this motorcyclist has to maintain at time t_a can be formulated as:

$$\Delta D_n^{unswerving} = v_n \tau - \frac{v_n^2}{2b_n} + \frac{v_{n-1}^2}{2b_{n-1}}, \quad (1)$$

n : the nth vehicle in the lane,
n-1 : the vehicle preceding vehicle n,
$\Delta D_n^{unswerving}$: the safety gap that the motorcyclist n maintains before observing an incident under the condition of unswerving,
v_n : the initial speed of vehicle n,
τ : the reaction time, and
b_n : the braking deceleration of vehicle n under the circumstance of no swerving, $b_n < 0$.

When the motorcyclist decides to carry out a swerving manoeuvre, the safety gap could be shorter than that in an unswerving manoeuvre. This is illustrated in Figures 2a and 2d. When the motorcyclist adopts the swerving manoeuvre to swerve off to the left of the leading vehicle soon after the rider starts to brake at time t_b, he is able to avoid collision at time t_c. This swerving manoeuvre enables him to save a safety margin D_a. Therefore, the safety gap is reduced to $\Delta D_n^{unswerving} - D_a$, which is equal to $D_b - D_c$, given by:

$$\begin{aligned} \Delta D_n^{swerving} &= \Delta D_n^{unswerving} - D_a = D_b - D_c \\ &= [v_n \tau + v_n t_n^w + \frac{1}{2} b_n' t_n^{w2}] - [v_{n-1}(\tau + t_n^w) + \frac{1}{2} b_{n-1}(\tau + t_n^w)^2] \\ &= \Delta v_n(\tau + \frac{d_n^w}{v_n^w}) + \frac{1}{2}(b_n' - b_{n-1})(\frac{d_n^w}{v_n^w})^2 - \frac{1}{2} b_{n-1} \tau (\tau + \frac{2d_n^w}{v_n^w}), \text{ where} \end{aligned} \quad (2)$$

$\Delta D_n^{swerving}$: the safety gap that the motorcyclist n maintains before observing an incident under the condition of swerving,
Δv_n : the speed difference, $\Delta v_n = v_n - v_{n-1}$,
t_n^w : the time needed for the motorcyclist n to make the lateral movement d_n^w ,
b_n' : the braking deceleration of the motorcyclist n under the circumstance of swerving, $b_n' < 0$,
d_n^w : the lateral movement needed to travel, and
v_n^w : the lateral speed.

Equations (1) and (2) represent two constraints on the safety gaps of motorcycles, but do not eliminate some conditions that could cause collisions. For example, as illustrated by curve C in Figure 2a, a motorcycle with a small following gap and a sharp deceleration rate satisfies Equation (1) but still causes a collision. Hence, another constraint is imposed on the formulation of the safety gaps, i.e. the following distance between the car and the motorcycle at time t_b should be greater than 0, $D_d > 0$, expressed as:

$$\Delta D_n > v_n \tau - v_{n-1} \tau - \frac{b_{n-1} \tau^2}{2}, \quad (3)$$

ΔD_n : the safety gap that the motorcyclist n maintains before observing an incident.

When a motorcyclist is maintaining a safety gap by the principle of collision avoidance, he should preserve an ultimate safety margin into which he is not willing to intrude before the motorcycle has stopped safely. Such a concept has also been adapted in Gipps following model (Gipps, 1981). Thus, a non-negative random variable, denoted by u_n, is added to this model to represent the safety margin.

Equations (1), (2),

(3) and the safety margin u_n represent the constraints on the safety gaps of motorcycles. Hence, the minimum safety gap of a motorcycle can be formulated as:

$$\Delta D_n^{min} = \max\{\Delta D_n \quad , \min\{\Delta D_n^{unswerving} , \Delta D_n^{swerving}\}\} + u_n, \text{ i.e.} \tag{4}$$

$$\Delta D_n^{min} = \max\{ v_n\tau - v_{n-1}\tau - \frac{b_{n-1}\tau^2}{2}, \min\{ v_n\tau - \frac{v_n^2}{2b_n} + \frac{v_{n-1}^2}{2b_{n-1}}, \Delta v_n(\tau + \frac{d_n^w}{v_n^w}) + \frac{1}{2}(b_n' - b_{n-1})(\frac{d_n^w}{v_n^w})^2 - \frac{1}{2}b_{n-1}\tau(\tau + \frac{2d_n^w}{v_n^w})\}\} + u_n. \tag{5}$$

