# DETERMINING THE EFFECTS OF RISKY RIDING BEHAVIOR ON GAP ACCEPTANCE OF RIGHT-TURNING MOTORCYCLISTS FROM MINOR ROADS AT T-JUNCTIONS

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by

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# ABSTRAK

Pusingan kanan dari jalan kecil adalah pergerakan yang paling kritikal di simpang T.Walau bagaimanapun, risiko penunggang motosikal berpusing kanan untul terlibat dalam kemalangan adalah sangat tingggi disebabkan oleh tingkah laku menunggang mereka. Kajian tapak telah dijalankan di tiga jenis simpang-T iaitu jenis A (simpang-T konvensional), jenis B (simpang-T tidak konvensional dengan satu lorong keluar pendek untuk kenderaan jalan kecil yang berpusing kanan) dan jenis C (simpang-T tidak konvensional dengan satu lorong keluar pendek untuk kenderaan jalan utama yang bergerak terus). Lima tingkah laku penunggang motosikal berbelok kanan yang berisiko seperti tidak mengikut konsep ''First-In-First-Out'' (FIFO) (R1), belok tanpa henti sepenuhnya (R2), tidak mengikut laluan pemusingan kanan yang tetap (R3), tidak mengikut peraturan keutamaan (R4) dan pembelokan kanan ke jalan utama secara paksa (R5) telah dianalisis. Simpang-T jenis A adalah yang paling selamat kerana ia mempunyai peratusan tingkah laku berisiko penunggang motosikal berbelok kanan yang paling rendah. Kemudian, keputusan juga menunjukkan tingkah laku R5 menerima sela yang lebih kecil (1.638 s) daripada sela biasa (7.267 s). Seterusnya, pembelokan kanan yang melibatkan kedua-dua motosikal dan kereta menggunakan satu sela yang sama telah dikaji. Purata penerimaan nilai sela untuk tingkah laku ini adalah 9.318 s (jenis A), 8.319 s (jenis B) dan 8.759 s (jenis C), manakala nilai sela kritikal adalah 9.20 s (jenis A), 7.00 s (jenis B) dan 7.20 s (jenis C). Masa susulan yang melibatkan kedua-dua motosikal dan kereta adalah 3.315 s (jenis A), 2.504 s (jenis B) dan 2.630 s (jenis C). Secara keseluruhan, konfigurasi geometri simpang-T jenis B mempunyai prestasi terbaik kerana penunggang motosikal lebih berkelakuan baik dan ia menunjuk nilai terkecil bagi nilai sela kritikal dan masa susulan untuk motosikal belok ke kanan dengan kereta.

# ABSTRACT

Right turning from minor are the most critical movement at T-junction. However, the risk of right-turning motorcyclist involved in an accident is extreme high because of their riding behaviour. The site study was carried out at three T-junction types which are type A (conventional T-junction), type B (unconventional T-junction with short exit lane for right-turning minor road vehicles) and type C (unconventional T-junction with short exit lane for through major road vehicles). The frequency distribution of five risky riding behaviours of right-turning motorcyclists such as not following the concept of First-In-First-Out (FIFO) (R1), turning without fully stopping (R2), not following the conventional right-turning path (R3), not following priority rules (R4) and forceful turning into major road (R5) was determined and the number of risky riding behaviour performed by each motorcyclist was then analysed. Type-A T-junction is the safest as it has a lower percentage of risky riding behaviour but motorcyclists at type-B T-junction are more behaved as most of them only performed one risky behaviour (56%) or none (34%). Then, the frequency distribution and mean accepted gap of forceful entries by motorcyclists were studied and compared with the mean accepted gap of motorcyclists without any risky riding behaviour at type-C T-junction. Results showed motorcyclists accepted smaller gap (1.638 s) for forced entry than the usual gap (7.267 s). Next, entry behaviour for motorcycle and car to turn right together using the same accepted gap was studied. The mean accepted gap for this behaviour were 9.318 s (type A), 8.319 s (type B) and 8.759 s (type C), while the critical gap were 9.20 s (type A), 7.00 s (type B) and 7.20 s (type C). The follow-up time that involved both motorcycle and car were 3.315 s (type A), 2.504 s (type B) and 2.630 s (type C). In conclusion, the geometrical configuration of type-B T-junction provides the best performance as the motorcyclists were more behaved and it recorded the smallest critical gap and follow-up time.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Traffic volume in Malaysia is rising annually in tandem with the rapid urbanisation of the country. Along with the growth of vehicle volume on the streets, motorcycle has become a popular choice for individual private transport, as it is easy to be used in short and medium distance trips, and it is affordable. Referring to the statistic from Road Transport Department Malaysia, there was 495,610 new motorcycle registration in 2017, and the value has risen by 11.5% to 552,741 in 2018. Based on Table 1.1, motorcycle is the second-highest vehicle in Malaysia involved in road accidents, just after passenger car from 2009 to 2018. However, even though it is not the top vehicle, the highest road fatalities (59%) were recorded from motorcyclists, as shown in Figure 1.1.

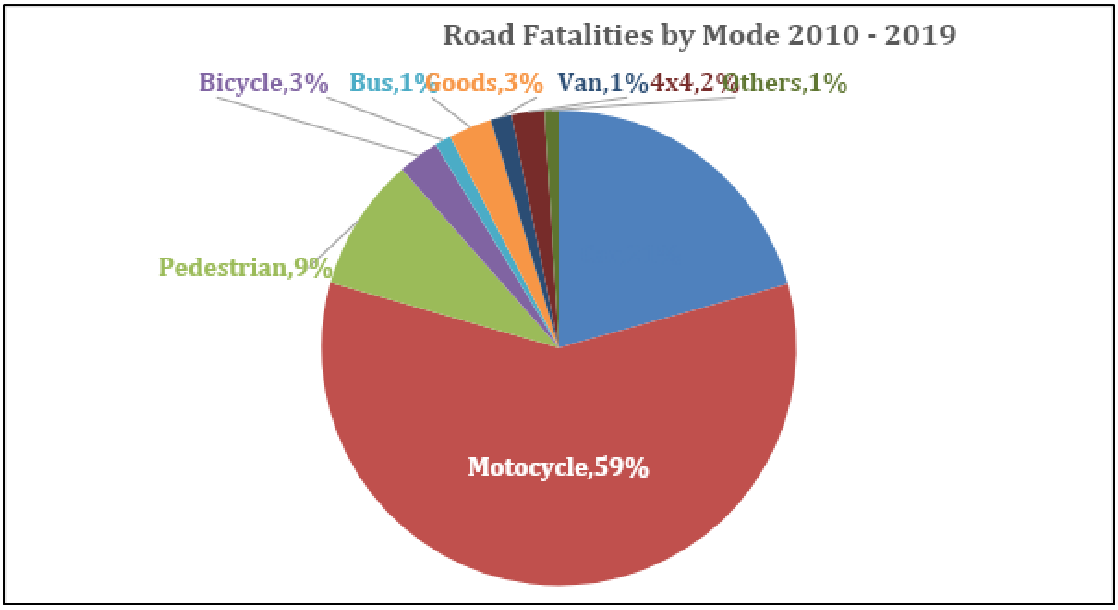



Figure 1.1: Road fatalities by mode 2010-2019 (Ministry of Transport Malaysia, 2021)

