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Safe Braking Distance at Signalized Intersection

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Abstract*: Signalised intersection is an area where most of the drivers having dilemma in making decision to either pass through the intersection or stop when the light turns to yellow. During this phase, a sudden deceleration and incorrect estimate of intersection clearance time cause rear-end collision, severe right-angle crash and left-turn head-on collision. Therefore, the aim of this study was to determine the safe braking distance at signalised intersection by using the concept of stopping sight distance, so that a set of road marking and road sign can be proposed to help the driver in making decision within the dilemma zone. Samples of vehicle's approaching speed were collected at a signalised intersection within the Ipoh-Lumut Highway in Perak Tengah. Statistical analysis showed that the observed 15th and 85th percentile speed at the intersection were 66.2km/h and 88.5km/h, with a mean and standard deviation of 77.5km/h and 9.99km/h. Goodness-of-fit tests showed that the distribution of the approaching speed at the intersection was normally distributed with a probability of 14.4%. It was concluded that safe braking distance from the stopping line of the signalised intersection is between 97m for lower speed limit to 152m for the upper speed limit.

***Keywords*: Signalised Intersection, Safe Braking Distance, Yellow Light, Dilemma Zone**

I. INTRODUCTION

At-grade Intersection refers to a location on the roadway where two or more roads crossed whose primary function is to provide an avenue for change in route direction. Intersection can be classified as simple or complex intersection, if only two roads crossed each other at right angle, it is term as simple while the latter is having more than two roads crossing at the same area [1]. It is an area with high potentials for accidents and crashes because drivers are required to make a complex decision in a relatively short period of time as to which direction they may wish to take [1, 2]. There are many methods employed to reduce the conflicts occurring at intersection such as accident, crashes and delay at intersection some of which are Channelization, circles or rotaries, grade separation, and Signalisation [1].

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Intersection signalisation is the most effective and common intersection dynamic control system used in many countries to effectively reduce and manage traffic conflict and also decrease excessive delay of commuters at intersection. Mannering et al. [3] underlined that the installation of traffic signal at intersection is by no means the perfect solution for delay or accident problems. Some traffic signals are installed with count-down timer while others are not having it. Ibrahim et al. [4] studied the effect of count-down timer at some intersections in Malaysia, he reported that count-down timer has significant effect on headway with small effect on initial delay. Compared to non-count-down timer, the count-down timer motivate higher speed of drivers [5]. However, Traffic signal is arguably blamed for the increase of rear-end-collision [6]. All commuters driving at the design speed are expected to clear the intersection safely at the end of the green period or safely stop at the stopping line at the end of the yellow period. Vehicle type, speed, distance of the vehicle from stop line and duration of yellow light signal were found to have significant effect on the driver's decision making process [7]. However, according to the 2015 accident data from Royal Malaysian Police (RMP), a total of 489,606 accidents occurred in Malaysia and over 1,000 of them happened at signalised type intersections. Many of the accidents at this spot are believed to be closely related to drivers' decision of running through the intersection during yellow light. Every driver that undergoes this phase will eventually question his/herself whether to go or stop during this time. This zone is known as dilemma zone or yellow light dilemma zone where the driver neither safely stop before the stop line nor proceed through the intersection during the interval time between yellow light and red light [8].

Lu et al. [8] stated that dilemma zone is an area where the driver neither can pass through the intersection nor stop before the stop line without sudden deceleration. Dilemma zone is categorised into Type 1 dilemma zone and Type 2 dilemma zone. According to Zhang et al. [9], Type 1 dilemma zone was discovered by Gazis et al. [10] which defined dilemma zone as a zone where driver neither successfully pass through the intersection nor comfortably stop before the stop line if they are within this area as illustrated in Figure 1.

