UNIVERSITI PUTRA MALAYSIA

EFFECTS OF MOTORCYCLE LANE GEOMETRY ON SPEED VARIATION USING GPS-BASED NATURALISTIC MOTORCYCLE RIDING

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By

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Chairman : Associate Professor Hussain bin Hamid, PhD
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Exclusive motorcycle lane is a facility that can completely segregate a motorcyclist from the traffic mix to reduce the risk of collision with other motorists. In Malaysia, the introduction of an exclusive motorcycle lane along the Federal Highway Route 2 (F02) in the state of Selangor has been proven to reduce the number of motorcycle crashes along the route significantly. However, despite its proven success in reducing the number of crashes, previous studies have indicated that the initial construction of the lane was lacking motorcycle-specific design standards. In addition, review of the available literature yields a limited answer on the level of safety of exclusive motorcycle lanes especially on the impact of lane geometry and speed variation. On the other hand, there were reports of an increase in numbers of motorcycle crashes on the lanes, including run-off-road crashes and crashes involving fixed roadside objects.

This study used a dataset generated by modified 100 cc motorcycles installed with Global Positioning System (GPS) unit and other devices to determine the effects of geometric designs of an exclusive motorcycle lane on speed variation and overall riding behaviors of motorcyclists riding on the lane. Twenty-nine participants rode the instrumented motorcycles on a 20 km predefined sections of the exclusive motorcycle lane along the Federal Highway Route 2 (F02). The speed profiles collected in this study indicated a high overall distribution of speeds on tangential sections of the exclusive motorcycle lane. Participants were also found to frequently change their operating speeds either by sudden (i.e., braking) and gradual deceleration or acceleration. The most frequent speed changes occurred when participants traveled from tangent to horizontal left curves. It was also found that participants could hardly achieve their cruising speeds and were

not able to maintain them over a long period due to frequent changes in road alignment.

This study found a wide variance of speeds across different horizontal curves with some extreme cases of speed reduction in certain individual curves, suggesting low operating speed uniformity. The results also show that cross-section elements including lane width and length of preceding tangents, roadside elements including guardrails, curb and grass, had significant effects on speed variation during tangent to horizontal curve transitions.

Overall, the findings of this study highlighted the risk of a crash due to high approach speeds and large speed reduction, especially during frequent transitions between tangential sections and horizontal curves. The findings also underlined the need for better understanding of riding behaviors and road design factors that can contribute to the risk of crashes. The GPS-based naturalistic data collection methodology used in this study has paved the way for better understanding of motorcyclists' riding behaviors on exclusive motorcycle lanes. The results can be used as a baseline and reference for speed management and ultimately for identification and treatment of design inconsistency on exclusive motorcycle lanes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

KAJIAN KESAN GEOMETRI LORONG MOTOSIKAL KE ATAS PERBEZAAN HALAJU MENGGUNAKAN KAEDAH PENUNGGANGAN MOTOSIKAL SECARA NATURALISTIK BERASASKAN GPS

Oleh

MOHD KHAIRUL ALHAPIZ BIN IBRAHIM

April 2017

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Lorong motosikal eksklusif adalah sejenis infrastruktur khusus yang boleh mengasingkan penunggang motosikal daripada aliran trafik untuk mengurangkan risiko kemalangan dengan pengguna jalan raya yang lain. Di Malaysia, pembukaan lorong motosikal eksklusif di sepanjang Lebuhraya Persekutuan Laluan 2 (F02) di negeri Selangor telah terbukti berjaya mengurangkan bilangan kemalangan motosikal secara signifikan di sepanjang laluan tersebut. Walaupun telah terbukti berjaya mengurangkan bilangan kemalangan, kajian terdahulu telah mendedahkan bahawa pembinaan lorong ini pada awalnya tidak menggunakan piawaian reka bentuk yang khusus untuk penunggang motosikal. Selain itu, sorotan kajian terdahulu memberikan jawapan yang agak terhad berhubung tahap keselamatan lorong motosikal eksklusif terutamanya berkaitan impak rekabentuk geometri dan kelainan halaju. Sebaliknya, terdapat kajian yang melaporkan peningkatan jumlah kemalangan motosikal di laluan tersebut, termasuk kemalangan yang melibatkan penunggang motosikal terbabas sendiri dan kemalangan yang melibatkan perlanggaran dengan struktur dan objek di bahu jalan.