Table 1.1: Total Motor Vehicle Involved in Road Accidents by Type of Vehicle, Malaysia, 2009 – 2018 (Ministry of Transport Malaysia, 2019)

| Year | Motorcycle | Motorcar | Van | Bus | Lorry | Four Wheel Drive | Taxi | Bicycle | Others | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | 113,962 | 472,307 | 19,220 | 9,380 | 46,724 | 23,581 | 8,669 | 2,486 | 9,294 | **705,623** |
| 2010 | 120,156 | 511,861 | 18,788 | 9,580 | 50,438 | 25,777 | 9,899 | 2,178 | 11,756 | **760,433** |
| 2011 | 129,017 | 546,702 | 17,916 | 9,986 | 53,078 | 30,828 | 11,197 | 2,033 | 16,394 | **817,151** |
| 2012 | 130,080 | 655,813 | 15,143 | 10,617 | 42,158 | 32,891 | 11,680 | 1,310 | 21,540 | **921,232** |
| 2013 | 121,700 | 632,602 | 17,148 | 10,123 | 39,276 | 52,512 | 11,651 | 1,370 | 15,441 | **901,823** |
| 2014 | 125,712 | 617,578 | 15,041 | 9,193 | 37,481 | 41,464 | 10,856 | 1,275 | 27,743 | **886,343** |
| 2015 | 123,408 | 625,758 | 14,565 | 8,804 | 34,942 | 46,163 | 9,591 | 1,119 | 29,924 | **894,274** |
| 2016 | 135,181 | 670,935 | 14,470 | 9,462 | 35,064 | 48,907 | 8,399 | 1,318 | 36,833 | **960,569** |
| 2017 | 108,221 | 564,491 | 13,347 | 7,258 | 34,747 | 44,297 | 5,328 | 787 | 24,047 | **802,523** |
| 2018 | 113,288 | 591,399 | 17,226 | 7,328 | 36,915 | 45,757 | 3,912 | 727 | 21,143 | **837,696** |

In Malaysia, motorcycle lane is not common on road, thus motorcyclists usually share the lane with other larger vehicles. Motorcyclists are considered as a vulnerable group on the highway because a motorcycle is relatively small, so driver tends to ignore them. Sometimes, the motorcyclist is blocked by the blind spots of the vehicles itself or other vehicles on street, turns up the driver is unable to view the location of motorcycle properly. Motorcyclists are unprotected too, unlike the other drivers which are fully covered by the vehicle's structure. Hence, a motorcyclist is more susceptible to severe injury in the event of an accident.

Abdul Manan (2014) explained in his study about the factors influencing motorcyclists' accidents include motorcyclists' driving behaviour, age, gender, experience, traffic rule violations, safety attire and helmet usage, alcohol consumption, and education. Conditions of the road and environment such as type of area, the geometry of road, infrastructure condition, pavement surface condition, visibility, and weather condition, are also the reason for motorcyclists' accidents.

According to Sultan *et al.* (2016), the biggest factor of motorcyclist fatalities is human (motorcyclist) behaviour. Since motorcycle is small size with narrow width, short length and high power-to-weight ratio, motorcyclist has higher adaptability on road which subsequently tend to ignore the traffic regulations (Patil and Sangole, 2016). When facing heavy traffic, they can easily perform risky riding behaviour, such as filtering, riding diagonally, moving on the side of another different vehicle in the same lane, tailgating, and swerving to save time. A motorcycle is filtering if it is travelling at low speeds through stopped or slow-moving traffic; while swerving is defined as two consecutive turns or counter steers, one to avoid an obstacle followed immediately by another to regain original direction.

Various designs and elements are implemented on roadways to control transport flow and to ensure the safety of road users. Intersection is one of the important designs on road. It is defined as the location where traffics from two or more direction meet. Intersection allows the drivers to change direction to reach their destination. In general, intersection can be divided into two types: grade-separated intersection and at-grade intersection. Grade-separated intersection refers to roads that intersect at different levels, while at-grade intersection refers to roads that intersect at same level. At-grade intersection again can be divided based on the type of traffic control being enforced. It consists of signalised intersection, priority intersection and roundabout. It can also be categorised based on the number of approach lanes, such as three-legged intersection (T-junction), four-legged intersection (cross junction) or five-legged intersection.

Priority intersection is junction in which the traffic is controlled by a 'yield' sign or a 'stop' sign. In other words, it is an unsignalised intersection. The right-of-way for vehicle is not controlled by a traffic signal. Priority intersection is widely used to reduce conflict between merging and crossing vehicles in Malaysia. It is more suitable for low-volume junction.

At a T-junction, the right-turning vehicle from a minor approach stops and waits for a suitable gap for it to cross to the major approach safely. The gap is the time interval between the first vehicle's rear bumper and the second vehicle's front bumper, who are both traveling in the same direction in the same lane. Figure 1.2 illustrates the definition of the gap for the minor approach at the T-junction. A critical gap is a minimum gap between two successive vehicles at the major road in which the vehicle on a minor road can make a manoeuvre safely. It is an important element when studying a junction as it will affect the capacity and level of service.