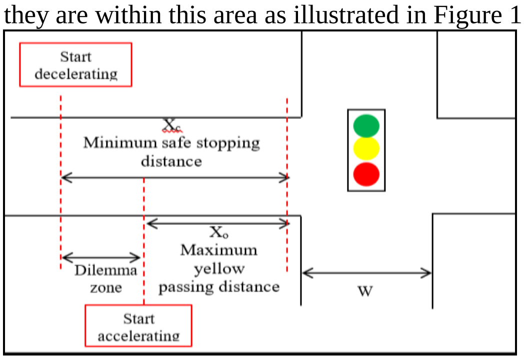

Figure 1. Type 1 dilemma zone

Refer to Figure 1, X_c is the minimum distance required by driver to be able to safely stop before the stop line. In other words, this is where the driver need to start decelerating their vehicles. X_o is the maximum distance that the driver can have if they want to run through the intersection without violating red light.

Type 2 dilemma zone can be explained from a study conducted by Lu et al. [8]. They stated that at signalised intersection, every driver will encounter four different zones. These four zones are named as “should-go zone”, “should-stop zone”, “dilemma zone” and “optional zone” as shown in Figure 2. Depending on signal timing, approaching vehicle speed and vehicle distance from the stop line every driver need to decide to either pass through the intersection or stop when the light turns to yellow.

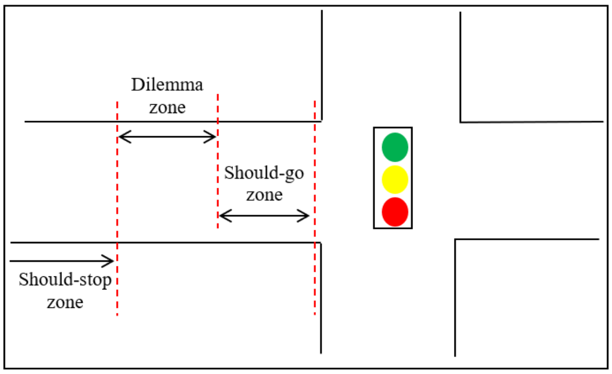

Figure 2. Type 2 dilemma zone

Klein et al. (2006) also found that these four zones was used by the Federal Highway Administration under difference term which are “Cannot Stop Zone”, “Cannot Go Zone”, “Dilemma Zone” and “Optional Zone”. Compared to that of Type 1 dilemma zone, it was discovered that an optional zone exist where the driver may have trouble to decide upon seeing the yellow light. The driver will encounter this optional zone when the minimum safe stopping distance (X_c) is less than the maximum passing distance (X_o) [8]. The Dilemma zone is usually encountered when the driver approaches the intersection with a high speed [11]. Moreover, the length of the dilemma zone increases as the approaching speed increases [9].

A number of studies have been done regarding the human behaviour and dilemma zone. According to Hurwitz et al [12] Type 2 dilemma zone can cause an accident when the driver makes a sudden deceleration and incorrect estimate of intersection clearance time, the situations which usually cause rear-end collision, severe right-angle crash and left-turn head-on collision. It was stated that Dilemma zone is a zone of greater risk of collision occurrence as the drivers become confuse as to whether proceed the intersection or to stop [13]. This phenomenon is the main reason for the installation of green extension at high-speed intersection.

This study was aimed to determine the safe braking distance from the stop line when vehicle encounter yellow light running at signalised intersection, so that a set of road marking and road sign can be proposed to help the driver in making decision within the dilemma zone. This was achieved by investigating the approaching speed of vehicles at the observed signalised intersection and determining the minimum and maximum distance from stopping line by using concept of stopping sight distance. Three basic elements were considered in this study: human factor (perception reaction time), traffic consideration (vehicle speed), and physical elements (conflict area, sight clearance).

