Factors Associated with Motorcylists' Safety at Access Points along Primary Roads in Malaysia

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Factors associated with motorcyclists' safety at access points along primary roads in Malaysia

Muhammad Marizwan bin Abdul Manan

DOCTORAL DISSERTATION

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Keywords: Motorcycle accident fatality, Safety Performance Function, motorcyclists' behavior, primary road, access point

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And spend of your substance in the cause of Allah and make not your own hands contribute to (your or others) destruction; but do good; for Allah loveth those who do good
(Holy Quran: Chapter 2, verse 195).

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Contents

Abstract

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List of Publications

This thesis is based on the following papers, which will be referred to in the text. The papers are appended at the end of the thesis.

Paper 1 Abdul Manan, M. M., & Várhelyi, A. (2012). Motorcycle fatalities in Malaysia. IATSS Research, 36, 30-39.
My contribution: Analysis of the data and writing a large part of the paper.

Paper 2 Abdul Manan, M. M., Jonsson, T., & Várhelyi, A. (2013). Development of a safety performance function for motorcycle accident fatalities on Malaysian primary roads. Safety Science, 60, 13-20.
My contribution: Developing the predictive model with comments from co-authors and writing a large part of the paper.

Paper 3 Abdul Manan, M. M., & Várhelyi, A. (2013). Motorcyclists' road safety related behavior at access points on primary roads in Malaysia - A case study. Transportation Research Part F: Traffic Psychology and Behaviour, (submitted).
My contribution: Observational data collection, data analyses and writing a large part of the paper.

Paper 4 Abdul Manan, M. M. (2013). Motorcycles entering from access points and merging with traffic on primary roads in Malaysia: Behavioral and road environment influence on the occurrence of traffic conflicts. Accident Analysis & Prevention, (submitted).

Introduction

According to the WHO (2013), close to a quarter (24.1%) of the world's road traffic deaths occur among motorcyclists (see Table 1). Of these motorcycle fatalities, the South-East Asia region (i.e. mostly low- to middle-income countries) has the highest rate with 49.9%, compared to "only" up to 10.9% motorcycle fatalities in high-income countries in the European region (see Table 1). According to Shinar (2012), the increase of motorization, coupled with improved roadways, in high-income countries has reduced the exposure and fatalities of pedestrians and bicyclists. However, the rising costs of fuel and other changes in lifestyle have increased the exposure of motorcyclists, and their safety has lagged behind, to the point that in some countries (most notably Australia, France, Portugal, and the U.S.) the number of motorcyclists who die in crashes has actually increased over the past 3–4 decades (Shinar, 2012).

Sixty five percent of the world's motorcycles are in Asia, whereas Europe and North America account for only 16% (Haworth, 2012). The 4 countries with the highest numbers of motorcycles per 1000 of population are Malaysia, Thailand, Cambodia and Japan (Haworth, 2012; Senbil et al., 2007). In developing and low to middle-income countries, such as those in the Asian region, motorcycles are used and exposed frequently as they are relatively affordable to buy and run (Haworth, 2012; WHO, 2013). Hence, the high number of motorcycles on Asian roads is reflected in their high proportion of fatality accidents.

Table 1: Road traffic death by World regions (WHO, 2013)

World Region	Estimated number of road traffic deaths	Estimated number of motorcycle fatalities	% MC fatalities of all
Africa	194,368	8,267	4.3
Americas	148,075	24,418	16.5
Eastern Mediterranean	97,865	7,437	7.6
Europe	91,616	10,026	10.9
Central Asia	276,570	95,308	34.5
East Asia	16,023	2,509	15.7
South-East Asia	117,360	58,560	49.9
West Asia	281,307	89,217	31.7
Western Pacific	2,879	281	9.8
Grand Total	1,226,063	296,024	24.1

Central Asia – Bhutan, China, Mongolia
East Asia – DPR Korea, Japan, Rep Korea
West Asia – Bangladesh, India, Maldives, Pakistan, Sri Lanka
South-East Asia – Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam

The large variation in motorcycle fatal accidents among different regions of the world may reflect the usage and purpose of usage and exposure of motorcycles. For example, in Europe and North America (i.e. US and Canada), the share of motorcyclist fatalities is low, because motorcycles (mostly for single riders) are used for touring and leisure purposes (Haworth, 2012). In Sweden, 36% of the motorcycle fatalities are associated with high engine capacity motorcycles (i.e. custom-built bikes, touring and supersport bikes), whereas mopeds and scooters are only involved in about 4% (Trafikverket, 2010). In Germany, motorcycle accidents occur mostly during recreational rides on weekends in the summertime (Wick et al., 1998). Motorcycles are commonly used for commuting in the large cities of some developed countries, particularly European, e.g. Barcelona and Paris (Albalate and Fernández-Villadangos, 2010; Clabaux et al., 2012; Haworth, 2012); thus, the majority of motorcyclists' accidents occur in an urban environment (Albalate and Fernández-Villadangos, 2010; Clabaux et al., 2012) rather than in rural areas. In contrast, fatal motorcycle accidents in the Asian region are more or less evenly distributed along rural and urban roads (ADB-ASEAN, 2003; ESCAP, 2009). Moreover, apart from the recent growth in the number of motorcycles, the problems of mixed traffic and underdeveloped infrastructure, safety regulation and institutions make the matter worse.

The proportion of two and three wheeled vehicles is high in some Asian countries. The number of registered motorcycles in Taiwan comprises 50% of the total number of registered vehicles; in Thailand it is 63%, in Cambodia 84%, in Vietnam 95%, in Lao 79% and in Indonesia 73% (Hsu et al., 2003; Pongthanaisawan and Sorapipatana, 2010; WHO, 2009). Although most of the Asian countries are undergoing rapid economic development, the majority of motorcyclists in Asia, except in the developed high-income countries (Singapore and Japan), still belong to the middle and low-income group categories (WHO, 2013). In these countries, motorcycles are used as the daily means of transportation of people, goods and services (Hsu et al., 2003), rather than as a leisure vehicle, as seems to be the case in the developed European countries (Jacobs et al., 2000).

The most typical accident cause involving motorcyclists has been found to be the right of way violation, where a vehicle pulls out from a minor road onto a major road and into the path of an approaching motorcycle (Crundall et al., 2008b; de Lapparent, 2006; Pai, 2009). Pai (2011) provides a thorough review of such crash settings, and underlines the impact of the lack of motorcycle conspicuity and the automobile driver's speed/distance judgment error, i.e. gap acceptance. Run-off-road and head-on collisions are predominantly the result of one or more errors on the part of the motorcyclist (Preusser et al., 1995). Collisions at intersections between cars and motorcycles are usually due to the automobile drivers not "seeing" the motorcycle, either because of the size, shape and color of the motorcycle, or automobile drivers just notice other cars and overlook motorcycles even though they are clearly visible (Glad, 2001). Haque et al. (2009), on the other hand, showed that at-fault crashes on expressways were found to increase when motorcycles with higher engine capacity were in the median lane.

The injury severity sustained by motorcyclists varies with the type of collision. Collisions with stationary objects, for example, result in more severe injuries (Keng, 2005; Quddus et al., 2002; Savolainen et al., 2011). A recent in-depth study in Malaysia has shown that a single vehicle crash, i.e. collision with a fixed object, has a significant influence on motorcyclists sustaining spinal injury, and that rear-end impact shows the highest risk of spinal injury (Zulkipli et al., 2012). Motorcyclists are also likely to be involved in a severe accident during overtaking or while other vehicles (i.e. either motorcycles or automobiles) are making a turn (Pai and Saleh, 2008). Collisions with heavier vehicles result in more severe injuries (Pai and Saleh, 2007; Quddus et al., 2002; Zulkipli et al., 2012). The types and characteristics of motorcycles also have an important influence on the likelihood and severity of accidents. Studies have shown that greater motorcycle engine size may increase the injury severity levels (de Lapparent, 2006; Harrison and Christie, 2005; Quddus et al., 2002; Savolainen and Mannering, 2007).

According to Hurt et al. (1981) and de Lapparent (2006), the probability that a severe/fatal accident occurs at an intersection is higher than elsewhere. More than half of motorcycle crashes occur at T-intersections where minor roads meet a major road. For un-signalized intersections the following factors are found to contribute to motorcyclist injury severity: elderly rider, greater engine size of motorcycle, riding early in the morning, on weekends and in fine weather, street lights unlit, riding on uncongested roads, collisions with bus/coach (Pai and Saleh, 2007, 2008). As for signalized intersections, the engine size, collision with bus/coach, riding in fine weather and on a rural road and type of collision are critical for motorcyclists' safety (Pai and Saleh, 2007, 2008).

Motorcyclists, as defined by the World Health Organization (WHO), are road users of powered (i.e. motorized) two- or three-wheeled vehicles (WHO, 2013). The term powered two wheelers (PTW) is often used to refer to mopeds, scooters, and motorcycles, and commonly includes similar three-wheeled vehicles (Haworth, 2012). The use of mopeds is generally restricted to low speed zones in urban areas, by a combination of legislation and rider discretion, while larger scooters or motorcycles are typically capable of highway speeds and in some cases long distance touring (Haworth, 2012; WHO, 2013). Many jurisdictions, such as in Australia and developing countries, define mopeds in terms of engine capacity (usually lower than 50 cc) and top speed (often lower than 50 km/h) (Haworth, 2012). However, in Asian countries such as Taiwan, Malaysia and Vietnam, by far the most common PTWs are those with engines up to 150cc; PTWs with engines above 150 cc are considered large or high capacity motorcycles (Hsu et al., 2003; Hussain et al., 2005). Despite the number of wheels or engine capacity assigned to these type of vehicles, they are commonly identified as 'motorcycles', and their riders have been categorized as vulnerable road users (Broughton et al., 2009; Haworth, 2012; Pai, 2011; Radin Umar, 2006; Van Elslande and Elvik, 2012). Thus, for the generalization purposes of this thesis, the word 'motorcycle' or 'MC' is used for these PTWs.

1. 1 Motorcyclists' traffic safety situation in Malaysia

In terms of the highest number of road traffic deaths per 100,000 population, Malaysia is ranked 19th out of 182 countries in the world (see Table 2). Malaysia also has the 2nd highest death rate in Asia (WHO, 2013). Moreover, it is currently ranked number 5 in the world among countries with a high percentage of motorcycle accident fatalities, i.e. more than 50% of the total road fatalities are associated with motorcycles (see Table 2) (WHO, 2013). Hence, Malaysia typifies the countries with safety problems for motorcyclists (i.e. motorcycles account for more than 25% of registered vehicles, and reported accident fatalities) and its data is close to the average, i.e. 47% of registered vehicles are motorcycles and 59% of the victims of reported accident fatalities are motorcyclists (WHO, 2013).

Table 2: World road safety data for countries with more than 25% motorcycle accident fatalities (WHO, 2013)

Rank	Country	Region	Population	Estimated number of road traffic deaths per year	Estimated road traffic death rate (per 100 000 population)	% of MC accident fatalities of the total of road fatalities
1	Cook Islands	West Pac	20,277	2	9.9 (136th)	100.0
2	Lao P.D.R.	S.E. Asia	6,200,894	1,266	20.4 (51st)	74.4
3	Thailand	S.E. Asia	69,122,232	26,312	38.1 (3rd)	73.5
4	Cambodia	S.E. Asia	14,138,255	2,431	17.2 (78th)	66.6
5	Malaysia	S.E. Asia	28,401,017	7,085	25 (19th)	58.7
6	Dominican Rep.	Americas	9,927,320	4,143	41.7	57.8
7	Benin	Africa	8,849,892	2,119	23.9	50.2
8	Dominica	Americas	67,763	8	11.8	50.0
9	Singapore	S.E. Asia	5,086,418	259	5.1	46.1
10	Paraguay *	Americas	6,454,548	1,383	21.4	41.4
11	Colombia	Americas	46,294,842	7,225	15.6	39.1

Rank: Ranking by the highest percentage of MC accident fatalities of the total of road fatalities
* Data are for 2009;
West Pac: Western Pacific, S.E. Asia: South-East Asia, East Med: East Mediterranean,
The number in brackets is the ranking of the estimated road traffic death rate (per 100,000 population); the highest ranking (i.e. smallest number) has the highest death rate.

Table 2 (continue): World road safety data for countries with more than 25% motorcycle accident fatalities (WHO, 2013)

Rank	Country	Region	Population	Estimated number of road traffic deaths per year	Estimated road traffic death rate (per 100 000 population)	% of MC accident fatalities of the total of road fatalities
12	Pakistan	East Med	173,593,384	30,131	17.4	38.6
13	Mauritius	Africa	1,299,172	158	12.2	37.3
14	Suriname	Americas	524,636	103	19.6	36.8
15	Indonesia	S.E. Asia	239,870,944	42,434	17.7	35.7
16	Cyprus	Europe	1,103,647	84	7.6	35.0
17	China	Asia	1,348,932,032	275,983	20.5	34.5
18	Maldives	West Pac	315,885	6	1.9	33.3
19	Kiribati	West Pac	99,488	6	6	33.3
20	India	Asia	1,224,614,272	231,027	18.9	32.4
21	Greece *	Europe	11,359,346	1,385	12.2	30.6
22	Italy *	Europe	60,550,850	4,371	7.2	30.3
23	Guatemala	Americas	14,388,929	958	6.7	30.0
24	Costa Rica *	Americas	4,658,887	592	12.7	28.3
25	Comoros	E. Africa	734,750	160	21.8	27.3
26	Malta	Europe	416,515	16	3.8	26.7
27	Brazil *	Americas	194,946,488	43,869	22.5	24.8
…	…	…	…	…	…	…
46	Sweden	Europe	9,379,687	278	3	16.9
63	Iceland	Europe	320,136	9	2.8	12.5

Rank: Ranking by the highest percentage of MC accident fatalities of the total of road fatalities
* Data are for 2009;
West Pac: Western Pacific, S.E. Asia: South-East Asia, East Med: East Mediterranean, E. Africa: Eastern Africa
Sweden and Iceland are included in this table for comparison purposes.
The number in brackets is the ranking of the estimated road traffic death rate (per 100,000 population); the highest ranking (i.e. smallest number) has the highest death rate.

In Malaysia, road fatalities are increasing yearly (ADSA, 2011; WHO, 2009, 2013). The major contributor to this is the steady rise of motorcycle accident fatalities since the year 2000 (see Figure 1). In 2011, the number of motorcycle accident fatalities reached the highest in a 10-year period, with 4,169 accident fatalities. The economic impact of this is that Malaysia loses approximately $1.3 USD to $1.6 USD billion per year (since 2001), based on the value of $400,000 USD per motorcycle fatality (Nor et al., 2001). Thus, if nothing is done to mitigate or curb Malaysia's motorcycle accident fatalities, the figures may continue to increase over the coming years, and Malaysia will continue to suffer severe economic losses.

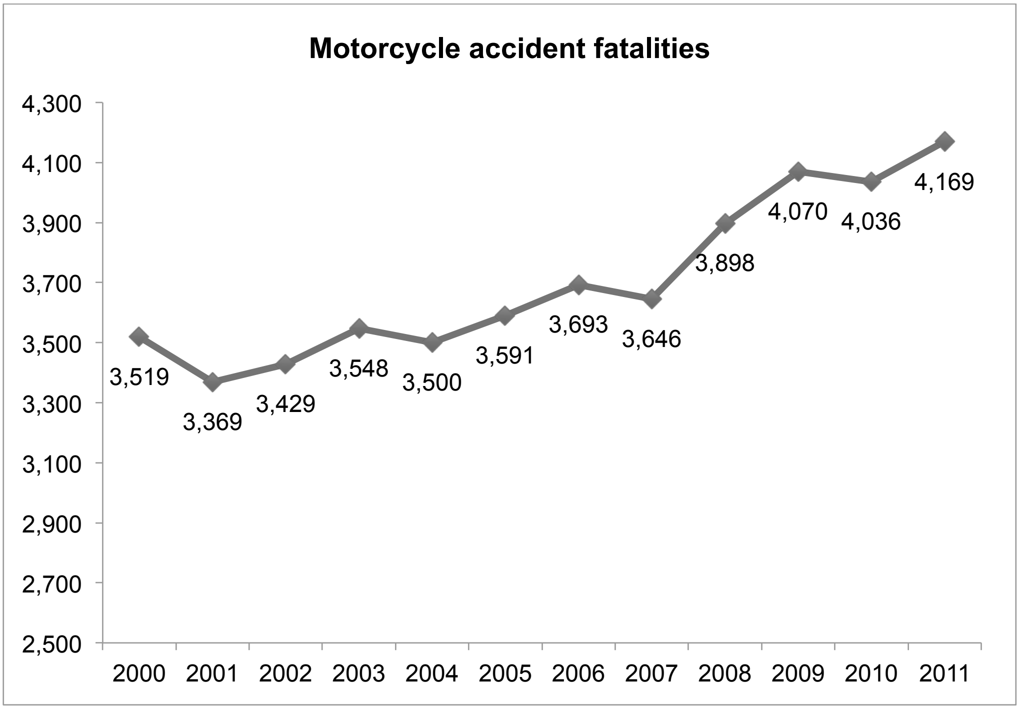


Figure 1: Number of motorcycle accident fatalities from the year 2000 to 2011 in Malaysia (ADSA, 2011; WHO, 2013)

1.2 Motorcycle population in Malaysia

Motorcycles constitute the main transportation mode in Malaysia. Over the period 2007 to 2011, the average share of registered motorcycles was 47.0%, while that of passenger cars was 44.8%, out of the total number of registered vehicles in Malaysia (MOT, 2011). Although the trend of the total number of registered motorcycles is slightly decreasing (see Figure 2), the total number of newly registered motorcycles has been somewhat constant at about 3%. The choice of the motorcycle as a mode of transport is mainly due to Malaysia's inadequate public transportation network (Ibrahim et al., 2006; Yamamoto, 2009). Moreover, the majority of the Malaysian road users consider that using motorcycles reduces their travel time during traffic congestion, and that motorcycles are economical to maintain and own (Ibrahim et al., 2006). A motorcycle is often the first choice for private transport (Hsu et al., 2003; Ibrahim et al., 2006), as well as the main individual vehicle choice for the majority of the workers from the industrial (27%) and service (57%) sectors (Hsu et al., 2003). However, as one's career progresses, one often saves money to buy a car (Ibrahim et al., 2006).