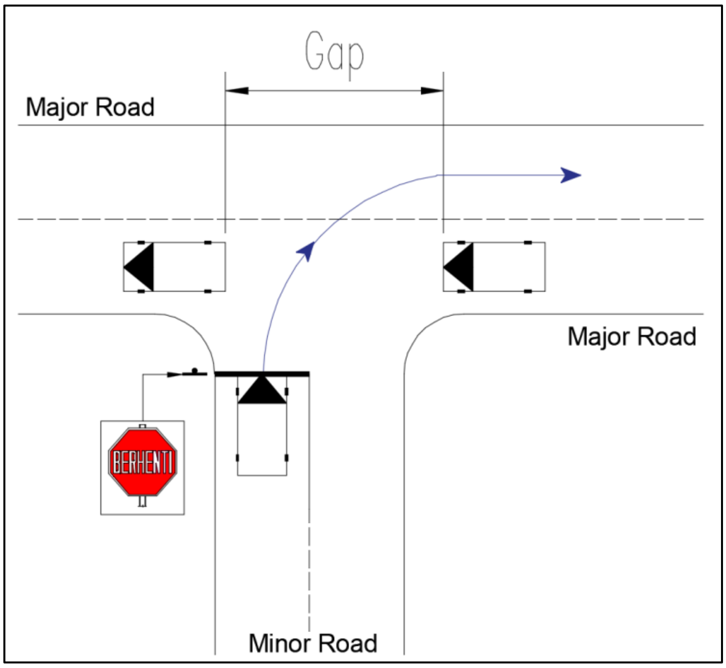



Figure 1.2: Gap for minor approach at T-junction.

Driver behaviour at a priority intersection is directly related to the performance of the intersection. The driver on a minor road must decide when to join, cross or merge into the opposite major road, as there is no traffic signal given. Drivers may perform risky behaviour when they are waiting for a suitable gap at a junction, especially if there is heavy traffic on the major road. Long-queue waiting time may reduce the driver's accepted gap and affect the critical gap. Hence, the critical gap depends highly on the driver's behaviour. This study focused on the relationship between the risky behaviour and their gap acceptance, specifically behaviour of right-turning motorcycle from the minor road at T-junction. Three T-junctions in Malaysia were selected as case study for this research.

## 1.2 Problem Statement

Driver who wants to turn right from a minor road must stops and waits for an acceptable gap to cross over a major road since Malaysia follows Left-hand Driving System (LDS). However, as Harnen *et al.* (2003) mentioned, an intersection is an accident-prone zone as most of the accidents recorded have happened at an intersection. Motorcycle–vehicle angle crash was ranked as the top crash type at T-junctions, while the approach-turn accident was identified as the second in terms of accident severity in T-junction. Most of the road accident fatalities in Malaysia involve motorcyclists, and the primary cause of motorcycle crashes is human behaviour (Pai, 2009). Motorcyclists tend to not follow the rules at T-junction, which will influence the critical gap. One of the risky behaviours that always performed by right-turning motorcyclists is not following the concept of First-In-First-Out (FIFO). First-In-First-Out means when there is a vehicle at the stop line or when there is a queue, vehicles that reaches after them should queue and wait for their turn. However, motorcyclists tend to move to the front of queue and turn right with other vehicles as they are small. Hence, this study will investigate the entry behaviour of motorcyclist that turns right together with a car using the same accepted gap. Next, another dangerous entry behaviour of right-turning motorcyclist from minor road is forceful turning that induce the slowing down/stopping of vehicles on major road. When there is high volume of vehicles on major road, motorcyclist from minor road is unable to turn right. When they are waiting for long time, they become aggressive and eventually they are willing to accept short gap to turn right. As they turn right forcefully, making the vehicles on major road to slow down/stop. Thus, this research also studies the gap acceptance behaviour of motorcyclist that perform such forceful turning.

A critical gap can estimate the capacity of a junction. Then, it will eventually affect the level of service (LOS) of the junction. Thus, it is an important element for T-junction. There are extensive longitudinal research studies examining drivers' gap acceptance when intersecting with cars; but, considering the high numbers of accidents involving motorcycles, relatively few research attempts have been made to examine motorcyclist' gap acceptance behaviour. Furthermore, previous research only concentrated on the time gap concept and seldom included the relationship between the driver's behavior and the gaps available on the roadway (Lord-Attivor and Jha, 2012). Most of the research also only focused on risky driving behavior alone, but there is still a lack of study that investigate the impact of motorcyclist risky riding behavior on the gap acceptance in T-junction. A detailed study of gap acceptance that focuses on motorcyclist behavior is indeed needed.

Next, there are conventional and unconventional T-junctions in Malaysia. For unconventional T-junction, a short merging lane is implemented on the receiving approach of the far side of the major road which is aimed to reduce the conflicts between right-turning vehicles from the minor road and through-movement vehicles from the major road. It should be able to reduce the delay of right-turning vehicles as they are easier to merge in. However, there is still a very small number of studies that concentrate on the effectiveness of the short lane and the impact of the geometrical configuration of the junction on gap acceptance. Thus, designers do not know which type of T-junction is improving the performance of a T-junction, or vice versa.

## 1.3 Objectives

The objectives of this project are:

1. To determine the risky riding behaviour of right-turning motorcyclists from minor roads at three types of T-junctions.
2. To identify the mean accepted gap of forceful right-turning motorcyclists from minor roads at three types of T-junctions.

3. To investigate the behaviour of motorcyclists and cars that perform right-turning together using the same accepted gap from minor roads at three types of T-junctions.

## 1.4 Scope of study

The scope of this study is limited to the relationship between right-turning motorcyclist risky riding behaviour and their gap acceptance on the minor road at T-junctions. The field study is carried out at three different T-junctions in Malaysia. Type A is a conventional T-junction, type B is an unconventional T-junction with short entrance lane for right-turning major road vehicles and short exit lane for right-turning minor road vehicles and type C is an unconventional T-junction with short entrance lane for right-turning major road vehicles and short exit lane for through major road vehicles. This study is particularly focusing on right-turning motorcycles on a minor approach. In this study, motorcycles are defined as two-wheeled motorised vehicles for one or two passengers, which is class 5 in vehicle classifications in Malaysia (Ministry of Works, 2006). Video recording of the sites are set up for further observation and investigation when off-site. With the recorded videos of the sites, video replay can be done in slow motion to obtain an accurate result.

Five motorcyclist risky riding behaviours that are suspected to be related to gap acceptance behaviour are studied. For objective (1), the frequency distribution and the number of risky riding behaviour performed by each motorcyclist at each junction are analysed. For objective (2), the accepted gaps of forceful right-turning motorcycles and right-turning motorcyclists that do not perform any risky riding behaviour are observed. For objective (3), the accepted gap and rejected gap of motorcycles that turn right with cars from the minor road are studied. The T-junction with the best geometrical configuration can be concluded based on the result and discussion.

