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USE OF THE SAFETY FACTOR AND MARGIN OF SAFETY IN MOTORCYCLIST ACCIDENT RISK MANAGEMENT

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ABSTRACT

Deceleration rate, time to collision and impact speed have been commonly employed as accident risk indicators. However, it is hard to assess the level of accident risk since these indicators have not been developed with measurable score criteria. This study focuses on the determination of measurable risk indicators which could be used to assess accident risk level and to determine more appropriate accident risk management strategies by using the descriptive qualitative approach. The data were collected from a braking maneuver test conducted on a dry and level closed circuit course. Risk was a function of accident probability and its possible consequences, while accident probability was determined based on the safety factor, i.e. the ratio of available stopping sight distance (ASSD) to minimum SSD (MSSD), which was used to determine the margin of safety. Subsequently, accident consequence was determined using the impact speed at a predicted point of collision along the braking distance path. The results show that accident risk could be easily determined using the proposed indicators, whilst an objective and appropriate accident risk management strategy could be determined based on the minimum margin of safety value which could be obtained from each risk exposure.

Keywords: Accident risk management; Impact speed; Margin of safety; Motorcyclist, Safety factor

1. INTRODUCTION

Although riding at an excessive and/or inappropriate speed (speeding) has been reported to be a factor associated with fatal accidents (WHO, 2008; DaCoTA, 2013), riders, particularly motorcyclists, have a tendency to increase their vehicle speed due to socio-economic advantages purposes (Chen & Chen, 2011). As the motorcycle is the primary means of transport in developing countries, particularly in Indonesia (Santosa et al., 2017), its risk should be the subject of in-depth investigation, mainly because its index of fatality tends to be constant, not only in developing countries such as Indonesia (da Costa, 2012), but also in European Union countries (index (200=100)) (Joshi et al., 2010). The fatality index (the ratio between the number of fatalities and number of accidents) in Kupang (the capital city of East Nusa Tenggara province, Indonesia) in 2011 was almost 80% (da Costa, 2012). Almost every day around 60% of motorcyclists have the tendency to increase their vehicle speed and exceed the speed limit in order to save time (41%) and for sensation seeking (19%) (da Costa et al., 2016b). Accordingly, it is understandable that accident risk management is top of the agenda in the Decade of Action (DoA) of Road Safety 2011-2020 (WHO, 2011). The Indonesian National General Plan of

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Road Safety (NGPRS) 2011-2035 was also published for the same reason, in which Road Safety Inspection (RSI) and Speed Management were also recommended as strategic agendas. However, Road Safety Inspection implementation has not been based on measureable criteria, so accident risk is assessed subjectively. Consequently, since the RSI results have been influenced by suitable inspection methods, such as the scope of inspected objects, the time period, and the duration of the survey, it is felt that its subjective recommended solutions are difficult to be implemented (da Costa et al., 2016c). On the other hand, exceeding the speed limit is common in Indonesia, but sanctions for the violation are never imposed.

According to Nassar (1996), accident risk is a function of accident probability and its possible consequences. Some previous studies use the deceleration rate (DaCoTA 2013), time to collision (Lamble et al., 1999) and the safety factor (SF), i.e. the ratio between sight distance to stopping distance (Smith et al., 2013), as accident risk indicators. However, these factors have not been used properly in speed management devices, so the use of such SF models, such as the ratio between the available stopping sight distance (ASSD) and the minimum stopping sight distance (MSSD), has been recommended not only as an accident probability indicator, but also as a criterion of speed limit determination (da Costa et al., 2017). However, since the SF obtained was based on secondary data, particularly when determining the MSSD, the results have been accepted as alternative tools for accident risk reduction schemes. Consequently, in order to obtain an objective risk level, all input data should be based on measured data appropriate to the study location characteristics.

To date, in order to calculate the MSSD for particular conditions, AASHTO (2011) recommends the use of a reaction time of 1.64 s, whereas Davoodi et al. (2012) found that this could be less than 1 s, i.e. 0.68 s. In addition, although previous studies have found that the braking deceleration rate could be greater than 4.5 m/s² (Fambro et al., 1997), i.e. 6 m/s (Malkhamah et al., 2005), or even 7.72 m/s² (Winkelbauer & Vavryn, 2015), AASHTO (2011) recommends the use of 3.4 m/s² to accommodate all types of driver. These differences indicate that there is a margin of safety (MS) in the SSD model. Consequently, if the speed limit is determined based on AASHTO's recommended values, awareness of the differences in the obtained MSSDs might trigger a negative perception of the accident risk probability and/or consequences. Therefore, for accident risk analysis and/or evaluation, the calculation of an MSSD should take into account the effect of all possible factors influencing it, such as reduced speed due to downshifting, a minimum reaction time and a hard braking capability. It is predicted that a decrease in speed due to downshifting could reduce vehicle speed before braking, impacting it significantly. This issue needs to be investigated, as WHO (2008) reported that a decrease in speed of around 5 km/h could reduce the fatal crash probability by up to 20%. Other studies confirm that novice riders could increase their braking capability by up to 2.07 m/s² through short braking maneuver training (Winkelbauer & Vavryn, 2015). This clearly indicates that accident risk management schemes could be developed based on the SF and a MS obtained from the differences in their determinant variables.