A. Perception Reaction Time

Drivers or human behavior is one of the critical components that affecting the traffic system. Perception reaction time (PRT) is the second critical driver characteristic that need to take a consideration when involving traffic engineering [14]. Perception reaction time is a time needed for a driver to make an action after they encounter to some events. Roess et al. [14] stated that the driver need to go through four processes during the perception and reaction time. The processes are detection, identification, decision and response. The same concept also was used by Fu et al. [15] to explain and defined about PRT which they simplified it into perception, judgement and manipulation. Like all human characteristic, PRT are varies among drivers because every driver has different time to response and take an action on something. Furthermore, PRT is an important parameter that need to take into consideration to compute stopping sight distance. The current PRT value that recommended by the American Association of State Highway and Transportation (AASHTO) is 2.5s. This value was adopted after all the factor was take into a consideration including driver’s age, emotional and physical conditions. The PRT value that recommended by Institute of Transportation Engineers (ITE) is 1.0s but many studied disagreed and argue that 1.0s for PRT value is not sufficient. Taoka [16] stated and recommend that PRT value is between 1.5 s-1.8 s since this PRT represented by 75th and 85th percentile of the drivers. Usually the PRT value that obtain from road studies are shorter compare to the real value [15]. A field study that was conducted by Gates et al. [17], shows that the 15th, 50th and 85th percentile brake reaction time in dilemma zone for first-to-stop vehicles were 0.7s, 1.0s and 1.6s. Recent research by Shawarby et al. [18] that take consideration of rainy weather stated that PRT value increase as time to intersection increase. They also claimed that the PRT value will increase when the vehicles moving towards upgrade section. Fu et al. [15] was conducted a study to compare the Brake Perception Reaction Time (BPRT) value at signalize intersection with and without countdown timer. Their research shows that BPRT without countdown timer was ranged from 0.12 s to 3.8 s while BPRT with countdown timer ranged from 0.04 s to 4.02 s. They also claimed that the value of BPRT was greater than recommended by ITE which 1.0s whether there is presence of countdown timer or not. The study also concluded that BPRT value for 85th percentile with countdown timer (2.52s) is longer compared to without timer (1.26s). Another study that was conducted by Li et al. [19] shows that BPRT without timer are greater compared to with timer. They claimed that drivers enter the intersection faster when there is presence of countdown timer.

B. Braking Distance

Braking distance of a vehicle on a roadway is one of the elements that need to consider when calculating the stopping sight distance. Braking distance can be calculating by using equation 1.

$$d = 0.039 \frac{V^2}{a} \quad (1)$$

While d is the braking distance, V is the design speed in km/hr and a is the deceleration rate in m/s^2.

Design speed is a selected speed used to determine the various geometric design features of the roadway. To determine the design speed, several factors need to be consider such as the topography, operating speed adjacent land use, and functional classification of the highway. Most of the drivers decelerate their vehicle when faced unexpected situation or object at a rate greater than 4.5m/s2 (14.8ft/s2). From the studies, 90th percent of all drivers decelerate their vehicle at a rate greater than 3.4m/s2 (11.2ft/s2). Therefore, AASHTO (2011) recommended 3.4m/s2 (11.2ft/s2) as the deceleration for determining the stopping sight distance such this deceleration is within the driver's capability to maintain steering control and stay in their lane during the braking process.

C. Stopping Sight Distance

Stopping sight distance is a minimum sight distance required for a driver to stop the vehicle after seeing an object during the path without hitting the object. According to AASHTO (2011) [20] sight distance is the length of the roadway ahead that is visible to the driver. This distance should sufficiently enough for a vehicle traveling at or near the design speed to stop before reaching the object. Stopping sight distance is the summation of distance travelled during driver perception/reaction time and the braking distance [21]. This concept also applied by AASHTO (2011) [20] which define stopping sight distance is the sum of the distance traversed during the brake reaction time and the distance to brake the vehicle to a stop. By assuming the worse-case condition (wet pavement conditions) and on level roadways stopping sight distance are expressed as follows,

$$SSD = 0.278Vt + 0.039\frac{V^2}{a} \quad (2)$$

Where, SSD = Stopping Sight Distance
V = Design Speed, km/hr
t = Braking Reaction Time, 2.5s
a = Deceleration rate, $3.4m/s^2$

When the road is on a grade the formula for stopping sight distance will be modified as follows,

$$SSD = \frac{V^2}{254\left(\left(\frac{a}{9.81}\right) \pm G\right)} \quad (3)$$

Where G is the percent of grade divided by 100 and the other parameters are as previously stated.