## 1.5 Significance of Study

A motorcyclist is the most vulnerable driver on road due to the uncovered motorcycle's structure. They are less visible to other drivers as motorcycles are small, which increase the possibility of crashes. However, due to the high accessibility of motorcycle, a motorcyclist is easier to perform risky riding behaviour compared to other modes of transport. Hence, motorcyclist tends to violate the traffic rules at priority junction, as there is no traffic signal to be followed. The risky riding behaviour of right-turning motorcyclist identified in this study may be taken into consideration by engineers when designing a T-junction in future and certain prevention aspects can be added to improve the safety performance of T-junction. Subsequently, the results of the effect of motorcyclist risky riding behaviour on gap acceptance determined from this study can assist in the analysis of T-junction's capacity and level of service. Since both conventional and unconventional T-junction are analysed, the outcome of this study also provides data on the differences of both types of T-junctions in term of motorcyclist risky riding behaviour and gap acceptance. The effectiveness and impact of the additional merging lane in unconventional T-junctions can be identified, and the design configuration of T-junction with better performance can be suggested to be implemented more on the stop-controlled T-junction in Malaysia.

## 1.6 Thesis Organisation

The organisation of this thesis is as follows. Chapter 1 gives a general introduction of the overall dissertation content and the general background of traffic condition at unsignalised intersection. The current problem of motorcycle in Malaysia is described, as well as a brief description of the scope and significance of this study are stated. Chapter 2 reviews the relevant literature related to unsignalised intersection, gap acceptance behaviour and motorcyclist riding issues. Subsequently, Chapter 3 discusses the method and procedure carried out in this study. Three different types of T-junctions in Pulau Pinang, Malaysia have been chosen as the site for data collection. Raff's method is used to determine the critical gap as it is recommended by many researchers in Chapter 2 due to its simplicity. Chapter 4 is the data analysis and discussion. Risky riding behaviours, forceful entries of motorcyclists and entry behaviour that involve motorcycle and car are determined. Frequency distribution, critical gap and follow-up time are then analysed and discussed in detail. Finally, Chapter 5 concludes this dissertation and recommendations are given to other researchers that will be involved in similar studies.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

Malaysia is one of the countries with a high composition of motorcycles on road, especially during peak hour. However, the motorcyclist accident fatality rate is increasing not only because they are unprotected, but also because motorcyclists always involve themselves in risky riding behaviour.

Priority junction is a junction on the road network, without signals, operating with priority markings or signage. Without traffic light, the minor road(s) has either a 'yield' or a 'stop' signage which is used to regulate the low volume of traffic flow between the major and minor roads. A three-legged priority junction with stop control, termed as stop-controlled T-junction, is popular in Malaysia. Vehicles from major approaches have the highest priority while vehicles from minor approaches must stop and wait for the available gap to join into the intersection. Numerous researchers have mentioned priority intersection is an accident-prone area as drivers can decide on their own on when, where, and how to perform their manoeuvre based on the gap available.

Previous studies only focus on gap acceptance or riding behaviour, but there are no researchers investigating the relationship between them. Since crashes always happened at priority junction, a study on the effect of motorcyclist risky riding behaviour on gap acceptance behaviour at T-junction is indeed crucial.

This chapter is organised into 9 sections, including this section. In section 2.2, a literature review on the introduction of priority junction is presented. The details of stop-controlled T-junction is further discussed in Section 2.3, and the characteristic of a motorcyclist on road is presented in Section 2.4 which includes the factors that contribute to motorcyclist risky riding behaviour. Gap acceptance behaviour is discussed in Section

2.5 in which many researchers have studied the gap, critical gap, and the follow-up time of the intersection. Section 2.6 reviews the factors affecting gap acceptance. In section 2.7, various methods to determine critical gap is reviewed such as Siegloch's method, model of Troutbeck, Lag method, Ashworth's method, Logit method and Raff's method. Literature about the influences of a motorcycle on the critical gap are reviewed in section 2.8. Lastly, section 2.9 gives a summary that concludes the overall literature review.

## 2.2 Introduction to Priority Junction

According to Ali Sahraei *et al.* (2018), a junction is a location where two or more streets intersect or merge. Priority junction, also known as unsignalised intersection, is an intersection that is not controlled by traffic signal and allows traffic to change their direction of travel. Priority junction is commonly used at intersections to solve merging and crossing conflicts (Leong *et al.*, 2020). Interactions between vehicles at unsignalised intersections are particularly complex (Ashalatha and Chandra, 2011), as vehicles from different directions compete to occupy the same space at the same time which potentially creating collisions (Advani *et al.*, 2020). The road with priority is named as major road, while non-priority roads, or named as minor roads, require vehicles to stop completely at the intersection. A driver approaching an intersection on a minor road onto the major road must decide on when to join, cross or merge into the roadway. The traffic flow at priority junction is controlled manually by road user where no clear signal to the driver that it is safe to cross the intersection (Kaysi and Alam, 2000). The main advantage of priority junction is that the major road traffic flow does not generally experience any delay (Ali Sahraei *et al.*, 2018). There are two types of priority junction which are yield-controlled junction and stop-controlled junction.

The majority of priority junctions are located on single-lane roadways such as next to a bus lay-by, spot of activities, and signalised intersection. Hence, it is the most hazardous place for an accident (Ahmed *et al.*, 2016). When measuring traffic operation at priority intersections, Kaysi and Alam (2000) mentioned two key elements that are often considered: gap acceptance to characterise traffic efficiency, and traffic conflict analysis to study the risk of an accident.

### 2.2.1 Yield-Controlled Junction

For this type of unsignalised intersection, entrance into the intersection from one or more of the approaches is controlled by a yield sign. In Malaysia, it is controlled by a "BERI LALUAN" signboard, which means 'GIVE WAY'. Drivers from approaches that controlled by a yield sign are required to slow down to yield the right-of-way to vehicles from other approaches in the intersection; therefore, adequate sight distance must be present so the driver approaching the yield sign can stop if necessary (National Academy of Sciences, n.d.). motorists. Yield signs are usually placed to control the minor road. Intersections with yield control assign the right of way without requiring a stop. This is mostly used at rural low-volume ramps and wye (Y) intersections. Yield control is generally not recommended in urban locations or where pedestrians are expected.

Yield control is more efficient than stop control since yield control does not require vehicles on the minor road to stop completely and therefore allows vehicles to make use of a much smaller gap in the major road traffic stream to cross an intersection. However, when intersection's sight distances are insufficient, stop control should be used to ensure the safety performance of the intersection (Zhang *et al.*, 2008).

### 2.2.2 Stop-Controlled Junction

In a stop-controlled junction, a stop sign is utilised to control automobile maneuver. In Malaysia, it is controlled by 'BERHENTI' sign board, which represents 'STOP'. Based on the study from Leong *et al.* (2020), stop-controlled junction is again separated into two, which are Two-Way Stop-Controlled (TWSC) junction and All-Way Stop-Controlled (AWSC) junction.