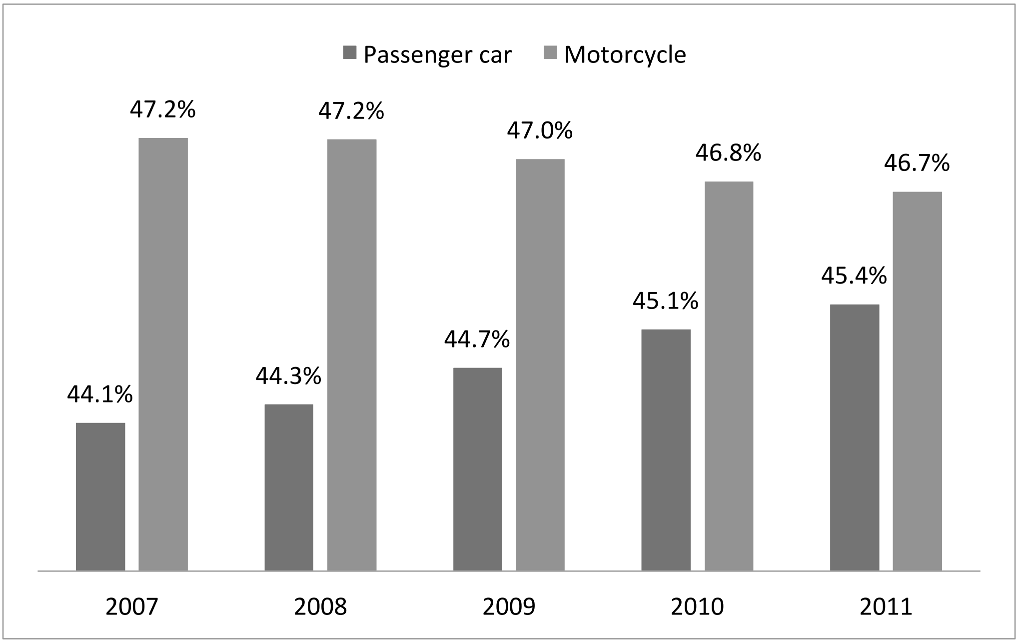


Figure 2: The percentage of registered motorcycles and passenger cars of all registered vehicles from 2007 to 2011 in Malaysia (MOT, 2011).

The proportion of the motorcycle population on Malaysian roads varies from state to state. In less developed states such as Perlis and Kelantan (northern part of Malaysia), the motorcycle population is more than three-quarters of the total vehicle population (Hussain et al., 2005). In more developed states, such as Selangor, motorcycles represent one-third of the total vehicle population, and are the major mode of personal transport for the low-income urban community (Radin Umar, 1999). Of the various road types in Malaysia, (expressways, primary and secondary road), secondary roads (24%–26%) are mostly used by motorcycles in both urban and rural environments (see Table 3). Expressways have the least amount of motorcycle traffic with 2.2% of the traffic composition. However, in terms of the number of motorcycles per 10 km per day, primary roads in urban areas have the highest density of motorcycles. In addition, Hsu et al. (2003) claim that motorcycles in general account for 64.2% of the traffic composition in the commuting corridor between Malaysia and Singapore, 40.8% in urban areas and 20.6% in the suburban rural areas.

Table 3: Mean percentage of average daily traffic of motorcycles with respect to the road hierarchy (DOSM, 2012; HPU, 2009; LLM, 2011; PWD, 2009)

Road hierarchy	Km	Mean ADT (veh/day)	No. of MC per 10km per day	Mean % of MC
Expressway	1,635	64,002	0.85	2.2
Primary (Urban)	5,082	49,220	19.95	20.6
Secondary (Urban)	16,404	52,550	7.71	24.1
Primary (Rural)	11,857	8,303	1.77	25.3
Secondary (Rural)	38,277	7,893	0.53	25.9
Local Street	43,363	NA	NA	NA
Minor Roads	8,038	NA	NA	NA
Total	124,656			

ADT: Average daily traffic in vehicles per day, MC: Motorcycle, S.E.: Standard Error, veh: vehicles
Urban / Rural: The road used is in urban / rural areas, N.A.: data not available,

Malaysian primary roads, which are under the responsibility of the Federal and State government, are similar in road design standard to ‘arterial’ roads in the United States and the United Kingdom (PWD, 1986). All federal government primary roads are assigned a number from 1 to 49, whereas roads belonging to the state government are assigned a capital letter prefix followed by a number from 1 to 49 (e.g. A1 is a primary road in Perak, B2 is a primary road in Selangor, etc.).

Based on observations and documentations by Hussain et al. (2005) and Hsu et al. (2003), the typical motorcycles on Malaysian roads are small and medium sized with engines of 150 c.c. and below (see Figure 3). Only one to two percent are large sized motorcycles with engine capacity above 150 c.c. (DOSM, 2012; Hussain et al., 2005).

Figure 3: A typical motorcycle in Malaysia (Photo by author, 2012)

2. Contributory factors to motorcycle accidents

In order to understand the phenomenon of motorcyclists' fatalities from a broader perspective, this thesis reviews earlier research findings to identify the critical factors associated with motorcycle accidents. The emphasis is on factors such as the behavior of motorcyclists, the interaction between motorcyclists and automobile drivers, the interaction of motorcyclists with the road infrastructure, and factors associated with weather conditions.

2.1 Behavior-related accident risk factors

2.1.1 Motorcyclists' attitude and driving patterns

Motorcyclists' attitude towards safety varies significantly as observed in several studies. Mannering and Grodsky (1995) state that motorcyclists have a reasonable grasp of the factors that increase the likelihood of accident involvement. These factors include exposure (miles ridden), engagement in risk taking behavior such as regularly riding above the speed limit, and passing vehicles on the shoulder or passing between lanes of traffic (Mannering and Grodsky, 1995). Risk taking and sensation seeking are typical rider behaviors (Wong et al., 2010). Several studies have also shown that motorcyclists' risk taking behavior is usually reflected in activities such as speeding, disobeying traffic signals or give-way or stop signs, non-compliance with overtaking restrictions or pedestrian crossings, making illegal turns, maintaining short gaps to following vehicles, and so on (Horswill, 2003; Njå and Nesvåg, 2007; Wong et al., 2010). Such factors may suggest increased risks of crash involvement, as well as an increased tendency for being found at-fault in the event of a crash (Schneider Iv et al., 2012).

Clarke et al. (2005) suggest that overconfidence is a primary cause of the risky riding behavior of young motorcyclists. According to Falco et al. (2013), it is highly plausible that a 14–15-year-old adolescent may be oriented towards strong emotions and new sensation-seeking, with a craving to assert his/her own identity and overcome limits, an inclination towards anti-social behavior, and a certain presumption of invulnerability and immunity to involvement in negative events. Thus, according to Falco et al. (2013) a young person is more likely to engage in risk-taking and irresponsible riding behaviors. Watson et al. (2007) also found that risky rider intentions were primarily influenced by attitudes and sensation seeking, while safer intentions were influenced by perceived behavioral control. Wong et al. (2010) showed that personality attitudes, such as sensation seeking, amiability and impatience may influence risky riding behavior, especially in young riders; sensation seeking or impatient riders think of unsafe riding intrinsically, whereas amiable riders think of unsafe riding largely due to their worry or concerns about traffic risks.

Hazard perception among motorcyclists is different compared to automobile drivers. Horswill and Helman (2003) conducted a comparative study between a group of motorcyclists and a matched group of automobile drivers, and found that motorcyclists chose faster speeds than car drivers, overtook more often, and pulled into smaller gaps in traffic, which may exhibit a better hazard perception (i.e. faster at detecting and responding to hazards than automobile drivers). This study was supported by Rosenbloom et al. (2011), who also reported evidence of motorcyclists having higher hazard perception ability than automobile drivers.

Motorcyclists' behavior is related to riding exposure in that a period of absence from riding might lead to a decline in safety related motorcycle skills, whereas high exposure appears to moderate crash risk (Harrison and Christie, 2005). There is a relationship between annual exposure and crash risk, such that riders who ride relatively little have higher crash risks (per 100,000 km travelled) than those who ride more often (Harrison and Christie, 2005).

Socio-cultural factors and socio-economic factors are found to influence motorcyclists' attitudes (Njå and Nesvåg, 2007; Preusser et al., 1995). Njå and Nesvåg (2007) conclude that the massive quantities of data on numbers of accidents, the categorization of situations, the causal explanations related to speed, gender, age, lack of concentration and so forth, can only be employed as support for safety measures as long as they are linked to social and cultural factors.

2.1.2 Age, gender and experience of motorcyclists

Age, experience and gender may influence both motorcyclists' attitudes and behavior. According to Yeh and Chang (2009), risk taking behaviors, which are associated with young and inexperienced riders, increase their risk of being involved in a collision. In addition, the highest number of motorcycle injuries is typically found in age groups close to the lowest legal age limit for riding a motorcycle. They portray specific patterns of youth behavior, such as a willingness to break the law and violate the rules of safe riding, which have a much greater role in accident involvement than inexperience (Rutter and Quine, 1996). In addition to this, Rathinam et al. (2007) studied the traffic accidents among underage motorcyclists and concluded that aggressive behavior and previous encounters with the police were the two strong predictors of motorcycle accidents. Moreover, studies have shown that young, male motorcyclists have a stronger propensity for risky behavior, which has been shown to be associated with increased risks of accidents and at-fault crashes, and a higher tendency towards negligence of traffic regulations and motorcycle safety checks (Chang and Yeh, 2007; Haque et al., 2009; Mannering and Grodsky, 1995; Rutter and Quine, 1996). On the other hand, older motorcyclists are more likely to be involved in severe injury crashes due to (i) decreased physical resilience to crashes and (ii) slow reaction time and reduced sensory and perceptual ability (Pai and Saleh, 2007; Savolainen and Mannering, 2007).

The age and riding exposure of motorcyclists is related to their behavior, which may affect their safety on the road. Harrison and Christie (2005) have shown that the amount of riding reported for different purposes changed with age, with older riders more likely than younger riders to ride for recreational reasons and on weekends. Their findings suggest that a period of absence from riding might lead to a decline in safety-related motorcycle skills, whereas high exposure appears to moderate crash risk (Harrison and Christie, 2005). As for experience, it would seem to be more important for motorcyclists than for automobile drivers (Haworth et al., 2005; Hosking et al., 2010). For example, experienced motorcycle riders were faster to respond to hazards than inexperienced riders, and such faster response times may be due to experienced riders having a visual search pattern that is more flexible than that of inexperienced riders (Hosking et al., 2010).

2.1.3 Motorcyclists' traffic rule violations

The willingness to commit traffic rule violations has been associated with motorcycle accident involvement (Rutter and Quine, 1996). For example, speeding, which is a frequent violation among motorcyclists, has been analyzed in many studies and may result in accidents (Elliott et al., 2007; Horswill and Helman, 2003; Hurt et al., 1981; Steg and Brussel, 2009). Inexperienced motorcyclists have also shown a tendency to violate traffic rules (Perez-Fuster et al., 2013). Steg and Brussel (2009) found that moped riders were more likely to exceed speed limits, and had a stronger intention to do so when they had a positive attitude toward speeding or thought that others expected them to speed. Furthermore, the effect of speeding is intensified at un-signalized junctions (Pai and Saleh, 2007). Besides the willingness to commit traffic violations, road infrastructure, e.g. signal setting of intersections, is also associated with traffic violations by motorcyclists. Law and Lin (2003) have found that red light running violations at signalized intersections high motorcycle traffic volume, are associated with shorter change interval time, shorter amber time, longer cycle length, more signal phases and more approach legs.

2.1.4 Helmet usage and other safety outfit

A typical protective measure is the helmet, the importance of which has for long been supported by the literature. However, the use of helmets by motorcyclists remains low in smaller cities in developing countries or countries with a hot climate (Ambak et al., 2011; Dandona et al., 2006; Li et al., 2008). On the other hand, Malaysia has shown a high rate of helmet usage (more than 50%), but 21.4% use them improperly; for example, they do not fasten them securely or use less crashworthy helmets (Kulanthayan et al., 2000; Kulanthayan et al., 2012). Research on the effect of mandatory helmet laws generally indicates that these laws enhance motorcycle safety (Houston and Richardson, 2008; Morris, 2006; Sass and Zimmerman, 2000). Little evidence is found to suggest that helmet use varies with age or gender (Norvell, 2002). Nevertheless, Houston and Richardson (2008) underline the negative effect of any downgrading of universal helmet laws, i.e. laws that require all riders to be helmeted, to young riders. Recent evidence has suggested that legislation may be a more efficient strategy (if enforced) than education to increase helmet use (Ranney et al., 2010).

The usage of protective clothing may be associated with the purpose of the trip and drivers' education (de Rome et al., 2011). However, no evidence was found to support any association between riding with non-protective clothing and other indicators of risk taking (de Rome et al., 2011). On the other hand, Lin and Kraus (2009) reviewed previous studies on protective clothing and concluded that such clothing reduced soft tissue injuries, but did not provide protection against the occurrence of fractures.

2.1.5 Alcohol and other impairments

Many studies point out that drugs and alcohol have a prominent influence on, or motivation for, risky behavior (Harrison and Christie, 2005; Steg and Brussel, 2009). According to Creaser et al. (2009), alcohol affects the riders' weaving skills, attention allocation and hazard perception, while Haworth et al. (2009) have found that the tendency to drink and drive may be associated with speeding, non-use of helmets and unlicensed riding for moped and motorcycle riders.

2.1.6 Conspicuity and perception of motorcyclists by other road users

Due to their comparative size (conspicuity), motorcycles may be difficult for other users to detect. Crundall et al. (2008a) find that automobile drivers have difficulties in perceiving motorcycles, particularly at far distances. "Look but fail to see" and poor driver perception are among the most important contributing factors to PTW accidents in the UK (Clarke et al., 2007; Huang and Preston, 2004). Conspicuity is related to the 'expectation' factor of automobile drivers; if the driver does not expect to encounter a motorcycle, he or she will most likely fail to see it (Clarke et al., 2007; Simons, 2000). Labbett and Langham (2006) suggest that novice automobile drivers might fixate on an oncoming motorcycle sooner than their more experienced counterparts. Pai (2011) provided a thorough review of the conspicuity issues and automobile driver's decision errors affecting the right-of-way accidents, and summarized that most right-of-way accidents involving motorcycles were attributable to conspicuity issues.

2.1.7 Training and education of motorcyclists

Education and licensing are considered to be common countermeasures to curb motorcyclists' risk. Besides training, the literature has for long demonstrated the benefits of an effective rider's education system in terms of the alleviation of motorcycle accident risk (Chesham et al., 1993; Elvik et al., 2009). Nevertheless, although motorcycle rider education and licensing play key roles in reducing motorcycle crashes and injuries, little is known about what constitutes effective rider training and licensing (Baldi et al., 2005). For example, according to Yeh and Chang (2009), students had a greater chance of experiencing unlicensed riding, and riding at an earlier age, if they were attended a vocational senior high school and lived in districts with a higher motorcycle ownership rate.

To encourage motorcyclists to behave safely, training is usually suggested as a way to increase awareness of negative behavior. Law and rule-breaking behavior is mainly habitual and needs tackling at an early stage of motorcycling (Elliott et al., 2003a). Swezey and Llaneras (1997) suggest that the skill declines with experience or learning trials, while exposure to riding may have an ongoing effect on crash risk that is similar to the effect of learning. Hosking et al. (2010) found a significant decrease in hazard response times as motorcyclists' experience increased, and underlined the potential benefit of training hazard perception and visual scanning. However, it remains unclear whether the training of riding skills can reduce motorcycle accidents; thus, caution must be taken with educational efforts aimed at expanding motorcyclists' skills (Savolainen et al., 2011). For example, training is likely to be made more difficult by the sensation-seeking motives that are important for some riders, and training concentrating on control skills may lead to more accidents if riders become over-confident (Elliott et al., 2003a).

2.2 Road infrastructure, light and weather related risk factors

2.2.1 Type of area

The type of area that the road network encompasses could be one of the influential characteristics of infrastructure that affect the probability of motorcycle accidents. In European countries, most accidents involving motorcycles occur in urban areas (ACEM, 2003). In Australia, approximately 70% of motorcycle injuries occur on local area roads (CARRS-Q, 2010). In the US, the urban and suburban PTW accidents have been found to be 80% of all the PTW accidents observed (Hurt et al., 1981). On the other hand, the prevalence of death on rural roads and at intersections in Taipei is relatively higher for motorcycle drivers compared to automobile drivers (Lin et al., 2004). In Malaysia, 59% of the motorcycle accidents occur in rural areas (Jaafar et al., 2003).

2.2.2 Road geometry and infrastructure

A serious consideration in motorcycle safety is the influence of road geometry, road markings and roadside installations, such as barriers, posts and so on. According to (Elliott et al., 2003a), parallel longitudinal grooves in the road surface (for example, to avoid aquaplaning), as well as inefficient marking, can also induce instability for motorcycle riders. Moreover, in wet conditions, road markings, manholes and cattle grids can become more slippery than the rest of the road surface (NPRA, 2004).

The risk associated with road geometry, e.g. curves or straight road sections, has been underlined by some studies. Hurt et al. (1981) highlighted the high frequency of right of way violations and single vehicle accidents on bends. A high portion of motorcycle accidents that involve going out of control on a curve was also identified in Preusser et al. (1995) and Clarke et al. (2007). Schneider et al. (2010) conclude that the radius and length of the horizontal curve, along with the shoulder width, annual average daily traffic, and the location of the road segment, in relation to the curve, significantly influence the frequency of single-motorcycle crashes. On the other hand, studies from Malaysia have shown that the majority of motorcycle fatal crashes occur along straight road sections (Jaafar et al., 2003; Radin Umar, 2005).

2.2.3 Pavement surface condition

The following road surface conditions may present a hazard to motorcyclists: slippery surfaces, repaired patches on the road, unevenness, road markings, longitudinal parallel grooves, cobbles, drain covers and gratings (Elliott et al., 2003b). Sudden changes in road surface friction, which may provoke instability in one-track vehicles, can be caused by patches of diesel and oil on the road, and, in some areas, by spillage of grease from stationary buses (Elliott et al., 2003b). Moreover, motorcyclists are particularly vulnerable when it comes to bitumen, a material used frequently in modern road repair mainly to fill and patch road fissures (Elliott et al., 2003b).