Furthermore, accident risk levels should be categorized clearly so that accident risk management and/or funding systems could be developed based on such an accident risk level hierarchy. There is an urgent need for this, because 7 years since the NGPRS was released not every province owns the Traffic and Transport Modes Board, which had been hoped to be the primary institution for managing the success of the NGPRS agenda. It is predicted that the lack of institutional arrangements in accordance with (DaCoTA, 2013), as well as the absence of measureable accident risk indicators, will be the main causes of road safety management problems. To cover these needs, it is necessary to improve accident risk management strategies by providing measureable accident probability, as well its possible consequences.

Accident probability arises when a hazardous situation and/or object suddenly appears on the roadway. At an unsignalled intersection, this risky situation might occur not only due to the speculative behavior of a rider who has become impatient and has insisted on crossing the major road due to traffic delays (da Costa et al., 2016a), but also due to concurrent inappropriate speed choices of drivers. This sample case indicates that accident risk indicators should be developed based on the contextual risk conditions at each study location.

Moreover, in Indonesia speed limits have been determined based on road function classification, land used and road geometric characteristics (Ministry of Transportation, 2015), whilst globally they are also determined based on traffic composition characteristics (DaCoTA, 2013). However, almost every day motorcyclists exceed these limits in order to save time or for sensation seeking reasons, believing in their braking capability (da Costa et al., 2016b). Since motorcyclists' braking capability could be increased by up to 2.07 m/s^2 (Winkelbauer & Vavryn, 2015), it is thought that the awareness of this fact, obtained from riding frequency and/or duration of riding, could trigger risky behavior such as speeding. However, the correlation between riders' mobility needs and their safety requirements should be studied in more depth, because it is believed that speed limit violations occur due to this unresolved conflict of interest.

These phenomena strongly indicate that accident risk management needs to be improved. Moreover, in order to evaluate and recommend a more appropriate accident risk management strategy, the availability of measureable and objective accident risk indicators is an urgent and important need. Therefore, the aim of this study is to determine more appropriate accident risk indicators and to recommend a suitable accident risk management scheme. The availability of measureable accident probability (i.e. by using the ratio between ASSD and MSSD) and its possible consequences (i.e. by using predicted impact speed along the braking distance path, obtained from the relevant approach speed and hard braking deceleration rate) could be used to determine the accident risk level easily, as well as to recommend more contextual and objective solutions.

It is believed that the use of the proposed accident risk analysis model could not only minimize the subjectivity and/or uncertainty of results obtained from the previous accident risk analysis models, such as road safety inspection/audit (RSI/A) (da Costa et al., 2016c), but could also be used to determine appropriate accident risk management strategies and/or techniques. It is hoped that these objectives and the measureable model might also being adopted in other risk analysis approaches, depending on the risk conditions (risk indicators). Moreover, the results of this study could be used to support one of NGPRS's primary aims, to provide better speed management guidance and its institutional arrangement.

2. METHODOLOGY

In order to avoid crashes, all riders need adequate time and space to react and brake safely. Therefore, this study uses the safety factor (SF), i.e. the ratio between ASSD to MSSD, as the accident probability indicator. As previously mentioned, since downshifting might reduce vehicle speed before braking (V_1), the MSSD model is defined as a function of the minimum perception reaction and braking distance. The reaction and braking distance ($d_1 = V_0.t_1$ and $d_3 = V^2/2a_2$) were determined using the AASHTO model. The braking distance model was determined based on speed and braking capability (which correspond to pavement conditions). Hence, as reduced speed due to downshifting is not influenced by the pavement coefficient, in accordance with the theory of kinematics the downshifting distances (d_2) were calculated by using the formula $V_0.t_2\text{-}1/2a_1.t_2^2$. When the sudden appearance of a hazardous object or situation occurs in the near distance, riders usually downshift instantly (with a reaction time of almost zero), hence the sum of the reaction and downshifting distance is $V_0.t_3$-1/2$a_1.t_3^2$, where t_3 is the sum of t_1 and t_2. Therefore, MSSD is the sum of reaction, downshifting and braking distance, as can be seen in Figure1 and as calculated by using Equation 1.