At TWSC junction, the roadway with stop sign is known as the minor road; the roadways that are not controlled by stop signs are known as the major road. Only vehicles from minor road are required to stop. A three-legged junction (T-junction) with only one minor road controlled by a stop sign is considered a typical TWSC junction. Ali Sahraei *et al.* (2018) mentioned that a three-legged junction where two of the three approaches are controlled by stop signs is a rare type of priority junction. According to Lord-Attivor and Jha (2013), TWSC junction is the most difficult intersections to be analysed as drivers tend to behave stochastically at the junction. Based on Transportation Research Board (2010), the capacity of the controlled legs is based primarily on three factors: the distribution of gaps in the major road, driver judgement in selecting the gaps, and the follow-up headways required by each driver in a queue.

An AWSC junction has STOP signs at all approaches. The driver's decision to proceed is based on a consensus of right-of-way governed by the traffic conditions of the other approaches and the rules of the road (e.g., the driver on the right has the right-of-way if two vehicles arrive simultaneously). At AWSC junction, vehicles from all the approaches are required to stop completely at the junction before proceeding. If no traffic presents on the other approaches, a driver can proceed immediately after stopping (Transportation Research Board, 2010). Based on the study by Suresh Kumar and Surisetty (2016), as all drivers must stop before crossing the intersection, the decision whether to proceed to the desired direction depends on the traffic condition of the other approaches. A driver can precede instantly after a stop if there is no vehicle waiting at other approaches. If there is vehicle on any other approaches, a driver must wait, and he/she can proceed only after there are no vehicles in the junction.

## 2.3 Fundamental of Stop-Controlled T-junction

T-junction, or three-legged junction is formed by one roadway ended at a junction with another roadway (Ali Sahraei *et al.*, 2018). A T-junction is an at-grade three-way intersection with three road segments (arms), two of which are straight roads (Costa *et al.*, 2019). Motorcycle-automobile angle collision was recorded as the highest type of accidents in T-junction (Pai, 2009, Ahmed *et al.*, 2016).

In Malaysia, most of the priority intersections are T-junction, which is generally classified into two types: conventional/typical and unconventional T-junction. Leong *et al.* (2020) explained a conventional T-junction has two long lanes on the main road and two long lanes on the minor road, while the unconventional T-junction incorporates the conventional four-lane major/four-lane minor junctions with the two-lane major/two-lane minor junctions, which includes one short exit lane or short right-turn storage lane with stop control on the major approaches. They studied the drivers' behaviour at both conventional and unconventional T-junction and concluded that unconventional T-junction in Figure 2.1 is more effective in reducing conflict between vehicles from the major approaches and vehicles from the minor approaches.

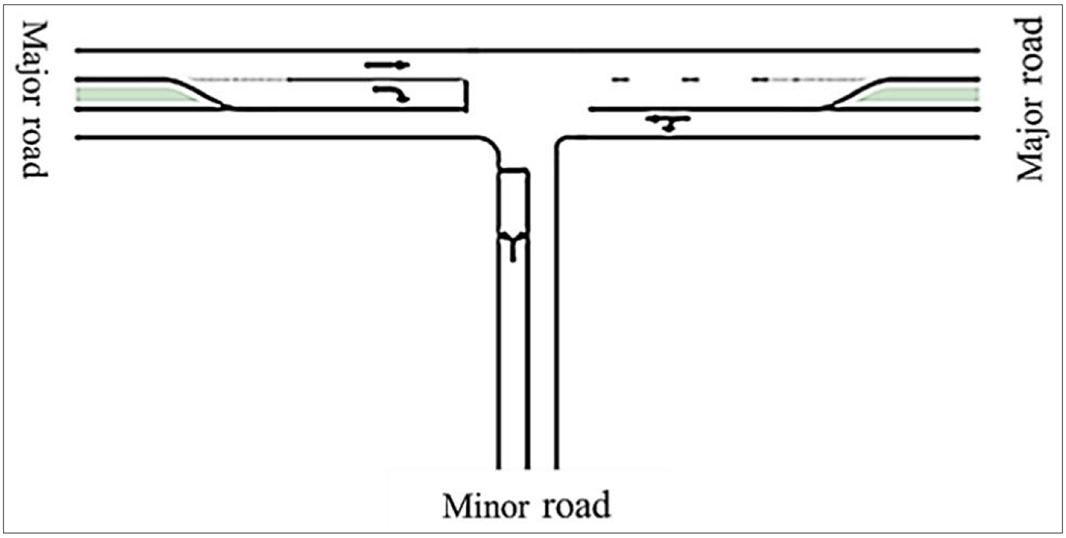
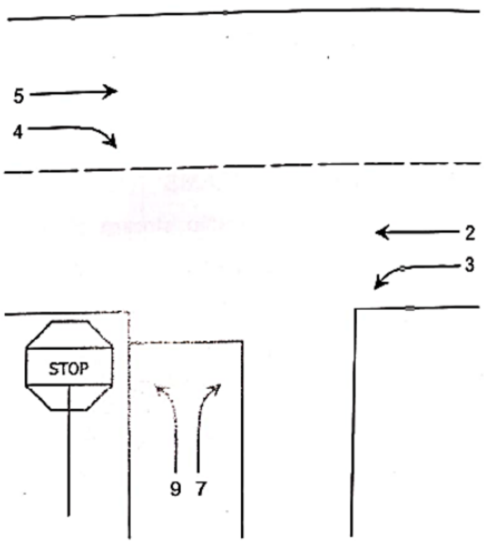



Figure 2.1: Unconventional T-junction with a short right-turn storage lane and a short right-turn exit lane (Leong *et al.*, 2020).

### 2.3.1 Priority Rules

The priority of right-of-way given to each traffic stream must be identified. At the T-junction in Malaysia, the priority is assigned to the vehicles approaching from the straight-through road (priority-to-straight-arm condition). Referring to the Malaysian Highway Capacity Manual (MHCM) 2006, the priority of movement in the T-intersection is described in three-level ranks. Movement of rank 1 includes traffic on the major road and the left-turning from the major road. For movement rank 2, it includes right-turning from the major road and left-turning from the minor road. The last rank 3 movement is right-turning traffic on the minor road. The hierarchy of priority rules is illustrated in Figure 2.2 below.

Priority rule is important in identifying the availability of gaps. For right-turning movement from a minor road, the first available gap of acceptable size would be taken priority by a right-turning vehicle on the major road. However, under mixed-traffic conditions, Advani *et al.* (2020) stated that priority rules are not strictly enforced when clearing the conflict zone, and vehicles on the main street are sometimes forced to reduce their speed due to the aggressiveness of minor-street drivers.




| Rank | Traffic stream |
| --- | --- |
| 1 | 2, 3, 5 |
| 2 | 4, 9 |
| 3 | 7 |

Figure 2.2: Traffic stream at a T-Intersection (Ministry of Works, 2006).

