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Two-wheeler Intersection Treatment: A Review

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ABSTRACT

Two-wheelers, either motorised or non-motorised, are known to be the cheapest mode of transport. The usage of two-wheelers, especially in low- and middle-income countries, help to fill the gaps when public transport systems are non-existence, inefficient, or unintegrated. In the past decade, the two-wheeler population has grown exponentially, mainly due to the rise in transportation cost and congestion issues. However, this has inevitably raised the number of traffic crashes involving two-wheelers. In Malaysia, more than 60% of road traffic crashes recorded involve two-wheelers and the exposure rate for two-wheelers is said to be the highest at signalised intersections. Therefore, this study is initiated to make the intersections safer for two-wheelers. Thus, resulting in a reduction of road traffic crashes involving two-wheelers at intersections. Findings from previous studies conducted on this subject and existing guideline on the provision of two-wheeler facilities as well as intersection treatments for two-wheelers adapted by other countries were analysed within the study. This study reveals that the design of friendly intersection treatment for two-wheelers are site specific as the mix of traffic, right-of-way, property access, traffic volume and operating speed of a road, as well as safety performance and community goals have a big impact on the type of treatment to be implemented. Saying said so, it is suggested that an assessment on how safe, comfortable and adaptable the treatment is required upon implementation. Such assessment will allow room for improvements as well as monitoring of how such treatments achieve the desired goals can be attained.

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1. Introduction

Two-wheelers can be classified as motorised and non-motorised two-wheelers. Motorised two-wheelers include motorcycles and mopeds, whereas non-motorised two-wheelers may refer to bicycles and scooters. According to Partnership for Clean Fuels and Vehicles (PCFV) (2010), two-wheelers fulfil the needs of low- and middle-income users and help fill the gaps when public transport systems are inefficient, not integrated, or non-existent.

In Malaysia, the ownership of two-wheelers has increased rapidly over the years. An increment of 21% in newly registered two-wheelers was observed between 2016 and 2018 (RMP, 2018). According to Law, Hamid, and Goh (2015), the increment of two-wheeler ownership is mainly due its small size and cheap price. Other than that, two-wheelers are also said to be the fastest form of transport in congested areas as it requires less space on the road as well as in parking areas (Law, Hamid, & Goh, 2015; Leong & Sadullah, 2007).

According to the Global Status Report on Road Safety, (WHO, 2013), Malaysia recorded the third highest number of motorised two-wheelers ownership in the world (332 motorised two-wheelers per 1,000 people). With an annual average increment rates of 5.6%, more than half of the registered vehicle population within Malaysia consists of motorised two-wheelers (Ministry of Transport Malaysia, 2017). According to statistics by the RMP (2018), more than 45% of the registered new vehicles are classified under the motorised two-wheeler category yearly.

However, regardless of how convenient two-wheelers are, two-wheelers are considered to be more vulnerable in mixed traffic conditions while also adding to unsafe driving conditions owing to their tendency towards speeding or rash driving and traffic indiscipline. According to WHO (2015), Malaysia has the eighth highest motorised two-wheelers related fatality rate in the world, 55.8 per 100,000 registered motorised two-wheelers. The breakdown of fatalities recorded within Malaysia showed that the motorised two-wheelers related fatalities contributed to more than 60% of the total fatalities recorded within country (RMP, 2018).

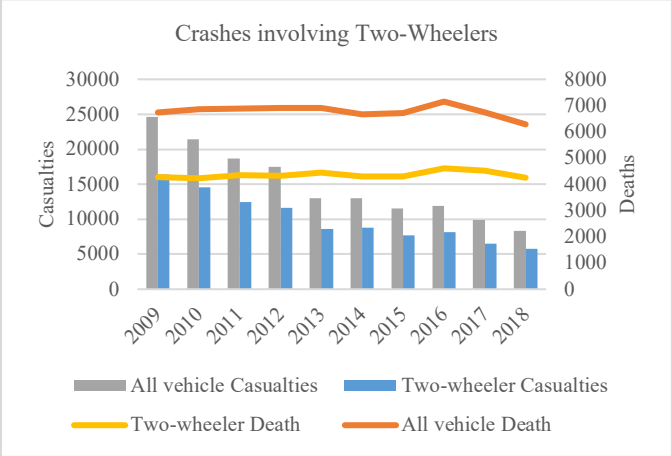

Figure 1: Crashes involving two-wheelers (*Source:* Malaysian Road Accident Statistics Report RMP, 2018)

1.1 Two-Wheelers at Intersections

Based on previous studies related to two-wheelers at intersections, it can be concluded that the exposure rate as well as the behaviour of two-wheelers at intersections are highly affected by the intersection layout and traffic properties.