The road surface actively contributed to 15% of crashes examined by the Victorian motorcycle case control study (Haworth et al., 1997), in which the authors suggested that the important factors in these collisions were the surface grip, surface irregularities and potholes, loose materials, patch repairs and road markings. A study done in Singapore shows that a wet pavement surface is also a cause of at-fault motorcycle accidents at non-intersections (Haque et al., 2009). However, despite poor road surface conditions being frequently mentioned by motorcyclists in the UK, road surface was found to contribute to only 5% of errors made by riders on built-up and non-built-up roads (Hurst, 2011).

2.2.4 Light conditions and visibility

Motorcycle visibility is a significant concern. According to Wanvik (2009) and Savolainen and Mannering (2007), increased motorcyclist injury severity is associated with poor visibility (due to horizontal curvature, vertical curvature, darkness). Poor sightline visibility and rider conspicuity are likely to contribute to motorcycle accidents at intersections (NPRA, 2004; Radin Umar, 2005). Riding in darkness without street lighting is related to severe motorcyclist injury accidents (Pai and Saleh, 2007, 2008). In general, injuries resulting from after midnight night riding (0:00–07:00) have been found to be the most severe, especially in stop controlled junctions (Pai and Saleh, 2007). Motorcyclists are more vulnerable during nighttime at intersections and on expressways, perhaps because of increased speeds and hence stronger impacts (Haque et al., 2009). On the other hand, motorcyclists often experience reduced visibility when wearing glasses, visors or wind shields that may decrease their view when riding inside tunnels (NPRA, 2004).

2.2.5 Weather conditions

Riding in fine weather appears to result in more severe injuries than in bad weather (ADSA, 2011; Pai and Saleh, 2007; Pang et al., 2000; Pang et al., 1999). Intuitively, riding a motorcycle is heavily influenced by the weather. However, studies have shown that weather is a less influential factor in accident outcome (ACEM, 2003; Kasantikul, 2001). Research conducted in California (Hurt et al., 1981) showed that weather was less influential in 98% of motorcycle accidents, compared to other prevailing factors related to type of collision, age, gender, etc.

Weather also made no contribution to accident causation in 92.7% of accident cases in the European countries (ACEM, 2003). An in-depth accident investigation of 1082 motorcycle crashes in Thailand in 1999 and 2000 reported that the weather factor was rarely a contributing factor (Kasantikul, 2001). This is mainly because, first, the motorcycle is not an all-weather vehicle, and it does not have accident characteristics similar to automobiles concerning the effect of weather. Second, in many developed countries, riding is mainly a recreational activity, heavily influenced by adverse weather. Even motorcyclists, who may use the vehicle as a means of transport on a daily basis, change to other modes (e.g. car, public transport) when they expect bad weather conditions.

3. Research gaps concerning motorcycle safety in the Malaysian context

The most typical automobile-motorcycle fatal crash in developed countries, e.g. Western countries, is one in which an automobile violates the motorcycle's right of way (see Figure 4) (Pai, 2011). Developing Asian countries, such as Malaysia, may also have a similar problem. Previous local research has found that the majority of motorcycle fatal accidents occurred when motorcyclists had the right-of-way, particularly while they were travelling straight ahead on primary roads (Radin Umar, 1999). However, the police records in Malaysia have not specified the details of these types of fatal crashes; thus the most probable explanation of these fatal collisions is that the motorcyclists' right of way was infringed by motorists (or vice versa) when entering the primary road from an access point. Earlier research has also pointed out that one of the main contributing factors to infringing of motorcyclists' right-of-way accidents is the failure of motorists to stop or yield when entering a primary road from an access point (Pai et al., 2009; Preusser et al., 1995), and the most common of these crashes is between a car and a motorcycle in urban speed zones (Walton et al., 2013).

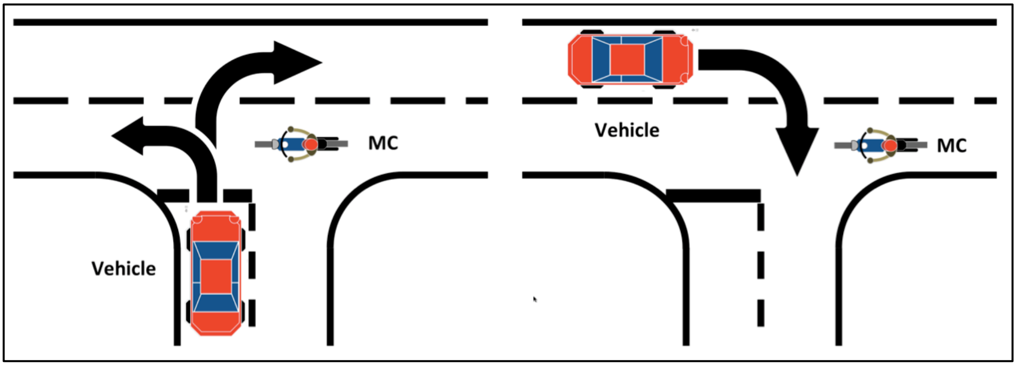


Figure 4: Schematic diagram of motorcycle right-of-way accidents at T-junctions (Pai, 2011).

Research has pointed out that motorcycles travel faster and exceed the speed limit in urban areas more often compared to other vehicles, and that the speed of motorcycles along a main road is not influenced by a vehicle appearing at a T-junction (Walton and Buchanan, 2012). Moreover, accidents involving motorcyclists in urban areas (high traffic volume) are related to initial speeds that are significantly higher than those of other types of accidents at intersections (Clabaux et al., 2012). The speed of motorcycles that travel faster than others on the same road may be underestimated by a turning motorist, resulting in less time to clear the collision zone (Pai, 2011).

Although several well known accident prediction models have been developed world wide for motorcycles, e.g. Shankar and Mannering (1996), de Lapparent (2006), Law et al. (2009), Pai et al. (2009), Elliott (2010), Haque et al. (2010), Wong et al. (2010), etc., the number of accident prediction models for Malaysian motorcycles is still very limited. There are only two prominent accident-modeling studies specifically targeting motorcycles: one by Harnen et al. (2006), where the authors develop an accident prediction model, via a generalized linear model, for motorcycle accidents at junctions on urban roads in Malaysia. Their model reveals that motorcycle accidents are proportional to the power of traffic flow, and the estimates indicate that an increase in non-motorcycles and motorcycles entering the junction is associated with an increase in motorcycle accidents (Harnen et al., 2006). The other study, by Radin Umar et al. (2000), uses multivariate analysis of the impact of the exclusive motorcycle lane on motorcycle accidents along a major primary road in Malaysia (Federal Highway Route 2). They find that motorcycle accidents are directly proportional to the cubic power of traffic flow, and are reduced by approximately thirty-nine percent (39%) with the existence of motorcycle lanes (Radin Umar et al., 2000). Hence, with the limited research done on predicting motorcycle accidents, especially on Malaysian primary roads, and most of it more than ten years old, the need for this kind of research is obvious.

4. Aim

4.1 Research aim

Based on the findings of earlier research and the current situation of motorcyclists' road safety in Malaysia, the aim of the thesis is:

1. To identify motorcyclists' road safety problems and the contributory factors to motorcycle accident fatalities.

2. To narrow down the focus of the research to the most salient road infrastructure related risk factors.

3. To observe and analyze road user behavior at the identified high-risk sites in order to establish behavioral and design factors associated with a hazardous outcome of interaction between motorcyclists and other road users.

4.2 Scope of the thesis

The scope of the thesis is to investigate the factors associated with motorcyclists' safety at access points along a primary road in Malaysia. The thesis comprises 4 scientific papers, an introduction and a summary. For a schematic diagram of the scope of the thesis, see Figure 5.

Paper 1 analyses motorcycle accident fatalities in Malaysia in general in order to identify the most salient safety problems of motorcyclists.

Paper 2 identifies factors associated with fatal motorcycle accidents on primary roads in Malaysia by developing a Safety Performance Function.

Paper 3 conducts an observational study at access points of straight road sections of primary roads to gain more insight into the course of events in interactive situations involving motorcyclists at these locations.

Paper 4 further analyses, by means of mixed-effect logistic regression, the collected observational data in order to investigate the relationship between, on the one hand, motorcyclists' behavior and road environment attributes, and, on the other, the occurrence of serious traffic conflicts involving motorcyclists entering the primary road from the access points.

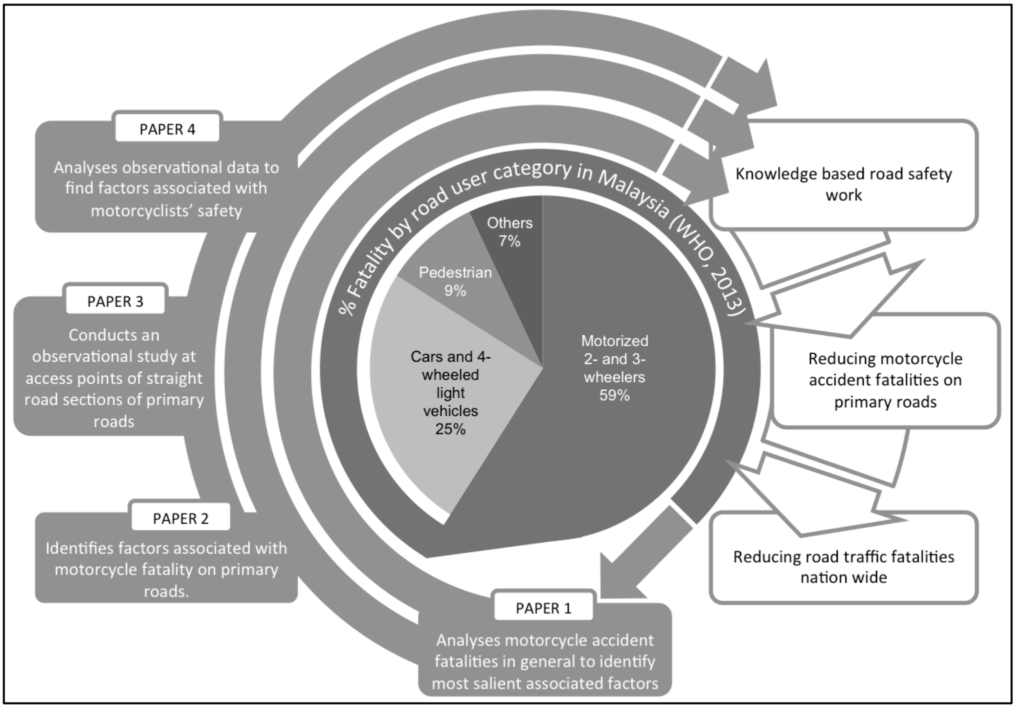


Figure 5: A schematic diagram of the scope and aim of the thesis with the corresponding papers.

5. Method

The thesis is divided into four stages, described briefly in the following sections and in more detail in the four research papers attached.

5.1 Analyzing motorcycle fatalities in Malaysia

A cross sectional analysis of accident data concerning motorcyclists in Malaysia is carried out by type of location, area, road, time, crash type, gender, age, ownership and type of license. The data comes from various sources, such as the Malaysian Royal Police Department, Malaysian Institute of Road Safety Research (MIROS), Department of Statistics (DOSM), Highway Planning Unit (HPU), Road Transport Department (JPJ), Department of Road Safety (JKJR), Public Works Department (JKR) and World Health Organization (WHO) reports. The main core of fatal motorcycle accident data, however, comes from the Malaysian Royal Police Department.

Before the detailed analysis, the Malaysian motorcycle accident data is compared with Swedish motorcycle accident data in order to estimate the level of underreporting of injury accidents. Swedish data is chosen because Sweden has more reliable accident records, i.e. integration of police and hospital data.

For more details refer to Paper 1.

5.2 Predicting motorcycle accident fatalities

Once the overview of the current status of Malaysian motorcycle fatalities has been made, the factors that are associated with motorcycle fatalities, e.g. area type and road geometric features, are used to develop a motorcycle accident prediction model for motorcycle accident fatalities occurring on Malaysian primary roads. The Safety Performance Function (SPF), which is a mathematical function that relates the expected crash frequency of a roadway element, e.g. a road segment, to the traffic volume and other characteristics of that element (Jonsson et al., 2009), is utilized for this purpose. This function has been adopted successfully for the past ten years (Garber et al., 2010; Hauer et al., 2002) to identify sites with the largest potential for safety improvement (Tegge et al., 2006). SPFs are calibrated with data by statistical techniques, with the assumption that the accident data counts are from a negative binomial distribution (Hauer et al., 2002). Despite its success, the SPF has only been applied to all vehicles generally; there have been no attempts to implement SPF specifically for motorcycles. A detailed theoretical approach can be found in Paper 2.

Manual data on land use (commercial and residential areas etc.) and road geometry properties (number of curves, access points, etc.) has been collected by means of reference to satellite photos and various maps from the Malaysian road authorities. Three states, Perak, Selangor and Johor, which have the best available data, have been chosen as samples in order to minimize time and resources. A large amount of data, pertaining to road geometry and land use along all primary road sections, has been collected from these three states. In order to form a complete database, these data are then matched and integrated with the 3-year fatal accident data (reported within 30 days after a crash) and the vehicle traffic census for every road section. Table 4 shows the variables obtained for the period 2007 to 2009. The dependent variable is the Motorcycle accident fatalities per kilometer for each section. The rest of the data is categorized as independent variables and divided into continuous and categorical data as seen in Table 4.

Table 4: Data considered for the SPF model (see Paper 2)

No.	Type of data	Description of content	Source (see reference)
1.	Motorcycle accident fatalities	1. Data from 2007 to 2009 2. Location of fatal accident by state, district, route number, type of land use, type of road hierarchy and type of road geometry.	(ADSA, 2011; PDRM, 2007, 2008, 2009)
2.	Road traffic volume on each section of Malaysian primary roads	1. Average Daily Traffic volume of cars, heavy vehicles and motorcycles	(HPU, 2007, 2008, 2009)
3.	Road statistics and inventory of all primary roads	1. Route number 2. Road length for each route 3. Location of route by state and district 4. Road properties: road width and existence of paved shoulders	(PWD, 2009)
4.	Road geometry features	1. Number of lanes 2. Number of curves and straight sections per km. 3. Number of access roads, minor roads, junctions and intersections per km 4. Existence of road median 5. Land use: Residential, Commercial or Industrial area	(HPU, 2007, 2008, 2009; PWD, 1986) and Google Earth and Google Maps from 2002 to 2010.

This study includes 124 road sections, each with 3 years of accident data. The road sections are primary roads located within the boundaries of the selected states; they vary from 1.61 km to 86.10 km in length and have non-homogeneous road features, i.e. different lane configurations and availability of median and paved shoulders. We note that there is at least 1 motorcycle fatal accident and a maximum of 29 fatal accidents on each road section. These road sections traverse many different land uses, but the majority of these are in rural areas with many small access roads. For the purpose of this study, an access road is defined as a three-legged priority control junction that serves to connect the main road, i.e. primary road, to a minor road leading into plantations, factories or villages.

A Pearson correlation matrix is used to investigate whether some independent variables are strongly correlated with each other. This is because strong correlation between independent variables in regressions could lead to difficulties in the interpretation of parameter estimates, as it might strongly affect the other model parameters (Abdel-Aty and Radwan, 2000; Maher and Summersgill, 1996). In this study, the correlation value (Pearson correlation) acceptance is set to be less than 0.5. As seen in the correlation matrix (see Table 4 in Paper 2), there is a strong correlation between independent variables that affects the models i.e., number of towns with residential, commercial and minor junctions, number of residential with commercial, number of industrial with commercial, number of commercial with minor intersection, and percent cars with heavy vehicles, and thus they are excluded from the modeling formulation process. The correlated independent variables, such as ADT, ADT of cars and ADT of motorcycles, are incorporated during the modeling computation, but are not included together in any of the individual trials. This is because the three ADT-variables are almost perfectly correlated with each other. Therefore adding more than one of them would not add to the quality of the models (Washington et al., 2003). In fact, having two of them at the same time makes the whole model non-significant.

Table 5 shows the selected variables to be included in the regression process. The introduction of an offset variable (Length, km) into the model fitting process yields the number of Motorcycle fatalities per kilometer as the dependent variable. This method is similar to the one used by Harnen et al. (2006). Moreover, as seen in Table 5, some of the variables have undergone transformation, i.e. Logarithmic computation, Ln, (see Eqn. 1) in order to suit the formulation of Eqn. 2 below.

$$MCFatal/_{km} = exp(\beta_0) \cdot \underbrace{[exp(lnX_i)]^{\beta_i} \cdot [exp(lnX_{i+1})]^{\beta_{i+1}} \cdot ...}_{continuous} \cdot \underbrace{[exp(X_i)]^{\beta_i} \cdot [exp(X_{i+1})]^{\beta_{i+1}} \cdot ...}_{categorical} \quad (Eqn.\ 1)$$

or in another term:

$$MCFatal/_{km} = exp(\beta_0) \cdot \underbrace{X_i^{\beta_i} \cdot X_{i+1}^{\beta_{i+1}} \cdot ...}_{continuous} \cdot \underbrace{exp(X_i\beta_i) \cdot exp(X_{i+1}\beta_{i+1}) ...}_{categorical} \quad (Eqn.\ 2)$$

Several interaction variables are also introduced, e.g. LnCurve_per_km x LnADTMC or LnAccess_per_km x LnADT, in order to obtain additional insights into the contributory factors.

Table 5: Variables computation and software coding

Category	Variables		Labeling	Computation / Designation	Coding
Dependent	Motorcycle fatalities	Y	MCFatal	-	-
Off-set	Length per section	-	LnLength	LnLength	
Independent Continuous variables (covariates)	No. of access	X_1	LnAccess_per_km	Ln (X_1 / Length)	
	No. of curves	X_2	LnCurve_per_km	LnX_2	
	Percent of Motorcycle	X_4	LnADTMC	Ln (ADT x X_4 / 100)	
	ADT	X_5	LnADT	LnX_5	
Independent Categorical variables (factors)	Lane configuration	X_6	Lane_config	2 lanes	1
				4 lanes	2
				6 lanes	3
				2 and 4 lanes	4
				4 and 6 lanes	5
	Median	X_7	Median	Not divided	1
				Divided	2
				Divided on certain stretches	3
	Paved shoulder	X_8	Paved_shoulder	Unpaved shoulder	1
				Paved shoulder	2
				Paved on certain stretches	3

The generalized linear model, i.e. negative binomial with log link analysis, is performed for this study. The response variable for the model is set as MCFatal and the predictors are set for Lane_config, Median and Paved_shoulder as 'factors' while LnAccess_per_km, LnCurve_per_km, LnADTMC, LnADT and/or interaction variables are set as 'covariates'. Categorical variables are included in the model using so-called 'dummy variables' which take the value 1 if belonging to the specific category, or 0 if not. One category level is used as the reference level and the others are represented by using a 'dummy', yielding as many dummy variables as number of category levels minus one. As mentioned previously, LnLength is set as an 'offset variable' and one of the predictors.