Kajian ini menggunakan set data yang dihasilkan oleh motosikal berkuasa enjin 100 cc yang telah diubahsuai dan dipasang dengan peranti Sistem Kedudukan Global (GPS) dan alatan lain untuk menentukan kesan reka bentuk geometri lorong motosikal eksklusif ke atas halaju pengendalian dan tingkah laku keseluruhan penunggang motosikal yang menggunakan fasiliti tersebut. Dua puluh sembilan peserta menunggang motosikal teralat di laluan tertentu sejauh 20 km sepanjang lorong motosikal eksklusif di Lebuhraya Persekutuan Laluan 2 (F02). Profil halaju yang dikumpulkan dalam kajian ini menunjukkan kadar

kelajuan keseluruhan yang tinggi di sepanjang tangen lorong tersebut. Peserta juga didapati kerap mengubah kelajuan motosikal sama ada melalui nyahpecutan dengan secara tiba-tiba (menggunakan brek) dan beransur-ansur atau melalui pecutan. Perubahan halaju motosikal paling kerap berlaku apabila peserta menunggang dari tangen ke lengkung kiri mendatar. Peserta juga didapati tidak dapat mencapai kelajuan maksimum atau tidak mampu untuk mengekalkan kelajuan tersebut untuk tempoh masa yang panjang kerana perubahan yang kerap dalam penjajaran jalan.

Hasil kajian ini mendapati terdapat perbezaan kadar perubahan halaju yang ketara di lengkung-lengkung mendatar si sepanjang laluan. Dapatan ini memberi petunjuk bahawa keseragaman kelajuan pengendalian motosikal di laluan tersebut adalah rendah. Hasil kajian juga menunjukkan bahawa elemen-elemen keratan rentas seperti lebar lorong dan panjang tangen, objek di tepi jalan seperti penyangga jalan, susur jalan dan rumput, mempunyai kesan yang signifikan ke atas perubahan halaju dari tangen ke lengkung mendatar.

Secara keseluruhan, dapatan kajian ini mengetengahkan risiko kemalangan yang berpunca daripada kelajuan yang tinggi dan kadar pengurangan kelajuan yang besar, terutamanya ketika peralihan dari tangen ke lengkung mendatar. Dapatan kajian ini turut menekankan kepentingan untuk memahami tabiat penunggangan dan faktor rekabentuk jalan yang boleh menyumbang kepada kemalangan. Metodologi pengumpulan data penunggangan motosikal secara naturalistik berasaskan GPS yang digunakan dalam kajian ini telah membuka jalan untuk lebih memahami tingkah laku penunggang motosikal di lorong motosikal eksklusif. Dapatan kajian ini boleh dijadikan sebagai asas dan rujukan untuk pengurusan halaju dan seterusnya untuk pengenalpastian dan penambahbaikan reka bentuk lorong motosikal eksklusif.