A study by Haque, Chin, and Huang (2009), revealed that even though the vehicle population of motorised two-wheelers in Singapore are relatively low (only 19%), the motorised two-wheelers exposure rate at signalised intersections was high (41.7%) due to the higher accumulation of motorised two-wheelers at the stop line. Higher exposure rate was observed at four-legged signalised intersections as compared to T-signalised intersections. Furthermore, previous studies have shown that the presence of a wide median and an uncontrolled left-turn lane at major roadways of four-legged intersections increased the exposure rate of motorised two-wheelers (Haque, Chin, & Huang, 2009).

According to Hawa et al. (2014), two-wheelers had the highest violation rate in red-light running at signalised intersections as compared to other types of vehicles. Regardless of the presence of AwAS (Automated Awareness Safety System) at the intersections, large number of red-light running cases involving two-wheelers were recorded, especially on weekdays during off-peak period. Abdul Manan et al. (2020) concluded that red-light running behaviour among two-wheelers at intersections is highly affected by the traffic volume at the intersections. Wider shoulder width, long and predictable amber or red time are also some of the factors leading to red-light running behaviour among two-wheelers at intersections (Abdul Manan et al., 2020).

1.2 Two-Wheelers Friendly Intersections

According to National Association of City Transport Officials (NACTO), intersections by definition are locations where the complexity of driving task and riding are at greatest as conflicting movements between motor traffic, cyclists, pedestrians and mobility of impaired users are concentrated at this location. Despite the lower percentage of motorised two-wheelers related fatalities observed at major intersections, the motorised two-wheelers exposure rate is said to be higher at signalised intersections. Intersections, particularly large and complex intersections, can present significant barriers and safety hazards for two-wheelers (NACTO).

An intersection is said to be two-wheeler friendly when provisions are provided for two-wheelers either motorised or non-motorised, and is measured based on how safe, comfortable, direct, coherent, attractive and adaptable these provisions are for two-wheelers without causing delay to other road users (FHWA, 2019). In implementing friendly intersection treatments for two-wheelers, it should be noted that the design of intersections should be able to reduce conflict between two-wheelers (as well as other vulnerable road users) with other vehicles by increasing the level of visibility, facilitating eye contact and awareness with competing modes as well as denoting a clear right-of-way.

1.3 Guideline on Two-Wheeler Facilities

The design of an intersection must be able to maximise the capacity and minimise delays during peak hour flow within the area. This tend to result in multi-lane approaches and large areas within the intersection with opposing or weaving traffic movements as the traffic demand grows. As intersections are locations of inherent risk for two-wheelers due to the conflicting movements between two-wheelers and other road users, the design or adaptation of intersections with two-wheeler facilities should mitigate these risks without introducing excessive detour or delay for two-wheelers, in other words, providing convenient and comfortable passage through the intersection, catering for all possible movements and wherever possible matching desire lines. All movements and how different user groups interact with each other must be considered when designing an intersection.

According to the Federal Highway Administration (FHWA) (2019), there are seven principles in designing a two-wheeler network. These principles can also be applied when designing two-wheeler facilities at intersections.

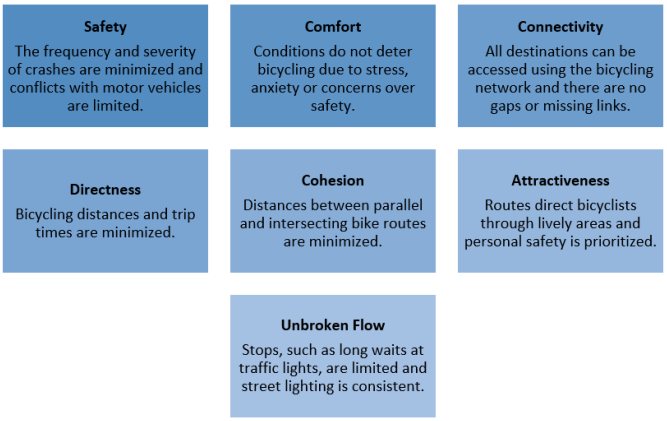

Figure 2: Principles of motorised and non-motorised two-wheeler network design

In Malaysia, three guidelines: ATJ 10/86 (Pindaan 2018) (A Guide to the Design of Cycle Track), NTJ 33/2015 (Guideline for Motorcycle Safety) and ATJ 35/2018 (Geometric Guideline for Exclusive Motorcycle) can be referred to in designing a two-wheeler network. However, only a few of the guidelines describe on the design of two-wheeler facilities at intersections. Nonetheless, as the overall connectivity of a two-wheeler network is of concerned, these guidelines can also be adopted in determining the needs of intersection treatments for two-wheelers.