For more details of the method, see Paper 2.

5.3 Observing behavior at access points along a primary road

The first sub-section describes the site selection process, followed by a description of the speed data collection and behavioral observations.

5.3.1 Site selection

Based on the fact that motorcycle accident fatalities occur mostly at access points situated on straight primary road sections, access points have been chosen as per the selection criteria below:

1. Primary roads with high traffic volume and low traffic volume, i.e. one with an average daily traffic (ADT) of over 10,000 vehicles and another with ADT of between 3,000 to 10,000 vehicles. This criterion was used because primary roads in Malaysia are classified according to these capacity classes (REAM, 2002).
2. The primary road should have a motorcycle volume ranging from 20% to 30% of the ADT; this to represent the average share of motorcycles in the modal split of Malaysian traffic.
3. The primary road should have a two-lane single carriageway configuration, with lane width between 3.25 m and 3.50 m and shoulder width varying between 2.50 m and 3.00 m. This is the standard cross section for Malaysian primary roads.
4. The access point should be on a straight road section of the primary road.
5. The access point should be "typical" for primary roads, i.e. the design of the access is simple with no provision of auxiliary lanes and channelizing islands to indicate that it is a proper junction.
6. The access point selected should have at least a stop line indicating that the road user must stop before entering the primary road – which is the typical regulation of an access point.
7. The primary road and access point should have an "average" history of motorcycle accident fatalities.
8. The access point chosen should permit collection of data unobtrusively, i.e. the site should have a strategic hiding place for the observer and for data collection without the road users noticing.

Table 6 shows the sites (n=8) chosen based on the selection criteria. Three of the sites are located in the North (Arau, Perlis and Kodiang, Kedah), two in the South-West (Kuala Selangor and Banting, Selangor) and three in the central part (Meru, Selangor) of Malaysia. The majority of the fatal accidents are associated either with side collision or single accident type (i.e. a type of road traffic accident in which only one vehicle and no other road user is involved (Liu and Subramanian, 2009)). Note that these accident data do not always refer to locations exactly at the access point (except for sites 1, 2 and 3) due to discrepancy of the police data, but they give some indication of a typical pattern of fatal accidents occurring within the vicinity of the selected access points.

Table 6: The characteristics of the selected sites

Access point		1	2	3	4	5	6*	7*	8*
Primary Road number designation		R6	R4	R3	5	5	B1		
District		Pauh	Arau	Arau	Kul. Slgor	Morib	Meru		
Area classification		Rural	Residential	Residential	Residential	Rural	Commercial	Commercial	Residential
Speed limit (km/h)		70	80	70	90	90	70	70	80
Lane width (m)		2.5m	2.5m	2.5m	3.0m	2.5m	3.0m	3.0m	3.0m
Presence of road shoulder		No	No	Yes	Yes	Yes	Yes	No	No
Traffic volume (ADT), veh/day		6,294	25,800	10,264	43,210	7,023	91,094	73,520	29,546
Total Number of Fatal MC accidents for the 5 years (2007-2011)		3	8	2	99	3	27		
Collision type	At angle collision	2	4	1	33	2	12		
	Single	1	3		45	1	8		
	Head on		1	1	12		1		
	Side swipe				9		6		
Type of vehicle involved with MC	MC	2	9	1	111	2	29		
	P.C	1	4	1	56	1	5		
	H.V.		2		24		14		

MC: Motorcycle, Veh: motor vehicle other than motorcycle, P.C.: Passenger Car, SUV, Van, H.V.: Heavy Vehicle, Kul. Slgor – Kuala Selangor
* Sites 6, 7 and 8 are on the same stretch of road.

5.3.2 Speed data collection

The speed of motorcycles and other vehicles along the primary road is measured for three scenarios: S1, S2 and S3 (see Figure 6). All 3 scenarios are on the same road stretch. As seen in Figure 6, Scenario S1 is on a stretch of road that has no access, while S2 and S3 are on a similar stretch, near S1, but with an access. The difference between them is that in S2 there is no road user present at the access point, while in S3 there is.

For each scenario type, one or more sets of 100 randomly selected free vehicles' speeds, i.e. vehicles that can choose their speed freely, have been measured with a radar gun, e.g. for S1, 100 speed-readings of motorcycles (MC) and another 100 for other vehicles (VE), (i.e. cars, SUVs, vans, buses and trucks) in each direction. For S2 and S3, speeds of motorcycles and other vehicles have been collected separately for each direction, i.e. speed data for the direction towards the access are designated as MC1 for motorcycles and VE1 for other vehicles, whereas MC2 (for motorcycles) and VE2 (other vehicles) are for those going in the opposite direction. Each scenario, vehicle type and direction has a specific label, for example, S1MC, S1VE, S2MC1, S2MC2, S2VE1, S2VE2 and S3MC1, S3VE1, S3MC2 and S3VE2. All speed measurements have been conducted in the daytime during non-peak hours in order to obtain uninterrupted free flow speeds.

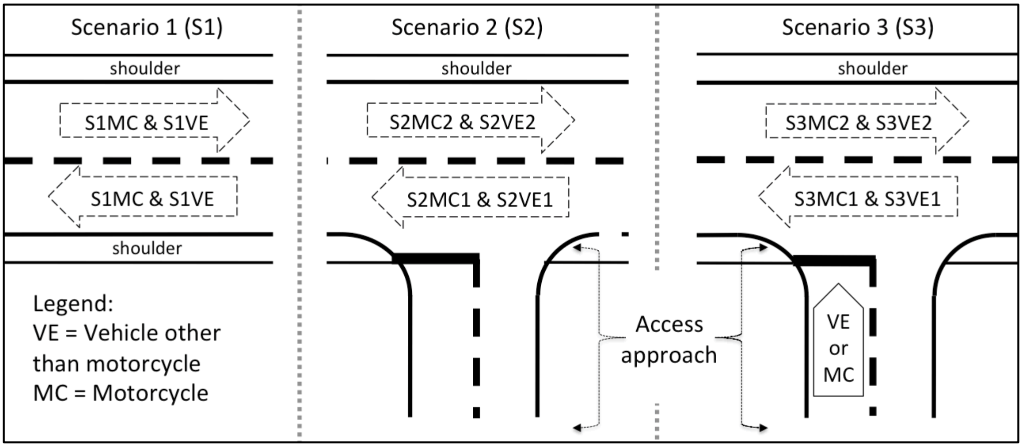


Figure 6: Scenarios for speed data collection (Note: Malaysia is a country with left-hand traffic).

Each set of speed data, e.g. S1MC and S2MC1, is processed and mean standard deviation, 85th percentile, and speed distribution are obtained for every selected scenario and situation. Then, all sets of speed data are compared with each other for each site, e.g. S3MC1 with S2MC1 or S1MC with S3VE2. Cumulative speed distributions are plotted and the statistical significance of difference of mean values are tested with a t-test for each pair compared ($p<0.05$).

5.3.3 Behavioral observations

Video recordings, with a total recording time of 24 hours, have been used to observe road users' behavior at the selected sites. The durations of the recordings per site, depending on traffic volume, are 4 hours per site for sites 1, 2, 3 and 5, and 2 hours per site for sites 4, 6, 7 and 8, all during daytime non-peak hours and in clear weather. The camera placement has enabled us to observe vehicles moving along the primary road as well as vehicles entering from the access point.

Motorcyclists passing the selected access point along the primary road are observed in terms of their compliance with helmet and headlight usage. This information helps to show whether motorcyclists adhere to the law of mandatory helmet and headlight usage introduced in 1992 (Radin Umar et al., 1996). The position of the motorcyclist in the lane is also observed, i.e. in the middle of the lane or near the road shoulder. In addition, in order to satisfy the research question (see Paper 3) on whether motorcyclists on the primary road slow down voluntarily when approaching the access point, the usage of brake lights is observed in the lanes, on the near side and far side of the access approach.

Vehicles entering from the access points are observed in terms of usage of turning indicator. For motorcyclists, head movement prior to entering the primary road is observed to see whether they look for approaching traffic. Compliance with the stop rule, (i.e. stopping or not stopping at the stop line) of those attempting to enter from the access approach is noted, as is the manner of entering of vehicles from the access point into the flow of the primary road based on gap acceptance. Excluding vehicles entering the primary road when the road is empty, three types of entering are recorded according to the following criteria (see Figure 7):

1. $t_G \geq 4$ seconds – the vehicle enters the primary road by accepting a longer gap (equal to or more than 4 seconds) between two vehicles on the primary road.
2. $t_G < 4$ seconds – the vehicle enters the primary road by accepting a shorter gap (less than 4 seconds) between two vehicles on the primary road.
3. $t_L < 4$ seconds – the vehicle enters the primary road before an approaching vehicle on the primary road, resulting in a time lag of less than 4 seconds.

The threshold value of t_G, and t_L for entering has been taken from the Critical Gap value of a minimum of 4 seconds for a two-way stop controlled intersection (TRB, 2000). Time lag (t_L) is the time from when vehicle A passes the imaginary meeting point on vehicle B's trajectory until vehicle B arrives at that point.

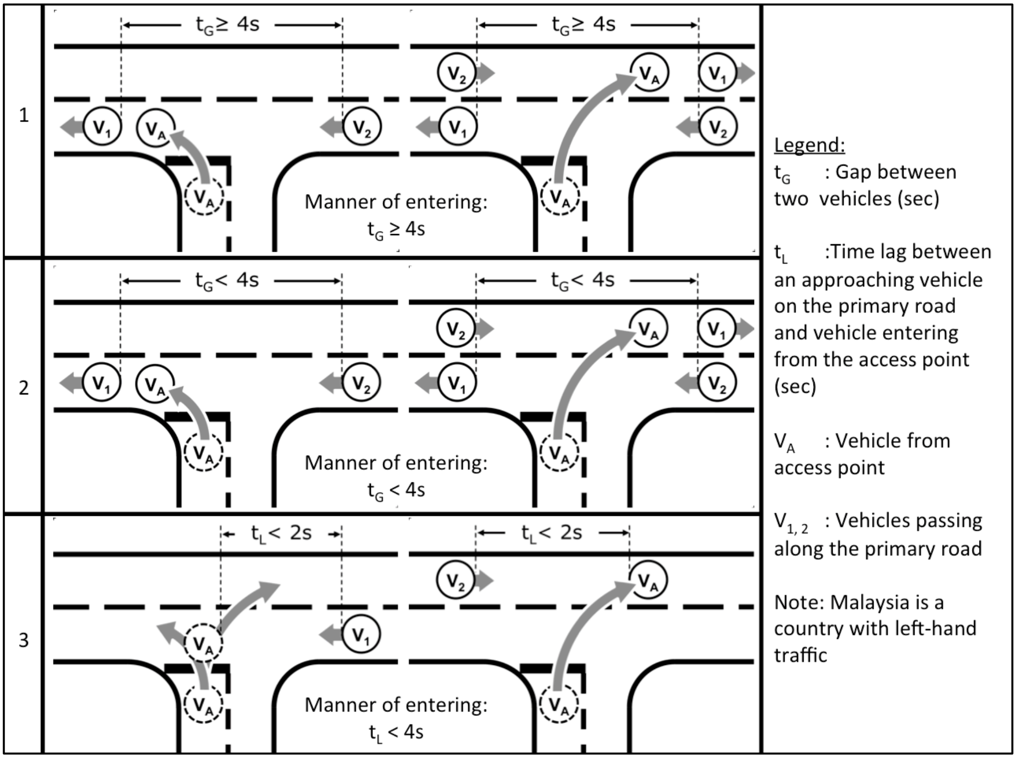


Figure 7: Way of entry into the flow of the primary road by a vehicle entering from the access point.

Interactions and the occurrence of serious traffic conflicts between motorcyclists on the primary road and those vehicles entering the primary road from the access point are also observed. An interaction in this study is defined as "A traffic event with a collision course where interactive behavior is a precondition to avoid an accident" (Svensson, 1998) or, in other words, a traffic interaction is an event in which the involved road users affect each other's movement and hence have to take action to avoid a collision. A serious conflict is an "… indicator of a breakdown in the interaction - a breakdown that could correspond to the breakdown in the interaction preceding a crash" (Svensson and Hyden, 2006).

The Swedish traffic conflicts technique (TCT) (Hydén, 1987), is used to identify serious conflicts at the sites. The conflicts technique is based on the relation between conflicts of a certain severity and accidents of the same type (Hydén, 1987). The definition of the severity of a conflict is based on two variables: time to accident (TA) and conflicting speed (CS). TA is the time that remains from the moment one of the road users takes evasive action until the collision that will occur if the speeds and directions of the involved road users remain unchanged. CS is the speed of the road user that takes evasive action, just prior to the evasive action. A serious conflict is defined by certain border values for TA and CS (Hydén, 1987). The relationship between serious conflicts and injury crashes reported by the police has been established through validation studies (Hydén, 1987). The author of this thesis, who is also a trained observer, has recorded all the serious conflicts at the access points. He has recorded the involved road-users' CS, TA, direction, etc., and described the course of events preceding the conflict and the factors influencing the course of events. The duration of conflict observations varies from 2 to 4 hours per site during non-peak hours.

The occurrence of serious traffic conflicts between those entering and those passing along the primary road has to be analyzed in association with different types of motorists' behavior, i.e. stopping behavior and way of entering the primary road, etc., in a consecutive study – see next section.

For more details see Paper 3.

5.4 Predicting the effect of motorcyclists' behavior and road environment on the occurrence of traffic conflicts at access points

In order to further analyze the collected variables in the observational study, the effect of motorcyclists' behavior and road environment characteristics on traffic conflict occurrence involving motorcyclists entering a primary road from access points is investigated via a mixed-effects logistic regression. The data used are observations that have traffic interactions between motorcycle entering from the access point and vehicles passing along the primary road.

5.4.1 Mixed-effects logistic regression

Since our data is collected from a roadside observational survey where the underlying behavioral details of the motorcyclists cannot be determined, additional heterogeneity across observations, i.e. motorcyclists' inherent attitude to the road surroundings or to safety, could be introduced (in addition to the unobserved heterogeneity we expect, relating to roadway, vehicle, driver and passenger factors). These behavioral-specific details can include factors such as motorcyclists' socioeconomic status (income or education level), risk perception (risky lifestyle, aggressive behavior), perceived usefulness of helmet and level of enforcement, all of which have been shown to affect the occurrence of accidents (see Crundall et al. (2008b); Nordqvist and Gregersen (2010)). One example of vehicle related unobserved heterogeneity is when motorcyclists, attempting to enter from the access point, are poor at utilizing the turning indicator. One sees that the turning indicator is not on, but it may be that it is malfunctioning; the mechanical state of the motorcycle itself is unknown during the observation. Thus, bias from unobserved heterogeneity is particularly important to take into account, because estimates of the effect of independent variables will be biased even if the unobserved heterogeneity is not correlated with the observed independent variables (Washington et al., 2003). Unobserved heterogeneity is typically dealt with either by conditioning through random effects, or by transforming the data to eliminate individual-specific fixed effects (Revelt and Train, 1998).

Analysis by logistic regression is a convenient way of modeling binary response with the assumption that each observation entered into the estimation procedure corresponds to an individual causality, and that the residuals from the model exhibit independence (Al-Ghamdi, 2002; Campbell, 2001; Jones and Jørgensen, 2003). However, the assumption of independence may often not hold true. For example, it is reasonable to assume that the characteristics of the road environment of the primary road section into which the motorcyclists enter from the access point will affect their probability of being involved in a serious traffic conflict. If this is the case, then serious traffic conflicts within the same road environment will tend to have more similar outcomes than serious traffic conflicts within a different road environment, and the assumption of residual independence will not be met. Moreover, it seems unrealistic to assume that the effects of the influential factors are the same, i.e. fixed, across all observed serious traffic conflicts (Jones and Jørgensen, 2003; Pai et al., 2009).

In view of the above mentioned reasoning, fitting a multilevel model is an alternative strategy that allows for the possibility that the effects of variables (i.e. motorists' behavior and road environment attributes), which influence the occurrence of serious traffic conflicts, may vary across the observations and circumvent all of the problems with traditional generalized linear model techniques. One such multi-level model is the mixed-effects logistic regression containing both fixed effects and random effects (Jones and Jørgensen, 2003). Thus, the graphical depiction appropriate for this method may be viewed as actually corresponding to a two-level hierarchy of occurrence of serious traffic conflicts involving motorcyclists entering the primary road from the access point (Level 1), and nested within different road environment attributes (Level 2) (see Figure 8).

The full mixed effect logistic regression model can be written as in Eqn. (3) with the subscript j added to identify the variation of road environment attributes, e.g. level of traffic volumes, road width category, etc.

$$y_{ij} = a + bx_{ij} + e_{ij} + u_j + v_j x_{ij} \qquad \text{(Eqn. 3)}$$

Where:
y_{ij} = the observed responses which are dichotomous (1,0), indicating whether each *i*th motorcyclist that enters the primary road from the access point is involved in a serious traffic conflict or not with respect to the variation of road environment attributes.
a = is the intercept, where the regression line meets the vertical axis
b = is its slope or regression coefficient.
e_{ij} = the deviation of the *i*th motorcyclist that enters the primary road from the access point with variation of *j*th road environment attribute.
u_j = the deviation of the *j*th road environment attribute's intercept from the overall value; it is a level 2 residual which is the same for all motorcyclists in road environment attribute *j*.

v_j = the deviation of the jth road environment attribute's slope (i.e. coefficient) from the overall value; it is a level 2 residual which is the same for all motorcyclists in road environment attribute j.

In Eqn. (3), both u_j and e_{ij} are random quantities, whose means are equal to zero; they form the random part of the model (3). The assumption is that, being at different levels, these variables are uncorrelated, and that they follow a normal distribution so that it is sufficient to estimate their variances σ^2_u and σ^2_e respectively (Jones and Jørgensen, 2003; Rasbash et al., 2009). It is the existence of the two random variables u_j and e_{ij} in Eqn. (3) that marks it out as a multilevel model. The variances σ^2_u and σ^2_e are referred to as random parameters of the model, whereas the quantities a and b are known as fixed parameters. A multilevel model of this simple type, where the only random parameters are the intercept variances at each level, is known as a variance components model. However, in a more complex model, the random parameter may have either a random intercept, u_j or a random slope, v_j (or both) associated in the level.