Reaction time should consider in order to calculate stopping sight distance. Brake reaction time is the interval from the instant that the driver recognizes the existence of an obstacle on the roadway ahead that necessitates braking to the instant that the driver actually applies the brake (AASHTO, 2011). Normally driver who travel with design speed or near the speed will more alert company to driver that travel lesser than the design speed.

Table 1 shows the stopping sight distance that was adopted by Malaysia different from the minimum stopping distance that was developed by AASHTO (2011) by using the design speed (km/h), 2.5s for break reaction time and 3.4m/s2 (11.2ft/s2).

Table 1: Minimum SSD (adopted by Malaysia)

Design Speed (km/h)	*Min Stopping Sight Distance (m)*
110	250
100	205
90	170
80	140
70	110
60	85
50	65
40	45
30	30

D. The 85th and 15th Percentile Speed

Statistical technique show that a normal probability distribution will occur when a random sample of traffic is measured. The speed of the vehicles either too fast or too slow can be determine from the frequency distribution curves. This mean that certain percentage of drivers drive too fast for the existing conditions and certain percentage of drivers travel at unreasonably slow speed compared to the trend of traffic can be determine. Most cumulative speed distribution curves "break" at approximately 15 percent and 85 percent of the total number of observations. Figure 3 show the example of cumulative speed distribution curve.

Vehicles that traveling above the 85th percentile are assuming to be exceeding a safe and reasonable speed while vehicle traveling lower than 15th percentile are considered to be traveling unreasonably slow.

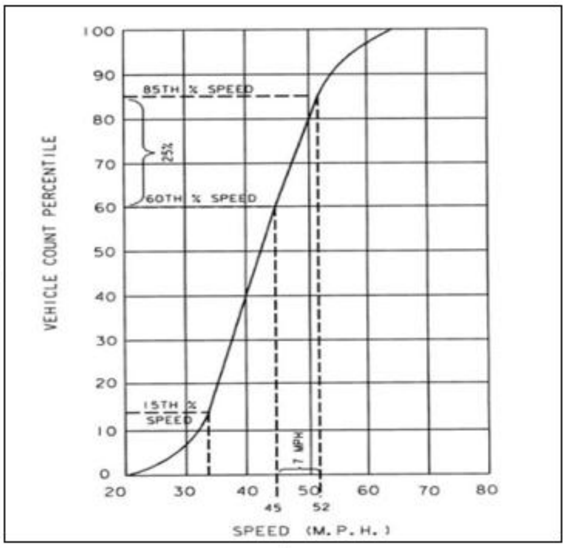

Figure 3: Cumulative speed distribution curve (adapted from manual of Procedure for Establishing Speed Zone, 2015)

E. The Standard Normal Distribution

Stati Normal distribution commonly used for statistical distribution which look like a bell- shaped curve as shown in Figure 4.

The total probability under the curve is 1.00 and as shown in figure below, the curve is equally divided or symmetrically from the mean.

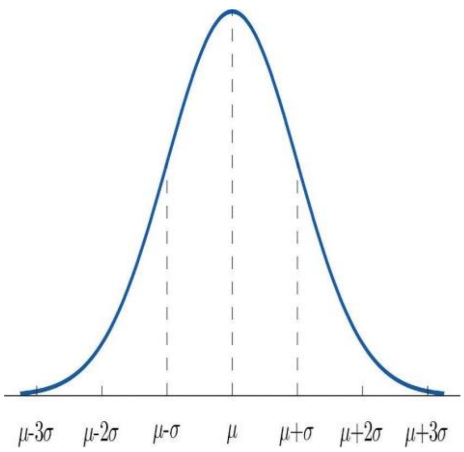

Figure 4: Shape of the Normal Distribution Function

Normal distribution usually involving of mean and standard deviation of data set. This can be calculated by computing the value in the formula as shown in equation 4.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-[\frac{(x-u)^2}{2\sigma^2}]} \qquad 4$$

where x = normally distributed statistic
μ = true mean of the distribution
σ = true standard deviation of the distribution
π = 3.14