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I certify that a Thesis Examination Committee has met on 21 April 2017 to conduct the final examination of Mohd Khairul Alhapiz Ibrahim on his thesis entitled “Effects of Motorcycle Lane Geometry on Speed Variation Using GPS-Based Naturalistic Motorcycle Riding” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science in Highway and Transportation Engineering.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACEM	Association des Constructeurs Européens de Motocycle (The Motorcycle Industry in Europe)
DAQ	Data Acquisition System
ECMT	European Conference of Ministers of Transport
GB	Gigabyte
GPS	Global Positioning System
GRSP	Global Road Safety Partnership
PRT	Perception Response Time
RMP	Royal Malaysia Police
TTLC	Time to Lane Crossing
TDH	Task Difficulty Homeostasis

CHAPTER 1

INTRODUCTION

1.1 Background

Twenty-two years ago, Radin Umar, Mackay and Hills (1995b) estimated that motorcyclists' relative risk of being killed in traffic crashes on Malaysian roads was 17 times greater than that of car drivers. The relative risk of being seriously injured was estimated to be 24 times greater. As of 2015, there are more than 11 million registered motorcycles in Malaysia (Ministry of Transport Malaysia, 2015) while the number of fatalities involving motorcyclists has consistently been more than 50% of the total annual road fatalities in the past decade (Royal Malaysia Police [RMP], 2015). In addition, the number of annual road-related injuries among motorcyclists in Malaysia was at least 70% of the total annual road-related injuries within the said period.

Besides the lack of physical protection in the event of a collision with other vehicles (Radin Umar et al., 1995b), motorcyclists in Malaysia typically ride in a mixed traffic environment which is unsafe due to problems of speed differentials and high risk of collision with heavy vehicle (Pang et al., 1999). Thus, a complete segregation of motorcyclists from the fast-moving traffic would theoretically eliminate the speed differentials and traffic conflicts between motorcycles and faster vehicles. The positive impact of complete segregation of motorcyclists from the main traffic was once proven by Radin Umar, Mackay and Hills (1995a). The researchers investigated the impact of the construction of exclusive motorcycle lane along Federal Route 2 in Shah Alam and found a significant reduction (34%) in the number of motorcycle crashes along the route.

The provision of exclusive motorcycle lanes is one of the road engineering initiatives to reduce the number of motorcycle crashes in Malaysia. Other initiatives include paved shoulders and non-exclusive motorcycle lane (Abdul Manan & Várhelyi, 2012; Radin Umar, 2006). In addition to significant reduction in the numbers of motorcycle crashes and fatalities as its direct impact, the construction of exclusive motorcycle lanes was also found to be very cost effective (Radin Umar, 2006). The provision of both exclusive and non-exclusive lanes for motorcycles has enjoyed a strong support from the Malaysian government through funds for new motorcycle lanes (Prime Minister's Office, 2005; Radin Umar, 2006) and policy to provide motorcycle path for new highways and primary roads (Hussain, Radin Umar, Ahmad Farhan, & Dadang, 2005). These initiatives and willingness to invest shown by the government are commendable and fitting considering the fact that around 53% of motorcycle

fatality in Malaysia occurred along primary roads and expressway (Abdul Manan & Várhelyi, 2012).

1.2 Problem Statement

In light of recent statistics on motorcycle casualties on Malaysian roads and findings on the effectiveness of exclusive motorcycle lane in reducing the number of crashes, the construction and sustainability of exclusive motorcycle lanes should obviously be self-evident. However, review of previous studies pointed to one major concern that could affect not only the sustainability of the exclusive motorcycle lane but also the safety of the motorcyclists who use the facility; the very purpose of its construction. The major concern is the absence of motorcycle-specific design standards to determine the design elements of an exclusive motorcycle lane and to assess the design criteria of the facility (Hussain et al., 2011, 2005; Law and Radin Umar, 2005; Tung et al., 2008). In fact, the design elements recommended by the oldest available guidelines (Public Works Department, 1986a, 1986b) were reported as to be a cross-reference between the design standards of a road and a bicycle track (Hussain et al., 2005), thus indicating that the design vehicle used during the initial construction of exclusive motorcycle lane was not a motorcycle itself.