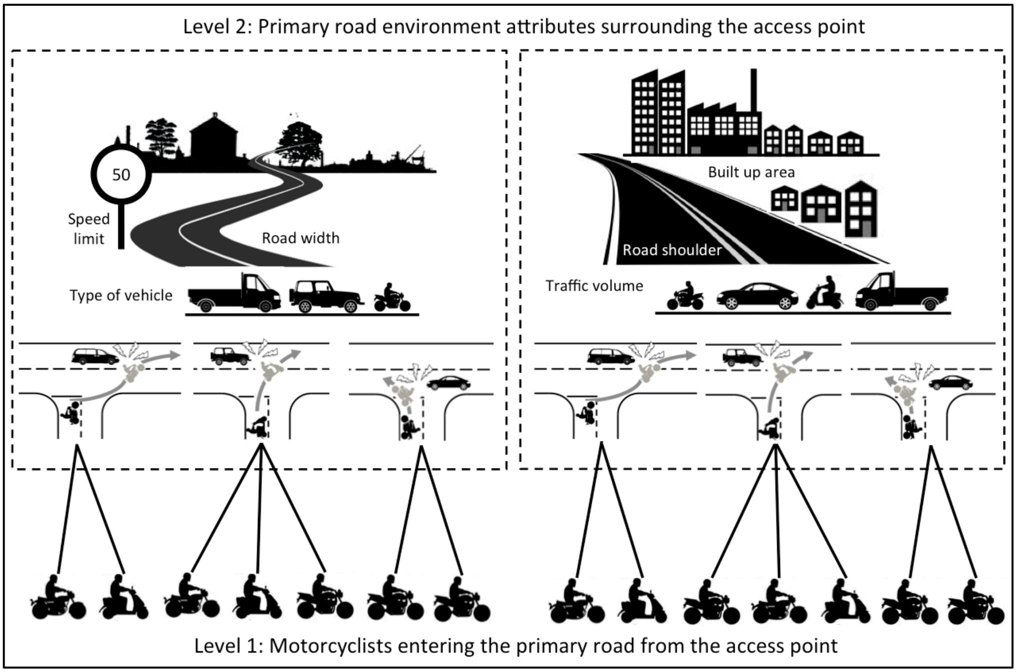


Figure 8: Graphical representation of the study, which may be seen as exhibiting occurrence of serious traffic conflicts involving motorcyclists entering the primary road from the access point (Level 1) and nested within different road environment attributes (Level 2)

As the number of observed serious conflicts (n = 36) in the sample is relatively small for a logistic regression, the probability of positive occurrence may be underestimated and result in low sensitivity. In order to deal with this, multi-level bootstrapping is adopted. Bootstrapping is a statistical technique that falls under the broader heading of resampling (Adèr et al., 2008; Campbell, 2001). It is the practice of estimating the properties of an estimator (such as its variance) by measuring those properties when sampling from an approximating distribution (Varian, 2005). According to Adèr et al. (2008), the bootstrap procedure is recommended when the sample size is insufficient for straightforward statistical inference, and, if the underlying distribution is well-known, bootstrapping provides a way to account for the distortions caused by the specific sample that may not be fully representative of the population. For more details, see Paper 4.

In order to ensure the robustness of this model, several 'bootstrap' mixed-effect logistic regression models are developed. Each model's goodness-of-fit for this study is measured in terms of Akaike's Information Criterion (AIC). The smaller the value, the better and more preferred the model will be, i.e. the best fitted model (Abdel-Aty and Radwan, 2000; Ayati and Abbasi, 2011). The AIC is calculated using the following equation:

$$AIC = 2LL + 2k \qquad \textit{(Eqn. 4)}$$

where LL is log-likelihood and k is the number of parameters.

The models are also compared in terms of their random parameters' residual variance at each level. To estimate the proportion of overall residual variability that is associated with each level, it is normal to calculate the ratio of each of the two-variance terms to total variance (Jones and Jørgensen, 2003). The result is known as the intra-unit correlation coefficient (ICC), ρ, and it can be calculated using the formula:

$$\text{ICC Level 1, } \rho_1 = (\sigma^2_{e0}) / (\sigma^2_{u0} + \sigma^2_{e0}) \qquad \textit{(Eqn. 5)}$$

$$\text{ICC Level 2, } \rho_2 = (\sigma^2_{u0}) / (\sigma^2_{u0} + \sigma^2_{e0}) \qquad \textit{(Eqn. 6)}$$

where σ^2_{e0} and σ^2_{u0} are the variances for level 1 and 2 residuals, respectively. As a guide, if the ICC Level 2 (ρ_2) approaches zero, then the random parameter effect would be considered useless and simple regression would suffice. On the other hand, if the ρ_2, approaches one, then there is no variance to be explained at level one, i.e. all motorcyclists that enter the primary road from the access point are the same.

For more details see Paper 3.

6. Results

This section presents the findings of the studies in four subsections corresponding to the content of Papers 1, 2, 3 and 4.

6.1 Frequency and pattern of motorcycle accident fatalities in Malaysia

The analysis of data concerning motorcyclist's accidents has revealed that the road accident statistics based on police injury records in Malaysia are inadequate and/or insufficient due to significant underreporting. Comparing Malaysian accident statistics to a highly developed motorized country like Sweden (see Table 7), it can be concluded that there are 9 severe injuries for each fatality in the Swedish statistics, but only 1.4 severe injuries per fatality in the Malaysian statistics. The rate of slight injuries per fatality is 57 to one in Sweden, and 4 to one in Malaysia. The rate of underreporting of injuries in Malaysia is similar for motorcycle injuries and fatalities. Due to the unreliable injury statistics in Malaysia, further analysis of road safety problems can only be based on fatalities, and including injury data in the analyses would induce bias in inferences and the marginal impacts of a variety of factors could be overestimated (Yamamoto et al., 2008). Thus, this study only uses motorcycle accident fatality data from the Malaysian police.

Table 7: Road accident severity in Sweden and Malaysia in 2008 (Paper 1)

	Fatalities	Severely injured	Slightly Injured	Severe : Fatal	Slight : Fatal
SWEDEN (2009)					
All types of accidents	397	3,657	22,591	9 : 1	57 : 1
Motorcycle accidents (Rider & Passenger)	51	341	898	**7 : 1**	**17 : 1**
MALAYSIA (2009)					
All types of accidents	6,527	8,868	25,747	1.4 : 1	4 : 1
Motorcycle accidents (Rider & Passenger)	3,898	5,472	10,326	**1.4 : 1**	**2.6 : 1**

A summary of the findings of the accident study can be seen in Table 8. The highest number of motorcycle fatalities is found in the West Coast Area of Malaysia, which has the highest number of registered motorcycles and population. Motorcycle fatalities are most frequent in rural locations (61%), half of them are on primary or arterial roads, and the majority of them are on straight road sections (66%). Motorcycle fatalities during the week are most frequent from Saturday to Tuesday and during the day between 4 pm and 10 pm.

Most of the fatalities occur during daylight (56%) and in clear weather conditions (93%). The largest group by type of collision is angular or side (28%). The age group with the highest motorcycle fatalities is 16 to 20 year old riders (23%), and 90% of the motorcycles involved in fatal crashes are privately owned. Of those motorcyclists involved in fatal accidents, 76% wore helmets, and 35% of them did not possess a proper license. Male motorcyclists involved in fatal crashes are dominant (92%), but the number of female fatalities in the age groups 31 to 40, 46 to 50 and 56 to 70 are larger compared to their male counterparts. Females are more frequently involved in motorcycle fatal accidents than males during the daytime, and the share of those not possessing a license and not wearing a helmet is higher among female fatalities than among males. See Paper 1 for more details.

Table 8: Summary of findings of the analysis of motorcycle accident fatalities in Malaysia (Paper 1)

The category which has the highest number of motorcycle accident fatalities			Percentage of the total motorcycle accident fatalities (%)
Location	Region	West coast	31
	Area type	Rural	61
	Road Hierarchy	**Primary** or arterial roads	**50**
	Road geometry	**Straight** section	**66**
Collision	By type	**Angular or side**	**28**
	With vehicle	Passenger car	28
Day		Saturday to Tuesday	60
Time		Between 4pm to 10pm	35
Light condition		Daylight	56
Weather		Clear weather	93
Gender		Males	92
Age group		16 to 20	23
Occupancy		Rider only	89
Ownership		Personal	90
Licence		Full licence	63
Helmet wearing		Wearing helmet properly	76
Injury type		Head injury	63

More detailed information regarding motorcycle accident fatalities based on road hierarchy and geometry can be seen in Table 9 and Figure 9. Related to the road length, the highest fatality rate per 100 km and per 100,000 motorcycles occurs along primary or arterial roads. There are more motorcycle fatalities per 100 km on Malaysian primary roads than on secondary roads, local streets and minor roads combined. Fatal accidents involving motorcycles are five times as high on straight road sections compared to the curved sections. Unfortunately, data on traffic volumes for the different types of roads is not available for all road types; hence, we cannot relate motorcycles crashes to their exposure on these roads.

Table 9: Motorcycle fatality by road type in Malaysia in 2009 (Paper 1)

Road Hierarchy	Road Length		ADT (million)		MC Fatalities		MC Fatal/ 100 KM	MC Fatal/ 100,000 MC
	KM	%	Veh	MC	N	%		
Expressway	1,635	1.3	**20.6**	*	121	3.0	7.4	*
Primary / Arterial	16,939	13.6	12.8	**2.6**	**2,021**	**49.7**	**11.9**	**76.7**
Secondary / Collector	**54,681**	**43.9**	6.3	1.6	672	16.5	1.2	42.0
Local Street	43,363	34.8	*	*	755	18.6	1.7	*
Minor Roads	8,038	6.4	*	*	501	12.3	6.2	*
Total	124,656	100	-	-	4,070	100	3.3	-

ADT – Average Daily Traffic, Veh – vehicle, MC – Motorcycle,
(*) – Data is not available.

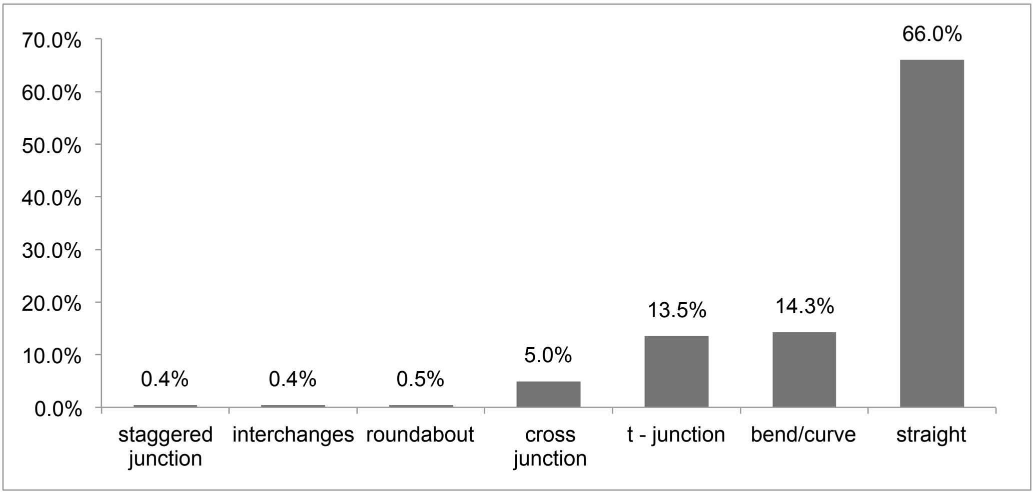


Figure 9: Percentage Motorcycle Fatality on various parts of the road network in Malaysia for 2009 (Paper 1)

The findings in respect to the Malaysian road infrastructure indicate that primary roads, especially straight sections, are associated with high motorcycle accident fatalities. Hence, these should be further analyzed in order to find out more about road attributes and environments associated with motorcycle accident fatalities.

6.2 Association between road infrastructure features and motorcycle fatalities on primary roads in Malaysia

The study generates various models, narrowed down to six (6) (see Table 10), which are overall statistically significant ($p<0.05$), based on the Omnibus test of the model as a whole. Models 1, 2 and 3 have 1 common variable, which is LnADTMC, whereas models 4, 5 and 6 have LnADT. However, Models 1, 2, 4 and 5 are not suitable representations of the data in this study due to the fact that some of the coefficients are not statistically significantly different from zero at the 5% level. Thus, there are 2 models suitable for consideration (Model 3 and 6), which have coefficients that are statistically significant ($p<0.05$). The goodness-of-fit statistics (see Table 10) for these two models show that the models fit the data very well. The Pearson Chi-square statistics are estimated to be 0.872 and 0.821, respectively, for models 3 and 6. The estimated values of the Pearson Chi-square are also within the permissible range (i.e. between 0.8 and 1.2), indicating that the Negative Binomial distribution assumption is acceptable (Bauer and Harwood, 2000).

Table 10: Estimation results for various alternative models

	Model 1		Model 2		**Model 3**	
Parameter estimates	β	p-value	β	p-value	β	p-value
(Intercept)	-4.721	.000	-4.665	.000	-4.891	.000
LnAccess_per_km	.299	.000	.281	.001	.262	.001
LnCurve_per_km	-.039	.600				
LnADTMC	.379	.000	.369	.000	.404	.000
LnADT						
[Lane_config=5.00]	-.375	.474	-.319	.516		
[Lane_config=4.00]	.082	.807	.119	.688		
[Lane_config=3.00]	.454	.451	.905	.094		
[Lane_config=2.00]	.481	.283	.456	.271		
[Lane_config=1.00]	0[a]	.	0[a]	.		
[Median=3.00]	-.364	.329	-.254	.431		
[Median=2.00]	-.226	.623	-.239	.575		
[Median=1.00]	0[a]	.	0[a]	.		
[Paved_shoulder=3.00]	.136	.579				
[Paved_shoulder=2.00]	-.195	.116				
[Paved_shoulder=1.00]	0[a]	.				
Overdispersion Parameter (Scale)	.801[b]		.847[b]		.872[a]	
Omnibus test	df=11	Sig.	df=8	Sig.	df=2	Sig.
Likelihood Ratio Chi-Square	80.011	.000	79.296	.000	66.741	.000
Goodness of fit	df=354 Value	Value /df	df=363 Value	Value /df	df=369 Value	Value/ df
Deviance	201.712	.570	207.846	.573	216.864	.588
Pearson Chi-Square	283.531	.801	307.634	.847	321.684	.872
Akaike's Info. Criterion (AIC)	1980.597		2009.561		2006.580	
Bayesian Info. Criterion (BIC)	2027.428		2044.831		2018.336	

a - Set to zero because this parameter is redundant.
b - Computed based on the Pearson chi-square.

Table 10 (continue): Estimation results for various alternative models

	Model 4		Model 5		**Model 6**	
Parameter estimates	β	p-value	β	p-value	β	p-value
(Intercept)	-6.798	.000	-6.809	.000	-6.381	.000
LnAccess_per_km	.341	.000	.323	.000	.316	.000
LnCurve_per_km	-.040	.573				
LnADTMC						
LnADT	.528	.000	.533	.000	.477	.000
[Lane_config=5.00]	-.795	.123	-.992	.001		
[Lane_config=4.00]	-.107	.744	-.313	.109		
[Lane_config=3.00]	.009	.988	.235	.518		
[Lane_config=2.00]	.251	.564	.047	.804		
[Lane_config=1.00]	0[a]	.	0[a]	.		
[Median=3.00]	-.288	.423				
[Median=2.00]	-.164	.710				
[Median=1.00]	0[a]	.				
[Paved_shoulder=3.00]	.155	.510	.114	.597		
[Paved_shoulder=2.00]	-.226	.056	-.220	.058		
[Paved_shoulder=1.00]	0[a]	.	0[a]	.		
Overdispersion Parameter (Scale)	.729[b]		.734[b]		.821[a]	
Omnibus test	df=11	Sig.	df=8	Sig.	df=2	Sig.
Likelihood Ratio Chi-Square	108.275	.000	113.348	.000	86.028	.000
Goodness of fit	df=354	Value /df	df=363	Value /df	df=369	Value/ df
	Value		Value		Value	
Deviance	186.910	.528	191.814	.528	204.440	**.554**
Pearson Chi-Square	257.914	.729	266.555	.734	302.857	.821
Akaike's Info. Criterion (AIC)	1965.794		1993.530		**1994.155**	
Bayesian Info. Criterion (BIC)	2012.626		2028.800		**2005.911**	

a - Set to zero because this parameter is redundant.
b - Computed based on the Pearson chi-square.
Bold – indicates the lower value between models 3 and 6

Models 3 and 6 can be written as:

$$MCFatal/_{km} = exp\ (-4.891) \cdot ADTMC^{0.404} \cdot Access\_per\_km^{0.262} \qquad \textit{(Model 3)}$$

$$MCFatal/_{km} = exp\ (-6.381) \cdot ADT^{0.477} \cdot Access\_per\_km^{0.316} \qquad \textit{(Model 6)}$$

The Average Daily Traffic (LnADT) and Average Daily Traffic of motorcycles (LnADTMC) are statistically significant ($p<0.05$) with positive estimated model parameters for both models; they have one common variable, i.e. LnAccess_per_km with a positive parameter value and a strong statistical significance. This indicates that the fatal motorcycle crash frequency increases with an increase in the traffic flow or number of access points per kilometer. Moreover, neither LnADT or LnADTMC are strongly correlated (Pearson correlation <0.07) with LnAccess_per_km (Paper 2).

Both models correspond to the 'Safety performance function' which can be written as Equation 7 (Elvik, 2003):

$$E(\lambda) = \alpha Q^{\beta} \cdot exp[\sum \kappa x] \qquad \text{(Eqn. 7)}$$

where Q measures exposure, i.e. traffic volume, raised to an exponent β. Exp is the exponential function, that is the base of natural logarithms raised to the sum of parameter estimates multiplied by the relevant values of the explanatory variables, representing risk factors ($\Sigma\kappa x$) (Elvik and Vaa, 2004). Hence, for models 3 and 6, the measure of exposure (Q) is ADTMC and ADT, respectively, while 'Access per kilometer' is the risk factor and α is the scaling constant.