$$\min SSD = v_0 t - \tfrac{1}{2} a_1 t^2 + \frac{v_1^2}{2a_2} \tag{1}$$

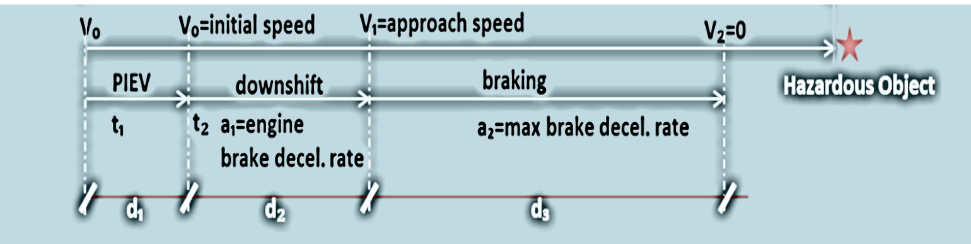


Figure 1 MSSD Scheme

It was planned that all the required data would be collected through field measurement at an unsignalled intersection. However, from the pilot survey it was found to be very difficult to measure the actual reaction time (t_1), downshifting time (t_2), engine braking deceleration rate (a_1) and hard braking deceleration rate (a_2) due to mixed traffic conditions. Consequently, these were measured at a dry and level closed circuit course with good pavement conditions, located around 4 km from the monitored intersection.

141 participants (local motorcyclists) were successfully recruited. All participated in the braking maneuver test and completed the questionnaire, so their perceptions could be directly compared with their actual braking performance. The substance of the questionnaire focused on riders' perceptions of their braking capability, as well as the reasons for their daily favoured speed choices and for exceeding the speed limits. The difference between their perception of their braking capability and their actual braking capability was then compared.

Before participating in the braking maneuver test, all the participants were asked to ride at their daily favored speed and then to stop their vehicle immediately, using their hard braking capabilities, as soon as they recognized the presence of a stop sign. However, they were not informed when and where the stop sign would appear. The reaction and downshifting times (t = the sum of t_1 and t_2) were measured using a video camera. These were defined as the elapsed time between the stop sign appearing and the rear brake light beginning to flash. Meanwhile, the braking distance was measured from the point where the rear brake started to flash and the line where the vehicle completely stopped.

The vehicle speed before braking was then simply calculated using Equation 2, whilst the hard braking deceleration rate was determined based on the obtained braking distance (S) and the vehicle speed before braking, using Equation 3.

$$V_1 = V_0 - a_1 t \tag{2}$$

$$a_2 = \frac{V_1^{\,2}}{s} \tag{3}$$

The proposed reaction and downshifting distance (Equation 4) is different to the reaction distance model recommended by AASHTO, because before braking riders usually utilize the engine brake force to slow their vehicle down, which is referred to as downshifting. As previously described, it is predicted that the reduced speed due to downshifting will not only decrease the vehicle speed before braking, but also, in particular, braking distance and impact speed, depending on the speed choice and gear transmission (Lee, 2009), and might also be influenced by the duration of downshifting. It is assumed that the reduced speed might decrease the fatal crash probability.

$$Srd = V_0 t - \tfrac{1}{2} a_1 t^2 \tag{4}$$

Accident probability was then determined based on the safety factor (SF). If this is less than 1.0, then a collision might occur (da Costa et al., 2017), as can be seen in Equation 5.

$$SF = ASSD/MSSD \quad \geq 1.0 \tag{5}$$

In the case of risky conditions at an unsignalled intersection, the ASSD could be referred to as the average critical crossing gap acceptance (CGA). This is defined as the distance between the approaching vehicles and those crossing, captured using a video camera (da Costa et al., 2016a). Accordingly, if the ratio is less than 1.0, then those vehicles might be involved in an accident. The average ASSD or CGA was determined using the following equation:

$$\mathrm{ASSD} = \mathrm{D_a/N} \tag{6}$$

where Da is the available distance between the position of approaching vehicles (the major stream) when the crossing vehicles start to cross from/into minor streets, and the predicted location of the collision, whilst N is the number of monitored CGA situations captured during the 9 hours/day survey.

Meanwhile, the possible consequences were determined using the curve correlation between impact speed and fatal crash probability (da Costa et al., 2017). Based on the vehicle speed before braking (V_1) and the hard braking deceleration rate (a_2), the predicted impact speed (V_2) along the braking distance path (S) and/or the predicted point of collision was calculated using Equation 7.

$$S = \frac{V_1^2 - V_2^2}{2a_2}, \text{ or } V_2 = \sqrt{V_1^2 - 2a_2 S} \tag{7}$$

Understandably, a decrease in minimum SSD due to the occurrence of minimum reaction time, and engine and hard braking deceleration rates, would decrease the accident probability. Moreover, a decrease in vehicle speed before braking due to downshifting might reduce not only braking distance but also impact speed. Therefore, accident risk management strategies and/or techniques should be determined based on the obtained impact speed and margin of safety, calculated using Equation 8. The MS reflects the minimum effort needed to improve the capacity of a safety system, such as rider braking capability or headway distance choice, meaning the smaller the MS, the greater the effort needed to brake.

$$\mathrm{MS} = \text{Safety Factor} - 1 \tag{8}$$

3. RESULTS AND DISCUSSION

From the results of the braking maneuver tests it was found that riders' mean perception reaction time was 0.53 s (Std. Dev. 0.23, min 0.25, max 0.96), which was obtained from a wide range of participant ages (13−54 years old) and/or riding experience (from less than 2 to more than 15 years). These values are similar to those of previous studies; for example, the 0.68 s found by (Davoodi et al., 2012). In addition, as the object (motorcyclists' braking capability) and experimental method (on a dry and level closed circuit course, with a speed range of 50−60 km/h, in expected conditions) were also similar, then the values can be used to calculate the minimum SSD. In addition, it is clearly indicated that in unexpected conditions reaction time would be similar, because riders would apply their brakes instantly, in accordance with AASHTO 2004 and 2011 editions, which state that this would be 35% higher than in expected conditions (AASHTO, 2011). Hence, their reaction and downshifting time in unexpected conditions would be around 0.72 s.