Selecting appropriate design vehicles during a highway design process is important because the physical characteristics, proportions, and sizing of the vehicles are the key controls in geometric highway design (American Association of State Highway and Transportation Officials [AASHTO], 2011). For instance, a truly representative dimension of a motorcycle is required to determine the space requirement and speed-flow-density relationships on the lane (Hussain et al., 2011, 2005). Hussain et al. (2011, 2005) substantiate the pressing need to look into the motorcycle traffic operations on the present exclusive motorcycle lane and establish the characteristics of the key components of a motorcycle-traffic system. Further, it is of greater importance and most fitting to have a typical motorcycle model used in Malaysia as the design vehicle in the design of an uninterrupted motorcycle path. An absence of a representative design vehicle could have a significant impact on the quality of geometric design and safety on the motorcycle lane.

Geometric design has a strong influence on the level of safety on a roadway. A poor geometric design is recognized as a typical form of road environment factors that produce a road crash (Wright & Dixon, 2004). Fitzpatrick, Carlson, Brewer, Wooldridge and Miaou (2003) define geometric design as the selection of road elements for the horizontal alignment, vertical alignment, cross-section, and roadside of a highway or facility. Apart from the suitable level of mobility and appropriate land use access, Fitzpatrick et al. (2003) list high degree of safety and consistency along different alignments as the characteristics of a good

geometric design. Further, the researchers clarify that consistency means there is no sudden and unexpected change in the alignment. In other words, the design conforms to drivers' expectation, thus reduces the likelihood of driver errors and crashes.

A facility constructed exclusively for motorcyclists along a major route that connects a number of highly populated cities is supposed to serve the function of the major routes, which means motorcyclists are very likely to choose higher operating speeds on the facility. However, the use of 60 km/h design speed is recommended in the available design guideline, with lower speed suggested when there are physical constraints (Public Works Department, 1986a). Considering the fact that motorcycle was not selected as the design vehicle during the initial design stage (Hussain et al., 2005; Public Works Department, 1986a), there is a possibility that the motorcyclists are facing alignment features that are not according to their expectations and thus affecting their desired speeds and compromising their safety.

An exhaustive literature search resulted in a limited number of studies that investigate the impact of geometric design and other factors on the operating speed on exclusive motorcycle lane in Malaysia. This gap of knowledge and the need to determine the level of safety on the present exclusive motorcycle lane are substantiated by the findings of previous studies. One of the earliest studies that look into motorcycle crashes on the exclusive motorcycle lane was conducted by Radin Umar (1996). The researcher reported that for both eastbound and westbound track, the types of reported crashes were mainly side-swipe collisions, followed by run-off-road single motorcycle crashes, which could point to unsuitable speed for the prevailing road and traffic conditions. Another study by Tung et al. (2008) reported that motorcycle crashes were happening on the lane, of which, an overwhelming 64.6% were run-off-road crashes and crashes involving fixed roadside objects. Earlier in 2007, Ibitoye, Radin Umar and Hamouda (2007) reported the risk of severe injury on the lane due to unsafe guardrails. From the perspective of riding behavior and risk-taking, a local study by Abdul Sukor, Tarigan and Fujii (2016) found a significant correlation between use of exclusive motorcycle lane and speeding behavior among motorcyclists. On the other hand, review of related legal documents revealed that there is no provision for speed limit currently applicable to motorcycle lanes in Malaysia (*Akta Pengangkutan Jalan 1987 [Road Transport Act 1987]*, 2013; Road Transport Department Malaysia, 2014).

A new approach to the study of motorcycle rider behaviors was explored in this thesis through a development of a GPS-based naturalistic motorcycle riding data collection methodology. The collected data were utilized to assess motorcyclists' speed profiles and determine the effects of lane geometry and environment factors on speed variations along exclusive motorcycle lane. The results can be used as a baseline and reference for speed management and ultimately for

identification and treatment of design inconsistency on the exclusive motorcycle lane.