### 2.3.2 Traffic Conflict Points

Traffic conflict points represent the potential of an accident to happen at an intersection. As the conflict points at an intersection increase, the risk of an accident increases too. Traffic conflict point constantly is defined as the spot where traffic conflict happens. The study of Pan *et al.* (2013) stated that not every conflict happen directly on the traffic conflict point. Thus, they defined traffic conflict point as the point where diverging, crossing and merging happen. Ukarande and Bhalekar (2018) also defined it as a spot at which a vehicle crossing, merging with, or diverging from a roadway, conflicts with another travelling vehicle. It is the intersection point where the paths of two through or turning vehicles meet. Traffic conflict points can result in delays and traffic congestion, as well as the risk of road accidents (Prasetijo *et al.*, 2014).

At a typical T-junction, there are 9 conflict points includes 3 crossing points (vehicle path crosses other traffic streams perpendicularly), 3 merging points (separate vehicle paths converge into one common path) and 3 diverging points (one common path of vehicles split into various separate paths), as shown in Figure 2.3. Crossing conflict is a major conflict and dangerous, while the rest are minor conflicts (Aditya, n.d.).

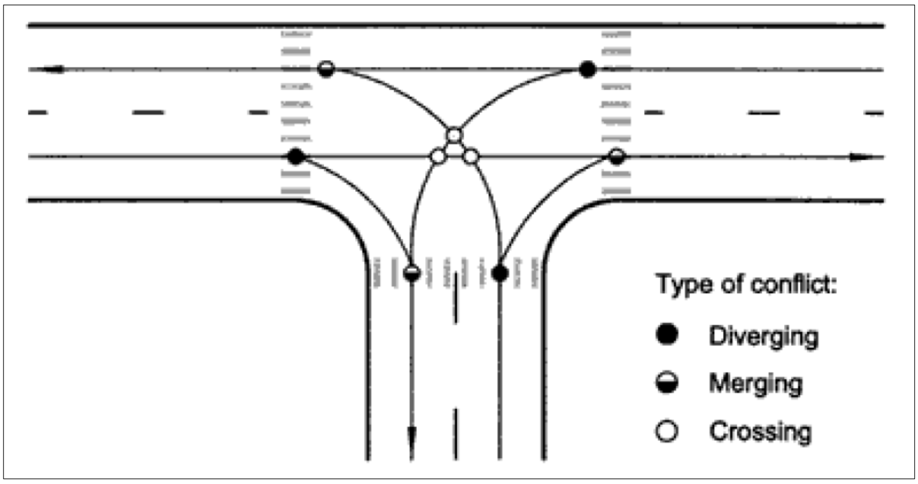



Figure 2.3: Conflict points at T-intersection (Nabaee, 2011).

## 2.4 Characteristic of Motorcyclist on Road

In Malaysia, the most popular form of a motorcycle on the road is one with a small engine capacity that less than 250c.c.(Leong *et al.*, 2008). Riding experience tends to be more important for motorcycle riders than for drivers of vehicles with more than two wheels, most likely due to the additional control and balance skills needed for motorcycle riding (Chang and Yeh, 2007). According to MHCM 2006 (Ministry of Works, 2006), motorcyclist volume is higher at typical morning and evening peak hours, with the evening peak volume is higher than the morning peak.

The size of a motorcycle is smaller than other vehicles on road. Ali Sahraei *et al.* (2018) mentioned that one special characteristic of motorcyclists is they can travel side to side with other vehicles within a lane, and Ministry of Works (2006) commented that this results in an unstructured discipline of flow. The length of the motorcycle's wheelbase is around 1.68 m only. It is much shorter as compared to the length of a passenger car which is around 5.8m, a single unit truck which is around 9.1m and a truck combination which is around 16.7m (Public Works Department Malaysia, 2000). As such, motorcycles can weave in and out of traffic flow easily due to their short length. Ali Sahraei *et al.* (2018) explained that this characteristic allows the motorcyclist to move nearer to the stop line at the front, eventually the delay of the motorcycle at a junction is less than other vehicles. The concept of First-in-First-out (FIFO) in unsignalised intersection is violated (Ministry of Works, 2006). However, the size of the motorcycle is also a concern for motorcyclists as it is. Pai (2011) pointed out that a motorist's inability to spot a motorcycle can also be due to the fact that a motorcycle may be easily camouflaged by its surroundings and concealed by larger vehicles nearby, or an in-vehicle/nature obstacle (e.g., tree or curved roadway).

According to De Lapparent (2006), the probability of a serious/fatal accident involving a motorcyclist at an intersection is greater than the probability of a serious/fatal accident involving a motorcyclist at non-intersection. Pai and Saleh (2008) pointed out the complexity of conflicting movements between a motorcycle and other vehicles at a junction increases the severity of motorcyclists' injuries. Besides, small-sized motorcycle in traffic is not prioritised as much as other larger road users. Moreover, motorcyclists are prone to severe injuries or fatality as motorcyclists do not have protective structure while riding motorcycles, unlike other vehicles' drivers (Pai and Saleh, 2008, World Health Organization (WHO), 2009). This means that motorcyclists are more vulnerable than other drivers when crashes happened.

### 2.4.1 Theory of Planned Behaviour

The Theory of Planned Actions (TPB) predicts a human's intention to participate in a behaviour at a given time and location. The theory was meant to describe all actions for which people have self-control ability. The main component of this model is the behavioural intention, which is influenced by the attitude about the probability that the action will have the desired result and the subjective assessment of the risks and gains of that outcome. Ajzen (1999) explained the stronger the intention to involve in behaviour, the more likely it will happen. The performance may be impacted by non-motivational factors such as the availability of required opportunities and resources. As a whole, these factors reflect people's actual control over their behaviour. If an individual has the necessary opportunities and resources, and intends to perform the behaviour, he or she should succeed in doing so.

In TPB, the behavioural outcome is dependent on both motivation (intention) and ability (behavioural control). Ajzen (1991) postulated three conceptually independent beliefs of intention: attitude toward the behaviour (global positive or negative evaluations of the behaviour), subjective norm (consideration of the social pressure which the performance of behaviour will gain social approval or disapproval from important social referents) and perceived behavioural control (if the behaviour is perceived to be easy or difficult to perform). Figure 2.4 depicts the theory in the form of a structural diagram.