5.2 Model calibration

The following distance model was calibrated by using WinBUGS (Spiegelhalter et al., 2003; The BUGS Project, 2004), a tool that uses Markov Chain Monte Carlo (MCMC) methods (Metropolis et al., 1953) to conduct Bayesian analysis and inference. The reasons for using Bayesian analysis are as follows: (a) The variables and parameters in these models cannot be assumed to be normally distributed due to limited information. (b) There are discontinuities between the three formulae within Equation (5). (c) These models are multi-dimensional and thus the boundaries of the parameters need to be defined carefully to obtain good local optimum calibration results. (d) It is assumed that the observed following distances are affected by two error terms, one accounting for random effects and the other for the assertiveness of a motorcyclist. (e) The variance of the response variable is not constant across the explanatory variables.

One major difficulty with this calibration is that the minimum safety gap ΔD_n^{min} cannot be observed directly from the real world. Since the following distances ΔD_n is observable, ΔD_n^{min} is assumed to be the mode of ΔD_n. Given that ΔD_n follows a lognormal distribution ΔD_n^{min} can be expressed as:

$$\Delta D_n \sim \text{lognormal}(\mu_n , \sigma_n^2), \tag{6}$$

$$\Delta D_n^{min} = \text{mode}(\Delta D_n) = e^{\mu_n - \sigma_n^2} \tag{7}$$

where μ_n , σ_n are the mean and standard deviation of the logarithm of the lognormal distribution respectively. Hence, ΔD_n is employed as the response variable to calibrate the parameters in (5):

$$\Delta D_n \sim \text{lognormal}\ (\ln[\Delta D_n^{min}] + \sigma_n^2, \sigma_n^2). \quad (8)$$

Equation (8) was calibrated by using MCMC method. The deceleration of the preceding vehicle b_{n-1} is latent and unknown at time t. Thus, it is replaced by a stochastic parameter, denoted by $\tilde{b}$, to represent vehicle n's speculation on this variable.

The calibration difficult in a swerving manoeuvre is difficult due to the high correlation between the reaction time τ, the lateral speed v^w, the speculative deceleration $\tilde{b}$ and the desired deceleration b' makes. Hence, The desired decelerations of the following motorcyclists under both swerving and non-swerving conditions, b'_n and b_n, are assumed to be identical. In addition, τ is set to be a constant with the value of 0.75.

Three MCMC chains and 20,000 iterations with a burn-in of 5,000 iterations were run in the calibration process. Each iteration includes three layers, using the data from both the right-half and the left-half areas behind the preceding vehicles, 375 observations in the right half and 426 in the left. The results are listed in Tables 5.

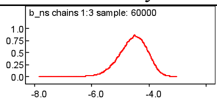
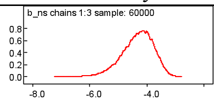
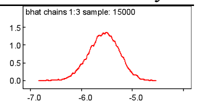
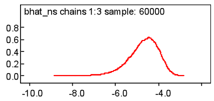
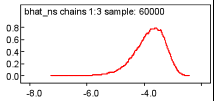
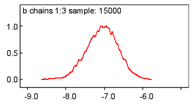
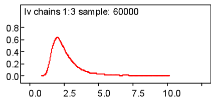
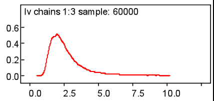
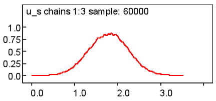
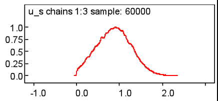
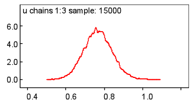
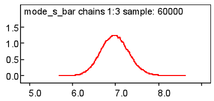
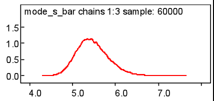
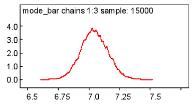
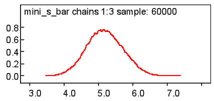
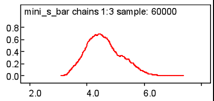
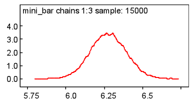
In addition, without including the swerving behaviour, Equation (4) was adapted to describe the behaviour of passenger cars, as shown in Equations (9) and (10). The calibration results of Equation (10) are also listed in Table 5.

$$\Delta D_n^{min} = \max\{\Delta D_n, \Delta D_n^{unswerving}\} + u_n, \text{ i.e.} \quad (9)$$

$$\Delta D_n^{min} = \max\{ v_n\tau - v_{n-1}\tau - \frac{b_{n-1}\tau^2}{2},\ v_n\tau - \frac{v_n^2}{2b_n} + \frac{v_{n-1}^2}{2b_{n-1}} \} + u_n. \quad (10)$$

The convergence of the MCMC models have been examined by using the assessment tools in WinBUGS, including the Gelman and Rubin plots, the plots of autocorrelation, the trace plots and kernel distribution curves. These diagnostics indicate that these models approximate to convergence, i.e. the following distances are lognormally distributed, and the model fits the data well.