Model 3 has a distinctly better fit (has lesser bias-in-fit) than model 6. Although model 6 has a slightly lower value of Deviance, AIC and BIC than model 3 (the smaller the value, the better and more preferred the model), i.e. best fitted model (Abdel-Aty and Radwan, 2000; Olsson, 2002; Shankar et al., 1996)), however, based on the Cumulative Residual (CURE) plot in Figure 10, the data fits model 3 better along the entire range of values assumed by a variable. These particular CURE plots are based on the Access per km variable due to the fact that both models share this variable. A good CURE plot is one which moves up and down and oscillates around 0 (Hauer, 2004). As shown in Figure 10, model 3 appears to be slightly closer, oscillating around 0 at 10 to 18 access points per km, which indicates that it is a better fit than model 6.

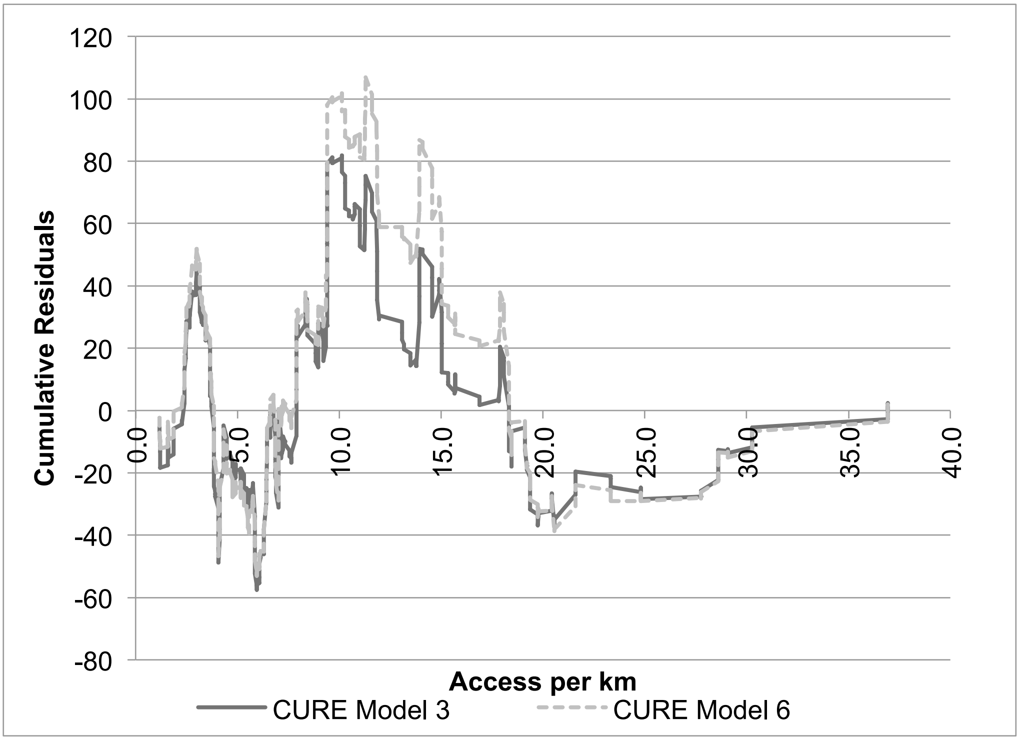


Figure 10: Cumulative residual plot (CURE) for Models 3 and 6.

The findings show that the estimates from both statistically significant models indicate that an increase of access points per kilometer and the average traffic volume, i.e. ADTMC and ADT, are closely associated with an increase in motorcycle fatal accidents per kilometer. Hence, an observation study should be conducted at these access points in order to gauge the real situation involving motorcycles at access points along primary roads.

6.3 Behavior observations and analyses

6.3.1 Speed data analysis

The speed analysis reveals that motorcycle mean speeds on a low volume site (Site 1) are lower than mean speeds of other vehicles in all scenarios ($p<0.05$) (see Figure 11). On the high volume site (Site 6), the difference in mean speeds between motorcycles and other vehicles is statistically significant in scenario 1 ($p<0.05$), but the difference is not statistically significant ($p\geq0.05$) in the scenario where there is no vehicle waiting at the access point. However, on the high volume site (Site 6), and when there is a vehicle waiting at the access point, motorcycles travel at higher speeds than other vehicles in both the near and far side lanes ($p<0.05$).

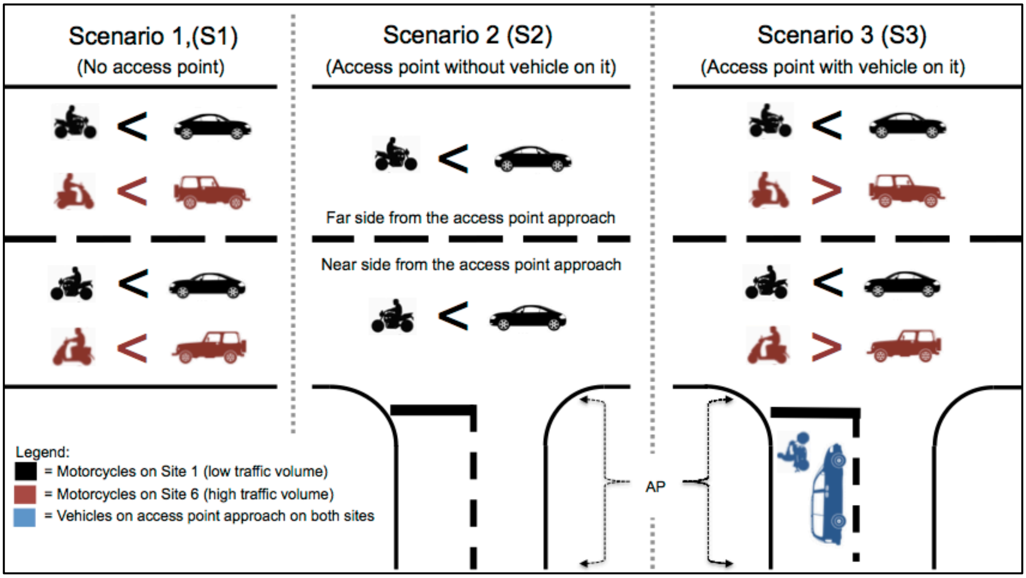


Figure 11: Graphical representation of vehicles speed comparison (t-test: $p<0.05$) for each scenario.

Only on the low traffic volume site (Site 1) is the mean speed of motorcycles statistically significantly higher when they are on a road stretch with no access point compared to the road stretch with an access point, with or without a road user waiting at the access point (see Figure 12). In both traffic conditions, speeds of motorcycles, in the near side lane from the access approach with waiting road users, are lower than speeds of motorcycles passing the access point when there is no vehicle on the approach, and lower than those on a similar road stretch without an access point. However, on Site 1, when there are road users at the access point, motorcyclists are faster in the near lane from the access point, compared to those in the far side lane. As for Site 6, most of the scenarios have statistically non-significant ($p \geq 0.05$) differences between mean speeds, probably due to the higher traffic volume.

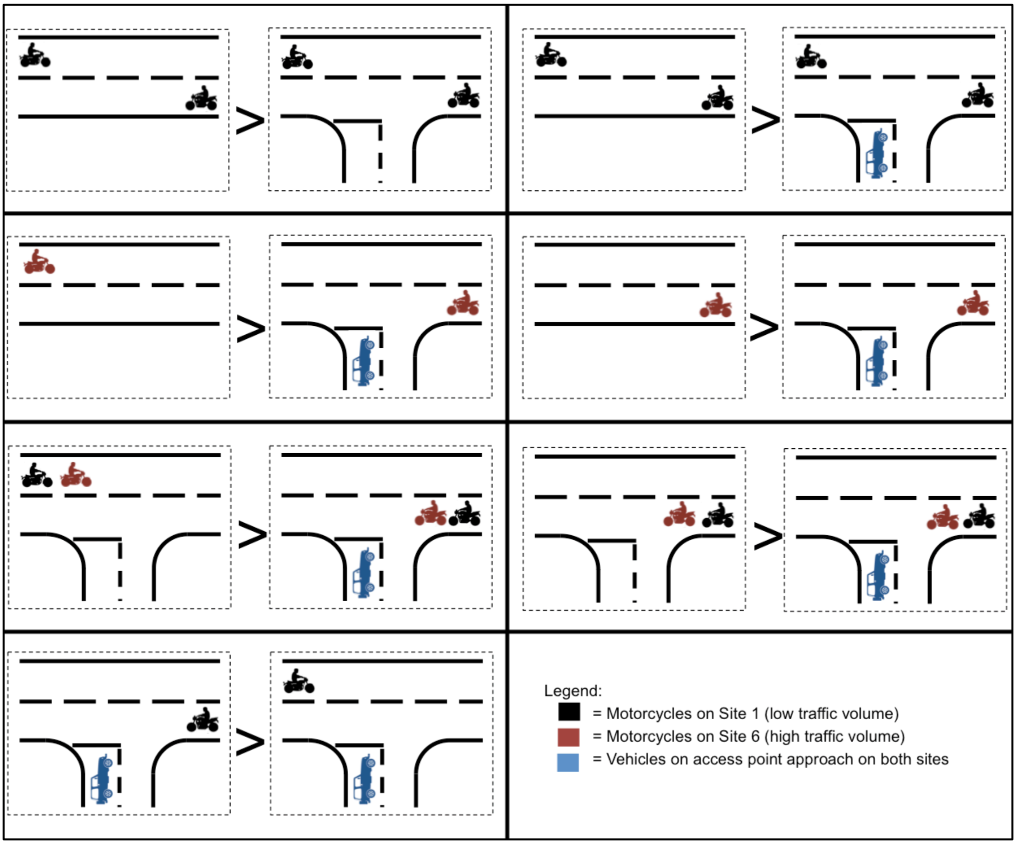


Figure 12: Graphical representation of motorcycle speed comparison (t-test: $p<0.05$) for each scenario.

In terms of speed limit violation, the cumulative speed distribution curves (see Paper 3 for more details) show that the majority of the motorcycles travel below the speed limit of 80 kph at the access point, but 8 – 14% travel at speeds over the limit at the site with a lower speed limit (70 kph). For more details, see Paper 3.

6.3.2 Motorcyclists behavior on the primary road

Both genders have higher compliance with helmet and headlight usage in lower traffic volume conditions ($p<0.05$) compared to high traffic volume conditions. However, in high traffic volume conditions, female riders exhibit lower compliance in terms of helmet usage (26%) compared to males (13%) ($p<0.05$).

Motorcyclists along the primary road use the middle of the lane and near to the shoulder equally regardless of the traffic volume. However, female riders are inclined to ride close to the shoulder more compared to male riders.

The observation of motorcyclists' usage of brake lights when approaching the access point shows that the percentage of motorcyclists that do not slow down when there is a vehicle on the approach to the access point is much higher in high traffic volume compared to low traffic volume ($p<0.05$). Nonetheless, when there is a vehicle waiting to enter from the access point, more motorcyclists do not slow down when they are near the shoulder compared to when they are in the middle of the lane ($p<0.05$). However, this difference is statistically significant only for high volume conditions.

6.3.3 Motorists' behavior when entering the primary road from the access point

A hazardous right turning movement is detected, i.e. the Opposite Indirect Right Turn (see Figure 13), apart from other typical entry movements. The Opposite Indirect Right Turn, which is mostly performed by motorcyclists, is a peculiar movement and a risky maneuver (see Paper 3 for more details). In this movement the vehicle makes a right turn into the opposite lane on the main road, and continues in the opposite direction before crossing the middle line into its desired lane. The Opposite Indirect Right Turn is performed by 18% to 26% of right turning motorcyclists entering the primary road from the access point (Paper 3). Unfortunately, this particular movement has never before been documented in Malaysia or in Asia, but it seems to be done frequently by motorcyclists on a high traffic volume road.

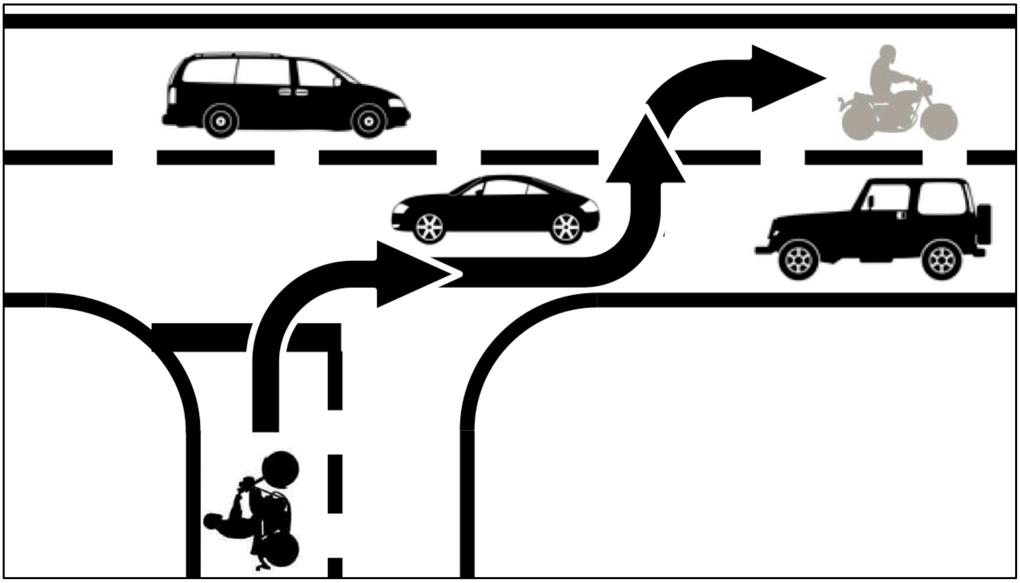


Figure 13: The Opposite Indirect Right Turn

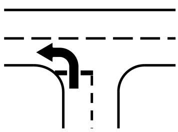
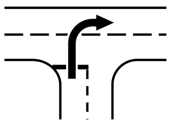
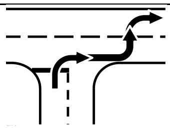
The behavior of vehicles exiting from the access point has been observed at the stop line in two types of situations: Situation 1 when there are no approaching vehicles along the primary road, i.e. an opportunity to enter without interaction, and Situation 2 when there are approaching vehicles along the primary road. Two types of movements performed by the vehicles exiting from the access approach are noted: the first, when motorists enter the primary road from the access and – according to the rule - stop at the stop line, and the second type when motorists do not stop before entering.

In Situation 1, motorcyclists are more non-compliant with the stop rule (97% not stopping at the stop line), compared to other vehicles (86%) ($p<0.05$), when performing the left turn maneuver. However, when there are vehicles approaching on the primary road, i.e. Situation 2, the percentage of motorcyclists complying with the stop rule is slightly higher, 16%, while for other vehicles it is 45% ($p<0.05$). There are no statistically significant differences between the different types of vehicles when they perform the right turn maneuver. Still, when there is no approaching vehicle on the primary road, i.e. Situation 1, 67% of motorcyclists do not stop at the stop line as compared to those in Situation 2, where 80% stop at the stop line ($p<0.05$) before executing the right turn. The majority of motorcyclists performing the Opposite Indirect Right Turn do not stop at the stop line (81%).

The head movement of motorcyclists has been observed in order to see whether they scan the primary road before entering from the access point. More left turning motorcyclists do not turn their heads (28%) to look for vehicles when entering the high traffic volume road, as compared to those turning left into the lower traffic volume road ($p<0.05$). More motorcyclists are seen to only turn their heads to the left (19%) when making a right turn into a low to medium traffic volume road as compared to those entering a high traffic volume road ($p<0.05$). Of those motorcyclists who perform the Opposite Indirect Right Turn, more are seen as either not turning their heads at all (27% on low traffic volume site and 36% on high traffic volume site) or turning only to the left as they enter the primary road (50% on low traffic volume site and 33% on high traffic volume site).

When making a left turn maneuver, motorcyclists more often enter the primary road by accepting a shorter gap (tG < 4 seconds) between two vehicles on the primary road (53% to 63%), compared to other vehicles (20% to 22%) ($p<0.05$), on both site conditions (see Table 11). On the other hand, when making a right turn maneuver, motorcyclists often enter the primary road by accepting a longer gap ($t_G > 4$ seconds) (57% to 59%) compared to a left turn (21% to 32%) maneuver ($p<0.05$). Moreover, motorcyclists frequently enter the primary road by accepting a shorter gap ($t_G < 4$ seconds) between two vehicles passing on the primary road when performing the Opposite Indirect Right Turn (59%), as compared to the right turn movement (57%), on a low to medium traffic volume primary road ($p<0.05$). On the other hand, on high traffic volume primary roads, motorcyclists often enter by accepting a longer gap ($t_G \geq 4$ seconds) via the Opposite indirect Right Turn compared to the "normal" right turn movement ($p<0.05$).

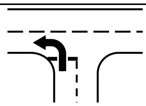
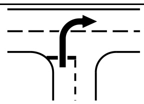
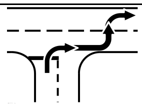
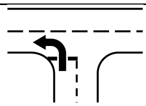
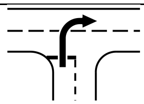
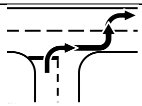
Table 11: Manner of entering the flow of the primary road in different traffic volumes.