Furthermore, from the braking maneuver test it was found that 28% of participants usually rode at a speed of 60−80 km/h, whilst 48% preferred to travel at around 50−60 km/h, similar to the approach speed at the compared study location, i.e. an unsignalled junction at Km.13. Jl. Raya Solo, Yogyakarta. Hence, for the minimum SSD simulation process, the initial speed range of 40−80 km/h was used.

Furthermore, the mean engine braking deceleration rate obtained was 1.29 m/s² (Std. Dev. 0.29, min 0.80, max 2.14) and braking capability was 6.75 m/s² (Std. Dev. 2.12, min 3.28, max 12.48). The mean engine braking deceleration rate was the average value between automatic (43%) and 57% of manual gear transmission types of the monitored motorcycle, because their mean values were relatively equal, i.e. 1.33 and 1.27 m/s², respectively. This indicates that for the medium speed choice (50−60 km/h) the engine braking deceleration rate obtained was greatly influenced by speed choice and gear position, in accordance with (Lee, 2009), and might also be influenced by the duration of downshifting. It should be noted that the engine brake deceleration rate was determined without taking into account the effect of tire air pressure or wind speed and/or direction. Moreover, this engine braking deceleration rate was slightly lower than the deceleration rate obtained at the study location, i.e. 1.73 m/s², as previously reported (da Costa et al., 2016a). This strongly indicates that the monitored roadway deceleration rate was influenced more by downshifting, rather than braking forces.

On the other hand, from the braking maneuver experiment on the closed circuit course it was also found that the average reduced speed due to downshifting was around 5−7 km/h, obtained during an average downshifting time of 1.29 s at a distance of approximately 20 m. Since the deceleration rate was virtually constant (Lamble et al., 1999; Lee, 2009; Ueckermann et al., 2015), it is thought that this reduced speed could decrease not only braking distance, but also impact on speed and fatal crash probability. Besides, it should be noted that the mean braking deceleration rate of 6.75 m/s² (Std. dev. 2.12, min.3.28, max.12.48) was obtained from an expected hard braking maneuver scenario, with optimal pavement conditions (dry, level, and with a skid resistance value/SRV of 60−67), and medium speed choices (40−75 km/h). The mean value of the braking deceleration rate was relatively equal to similar previous study findings, i.e. 6.6, 7.8, 10 m/s² (for non-ABS and ABS motorcycles as well as for passenger cars, respectively) at 60 km/h on a flat, dry and clean roadway) (NSW.Gov, 2012) and 5.65 m/s² (Std. Dev. 1.02, min 3.85, max 8.15, without an anti-lock braking system/non-ABS motorcycle, with a speed range of 50−60 km/h, and with expected scenario conditions) (Winkelbauer & Vavryn, 2015). Subsequently, based on the standard deviation value, these measured braking deceleration rates were classified into below average (< M-1SD), average (M-1SD to M+1SD) and above average (> M+1SD). The mean braking deceleration rate values for the three categories were 3.9, 6.57 and 10.7 m/s², respectively.

Consequently, although riders exercised their hard braking capabilities, a collision probability still existed, with its magnitude differing between riders' varying braking capabilities. Accordingly, since a previous study has reported that novice riders could increase their braking capability by 2.07 m/s² (Winkelbauer & Vavryn, 2015), the riders' braking capability, particularly of those in the below average and average categories, needs to be increased. This is also why the effect of such incapable riders on the accident risk probability and/or consequences should be further investigated. The results are described in the following sub-sections.

3.1. Accident Risk Indicator and Value

The accident risk indicator and its criteria are different from one risky situation to another, depending on traffic, road geometrics, road environment situations, and road user behavior. They may also be influenced by accident risk management measures. For example, for particular road design purposes and/or emergency situations, AASHTO recommends the use of a minimum reaction time of 1.64 s and a braking deceleration rate of 3.4 m/s². This minimum reaction time is less than for normal conditions, i.e. 2.5 s, indicating the presence of a tolerable margin of safety. Moreover, although the braking deceleration rate could be greater than 4.5 m/s² (Fambro et al., 1997), such as 1.12 g (Bartlett et al., 2007) or 6 m/s² (Malkhamah et al., 2005), AASHTO Edition 2011 still uses 3.4 m/s² to accommodate older car drivers' abilities. This clearly indicates that for road design purposes, including speed limit determination, AASHTO uses a maximum margin of safety design philosophy. Consequently, the determination of road infrastructure design, including speed limits, is based on this philosophy. However, traffic compositions in developed and developing countries are different, as are motorcyclist and car driver reaction times and braking deceleration rates. Therefore, awareness of the differences in braking capability might encourage speeding behavior and/or speed limit offences because although time saving and sensation seeking are the most popular reasons for speeding but not every speeding end up crashed. A previous study indicates that the imbalance between safety (braking capability) and mobility needs to be bridged (da Costa et al., 2017). That is why accident risk evaluation uses a minimum margin of safety philosophy, instead of a maximum one.