II. METHODOLOGY

A. Study Area/Location

One signalized intersection was chosen for field observation in Tronoh, Perak as shown in Figure 5. Tronoh is located 28km from Ipoh town. This intersection was on a federal road along Ipoh-Lumut Highway. This intersection is a three-leg or T intersection which is determined by the number of its intersecting legs. According to Road Traffic Volume Malaysia, road along this intersection is categorize under level of service (LOS) A which is defines as free flow traffic and higher speed. Several criteria were considered for selecting this intersection. The criteria are sufficient sight distance, on the level grades, not influence by countdown timer and on high-speed area. The main parameter of concern was the approaching speed of the vehicles. The device and the observation off-sight from the driver, this is because usually drivers will slow down their vehicles when they realize the presence of observer and they will think that they are being monitored. Currin [22], suggested that to collect a quality data which is true free flow speeds, the location of speed survey must not influence and give impacts to the behavior of the drivers. This will cause the speed obtained lower than normal speed than it should be.

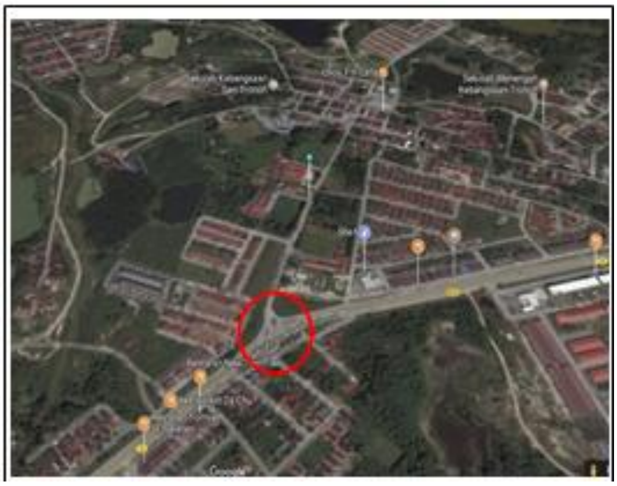

Figure 5: Site location (Intersection at Tronoh, Perak)

B. Measuring Device

In this research, field observation was done to obtain the approaching speed of vehicles before the drivers enter the intersection. ProLaser 4 which is a speed measuring device as shown in Figure 6 was used to collect the speed of vehicles throughout the entire survey. The parameter such as speed, distance and time during the observation were recorded and displayed on the device's screen.

Figure 6: ProLaser 4 (Adapted from Kustom signals inc, 2014)

The ProLaser 4 has an ability to measure speed from 0km/h up to 320km/h. To ensure this device can perform well during the field observation, range and speed accuracy test were done before the real field observation start. Therefore, the device was pointed to a stationary object and make sure the speed reading is 0km/h.

C. Field Observation

The approaching speeds of the vehicles were collected under free flow conditions. This is to ensure that the vehicle's speeds were not influenced by another factor except the road geometry.