Movement type	Vehicle type exiting from the access point (n=536)	Manner of entering the flow of the primary road	Sites with access points on low to medium traffic volume primary road	Sites with access points on high traffic volume primary road
 Left turn	MC (n=90)		(n=34)	(n=56)
		$t_G \geq 4$ seconds	32% ◆Δ	21% ◆Δ
		$t_G < 4$ seconds	53% ◆Δ	63% ◆Δ
		$t_L < 4$ seconds	15% ◆Δ	16% ◆Δ
	Other vehicles (n=83)		(n=32)	(n=51)
		$t_G \geq 4$ seconds	66% ◆Δ	71% ◆
		$t_G < 4$ seconds	22% ◆Δ	20% ◆
		$t_L < 4$ seconds	13% ◆Δ	10% ◆
 Right turn	MC (n=201)		(n=91)	(n=110)
		$t_G \geq 4$ seconds	57% Δ★	59% Δ★
		$t_G < 4$ seconds	12% Δ★	12% Δ★
		$t_L < 4$ seconds	31% Δ★	29% Δ★
	Other vehicle (n=102)		(n=38)	(n=64)
		$t_G \geq 4$ seconds	55% Δ	70%
		$t_G < 4$ seconds	5% Δ	8%
		$t_L < 4$ seconds	39% Δ	22%
 OIRT	MC (n=60)		(n=34)	(n=26)
		$t_G \geq 4$ seconds	26% ★	42% ★
		$t_G < 4$ seconds	59% ★	46% ★
		$t_L < 4$ seconds	15% ★	12% ★

◆ Statistically significant difference according to Chi-sq. test ($p < 0.05$) in comparison between different types of vehicles entering the primary road from the access point, and ways of entering based on similar site conditions and movement types.
Δ Statistically significant difference according to Chi-sq. test ($p < 0.05$) in comparison between similar types of vehicles entering the primary road from the access point, and ways of entering based on different types of movement in similar site conditions.
★ Statistically significant difference according to Chi-sq. test ($p < 0.05$) in comparison between motorcycles entering the primary road from the access point, and ways of entering based on right turn and OIRT movement in similar site conditions.
$t_G \geq 4$ seconds – the vehicle enters the primary road by accepting a longer gap (equal to or more than 4 seconds) between two vehicles on the primary road
$t_G < 4$ seconds – the vehicle enters the primary road by accepting a shorter gap (less than 4 seconds) between two vehicles on the primary road.
$t_L < 4$ seconds – the vehicle enters the primary road before an approaching vehicle on the primary road, resulting in a time lag of less than 4 seconds.
OIRT – Opposite Indirect Right Turn

Out of the 800 observed motorists, 537 interactions are between vehicles from the access point and vehicles passing along the primary road, resulting in 56 serious traffic conflicts (see Table 12). Of this total of serious conflicts, 64% are between a motorcyclist from the access point and a motorist on the primary road. The rate of serious conflict per 350 interactions with motorcycles involved when entering the primary road is 10.3%, whereas for the 187 interactions with other vehicles involved besides motorcycles it is 10.7%, which is not statistically significant different ($p \geq 0.05$). The rate of serious conflicts for motorcyclists making a left turn and right turn is around 11%. Motorcyclists entering the primary road via the Opposite Indirect Right Turn are involved in a smaller rate of conflicts compared to those making the right turn ($p<0.1$). This might be an indication of more cautiousness on their part, knowing that they are breaking the rules.

Table 12: Number and rate of serious conflicts with respect to the movement direction of vehicle entering the primary road from the access point during a total of 24 hours of observation.

Type of vehicle entering the primary road from the access point	Movement type	Observation with interaction	Number of serious conflict	Rate of serious conflict (%)
Motorcycle	 Left turn	90	10	11.1
	 Right turn	200	22	11.0 *
	 OIRT	60	4	6.7 *
	All	350	36	10.3
Other vehicle	 Left turn	83	6	7.2
	 Right turn	103	14	13.6
	 OIRT	1	0	0.0
	All	187	20	10.7
All		537	56	10.4

Rate of serious conflict = Number of serious conflicts / Number of observations x 100
OIRT – Opposite Indirect Right Turn
* Statistically significant difference according to Chi-sq. test ($p < 0.01$) in comparison between right turn and the OIRT movement with respect to the rate of serious conflicts involving motorcyclists entering the primary road from the access point.

The findings show that motorcyclists entering from the access point are involved in serious traffic conflicts to about the same extent as other vehicles. Further analysis is needed to establish the association between serious traffic conflicts on the one hand, and motorcyclists' behavior and road environment attributes on the other.

6.4 The relation between serious traffic conflicts and motorcyclists' behavior and road environment attributes

There is a statistically significant association between the Traffic conflict categorical variable and Built-up area ($p<0.05$), Speed limit ($p<0.05$), Traffic volume and Lane width ($p<0.1$) categorical variables (see Table 13). This is a good indicator that either one of them can be in the level 2 random effects parameter. On the other hand, it shows that the Traffic conflict categorical variable is only associated with the categorical variables MC gender ($P<0.1$) and MC manner of entering primary road ($p<0.05$). This shows that, to generate a well-fitting and significant model, both of the categorical variables MC manner of entering primary road and MC gender should be heavily considered in the modeling process. For more details on the association analysis, refer to Paper 4.

Table 13: Pearson's Chi-square test of association between serious traffic conflict occurrence and road environment variables and motorcyclists' attributes and behavior.

Variables	Road environment	Traffic conflict
Road environment	Built-up area category	6.40**
	Traffic volume category	5.07*
	Speed limit category	6.96**
	Lane width category	3.43*
	Road shoulder category	0.12
Motorcyclist attributes and behavior	MC gender	3.39*
	MC head movement	2.64
	MC occupancy	0.28
	MC headlight usage	0.12
	MC helmet usage	0.03
	MC turning indicator usage	1.48
	MC stopping behaviour	0.28
	MC entering direction	1.03
	MC manner of entering the primary road	32.67**
* p < 0.1, ** p < 0.05,		

After exhaustive attempts, only 2 models (Model 2 and 3) that are statistically significant are considered, as shown in Table 14. The table contains the results of 2 model estimations, after 3,500 bootstrap resampling on each. The table is divided into 3 sections: Fixed effects parameters, Random effects parameters and Model fit. Model 1, is just an intercept model. Models 2 and 3 are both statistically significant at the fixed and random parameters ($p<0.05$), and can be written as in Eqn. 8 and 9. In order to evaluate these models, each section of the table has to be examined.

Model 2:

$$\begin{aligned} &\mathit{logit}\ [Pr\ (\mathit{Traffic\ conflict}_{ij} = 1)] = \\ &\qquad 0.834\ (\mathit{MC\ Manner\ of\ entry:}\ t_G < 4s)_{ij} \\ &\qquad + 1.461\ (\mathit{MC\ Manner\ of\ entry:}\ t_L < 4s)_{ij} \\ &\qquad - 2.040\ (\mathit{Lane\ width\ category:}\ 3.5m)_{ij} \\ &\qquad + v_j\ (\mathit{Speed\ limit}) \end{aligned}$$

Model 3:

$$\begin{aligned} &\mathit{logit}\ [Pr\ (\mathit{Traffic\ conflict}_{ij} = 1)] = \\ &\qquad 1.060\ (\mathit{MC\ Manner\ of\ entry:}\ t_G < 4s)_{ij} \\ &\qquad + 1.417\ (\mathit{MC\ Manner\ of\ entry:}\ t_L < 4s)_{ij} \\ &\qquad - 0.768\ (\mathit{MC\ stopping\ behavior:\ Do\ not\ stop\ at\ stop\ line})_{ij} \\ &\qquad + v_j\ (\mathit{Speed\ limit}) \end{aligned}$$

In terms of goodness of fit of the models (see Table 14), Model 2 is a better fit than Model 3 based on the AIC, i.e. AIC-Model 2 < AIC-Model 3. Attempts to combine Models 2 and 3 result in the fixed effects parameters for Lane width becoming statistically non-significant ($p>0.1$). Thus, both models are accepted as they show similar variation in the random effect parameters and goodness of fit.

Table 14: Results from the mixed-effect logistic regression

		Model 1 (intercept only) **		Model 2 **		Model 3 **	
Fixed effects parameters		β	Odds ratio	β	Odds ratio	β	Odds ratio
Intercept	(Constant)	-1.699 ** (0.602)	-				
MC Manner of entry	t_G < 4s			0.834 (0.509)	2.302*	1.060 (0.567)	2.886*
	t_L < 4s			1.461 (0.441)	4.310**	1.417 (0.473)	4.125**
Lane width category	3.5 m			-2.040 (1.197)	0.130*		
MC stopping behavior	Does not stop at stop line					-0.768 (0.439)	0.464*
Random (Hierarchical) effects parameters		Model 1 (intercept only)		Model 2 ▲		Model 3 ▲	
Level 1 (Motorcyclists entering primary road from the access point)		Std. Dev.	Var. (σ^2_{e0})	Std. Dev.	Var. (σ^2_{e0})	Std. Dev.	Var. (σ^2_{e0})
Random Intercept	(Constant)	-	1	-	1	-	1
Level 2 (Traffic volume category)		Std. Dev.	Var. (σ^2_{u0})	Std. Dev.	Var. (σ^2_{u0})	Std. Dev.	Var. (σ^2_{u0})
Random intercept	(Constant)	-	0.635	-	1.151**	-	1.342**
Random slope	Speed limit	0.403 (3.005)		1.324** (0.418)		1.800** (0.335)	
Model fit	LL	-115.437		-111.237		-114.085	
	df	2		4		4	
	AIC	234.875		230.475		236.169	

Note: Number of observations = 350, Number of bootstrap resamplings = 3,500,
Number of groups = 3 (Low, medium and high traffic volume), MC – motorcyclist
Std. Dev. – Standard Deviation, Var - Variance
* $p < 0.1$, ** $p < 0.05$, ▲ = significant at $p<0.05$ level based on the likelihood ratio test versus ordinary logistic regression (fixed effect parameters)
( ) – The number in the brackets is the Bootstrap standard error
LL: Log-likelihood, AIC: Akaike's Information Criterion

The fixed effects parameters can be interpreted as a normal logistic regression. The fixed effects parameter *MC manner of entering* for both Models 2 and 3 has shown that motorcyclists who enter the primary road from the access point, before an approaching vehicle and with a time lag (t_L) of less than 4 seconds, are 4 times more likely to be involved in a serious traffic conflict compared to those accepting a longer gap between passing vehicles ($t_G \geq 4$ seconds) (see Table 14). The risk of being involved in a serious traffic conflict is also 2 to 3 times more likely if they accept a shorter gap ($t_G < 4$ seconds) between two passing vehicles. Examining Model 2, the fixed effects parameter *Lane width* category shows that the likelihood of motorcyclists being involved in a serious traffic conflict is almost 8 times higher (1/0.130=7.7) if they enter a narrow lane road (2.5-meter) compared with entering a wider lane road (3.5-meter). For Model 3, it is shown that motorcyclists who *stop at the stop line* are at double the risk (1/0.464=2.2) of being involved in a serious traffic conflict when they enter the primary road, compared to those who do not stop at the stop line.

After rigorous trials and attempts, the most statistically significant road environment attribute at Level 2 found for this study is the *Traffic volume* category (see Table 14). The categorical variable Speed limit is also found to be statistically significant ($p<0.05$), which is suited to the random slope in Level 2 of the random effect parameters. Moreover, the standard deviation of random slopes of Speed limit is more than twice its standard error in both models, suggesting significant variation within Level 2. As seen in Table 14, there is no random intercept for all of the models. This is because the random intercept affects the whole model, making it statistically non-significant ($p>0.1$). Omitting the random intercept results in a simplified random-slope model, which has the variance σ^2_{u0} (*Traffic volume* and *Speed limit* category share identical variance) and gives identical log likelihood. This simplified model implies that different *speed limits* have different effects on the outcome of traffic conflict for different *traffic volume* categories.

To estimate the proportion of overall residual variability that is associated with each level, Eqn. 5 and Eqn. 6 from the method section are used, and the results are shown in Table 15. Model 1 shows that, without any fixed parameters, 83% of the variations come from Level 1, but this is reduced once the fixed parameters are introduced, as seen in Models 2 and 3. Model 3 shows less variation (71%) in Level 1 (motorcyclists' attributes and behavior) compared to Model 2 (74%), because Model 3 has more fixed effects parameters of the motorcyclists' attributes and behavior (Manner of entry and MC stopping behavior) compared to Model 1, which has fixed effect parameters of Manner of entry and Lane width category instead. As for Level 2, the varying traffic volume and speed limit in a road system only contribute 26% to 29% of the variations in traffic conflict outcome. From another perspective, the level of variation at Level 1 is still very high compared to Level 2, which suggests that unmeasured, or undescribed attributes or behavior of motorcyclists are still an important influence in predicting the outcome of a traffic conflict.

Table 15: Intra-unit correlation (ICC) for each model.

Intra-unit correlation	Model 1	Model 2	Model 3
ICC Level 1, ρ_1	0.838	0.741	0.710
ICC Level 2, ρ_2	0.162	0.259	0.290

The findings show that the outcome of motorcyclists being involved in a serious traffic conflict is influenced by their manner of entry into the primary road from the access point, their stopping behavior and the lane width of the primary road. A discussion of the possible reasons for the results is presented in the next section.

7. Discussion

This study establishes an important ground for further research on motorcyclists' road safety related problems in Malaysia, one of which is: motorcycle accident fatalities are prone to occur along straight road sections of primary roads in the rural areas. Although there are other salient problems, which are thoroughly discussed in Paper 1, the focus is narrowed down to area type, road type and road geometry since at this stage they can be most amenable to treatment by physical engineering measures.

First and foremost, this thesis uses fatality data, since Malaysian road accidents statistics suffer from disproportional underreporting of severe and slight injuries when compared to Swedish road accident statistics (Paper 1): up to 600 % for severe injuries, and up to 1400% for slight injuries. Moreover, fatality data is found to be more accurate and consistent than injury data in the police records (Rosman and Knuiman, 1994). Due to underreporting, official police reports of road accident statistics are incomplete, inaccurate and biased (ETSC, 2007). Studies have shown that many more injured motorcyclists are identified through hospital databases than through police crash databases (Haworth, 2003). Moreover, police records of people injured in traffic and admitted to hospital are not representative with regard to the mode of transport and the age of the victims (Maas and Harris, 1984).

The fact that motorcycle fatalities are more frequent in rural areas may be due to higher speeds, made possible by lower traffic volumes and less traffic control (Broughton et al., 2009; Silva, 1978). In rural areas, the absence of rescue services or their late arrival at the scene of accidents may also contribute to fatality (Pang et al., 1999; Silva, 1978). Moreover, helmet compliance is reportedly low in Malaysian rural areas (Ambak et al., 2011; Kulanthayan et al., 2001) due to the lack of enforcement and road safety awareness (MIROS, 2008). Besides, a high motorcycle share of traffic is typical in rural areas in Malaysia, comprising 25% to 55% of total traffic (Hsu et al., 2003).

Primary roads in Malaysia have the highest number of motorcycle fatalities, which may be due to the fact that they are risky for motorcyclists as they are partially access controlled, mostly non-segregated or single carriageway (PWD, 2009), with intrinsically dangerous features such as trees, open culverts, access points to rural houses and sharp road barriers (Hsu et al., 2003; Jama et al., 2011; Tung et al., 2008). These explanations are, however, assumptions made due to the lack of studies on factors that are associated with crashes and relate to primary road features, e.g. presence of access points, curves, built-up areas, etc.; in other words, factors that could affect motorcycle accident fatalities. Previous studies in Malaysia have confirmed that fatal motorcycle crashes are likely to occur on straight road sections (Jaafar et al., 2003; Pang et al., 2000), which may encourage speeding (Várhelyi, 1996).

Hence, by regressing primary road attributes via a negative binomial model, a Safety Performance Function (SPF) is developed to predict motorcycle accident fatality and to identify the associated road attributes. The estimates for the best-fitted model indicate that an increase of access points per kilometer and average traffic volume of motorcycles are highly associated with an increase in motorcycle fatal accidents per kilometer. The significance of having 'access per kilometer' in the models is that it is vital in complementing the real scenario of motorcycle fatalities on Malaysian primary roads. According to Elvik and Vaa (2004), the number of access points has a major impact on accident rates. Paper 1 has shown that the most typical type of fatal crash for Malaysian motorcyclists is the crossing course type collision (28%), i.e. side or perpendicular angle crash, with vehicles entering a primary road from an access point and thus infringing upon the right-of-way (ROW) of the motorcyclist (Pai, 2011; Radin Umar, 2005). This violation of the motorcyclist's ROW could lead to collision with the side of the car (Pai, 2009; Radin Umar, 1999, 2005); this type of accident, occurring mostly at access points, is known to be the most hazardous crash pattern for motorcyclists, i.e. with stop-/yield-controlled junctions (Pai, 2009). A study by Ackaah and Salifu (2011), which uses a similar approach to our study, also acknowledges the importance of having 'number of access points' as one of the variables in predicting the number of crashes. Therefore, the fact that this variable is regarded as one of the major contributory factors to motorcycle fatalities is certainly justified, and an increase in the number of access points per kilometer will increase the number of motorcycle fatalities. In other words, having more access roads protruding into the primary road will increase the risk of motorcycles facing vehicles entering from the access road.

In the development of the SPF for motorcycles, there are some limitations, which have thwarted attempts to work efficiently and accurately on some occasions. First, the data collected from the police is not 100% accurate in terms of pinpointing the exact location of the fatal accidents. Most of the accident data in the police database has a route number identifying district and state; nonetheless, some fail to give the correct route number or assign it to a different district. This data, which is up to 5% of the total, is excluded from the analyses. Moreover, we may assume that some unobserved heterogeneities exist in our motorcycle accident fatality data, i.e. different fatal collision types (single-motorcycle and multi-vehicle accidents), different attributes and behavior of motorcyclists, etc. Attempts have been made to limit the heterogeneities in the data, such as identifying the exact collision type, but there are too many discrepancies in the police recording system for us to successfully identify and separate these fatal collision types. For example, according to the police, they sometimes record a single motorcycle accident as 'not at fault', 'crashed out of the road', 'victim of hit and run', and most of the time they leave the collision type section empty. Hence, in order to determine the exact motorcycle collision type, we have had to look at the free text in the accident record form, much of which, unfortunately, is illegible. Second, the maps provided by the government agency, i.e. the Malaysian Highway Planning Unit, Public Works Department, are not wholly accurate and complete in terms of providing the geometric properties of the roads. Therefore, we have had to opt for an alternative solution, such as relying on Google Earth and local street maps (private source). Consequently, we have not been able to obtain several vital variables such as speed limits and road vertical profiles. This study reflects our realization that Malaysia is in grave need of a proper system that stores and categorizes all information pertaining to traffic censuses and current road geometry of all primary roads in Malaysia, i.e. Malaysian Federal government owned roads.

An observational study is needed in order to gain more insight into the actual road traffic situation and the course of events at access points on primary roads in Malaysia. The association of the speed factor with motorcycle accident fatalities along primary roads cannot be extracted from the police records, as seen in Paper 1; nor can we sample it from external sources such as maps or government documents, as seen in Paper 2. However, through observational studies (Paper 3) of the primary road, speed analysis has been accomplished and the results are somewhat expected. Motorcyclists are shown to have a lower speed when approaching the access point, which is more apparent when other road users are on it. This finding is in contrast to a study by Walton and Buchanan (2012), who find that motorcycles are not influenced by the appearance of a vehicle at an urban T-junction. However, in line with their findings, our observations (based on motorcycle brake lights) have also shown that, in a high traffic volume situation, the percentage of motorcyclists that do not slow down while approaching the access point is higher on the near side of the access approach, especially when they are riding close to the shoulder. When a high number of motorcyclists do not slow down, especially when near the shoulder and approaching the access point, they may have to brake abruptly or swerve away from the protruding part of the vehicle waiting to enter the primary road. This shows that, while a road shoulder may be considered as a safe haven for motorcyclists, the feeling that they are safer somehow makes them less cautious (i.e. they do not slow down) when approaching the access point with a vehicle attempting to enter the primary road. This is an example of risk compensation (Elvik et al., 2009), which claims that people make adjustments of their behavior according to the level of risk or danger, and that they, most of the time, perceive these dangers to be less (i.e. when riding near or on the road shoulder), and tend to be bolder (i.e. do not slow down when there is a vehicle waiting on the access approach).