Accordingly, in this paper, accident probability is determined based on the safety factor, whilst its consequences are determined using the predicted impact speed along a braking distance path, as previously described. Since the accident probability indicator is also a function of MSSD, in order to obtain the MSSD it is necessary to combine the effect of all the potential variables involved.

This is the reason why the MSSD is calculated by considering the effect of minimum reaction time, downshifting and hard braking capability, because the maximum or higher risk potential contributing factor, i.e. speed choice, needs to deal with drivers' and vehicles' braking capability. This was considered because the misperception about braking capability could lead riders to choose inappropriate speeds, which might increase their probability of being involved in an accident.

Moreover, use of the decrease in vehicle speed due to downshifting was made in the proposed model because before braking riders usually instantly reduce their vehicle's speed by using the engine braking force (downshifting). As it was assumed that the use of decreased speed due to downshifting could shorten the braking distance as well as the impact speed, in order to clarify whether this hypothesis was statistically rejected or not, a chi-square test was conducted.

The braking distance, impact speed and minimum SSD were calculated using a perception reaction time of 0.72 s, an engine braking deceleration rate of 1.29 m/s², a reduced speed due to downshifting of 7 km/h and hard braking deceleration rates of 3.9, 6.57 and 10.7 m/s² for riders in the below average, average and above average braking capability categories respectively.

The results show that although the use of engine braking force does not influence the perception reaction distance and vehicle speed before braking significantly, it was found that the difference between approach speeds obtained from the proposed and AASHTO 2011 edition models, if the downshifting duration of 0.72 and 1 s, was around 4 and 5 km/h, respectively.

Therefore, when this reduced speed was used to calculate braking distance and impact speed it was found that the distance and speed obtained using the proposed model were significantly different to the braking distance obtained using the AASHTO 2011 edition model (the χ^2 of 17.669 calculated is greater than the standardized χ^2, i.e. 15.507) as can be seen in Table 1, and also the impact speed (the χ^2 calculated of 45.09 is greater than the standardized χ^2, i.e. 15.507). The approach speed was determined based on an initial speed of 60 km/h, an engine deceleration rate of 1.29 m/s² and reaction time of 0.25–2.5 s, whilst the braking distance was determined based on an approach speed and a braking deceleration rate for riders in the below average category, i.e. 3.9 m/s². This explains why riders in this category should increase their braking performance.

Table 1 Effect of reduced speed due to downshifting on braking distance

Approach speed (km/h)	Braking distance (m)		Residual	Std. Residual	χ^2
	Proposed model	AASTHO			
58.84	34.6	36	(1)	1.900617	0.053
57.68	33.3	36	(2.73)	7.4547674	0.207
56.66	32.1	36	(3.90)	15.191172	0.422
55.36	30.6	36	(5.35)	28.654851	0.796
54.20	29.4	36	(6.62)	43.877243	1.219
53.04	28.1	36	(7.87)	61.906083	1.720
51.88	26.9	36	(9.09)	82.540469	2.293
50.72	25.7	36	(10.28)	105.58384	2.933
49.56	24.6	36	(11.44)	130.84399	3.635
48.40	23.4	36	(12.58)	158.13305	4.393
				χ^2 calculation	17.669
				standardized χ^2	15.507

This finding demonstrates that, as previously predicted, the reduced speed due to downshifting significantly influences braking distance and impact speed and confirms the curve correlation between change in speed and crash probability reported by Nilson (WHO, 2008).

Subsequently, Figure 2 describes the scenario used to analyse accident risk. It shows that R (from A to B) is the sum of reaction and downshifting distance, whilst the impact speed (V_2) at a predicted collision location along the braking distance path (T) could be determined for various braking capabilities, as can be seen in Figure 3a. This is why the higher the braking capability, the shorter the minimum SSD produced. It is clear that the accident involvement probability for riders with above average braking capability will be lower than those in the average and below average categories. Hence, speed choice should involve braking capability. According to these explanations, it can be inferred that it is worth considering the effect of braking capability on accident risk management measures.