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According to Roess, et al, [14], speed studies should not be conducted if the capacity are 750-1000 veh/h/ln. Road traffic volume that was conducted by Department of highway planning division shows that the volume of vehicles along the road from Ipoh to Lumut and Lumut to Ipoh does not exceed 750veh/h/ln. This survey was done on Monday, Friday and Sunday (weekend) during the Morning (AM) and Afternoon (PM) peak hour periods. Basically, different location has different peak hour which was influence by human activities such as work, school, shopping and many more. According to Falcocchio and Levinson [23], AM peak hour begins at 6:00am and ends at 10:00am while PM peak hour begins at 3:00pm and ends at 7:00pm. The peak hour for this particular location are 8:00am to 9:00am and 5:00pm to 6:00pm. This field observation or speed survey at Tronoh intersection was conducted from 8:00am to 9:00am (morning peak hour) and from 5:00 pm to 6:00 pm (evening peak hour) on sunny days October 6th (Friday), October 8th (Sunday) and October 9th (Monday), 2017. Besides, this study only targeted vehicles that approaching the intersection during the green and yellow phase. Even though, this survey was done during peak hours, but it still under free flow conditions as stated by Road Traffic Volume Malaysia. The ProLaser device was located approximately 350m from the stop line and aimed at the targets (approaching vehicles). The vehicle's speed was measured in both direction which is from Ipoh to Lumut (Direction 1) and from Lumut to Ipoh (Direction 2). All the measured approach speeds were recorded in the spot speed studies form and the data were used for the analysis. Figure 7 shows the illustration of the set up.

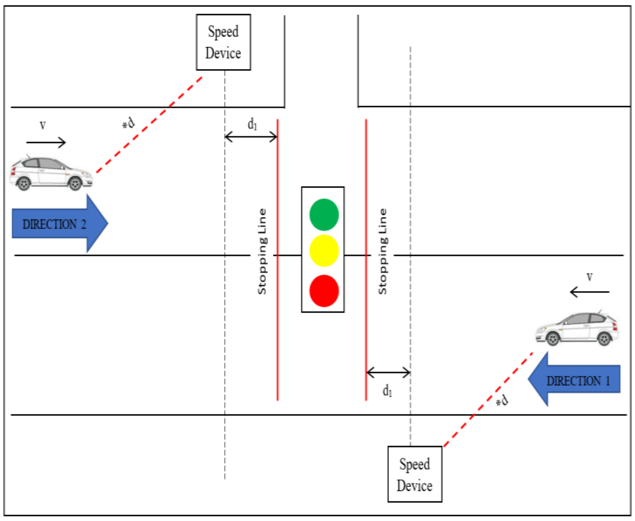

Figure 7. Illustration of experiment setup

III. RESULT AND DISCUSSION

A. Field Observation

From the field observation at Tronoh Intersection, a sample data of 377 speed of vehicles was collected for three days. As shown in Figure 8, most of the drivers drive their car within the ranged of 66km/hr to 90km/hr which is within the posted speed limit. This figure also shows that speed group between 76km/hr to 80km/hr have a greater number of frequency compared to others.

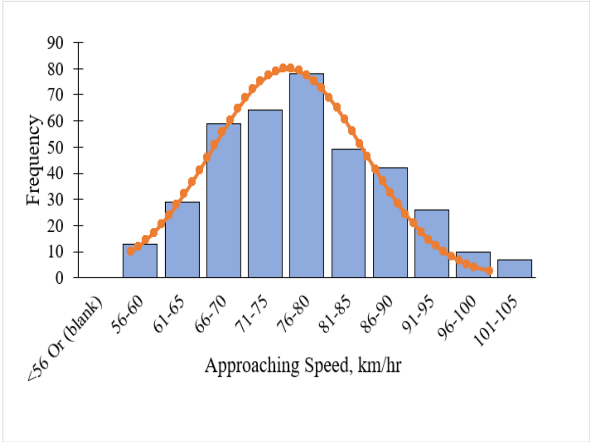

Figure 8. Distribution of approaching speed at the observed signalised intersection

At this intersection, the sample data of approaching speed ranged between 57km/hr to 104km/hr with a mean of 77.5km/hr. As shown in table 2, the data are normally distributed with a standard deviation of 9.994km/hr.

Table 2. Descriptive statistic of approaching speed

Statistic	Value
Sample size	377
Minimum	57.0
Maximum	104.0
Mean	77.5
Median	76.8
Std. deviation	9.994
Coeff. of variation	0.13

The value of standard deviation and coefficient of variation which are 9.994 and 0.13 shows that the data collected are quite widely dispersed around the mean value. The fact that volume of traffic is quite difference during the survey could explain the reason why the data have greater spread from the mean speed.