Table 5. The calibrating results of the model

Node	**Motorcycles**						**Passenger Cars**		
	Left half – using Eq. (5)			Right half – using Eq. (5)			using Eq. (10)		
	Mean	S.D.	Posterior density	Mean	S.D.	Posterior density	Mean	S.D.	Posterior density
$\tilde{b}$	-4.12	0.39		-4.04	0.47		-5.56	0.30	
b_n	-4.15	0.48		-3.53	0.44		-7.05	0.40	
v^w	2.68	1.23		2.83	1.42		-	-	-
u	2.05	0.42		1.01	0.38		0.77	0.07	
mode	7.00	0.32		5.42	0.34		7.05	0.11	
$\Delta D^{\min}$	4.95	0.49		4.41	0.57		6.28	0.12	
DIC	12,571	-	-	10,730	-	-	16,992	-	-

5.3 Implication of the model

When motorcycles were following in the left-half area, their average desired braking decelerations were -4.12 m/sec^2 and they expected preceding vehicles to brake at the level of -4.15 m/sec^2. The values were -4.04 m/sec^2 and -3.53 m/sec^2 respectively in the right-half area. This range of deceleration is fairly gentle compared to their kinematical maximum braking abilities, which are around -6 to -7 m/sec^2 (Ecker et al., 2001; Vavryn and Winkelbauer, 2004). However, psychologically this range of braking decelerations is rather severe in daily traffic because only 3% of the braking decelerations in the field data are more severe than this level. In addition, these figures show that motorcyclists in the right-hand area are more risk-taking. Motorcyclists in this area follow the preceding vehicles by smaller gaps, expect the preceding vehicles to have milder decelerations and prepare to undertake more severe brakes, in comparison with those in the left-hand area. Regarding passenger car drivers, they expected more severe decelerations, -5.56 m/sec^2 from the preceding vehicles and -7.05 m/sec^2 for themselves. This shows that motorcyclists exhaust no greater proportion of the kinematical potential of their vehicles than do car drivers.

The estimated lateral speeds were 2.68 m/sec for swerving to the left and 2.83 m/sec for swerving to the right. With these lateral speeds, though they are rather mild, the swerving manoeuvre can notably decrease the safety gaps although these lateral speeds are rather mild. This might explain for the extremely safety gaps of motorcyclists observed in the literature.

Given that the mode of the frequency distribution can represent the safety gaps, for motorcycles the average safety gap is 7.00m for the left half and 5.42m for the right.

However, without considering the psychological factor, i.e. the ultimate safety margin, the minimum safety gaps can be shorter: 4.95m for the left and 4.41m for the right. The average safety gap is 7.05m, including the ultimate safety margin of 0.77m. This shows that motorcyclists actually maintain a longer psychological safety margin although their observed and physical safety gaps are smaller.

6 Conclusions

This study tries to compare certain kinematical features of motorcycles with those of passenger cars. The hypothesis that motorcycles' capability of swerving to avoid a collision contributes to their seemingly assertive behaviour is examined. From the results of this study, the following points are concluded:

- In urban networks, the observable parameters indicate that motorcycles have shorter safety gaps, higher speeds and more severe acceleration and deceleration rates than do passenger cars. These results are consistent with the findings found in the literature.
- Given that motorcycles are able to perform swerving manoeuvres safely in low speed urban traffic, the risk-taking level of most of the observed motorcyclists was gentle. This finding provides a possible explanation for why motorcyclists are more likely to accept smaller safety gaps and higher speeds even if they would be vulnerable to road accidents.

The results of this study imply that when motorcyclists maintain the same risk-taking level as other road users, they can achieve comparatively higher speeds and smaller safety gaps in urban networks spontaneously and unconsciously. This finding could have important ramifications for policy in the area of motorcycle safety.

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