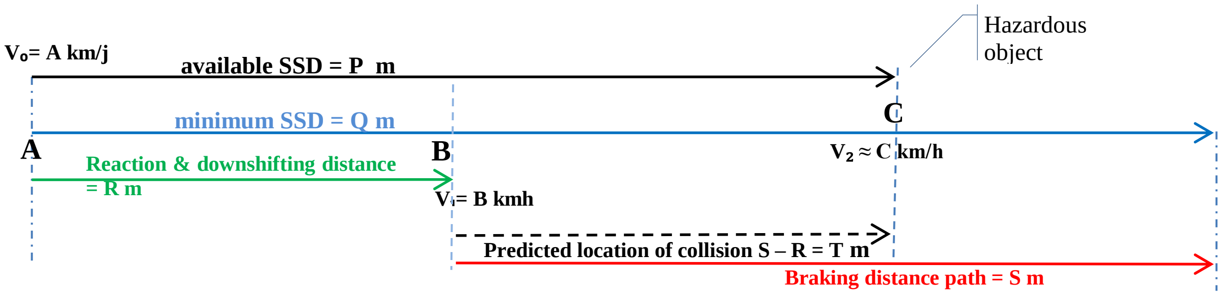
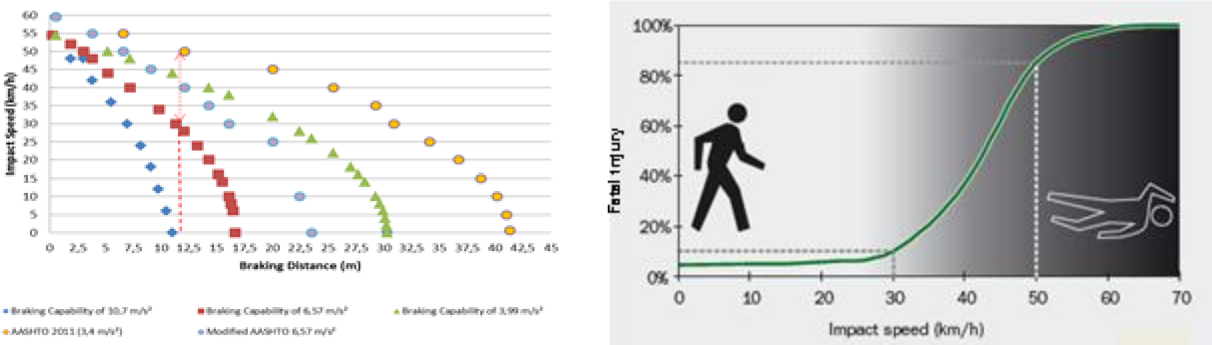


Figure 2 Accident risk analysis scheme

Furthermore, by using Equation 7 when braking distance is simulated, the predicted impact speed (V_2) at the predicted station of accident location (T) along the monitored braking distance path (S) can be determined easily. Figure 3a clearly shows that when the brake is first applied (T = 0 m), the speed is around 55 km/h. This will decrease in line with increasing braking distance. Thus, if the predicted station (T), particularly for riders in the average braking capability category, is around 12.5 m, then the different impact speed (V_2) obtained from the AASHTO and proposed models is around 10 km/h. Consequently, according to the curve correlation between impact speed and fatal crash probability (WHO, 2008), riders in the average braking capability category have the possibility to reduce their fatal crash probability by around 30%, as can be seen in Figure 3b. Since the difference between below average and average braking capability is around 2.58 m/s^2, similar to the potential braking capability which could be improved, i.e. 2.07 m/s^2 (Winkelbauer & Vavryn, 2015), it is reasonable to recommend that all riders should have a minimum braking capability of 6.57 m/s^2. This clearly indicates that speed choice should involve braking capability. Hence, this new perspective, i.e. the effect of the difference in maximum braking capability on accident risk, should be taken into account when determining future speed management measures.



(a) Predicted impact speed along braking distance path

(b) Correlation between impact speed and fatal crash probability

Figure 3 Effect of decreased speed due to downshifting on the braking distance and impact speed

This statistical evidence indicates very clearly that reduced speed as a result of downshifting plays an important role in determining braking distance, impact speed and MSSD. Consequently, the proposed safety factor determined from this obtained MSSD value is viable for use as an accident probability indicator.

For example, in order to determine the safety factor, if the ASSD is taken from the mean critical crossing gap acceptance (CGA), i.e. the position of an approaching vehicle (major stream), from the predicted station of accident location of 20 m, particularly when the vehicle starts to cross to/from a minor street at an unsignalled junction, as captured using a camera (da Costa et al., 2016a), then the predictive accident risk probabilities (SF) for riders' minimum reaction and downshifting time of 0.72 s, engine braking deceleration rate of 1.29 m/s^2, various braking capability categories (3.9, 6.57 and 10.7 m/s^2) and speed choices (40−80 km/h) is calculated using Equation 5 . The results can be seen in Table 2.

It should be noted that the average CGA of 20 m (Std. dev. 0.21; min.17.5; max. 23) was calculated using Equation 6, in which the 54 of monitored CGA situations occurred only when the approaching vehicle speeds were lower than 60 km/h. Hence, the actual SF value presented in Table 2 is only relevant or valid for a speed range of 40−60 km/h. The CGAs for the speed range of 70−80 km/h, if available, might be different (longer). However, calculation of the SF for speed choices of 70 and 80 km/h was also made and is shown in Table 2, purely to indicate that even for riders in the above average braking capability category, such CGA and speed choices could lead them to the probability of a fatal crash.