The existing warrants on the provision of two-wheeler facilities differs for non-motorised and motorised two-wheelers. For non-motorised two-wheelers, only the percentage of heavy vehicle, 85th percentile speed and total traffic volume are considered in the existing warrants. Whereas for the provision of motorised two-wheeler facilities, the total traffic volume, percentage of motorised two-wheelers, number of crashes involving motorised two-wheelers and side friction score are considered.

According to the FHWA (2019), the safety, comfort and also connectivity of two-wheelers are to be prioritised in designing two-wheeler facilities. Being said so, these principles should also be considered when warranting facilities for two-wheelers.

Two-wheelers are said to be vulnerable and are at high risk in occurrence of a crash. According to iRAP, vehicle speed has significant effect on the likelihood and severity outcome of a crash. Based on previous studies, it is also known that crashes involving

heavy vehicles and two-wheelers tend to result in a more severe outcome as compared to crashes involving two-wheelers only. Therefore, taking these facts into consideration, it is suggested that the 85th percentile speed and percentage of heavy vehicle as well as percentage of two-wheelers are to be incorporated the existing warrants on the provision of two-wheeler facilities (motorised and non-motorised).

1.4 Adaptation of Intersection Treatments for Two-Wheelers

Several intersection treatments, such as raised table intersection, coloured pavement marking, advanced stop line (ASL), two-wheeler signal phase, combined two-wheeler lane/turn-lane and sign improvement, have been adapted by other countries in order to increase the safety of two-wheelers at intersections (examples are as shown in Figure 3). The treatments were introduced and implemented to increase the visibility and level of service of two-wheelers as well as reduce the number of conflicts at intersections.

Raised table intersection | Advanced stop line (ASL)

Two-stage turn | Combined two-wheeler lane/turn lane

Coloured pavement marking | Two-wheeler signal phase | Sign improvement

Figure 3: Intersection treatment for two-wheelers

However, previous studies on this subject, as summarised in Table 1 revealed that each treatment has its pros and cons. Thus, it can be said that not all treatments are suitable to be implement.

Table 1: Summary of studies on intersection treatment for two-wheelers

Type of intersection treatment	Study by	Findings
Raised table intersection	Councils in South Australia	Raised table intersections are an alternative to make signalised or unsignalised intersections safer at a low-cost.
		This treatment creates a safer environment for all road users by reducing the speed of vehicles negotiating the intersection as well as increase the visibility of two-wheelers and pedestrians to other road users.
Coloured pavement marking	London Cycling Design Standards	Coloured pavement with strong tonal contrast from the carriageway may be beneficial to those with visual impairments or lowered vision.
	City of Portland Office of Transportation	The coloured pavement markings that have been implemented in European and Canadian cities at signalised and unsignalised intersections were found to increase the safety of two-wheelers by reducing the number of conflicts between two-wheelers and other vehicles.
	Jensen (2007)	Implementation of a coloured surface two-wheeler lane through an intersection reduced the number of casualties involving two-wheelers but it only can be achieved when a single lane is marked.
Advanced stop line (ASL)	Dill et al. (2011)	Road users perceived the intersections to be safer after the implementation of ASLs.
		Motor vehicle encroachment in the dedicated area prior to arriving at the intersection decreased when ASLs were

		implemented with coloured pavement.
	Norfaizah et al. (2019)	In Malaysia, only 57% of the motorcyclists utilised the ASL facility at signalised intersections. This mainly due to the misuse of ASLs by other vehicles.
Two-wheeler signal phase i. Two-wheeler scramble signal phase ii. Two-wheeler-only signal phase	Wolfe et al. (2006)	City of Portland installed two-wheeler scramble signals at intersections to improve the traffic condition as well as the safety of two-wheelers by allowing protected movement for two-wheelers.
	Korve and Niemier (2002)	This type of treatment increased the safety of two-wheelers by lowering the number of conflicts between two-wheelers and other vehicles.
Two-stage turn	Broose et al. (2011)	The provision of two-stage turns has encouraged safer crossing angle at track for two-wheelers.
	Pai et al. (2013)	A two-stage turn treatment is only applicable to non-motorised two-wheelers as motorised two-wheelers have low compliance rate for this type of treatment.
Sign improvement	Jensen (2007)	The provision of adequate signage reduced the number of conflicts involving two-wheelers and other turning vehicles, resulting in a crash reduction of 10% and 19% of injuries at intersections.
	Jeana, Karim, and Md Tazul (2014)	An intersection without a two-wheeler signage is three times more likely to result in a major collision as compared to intersections with a two-wheeler signage.
	Kirolos, Mohamed, and Kevin (2010)	Installing two stop signs on both minor approaches increases the frequency of crashes significantly as compared to the case of installing only one stop sign on one of the minor approaches.