1.3 Objectives of the Study

The general goal of this study is to relate motorcyclists' choice of speed to the geometry of exclusive motorcycle lanes using GPS-based instrumented motorcycle riding data. The more specific objectives are:

i. To determine motorcyclists' acceleration and deceleration behaviors on tangent sections.
ii. To determine lane geometry and road environment factors that influence speed variations during tangent to horizontal curve transitions.

1.4 Significance of the Study

From the viewpoint of traffic engineering and geometric design practice, looking into variability in operating speed is one way to assess safety level of a roadway. A noticeably large speed disparity along different segments could indicate sudden speed changes characterized by a geometric design that is not in accordance to drivers' expectation and lacking in consistency (Camacho-Torregrosa, Pérez-Zuriaga, Campoy-Ungría, & García-García, 2013; Fitzpatrick et al., 2000). Thus, the consistency in the geometric design is a surrogate measure of the safety level of a roadway. Departure from consistency is hypothesized to lead directly to an increase in crash rate (Lamm, Wolhuter, Beck, & Ruscher, 2001).

The research presented in this thesis set out to investigate the motorcycle speed profiles on exclusive motorcycle lane using design consistency as its foundation. Since the speed profile relates directly to the geometric design of the lane, this study could be very beneficial for speed management, engineering treatment and improvement of currently available design guidelines. One of the main motivations behind the use of GPS based instrumented motorcycle in this study was to significantly improve the depth and accuracy of speed data. Compared to spot speed studies, the instrumented motorcycle is more advantageous mainly due to its capacity to generate a database of naturalistic riding data comprising second-by-second speed profiles.

1.5 Scope of the Study

The research presented in this thesis is limited to an uninterrupted, one-directional, exclusive off-street motorcycle lane in a good weather, dry road surface and daylight settings. In addition, only horizontal alignments were considered in the data analysis. All participants in this study were male and young motorcyclists (average age of 25.6 years old). In addition, no pillion passengers were included in the data collection setup. In terms of Malaysian motorcycle crash data, male motorcyclists involved in more than 90% of fatalities and the majority of them were riders and below 20 years of age (Abdul Manan & Várhelyi, 2012). Review of literature on the effects of gender and age on safe riding performances revealed that male and young motorcyclists were more at risk of a crash due to risk-taking, while female motorcyclists were more at risk due to lack of skills. For instance, a study by Abdul Sukor, Tarigan and Fujii (2016) found that proneness to neglect safety helmets was more significant among male motorcyclists than female. Another study by Ibrahim and Mohd Yusof (2011) concluded that male novice motorcyclists were better at responding to hazards at unsignalized junctions, as compared to their female counterparts.

Compared to other groups, a previous study has reported a higher likelihood of crashes among young and male motorcyclists (Chang & Yeh, 2007). Older motorcyclists were reported as being generally safer than the younger group, although their physiological factors could lead to higher severity of injuries (Fitzpatrick & O'Neill, 2017). The effects of pillion on riding style were found to be limited to certain road section and riders' age group. For instance, Lemonakis, Eliou, Karakasidis and Botzoris (2014) reported higher riding speeds on curved sections among experienced motorcycle riders with pillions. Considering the financial constraint and the scale of the field data collection, the inclusion of only male and young motorcyclists in this study was reasonable. Moreover, they are among the most vulnerable groups on Malaysian roads. Thus, the findings based on their riding behaviors could have a high impact on motorcycle safety in Malaysia.

1.6 Organization of the Thesis

The thesis consists of three major parts. The first part establishes the gap of knowledge regarding the effect of geometric design on the safety of motorcyclists through a review of previous studies conducted on the exclusive motorcycle lane. The specific elements of design applicable to motorcycle facilities were also discussed especially on the impacts of the design elements on the safety of the intended users of a roadway. This part of thesis also justifies the need for research and the use of data collection methods.

The second part of the thesis describes the research design including the methods used for data collection and analysis. Construction of continuous speed profile database was also discussed. The final part of the thesis presents the results of statistical analyses on speed profiles and the effects of the geometric design on speed variation.

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