Table 2 Safety factor and margin of safety for various speed choices

Speed (km/h)		MSSDs*			ASSD	*Safety Factor**			*Margin of Safety**		
V_0	V_1	1	2	3		1	2	3	1	2	3
80	75	71.9	49.1	36.2	20	0.28	0.41	0.55	-0.72	-0.59	-0.45
70	65	55.9	38.8	29.1	20	0.36	0.52	0.69	-0.64	-0.48	-0.31
60	55	41.9	29.6	22.7	20	0.48	0.67	0.88	-0.52	-0.33	-0.12
50	45	29.9	21.7	17.1	20	0.67	0.92	1.17	-0.33	-0.08	0.17
40	35	19.9	14.9	12.1	20	1.00	1.34	1.65	0.00	0.34	0.65

*1, 2, 3 for below average, average and above average braking capabilities of 3.9, 6.57 and 10.7 m/s^2 respectively

Moreover, since such a hard braking deceleration rate was obtained because the pavement surface was in good condition (the obtained skid resistance value/SRV was around 60−67, measured in dry conditions using a British Pendulum Tester), the identified risk shown in Table 2 clearly indicates that it is necessary to ensure that all risky road stretches, such as unsignalled intersections, or the distance before a pedestrian crossing zone, should always be in kept in a well preserved state. In addition, speed limit determination in such road segments should be determined by taking into account the effect of riders' braking capability.

From Table 2, it can also be seen that for each speed choice, the higher the braking capability, the shorter the MSSD obtained, so the SF would be closer to the threshold value, i.e. 1.0. Besides, it is also clearly shown that for that CGA distance, particularly when the vehicle speed of the major flow is 50 km/h, and if vehicles are not able to cross the conflict lane normally due to traffic conflict between the entering and exiting vehicles, then only riders in the average and above average braking capability categories have the possibility to avoid a crash (the SFs are nearly equal or ≥ 1.0, i.e 0.92 and 1.17, obtained from 20/21.7 and 20/17.1, respectively). However, according to Figure 2, for a speed choice of 60 km/h, only riders in the below average braking capability category might be involved in crash leading to serious injury and/or have a fatal crash probability of 60%, because its prediction impact speed is almost 45 km/h greater than the tolerable head injury criterion/HIC of 43 km/h (Mihradi et al., 2017).

Therefore, since urban speed choice is usually around 60 km/h, in order to avoid a crash riders in the below average and average braking capability categories should increase their braking skills by up to 63.55 % and 38.59 % (from $\left|\frac{3{,}9}{10{,}7}-1\right|$ and $\left|\frac{6{,}57}{10{,}7}-1\right|$) or 6.8 and 4.13 m/s^2 (from 10.7−3.9 and 10.7−6.57), respectively. These minimum required values could be achieved because the range between the minimum and maximum braking capabilities obtained from the braking maneuver tests was very wide, namely from 3.28 to 12.48 m/s^2. In addition, a previous study has found that novice riders could increase their braking capability by up to 2.07 m/s^2 (max 4.9) (Winkelbauer & Vavryn, 2015), whilst another relevant study reported that an increase in braking capability was also influenced by the type of braking (the use of rear or front brakes) and the vehicle braking system (for example, anti-lock) (Bartlett et al., 2007).

3.2. Accident Risk Reduction Scheme

As previously mentioned, although speeding is commonly acknowledged to be a factor often associated with fatal crashes (DaCoTA, 2013; WHO, 2008), almost every day riders tend to exceed their daily favored speed and/or the regulated speed limit due to socio-economic advantages such as time saving or sensation seeking (da Costa et al., 2016a; 2016b). This speeding behavior is triggered by the belief in their braking capability (Chen & Chen, 2011;

Schroeder et al., 2013; da Costa et al., 2016b). This confirms that speeding intention is determined by perceived behavioral control (Tankasem et al., 2016).

On the other hand, in Table 2 it can also be seen that an accident risk management scheme should be based on a distance-based model reflected in margin of safety values. Besides, this study has also found that decreased speed due to downshifting significantly influences braking distance and impact speed, as previously predicted. Subsequently, overall the use of minimum reaction time as well as engine and hard braking deceleration rates influence the minimum SSD significantly. Therefore, it can be inferred that in order to avoid crashes, braking capability is one of the primary factors that should be managed systematically. This is an urgent and strategic task, because the study has found that out of the 141 participants, only around 24% were in the high braking capability category (Figure 4), and could therefore avoid crashes safely if an unexpected static object suddenly appeared 20 m ahead, as previously described in Table 2.