With regards to the above studies, it is concluded that the type of treatment to be implemented must be site specific, depending on the mix of traffic, right-of-way, property access, traffic volume and operating speed of a road, as well as safety performance and community goals. The cost of implementation will also have effect on the choice of treatment to be implemented. Therefore, some considerations, as listed in Table 2, must be taken in choosing the appropriate type of treatment to be implemented.

Table 2: Considerations in adapting intersection treatment for two-wheelers

Type of intersection treatment	Considerations in implementation
Raised table intersection	i. Should only be constructed on roads with a speed limit of 50 km/h or less and be extended from kerb to kerb. ii. Approach ramps should be located sufficiently far from the junction mouth. iii. Special attention should be given to drainage requirements to prevent standing water at the ramps.
Coloured pavement marking	i. Coloured pavement with strong tonal contrast from the carriageway. ii. Only a single lane is to be marked.
Advanced stop line (ASL)	i. The design of ASLs must be site specific. Considerations on factors such as location, number of approach lanes, vehicle swept path, signal staging, turning traffic volume and dominant cycle movement should be given. ii. The waiting area between the two stop lines should be between 4 m and 5 m deep. However, the revised Traffic Signs Regulations and General Direction, UK permits the waiting area to be up till 7.5 m deep.
Two-wheeler signal phase iii. Two-wheeler scramble signal phase iv. Two-wheeler-only signal phase	i. Two-wheeler scramble signals are suitable for non-motorised two-wheelers only. ii. Two-wheeler-only signal phasing starts 5 to 6 seconds before the traffic phase on the same arm. However, consideration to factors such as number of two-wheelers, distance to cross the intersection, nature of other road traffic and gradient in determining the appropriate timing is required. iii. The waiting area should be suitable for holding the peak cycle demand of two-wheelers at the intersection.
Two-stage turn	i. A dedicated area designated to hold queueing two-wheelers is required. ii. Under existing regulations, the waiting area shall be marked with a two-wheeler diagram and direction arrow, backed with coloured surfacing if needed. iii. For safety issues, the waiting area shall be placed in a protected area.

	iv. The waiting area must be clear from any pedestrian crossing and be of sufficient size for the number of two-wheelers waiting.
Combined two-wheeler lane/turn lane	i. Not suitable to be implemented at intersections with very high peak right turn demand. ii. Can only be implemented on roads where there is a right turn lane but not enough space to maintain a standard two-wheeler lane at intersections or on roads where no dedicated right turn lane is provided but high right turn volume that may cause conflict between two-wheelers and other vehicles is observed. iii. Conventional two-wheeler stencils or shared lane markings with dashed lines and signage advising two-wheelers as well as other vehicles of proper positioning are to be used to indicate the intended path for two-wheelers as well as other vehicles. iv. The two-wheeler area should be at least 4 feet wide. v. Regular maintenance on the markings are required.
Sign improvement	i. Clear, distinctive and efficient signing is to be provided in advance at intersections. ii. Signs should be installed according to the site and be kept to a minimum to reduce street clutter. iii. Use consistent two-wheeler sign. iv. Regular maintenance for signs and markings must be scheduled. Inspection on the structural condition, colour, retro-reflective properties, surface protective treatment and general performance is required.

2. Conclusion and Recommendations

Based on the studies conducted over the past few years on this subject, it can be concluded that different types of intersection treatment for two-wheelers are available and have been adapted by other countries. Summary for two-wheeler friendly intersection treatments available are as listed in Table 3 below based on its usage.

Table 3: Intersection treatment for two-wheelers

	Non-Motorized Two-Wheeler		**Motorized Two-Wheeler**	
	Unsignalised intersection	Signalised intersection	Unsignalised intersection	Signalised intersection
Raised Table Intersection	√	√	√	√
Coloured Pavement Marking	√	√	√	√
Advanced Stop Line (ASL)		√		√
Two-Wheeler Scramble Signal Phase		√		
Two-Wheeler-Only Signal Phase				√
Two-Stage Turn		√		
Combined Two-Wheeler Lane/Turn Lane	√	√	√	√
Sign Improvement	√	√	√	√

However, based on the previous studies reviewed, it should be noted that the mix of traffic, right-of-way, property access, traffic volume and operating speed of a road, as well as safety performance and community goals have a big impact on the type of treatment to be implemented. These factors are mainly determined by the land use of the location. In summary, it can be concluded that the design of friendly intersection treatment for two-wheelers must be site specific.

As the intersection treatment for two-wheelers are site specific, an assessment on how safe, comfortable and adaptable the treatment is required upon implementing the treatment. Such assessment allows room for improvements as well as monitoring of how such treatments achieve the desired goals can be attained.

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