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OPERATING SPEED OF VEHICLES DURING RAINFALL AT NIGHT: CASE STUDY IN PONTIAN, JOHOR

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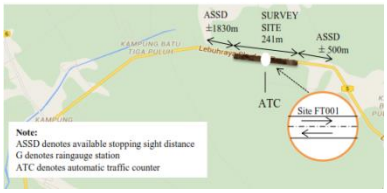
Graphical abstract



Abstract

Speed is one of the important parameters of traffic flow that can be used to determine the performance of driver's behaviour under various scenarios. Changes in weather conditions caused changes in drivers' speed due to various reasons. In Malaysia, there is slightly high number of road accidents at night. Rainfall at night does not only cause poor visibility to drivers, but it also gives a sense of insecurity especially as there is a significant reduction in the visibility of the object in front. Improper road conditions can worsen the situation, for example, rainfall can cause water accumulation on road surfaces which can increase skidding problem, potholes and hydroplaning effect. In relation to these situations, hence it is crucial to understand how the abrupt situation affect response of driver's in terms of the macroscopic behaviour. These unpredictable environmental changes seem like portraying a very unpleasant journey for drivers especially to travel under rainfall condition at night. Therefore, there is a need to observe how individual vehicles react in terms of speed adjustment and response to the different rainfall intensities downpour at night. Hence this study was conducted to determine the impact of different rainfall intensities at night on vehicles' speed. Traffic data was obtained using automatic traffic counter at a cross section of a road at Pengkalan Raja, Pontian for about three months during monsoon season. Rainfall data report was obtained from the Department of Drainage and Irrigation, Pontian. From this study, it was found that there is a speed reduction from the dry condition regardless of rainfall intensities at night. As rainfall intensities at night higher, the speed reduction is higher as well except for heavy rainfall condition. The mean speed, 15th percentile and 85th percentile of vehicles decrease with the increase in rainfall intensity at night. It can be concluded that rainfall have impact on vehicle's speed irrespective of their intensities. Findings from this study can be used to help local authorities and transport planners in planning an efficient traffic management system for a safer travel experience to road users in Malaysia.

Keywords: Speed, rainfall, night

1.0 INTRODUCTION

Weather is one of the important parameters affecting transportation performance on road. The intensity of light and rainfall are among other factors that contribute to the changes of speed and travel time during driving [1]. These factors have significant impact on visibility of drivers during driving that affect drivers psychologically and physiologically. Currently, there are only a few research works on tropical weather impacts on transportation systems especially rainfall at night. Even though the effect of rainfall has on transportation is not extreme as snow, fog, hurricanes, etc., but it has an implication on road

safety in Malaysia. Hence, this study was conducted to determine the impact of rainfall at night, at varying level of intensity, on vehicles' operating speed. This paper attempts to address some of the shortcomings derived from the literature. The findings of this study, derived from traffic and weather data collected in the Pengkalan Raja of Pontian, Johor can provide an understanding of the impact of various rainfall intensities on operating speed of vehicles. It is believed that the integration of weather data and traffic operation can improve transport system efficiency.

2.0 LITERATURE REVIEW

Climate change has some effect on transportation system [2]. Weather condition, particularly adverse weather conditions have a significant impact on road safety in Malaysia. Environmental factors contributes to the reduction of speed by reducing visibility of drivers and the conditions worsen due to darkness, fog, snow, wet pavements, high wind which as a whole degrades the driving experience and degree of safety of the driver [3, 4]. The effect of rainfall on transportation system can either be psychological perception of the driver, the mechanical condition of the vehicle used or pavement surface.

A laboratory study conducted by Yaacob, *et al*. has found that the worst skidding can happen on wet pavement condition during rainy day [5]. Mashros, *et al*. has assessed the impact of different rainfall intensity during day time and it was found that capacity and speed reduced during rainfall especially at higher rainfall intensity [6, 7]. The occurrence of rainfall at night happens naturally and affects the behaviour of drivers travelling on the road [8]. Physical tiredness, driver's age, traffic congestion has significant impact on the rear-following distance of drivers [9-11].Thus, it is also a natural response for people to avoid driving at night in the rain [12]. Study by Stanton and Pinton has shown that reduced visibility can cause drivers to reduce their speed and make drivers to feel insecure to overtake [13]. The decision making process takes into consideration the type of vehicles, acceptable gap distance between rear vehicle, speed and size of the vehicles to be overtaken, acceleration capabilities of overtaking vehicle and speed of oncoming vehicle [14, 15].In an accident analysis study conducted by Golob and Recker assessed that hit-object and collisions involving multiple vehicles associating with lane changing manoeuvres have high chance to occur on wet roads [16]. Strong, *et al*. commented that different intensity of raindrops reduces visibility of drivers on the road and leaves impact on drivers [17]. Rain precipitation can be in terms of light precipitation or heavy raindrops. Table 1 shows rain intensity in mm/hr as categorised by other researchers.