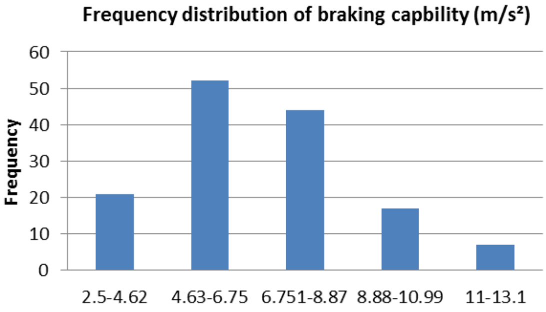


Figure 4 Braking Capability Characteristics

Accordingly, the potential effort that could be made is to increase braking capability. However, it should be noted that based on Equation 5, this capability should be increased exponentially, which might be very difficult to achieve when the speed is around 70 km/h or higher. Therefore, it is necessary to apply a minimum standardized braking capability built on a zero fatality philosophy to risky urban road segments. Accordingly, since only riders in the below average braking category might be involved in crashes leading to serious injury due to a speed of 60 km/h (refer to Figure 2), then a moderate braking deceleration rate of 6.57 could be proposed as the standardized braking deceleration rate. This strategy could be implemented because an increase of 4.9 m/s² in maximum braking capability could be achieved by novice riders (Winkelbauer & Vavryn, 2015). However, speed choice should involve braking capability. Consequently, mitigation efforts, such as determination of appropriate speed limits, providing appropriate information about safety distances, and increasing rider braking capability should also be undertaken based on this distance-based model analysis results.

Meanwhile, in order to analyse and/or evaluate other accident risk situations, the most important consideration is how to provide a measureable and contextual accident probability indicator, suited to each risky situation. Each situation should be clearly identified, so that its risk factor and/or risk trigger, as well as its explanatory variables, can not only be defined, but also completed with a measureable indicator (Fitch et al., 2010; da Costa et al., 2017). Regardless of the needs of other accident risk probability and consequence indicators, the results of this study strongly indicate that accident risk could be reduced by using the proposed safety factor and minimum margin of safety analysis model.

However, riders have the tendency to exceed their daily favored speed, almost every day, due to socio-economic advantages such as time saving and sensation seeking, which is triggered by the perception of their braking capability. Therefore, this risk exposure should be managed seriously, because the results of the braking maneuver tests show that such a perception could be wrong.

These findings clearly indicate that unbalanced mobility (speed choice) and safety (braking skill) are crucial issues. Appropriate speed limits should not only suit riders' mobility needs, but also their braking capability (da Costa et al., 2017). Consequently, it is believed that speed management policies such as speed limit guidance should be improved, because to date they have been determined by road function classification, traffic composition and road environment conditions. This study has shown that it is worth considering the effect of braking capability in future speed management and/or speed limit guidance. This is crucial, because a previous study has found that countries with higher efficiency in speeding law enforcement have a lower rate of fatal traffic accidents (Kumphong et al., 2016). If this matter is considered together with the NGPRS agenda, it is hoped that this distance-based safety analysis model could be adopted in RSI/A and speed management programs so that the NGPRS target could be achieved more quickly and effectively. Another previous study has reported that traffic safety facilities management could be conducted more effectively if facility and value management is integrated at the earlier and/or crucial stages, and as soon as possible (Isa et al., 2017). Moreover, the use of the proposed accident risk analysis model could not only bridge the gap between mobility (time saving, sensation seeking, etc.) and safety needs (braking capability), but could also minimize the subjective results obtained from previous accident risk analysis models, such as RSI/A. However, since risk situations vary, the availability of accident probability and consequence indicators, as well as their scoring criteria, is an urgent need.

In addition, as this study was undertaken based on motorcyclist performance and risk conditions at an unsignalled intersection, it is necessary to conduct further studies on other types of vehicle and other types of risk situation, such as in the dilemma zone, or because of traffic violations, because in order to avoid crashes riders need adequate time and space to react and brake safely. Even when they are involved in the possibility of a head-on crash due to insufficient passing sight distance, the collision might not be able to be avoided, but their braking ability could reduce the probability of it being a fatal crash.

4. CONCLUSION

From the previous discussions, it can be inferred that the decreased speed occurring during downshifting influences braking distance and impact speed significantly, so that a combined effect of the use of minimum reaction time, and engine and hard braking deceleration rates influences minimum SSD dramatically. Therefore, the safety factor and minimum margin of safety obtained from the differences in rider braking capabilities could not only be used in accident risk analysis and/or evaluation, but also to describe both the accident risk situation and risk management strategy more clearly, objectively and easily.

These findings confirm previous studies' recommendations, i.e. that riders' braking capability should be increased (Winkelbauer & Vavryn, 2015). This increase could be achieved by using the right type of braking and/or braking system (Bartlett et al., 2007). The implications are clear: (1) in order to obtain more appropriate speed management measures, such as future speed limit determination guidance, it is worth considering the effect of braking capability by using the proposed safety factor and minimum margin of safety models; (2) since such braking capability was determined because the pavement was in good condition, this clearly indicates that besides an appropriate speed limit, it is necessary to ensure that all risky road segments should always be in a well preserved condition; and (3) since braking capability could improve, and that this could reduce both the probability of accidents and fatal crashes, it is necessary to ensure that driving license processes should also accommodate braking capability in their knowledge-based training material and practical skill segments.

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