TPB was always used to explain human's behaviour, especially for aggressive and violated behavioural intentions and behaviours. Elliott (2010) implemented TPB in his motorcyclist speeding analysis and the results provide strong support for the TPB. Palat and Delhomme (2012) discussed the factors of drivers go through yellow traffic lights and concluded these TPB factors have a significant impact on people's decision to proceed at a yellow light.

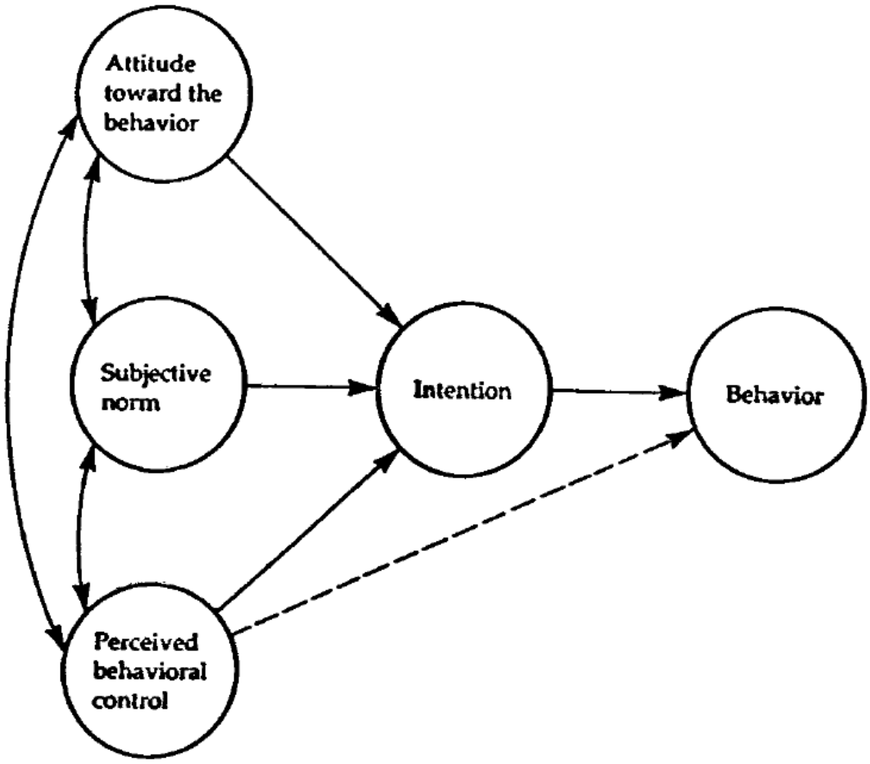



Figure 2.4: Theory of Planned Behaviour (Ajzen, 1999).

### 2.4.2 Motorcyclist Risky Riding Behaviour at T-junction

Motorcyclist collisions have long been linked to risky behaviour (Hj.Hamid *et al.*, 2005). It was found by Clarke *et al.* (2005) that the accidents involved by young motorcyclists were the consequence of their risk-taking riding behaviour, rather than lack of skills. For the young motorcyclists, especially males, driving or riding is a chance for them to show off.

Interestingly, Horswill and Helman (2003) did a behavioural comparison of the motorcyclists and a matched group of non-motorcycling car drivers and mentioned that in terms of behaviour factor and gap acceptance factor, motorcycle riders on the motorcycles were riskier than motorcycle riders in the cars and drivers in the cars. This concluded that risk-taking behaviour is not a characteristic of being a motorcyclist but a characteristic of being on a motorcycle. Table 2.1 summarises the potential factors for risky behaviour at the intersection (Abdul Manan and Várhelyi, cited in Varhelyi, 2018).

Table 2.1: The list of potential variables as risk factors identified by the qualitative observational study at access point sites (Abdul Manan and Várhelyi, cited in Varhelyi, 2018).

| Category | Elaboration |
|---|---|
| Age | young/middle-aged/old |
| Gender | male/female |
| Protective clothing | helmet: not worn/worn securely fastened/worn loosely<br>foot protection: considerable foot protection/no foot protection<br>with/without sun glare protection |
| Visibility of the rider | clothing: striking/dark/light<br>motorcycle appearance: striking/not striking<br>with/without headlight |
| Motorcycle condition | good/fair/poor |
| Approach behaviour | fast approach/slow approach |
| Turning signal usage | activated/not activated |
| Stopping behaviour | passing without slowing down/slowing down and creeping/full stop |
| Position of stopping | at the stop line/after the stop line |
| Head movement | none/only to the right/only to the left/in both direction |
| Eagerness to enter | eager/calm |
| Gap on major road | limited/ample |
| Entering angle | sharp/right-angle |
| Behaviour during entry | hesitancy: hesitant/non-hesitant<br>cautiousness: cautious/not cautious<br>eye contact with approaching vehicle: yes/no |
| Manner of entry into the flow on major road | enters after a passing vehicle/enters in front of a passing vehicle/squeezes in-between two consecutive vehicles/opposite indirect right turn |
| In case of traffic conflict | evasive action by subject rider: yes/no<br>evasive action by vehicle on major road: yes/no |

A risky right-turning maneuver, termed as 'Opposite Indirect Right Turn' (OIRT) is mentioned by Abdul Manan (2014). As shown in Figure 2.5, first the motorcycle turns right into the near side of the major road, then travels in the opposite direction, and crosses the middle line into the far side of the major road to continue its desired direction.

This behaviour was recorded by Amin and Maurya (2015) too as they found two-wheeled vehicles from a minor approach tend to move opposite to the traffic of major road slowly and exit through a smaller gap available upstream of the junction, especially in a harsh condition. Abdul Manan (2014) also observed that this movement is performed by 18% to 26% of motorcyclists when turning right from minor road to major road on a high traffic volume junction, as this movement could save the waiting time of motorcyclist. Since there is oncoming traffic as they move in opposite directions, there is a high risk of a head-on collision. This risky movement is common in Malaysia, however, there has not been much research done on it.