Some motorcyclists have the tendency to violate the speed limit more when passing access points along a stretch where the speed limit is lower. This may be due to that fact that motorcyclists can retain a certain speed due to their ability to weave around slow moving traffic which is complying with the speed limit (Lee et al., 2012). Furthermore, despite moving in the same traffic flow, motorcyclists are in comparatively freer and 'less congested' driving conditions than car drivers in the same traffic flow (Lee et al., 2012), and motorcyclists themselves have admitted that they are more likely to speed when overtaking (Broughton et al., 2009).

The observation study shows that motorcyclists have a 66% to 74% compliance rate of helmet and headlight usage. However, female motorcyclists have a lower rate of helmet usage compared to men. This situation is more prevalent in the rural areas where housewives or single female parents, usually aged 31 to 70, often wear 'Hijab' and commute along primary roads during the day. Their activities are varied, ranging from running small businesses to fetching their children. Thus, it is not surprising that, when not wearing helmets, female fatalities are higher than male fatalities (Paper 1).

Observing the movement of motorcyclists along the primary road, it is seen that they ride equally in the middle of the lane and near the shoulder regardless of the traffic volume. Female riders are more inclined to ride close to the shoulder compared to male riders. This comes back to the 'nature' of motorcycles, which manage to weave (Hussain et al., 2011) and move freely in tight spaces between vehicles (Lee et al., 2012). Consequently, motorcycles are highly exposed to various types of collisions, e.g. sideswipe and rear-end collision, especially on straight road stretches (Paper 1). This also shows that until primary roads in Malaysia separate motorcyclists from other vehicles, motorcyclists' riding patterns will remain the status quo and continue being subject to high risk of accidents. On the same aspect, we may assume that riding near the shoulder is safer as it is away from the main traffic. Thus, riding near the shoulder may indicate female motorcyclists' cautiousness.

This study is the first to detect a hazardous right turning movement, i.e. the Opposite Indirect Right Turn, apart from other typical entry movements (see Figure 11). This particular movement has never been documented in Malaysia or in Asia, although motorcyclists on a high traffic volume road often practice it. Despite the obvious impending risk of head-on collision with other vehicles on the primary road, the

Opposite Indirect Right Turn produces a relatively low rate of serious conflicts. This might be an indication of more cautiousness on the part of motorcyclists, knowing that they are breaking the rules and taking a huge risk in going in the opposite direction to oncoming traffic. Motorcyclists are probably motivated to execute this maneuver by high traffic volumes and limited gaps for entering. Moreover, they find this kind of maneuver easier because of the small size of their vehicles.

The head movement of motorcyclists when entering from an access point is basically to avoid detection failures. Much of the research has focused on manipulating the physical characteristics of motorcycles and motorcyclists in order to improve motorcycle conspicuity (Crundall et al., 2012; Pai, 2011; Radin Umar, 2005; Williams and Hoffman, 1979). Regardless, motorcyclists may also fail to detect other road users moving on the primary road due to their selective head movement direction. The findings show that motorcyclists turn their heads more in the opposite direction to their turning movement. For example, when making a left turn, they usually turn their head only to the right to scan for incoming traffic on the primary road. This might happen because, as they enter the primary road, they will face the oncoming traffic without turning their heads. Of those motorcyclists who perform the Opposite Indirect Right Turn, more are seen either not turning their heads at all or turning them only to the left as they enter the primary road. This is most probably because these motorcyclists rely on their side mirrors when making this particular movement into the primary road. As a consequence of this selective head movement, the motorcyclists may not notice vehicles coming from the other side.

Results from the observation of motorcyclists' stopping behavior and manner of entering the primary road show that motorcyclists in general do not comply with the stop line rule as they enter the primary road, especially those making left and the Opposite Indirect Right Turns. They may be hesitant to make a full stop due to the need to put a foot down to steady the motorcycle. If the opportunity of a perceived acceptable gap between vehicles on the main road appears, they would not hesitate to enter without stopping. When entering the primary road from the access point, the majority (57% to 59%) of motorcyclists accept longer gaps when making a right turn, but 29% to 31% of them still enter the primary road before an approaching vehicle, resulting in a short time lag ($t_L < 4$ seconds). These findings show that, although motorcyclists generally do not stop at the stop line, the majority of them still opt for a longer gap when entering. Thus, motorcyclists may use the Opposite Indirect Right Turn as a way of entering without stopping, but still choose a long gap while travelling in the opposite direction and waiting for a suitable gap between vehicles.

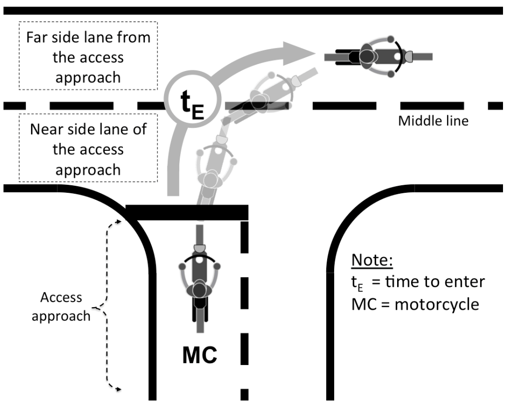
The method for observing risky situations applied in this study, i.e. The Swedish Traffic Conflict Technique, is well established, validated and reliable. It is one of the most commonly used techniques for safety research purposes, and is recognized in many countries all over the world (Archer, 2001). Questions concerning reliability are related to the subjective element in the registration process where trained observers judge speed and distance (Archer, 2001). Moreover, tests have shown rates of up to 80 per cent agreement among different observers (Archer, 2001). According to Svensson (1998), trained human observers are able to detect serious conflicts and make satisfactory estimates of the speed and TA value. In this study, one observer (the author) has made all the observations.

Out of the 537 interactions recorded between vehicles entering from the access point and those passing along the primary road, 56 are serious traffic conflicts. Of these 56 serious conflicts, 64% are between a motorcyclist from the access point and a motorist on the primary road. The observations have shown that there are instances of motorcyclists being involved in serious conflicts when approaching a vehicle entering from the access point. This is in line with findings of previous studies on gap-acceptance and time-to-arrival showing that the most common cause of motorcycle–automobile gap acceptance accidents is motorist's infringing upon motorcycle's right of way (Harnen et al., 2003; Pai, 2011; Pai et al., 2009; Radin Umar, 2005; Thomson, 1980). However, our observations also show that the rate of serious conflicts for motorcyclists who enter the primary road is as high as for other vehicles entering the primary road. In other words, motorcyclists may also be more likely to infringe the right of way of other vehicles, which is in contrast to claims by previous studies that other vehicles entering a primary road infringe the right of way of motorcyclists on the primary road.

A further analysis, using mixed-effects logistic regression, shows the factors that influence the occurrence of serious traffic conflicts when motorcyclists enter the primary road from the access point. Using random parameters to handle the unobserved heterogeneity, this study has constructed 2 statistically significant multilevel logistic regression models, which have 2 levels of random effect parameters, i.e. motorcyclists' attributes and behavior at Level 1, and Traffic volume category at Level 2. Both models have one common statistically significant fixed effect parameter, which is MC manner of entry, and each of them has another significant fixed effect parameter, which is Lane width category for Model 2 and MC stopping behavior for Model 3. As for the random effect parameters at Level 2, both models have a simplified random slope model, i.e. Speed limit, which implies that different speed limits have different effects on different levels of traffic volume, which in turn affect the outcome of a traffic conflict.

The mixed effects logistic regression model reveals that motorcyclists who stop at the stop line are 2 times more likely to be involved in a serious conflict with a vehicle on the primary road, compared to those who do not stop at the stop line. This contradicts previous findings, which suggest that infringing of motorcyclists' right-of-way accidents are caused by the failure of motorists to stop or yield when entering the main road from the access point (Pai et al., 2009; Preusser et al., 1995). Thus, to explore this contradiction, further analysis has been done to find out whether the time taken for motorcyclists to enter the primary road, i.e. time to enter (t_E), differs between those who stop at the stop line and those who proceed without stopping (see Table 16). The result shows that motorcyclists who stop at the stop line take, on average, a longer time (3.48s) to enter the far side lane from the access point approach, compared to those who do not stop at the stop line (2.28s) ($p<0.05$). Furthermore, 15% of the motorcyclists take longer than 4 seconds to enter the far side lane from the access approach when they stop at the stop line. This obviously shows that motorcyclists may have difficulties entering the lane quickly when they stop at the stop line, possibly due to the motorcycle's low acceleration capacity, implying that motorcyclists may need more time to accelerate after they stop at the stop line. Motorcyclists who pass the stop line without stopping are able to achieve higher acceleration when maintaining their speed before reaching the stop line. Hence, this may be one of the reasons for motorcyclists being reluctant to stop and choosing to make the Opposite Indirect Right Turn to enter the primary road. This phenomenon needs to be studied in greater detail.

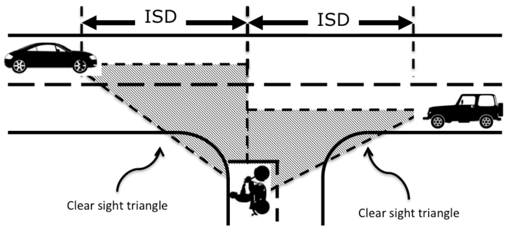
Table 16: Time to enter (t_E, sec) the flow of the primary road by motorcyclist



	Scenario 1: Motorcyclist stops at the stop line (n=100)	Scenario 2: Motorcyclist does not stop at the stop line (n=100)
Mean	3.48 s	2.28 s
Stand Dev.	1.01 s	0.90 s
Variance	1.02	0.81
85th Percentile	4 s	3 s
CI lower 95	3.28 s	2.10 s
CI upper 95	3.68 s	2.46 s
t-test (p-value)	0.000	

The possible effects of inadequate intersection sight distance (ISD), or the 'clear sight triangle' (AASHTO, 2011), for each access point have also been taken into consideration during observation of the motorcyclists' stopping or not stopping at the stop line. The clear sight triangle of each access point varies from one site to another, and it is inadequate especially in commercial and some rural areas (due to food stalls, lamp poles, signage, etc.). However, in the same scenario, and when there are vehicles passing along the primary road, the total number of those who do not stop at the stop line at the access points (see Table 17), with or without adequate ISD, does not statistically significantly differ from the number of those who stopped at the stop line with or without adequate ISD ($p>0.1$). Thus, we can conclude that motorcyclists' stopping behavior at the access point may not be affected by the adequacy of the access point sight distance.

Table 17: Motorcyclists' stopping and not stopping at the stop line related to the access point sight distance in a scenario with vehicles passing along the primary road.



	Intersection sight distance (ISD)	Number of MCs who did not stop at stop line	Number of MCs who stopped at stop line
Sites: 1,3,4 & 8	Adequate	72 Δ	81 Δ
Sites: 2,5,6 & 7	Inadequate	101 Δ	102 Δ

MCs - Motorcyclists
Minimum ISD for 70kph = 150m, 80kph = 170 and 90kph = 190.
Δ No statistically significant difference according to Chi-sq. test ($p \geq 0.1$) in comparison of the total number of motorcyclists who stopped and did not stop at the stop line considering access point ISD adequacy.

This study suggests that motorcyclists would be safer if they entered the primary road by accepting a longer gap ($t_G > 4$ seconds), compared to entering before an approaching vehicle and resulting in a short time lag ($t_L < 4$ seconds). However, as shown in Table 16, motorcyclists who stop at the stop line, and take a longer time to enter the primary road, may find themselves with a shorter lag ($t_L < 4$ seconds) in front of an approaching vehicle even when their intention is to enter well before it. This also shows that motorcyclists may require a longer gap acceptance in order to safely enter the primary road. Thus, further study may be required to determine the safe acceptable gap for low powered motorcycles, most of which are under 125 c.c. in the majority of Asian countries.

The mixed effects logistic regression model also shows that the likelihood of motorcyclists being involved in a serious traffic conflict is much less if they enter a wide road compared to a narrow lane road. This is probably due to the fact that, in a narrow lane road, the limited space is occupied by motorcyclists and bigger vehicles, and thus motorcyclists' space is likely to be infringed. Studies have shown that increasing lane width within the range permitted by design standards seems to reduce the number of accidents in urban areas (Abdel-Aty and Radwan, 2000; Elvik et al., 2009).

Obtaining a satisfactory number of serious traffic conflicts for statistical analyses has proved to be one of the limitations of this study. To observe and detect one serious conflict requires time, patience and resources. As described by Svensson and Hyden (2006), traffic conflict occurrence may prove to be problematic in analyses due to the low occurrence rate and focus on rather exceptional events. As a consequence of this, there has to be reliance on a small data sample, which has forced this study to adopt the use of a bootstrap resampling procedure. This, in turn, has required an exorbitant amount of time for computation, as the procedure relies heavily on the processing power of a computer.

Despite the limitations, this thesis has shown the importance of identifying motorcyclists' attributes and behavior, as well as road environment attributes, in order to understand the road safety situation of motorcyclists on Malaysian primary roads.

8. Future research

This thesis opens up for a vast amount of possible research relating to motorcycle safety. Some recommendations are:

1. Further study on the speed distribution of motorcycles on Malaysian expressways, secondary roads and local streets. This is because the motorcycle fatal accident rate (MC Fatal / 100km) on expressways is 7.4, second only to primary roads, while secondary roads and local streets account for 17% to 19% of the total motorcycle accident fatalities. Obtaining the distribution of speeds on these road types may shed some light on the occurrence of speeding, which is a known contributory factor to fatal accidents (Elvik et al., 2009).
2. The study of fatal single motorcycle accidents on primary roads, because this type of fatal accident constitutes up to 25% of the total motorcycle accident fatalities (Paper 1).
3. The study of the socioeconomics of motorcyclists involved in accidents. One of the unobserved attributes of motorcyclists involved in a serious traffic conflict or accident is their socioeconomics. It would be interesting to see the association of involvement in an accident with various socioeconomic factors such as the riders' income, family size, education, occupation, etc. Such a study may require extensive qualitative research.
4. The study of the Opposite-Indirect-Right-Turn (OIRT) by motorcyclists. Since OIRT is glaringly being used in a high traffic volume situation, it should be explored further in terms of investigating the riders' intention or the presence of social or environmental pressure (peer pressure, no gap for crossing, etc.).
5. Further study of accidents on straight road sections with respect to geometry attributes such as road width, shoulder width, median width and vertical sight distance. This is justified because straight road sections are associated with 66% of the total motorcycle fatal accidents (Paper 1) and narrow lane roads are riskier than wider lane roads for motorcyclists (Paper 4). The use of surrogate measures for accidents, e.g. speed and traffic conflict, as the outcome may help to find associations between risky behavior and road geometry factors.

9. Thesis contribution

This study stresses the importance of improving the Malaysian accident recording system. Establishing an injury recording system, and a database with hospital records to complement police records, could decrease the extent of underreporting and improve the reliability of crash data. Moreover, comprehensive traffic volume counts must be conducted on all road types in Malaysia in order to further analyze road user exposure and compare fatality risks on different road types.

The studies carried out in this thesis are the first of their kind in Malaysia and probably in Asia, in terms of the methods used and the results. The general analysis in Paper 1 has established some new findings, such as motorcycle accident fatalities associated with road attributes, gender aspects and weather factors. The study in Paper 2 is unique and the first in terms of developing Safety Performance Functions (SPF) for motorcyclists. As for Paper 3, it is probably the first attempt to study motorcyclists' behavior via quantitative observations at access points. The method used can be easily emulated by other researchers in Asian countries that face problems similar to those in Malaysia. This study also uncovers a peculiar entering maneuver executed mostly by motorcyclists, i.e. the Opposite Indirect Right Turn (OIRT), which is perceived as a hazardous maneuver, but the rate of the serious conflict it produces shows it is otherwise. Finally, Paper 4, which is also the key in closing the research loop for this thesis, has shown that the likelihood of motorcyclists being involved in a serious traffic conflict is influenced by their manner of entry into the primary road from the access point, their stopping behavior and the lane width of the primary road.

The finding that motorcyclists who stop at the stop line are more at risk of being involved in a serious traffic conflict, compared to those who do not stop, should be taken cautiously. This study does not intend to dispute any previous findings nor encourage motorcyclists to break the stop line rule, but this finding surely means that further research needs to be carried out in order to understand this situation better. Moreover, this finding is fairly new, and it seems to be special for developing Asian countries where traffic mostly comprises low-capacity motorcycles.

This study will benefit researchers and practitioners, engineers and decision makers on the subject of improving motorcycle safety not only in Malaysia but also in other countries that face similar situations. The SPF for motorcycle fatalities enables us to predict the expected motorcycle fatalities on certain Malaysian primary roads by just identifying the ADT of motorcycles and the number of access or minor junction points per kilometer. Thus, empirically speaking, reducing the number of access points would reduce the number of motorcycle accident fatalities. Hence, engineers or decision makers can make elaborate plans to test countermeasures at access points, e.g., by building more service roads that can combine several access points into one.

This study has also shown the importance of identifying motorcyclists' attributes and behavior, as well as road environment attributes, in order to predict traffic conflict or accident outcomes in Malaysia. To reduce the number of serious traffic conflicts (which are directly correlated with accidents of the same type), road safety measures to upgrade hazardous access points, e.g. equipping them with a channelizing island, should be carried out. The use of a channelizing island, i.e. median opening, provides improved path guidance for right turners, narrowed conflict areas, controlled vehicle movements and a refuge area (AASHTO 2011). Moreover, by utilizing the channelizing island as a refuge, right-turning motorcyclists would merge into the primary road quicker and probably with a longer gap. Widening the lane of the primary roads at hazardous access points would be another alternative. However, these countermeasures should be evaluated before their wide implementation.

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