B. 85th and 15th Percentile Speed

Frequency and cumulative frequency distribution curves were plotted by using data and information from prepared frequency distribution table as shown in figure 9. Frequency distribution curve shows that the value of modal speed is 78.0km/hr. This modal speed indicate that most of the drivers are likely to drive at a speed of 78.0km/hr during the green and yellow phase at the intersection. As shown in the figure, the median speed is 76.8km/hr. This value indicates that 50% of the drivers drive their vehicles at equal to or less than 76.8km/hr.

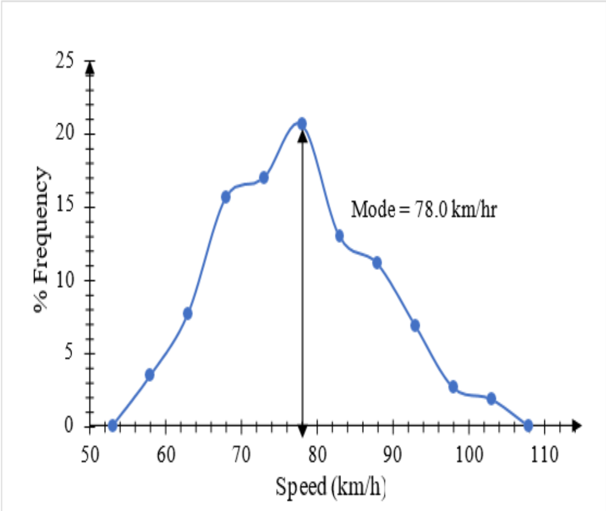

Figure 9: Frequency Distribution Curve

Figure 10 shows the cumulative speed distribution which have a normal like curve. As shown in the figure, the 85th percentile speed used to approach the intersection was roughly about 88.2km/hr. This shows that 85% of drivers drive their vehicles at 88.2km/hr and below. This indicates that the vehicles move approximately 24.5m per second during the green and yellow phase. Besides, Figure 10 also shows that 15% of drivers drive their car at 66.2km/hr and below during green and yellow phase light.

Using this 85th percentile as reference point, the percentile of vehicles that exceed this speed are not significant. This indicate the percentage of drivers that travel too fast for the existing roadway conditions. Same goes to vehicles that travel below the 15th percentile which represented that the vehicles travel at unreasonably slow speed compared to the trend of traffic along the roadway.

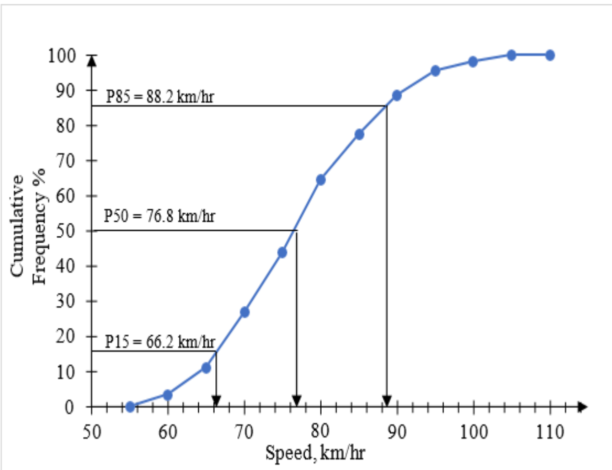

Figure 10: Cumulative Frequency Distribution Curves

85th and 15th percentile can be represented as upper and lower limit of the speed. Referred to Figure 10, the upper and lower limit speed to approach Tronoh intersection are 88.2km/hr and 66.2km/hr respectively.