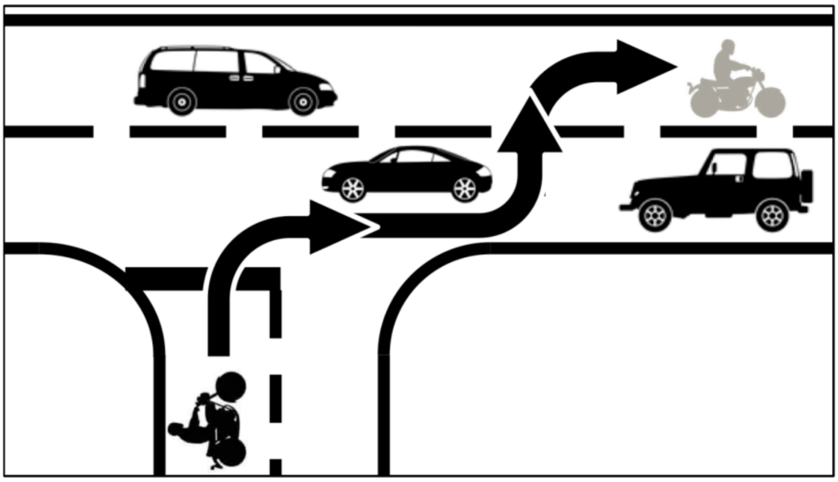


Figure 2.5: Opposite Indirect Right Turn (Manan, 2014)

Ahmed *et al.* (2016) recorded one risky right-turning behaviour performed by the motorcyclists on a narrow major road and named it as 'Weaving Merging Right Turn (WMRT)', which is different from a conventional right turning, as illustrated in Figure 2.6. A typical right turn allows the motorcyclist to turn, accelerate and merge at the same time, while WMRT performs three tasks separately.

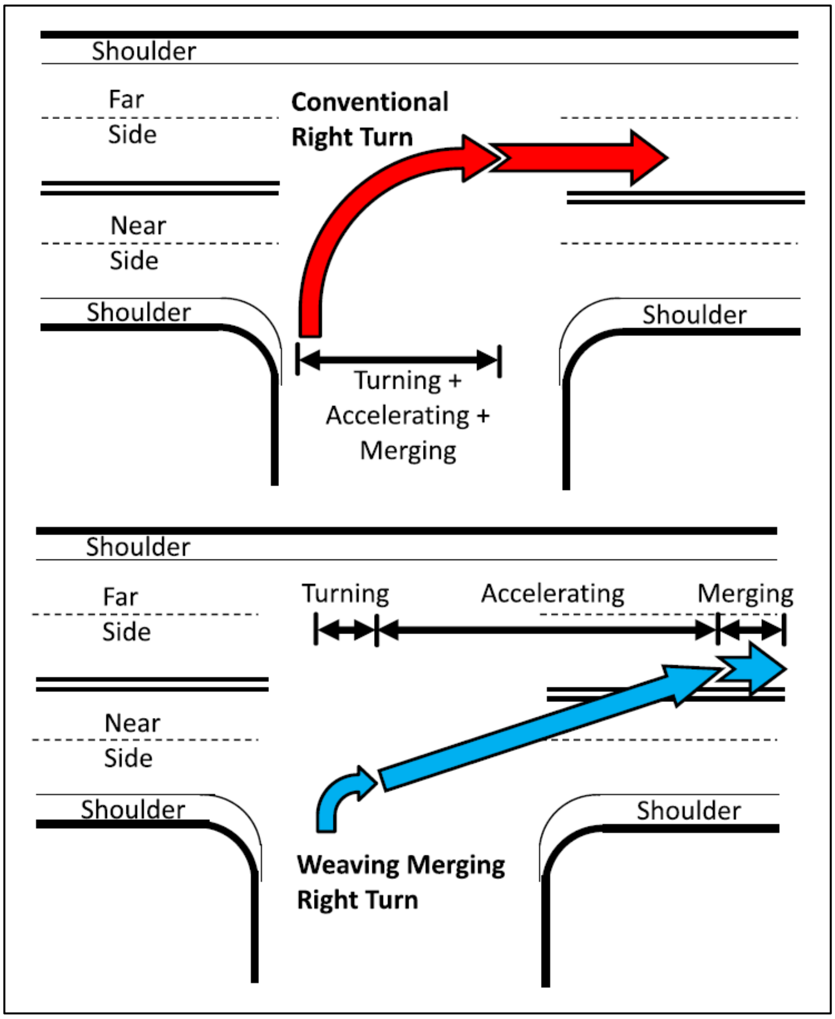



Figure 2.6: Weaving Merging Right Turn (WMRT) and Conventional Right Turn (Ahmed *et al.*, 2016)

According to Wan Ibrahim and Sanik (2007), the queuing characteristics of motorcycles usually do not follow the conventional traffic rules i.e. First-In-First-Out or Last-In-Last-Out. Motorcycles usually follow the First-In-First-Out and Last-In-First-Out rule due to the small size and agility of the motorcycles. Besides, turning without turning indicator is one of the motorcyclist risk-taking riding behaviours at T-junction (Pradhan *et al.*, 2005, Kosaka *et al.*, 2007, Muttart *et al.*, 2011, Abdul Manan, 2014, Ahmed *et al.*, 2016). It makes the drivers on a major street more vigilant, which tends to avoid collisions. Rusli *et al.* (2020) mentioned males engage in turn-signal neglect more than females.

Another risky behaviour is non-compliant with the stop rule (Abdul Manan, 2014, Ahmed *et al.*, 2016, Advani *et al.*, 2020). Stopping at the stop sign allows a driver to make the right decision about the availability of gap, speed and size of major road vehicle. From the result of Abdul Manan (2014), most motorcyclists do not make a complete stop at the stop line before turning right when there is no vehicle on the major road. He also stated that a small portion of motorcyclists just check the traffic on the far side of major road by turning their heads to the left only. Aggressive riding or force merging of a motorcyclist is also observed at T-junction, stated by Kaysi and Abban (2007), Kaysi and Alam (2000), Lord-Attivor and Jha (2012), Abdul Manan (2014). Advani *et al.* (2020) explained aggressive driving occurs when vehicles from a lower-priority stream (minor road) cross a higher-priority stream (major road), causing drivers on the major road to slow down to create a longer gap.

### 2.4.3 Contributary Factors to Motorcyclist Risky Riding Behaviour

#### 2.4.3(a) Human Factors

Most of the motorcyclist's risky riding behaviours on roads are related to human factors. Age is one of the human factors as Chang and Yeh (2007), Sultan *et al.* (2016) and Goh *et al.* (2020) found young motorcyclists are more likely to engage in risk-taking riding activity while on the road. Several traits of young people such as sensation seeking, attention attracting, high selfishness, anger and unrealistic optimism have increased greatly their willingness to take risks (Dahlen *et al.*, 2005, Wong *et al.*, 2010, Falco *et al.*, 2013, Hassanzadeh *et al.*, 2020). By performing risky riding behaviour on road, adolescents may prove themselves to the public, show their "adultness", be accepted by friends, and satisfy their need for challenges to prove that they are free and