C. Testing for Normality: The Chi Square Goodness-of-Fit Test

The Chi-Square Goodness-of-Fit Test was adopted to analyzed the data for Normalcy. From the analysis, it was shown that there were 14.4% possibility that a value of 11.137 or greater than that would occur if the distribution were statistically proven as normal distribution. In this research, the probability of 11.137 or higher is 14.4%. This test proved that the observed data (approaching speed) and the assuming mathematical form are not significantly different and shows that the data are normally distributed. This can be explained from Roess et al. [14] which stated that there is significant difference in the data collected when the probability is 5% or less.

D. Stopping Sight Distance

As stated earlier, concept of stopping sight distance will be used to determine the safe braking distance from stopping line at the signalized intersection. In this section, the safe braking line will be determining by using 88.2km/h and 66.2km/h as the approaching speed for upper and lower limit, 2.5s as the constant brake perception reaction time and 3.4 m/s2 as the constant deceleration rate of vehicles. As shown in Figure 11, the theoretical safe braking line for vehicles at the observed intersection is between 97m – 152m from the stopping line. These safe braking line indicate that for vehicles that are moving within the 85th percentile speed required at least 152m from the stopping line to start matching the brake in order to stop before traffic light turns to red. This is an area where the vehicles need to start decelerating their car so that they can comfortably stop before the stop line.

Amber light (length of yellow light to red light) at observed signalized intersection is 3s. Theoretically, with speed of 90km/hr (design speed), the vehicles moving at 20m per second will therefore need at least 60m to move within the 3s of amber light. Based on the results and analysis, the minimum distance from stopping line is 97m which exceed 60m so the minimum distance from the calculation can be used. This indicate that the vehicles can pass through the intersection during amber light if they are 97m from the stopping line. Therefore, for vehicles that are moving within the 15th percentile speed, they require shorter length to start decelerating their vehicles which is 97m from the stopping line. In this research, 85th percentile speed is more concern compared to 15th percentile speed because usually higher moving speed vehicles have difficulty to decelerate their car during the amber time. This condition usually occurs because of the brake perception reaction time. As mentioned by Fu et al. [15], driver's perception reaction time will decrease as approaching speed at yellow onset increased. This claims that vehicles that moving in higher speed have shorter reaction time and tend to proceed their car through the intersection during amber time. For vehicles that have higher approaching speed, they can use this safe braking line in order to help them to make a decision either to pass through the intersection or to start decelerating their car during the yellow-onset. This is means that the vehicles need to start decelerating their vehicles if during the amber time they still not within the safe braking line because they will not have enough time to clear the intersection even though they increase the acceleration rate.

Therefore, the vehicles can successfully clear the intersection during the amber light if they already pass through the safe braking line.

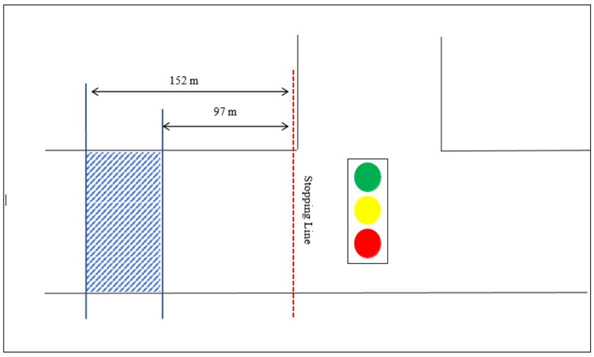

Figure 11: Theoretical Safe Braking Line at Tronoh Intersection

IV. CONCLUSION

In this paper, a safe braking distance at the signalised intersection was determined by using the concept of stopping sight distance. From the results of the descriptive statistics, the 15th and 85th percentile of speed is 66.2km/h and 88.2km/h. The results show that most of the drivers drive their car within the posted speed limit of 90km/h. The lower and upper limit of the speed were used in order to determine the distance of safe braking from the stopping line during yellow-onset time. From the study, it shows that the safe braking distance from the stopping line is between 97m to 151m. This study did not consider weather and roadway level condition. Hence, more factors need to be considered for future study.

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CONFLICT OF INTEREST

No conflict of interest.

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