In this study, only light, medium and heavy rainfall data would be taken into consideration as very heavy rain, which is above 50mm/hr generally will cause flooding and there will be no contact of friction between car tires and road surface. Generally, higher intensity of rainfall precipitation would result in a significant reduction of speed of vehicles [20]. Table 2 shows the rainfall impact on speed of vehicles in different countries.

Table 1 Precipitation of Rain Intensity

Researcher	Precipitation of Rain Intensity (mm/hr)			
	Light	Medium	Heavy	Very heavy
Gray and Jacobson [18]	0.25-1.00	1.00-4.00	4.00-16.00	>50.00
Macangus [19]	<2.00	3.00-7.00	>8.00	

Table 2 Rainfall Impacts on Speed of Vehicles in Different Countries

Researcher/ Country	Time	Speed Reduction		
		Light Rain	Medium rain	Heavy rain
Angel[21]/ Florida	Day	2.1 mph	3.9 mph	4.1 mph
	Night	1.6 mph	1.1 mph	7.5 mph
Sándor[22]/ Hungary	Day	10-20 km/hr	15-40 km/hr	>40 km/hr
Xu[23]/ China	Day	7.6 %	10.1 %	10.3 %

As shown in Table 2, it shows that speed of traffic would be reduced under different rainfall conditions at night. Effect of rain precipitation on driver and vehicle performance such as splashing waters, clouded windshield due to high humidity, reduced visibility as intensity of rain increase, glare effect from headlight of oncoming vehicles on water on road surface affects drivers psychologically and physically [24-26]. However, rainfall intensity has less effect on heavy vehicles than passenger vehicles [22]. In general, lower visibility results in decision to reduce vehicle speed to recover the confidence in sight distance for comfortable driving.

A study conducted by Smith, *et al*. [27] has shown that rainfall caused a significant reduction in operating speed of vehicles regardless of the level of rain intensity. However, the different level of rainfall intensity does not have significant impact in operating speed. In other words, the impact of heavy rain on operating speed is approximately same with the impact of light rain has on operating speed.

In Malaysia, speed is an important transportation consideration because it relates to safety, time, comfort and convenience and economics. Speed is a commonly highlighted parameter in various studies because it is directly related to the quality of service and traffic safety [28]. Speed data can be obtained via radar gun device which is light and easy to handle [29] and also by video recording. In this study, the pneumatic rubber tubes were utilised since automatic traffic count (ATC) which helps to retrieve speed parameters without the need to be at the site location 24 hours [30]. The data gathered is used to determine

vehicle speed percentiles, which are useful in making many speed related decisions.

3.0 METHODOLOGY

The road section selected for this specific study is a road section located in Pengkalan Raja, Pontian, a small city in the state of Johor. The road has fulfilled all criteria listed for the selection of site as below:

i. Site must be on main federal road and two-lane highway type;
ii. Location should be on a flat and geometrically straight road section;
iii. Section before and after the survey site should be straight by more than 120m;
iv. Section of the road should be uninterrupted traffic flow;
v. Section of the road should be away from any roadside facilities such as side parking; petrol stations, bus stations, mosques, entry to villages and intersection;
vi. Section should has side drain;
vii. Section should has good road surfaces condition;
viii. Section should meet safety requirements for installation of automatic counting system;
ix. The distance between survey site and the rain-gauge station should be less than 6 km;
x. Survey site should has daily traffic volume of more than 10,000 for both direction.

To ensure rainfall data can be collected and useful to the study, the selected rain-gauge stations must meet the following criteria:

i. The rain gauges station should be located nearby to the selected survey site;
ii. The rain-gauge station must be active;
iii. The rain-gauge station must use data logger to record rainfall data until 1-minute interval, intensity and period of rainfall.

Traffic data for around 3 months starting from 6th November 2010 to 31st January 2011 were collected. The data for these 86 days were then filtered so that only night time data were analysed. Night time for this study was considered to be the period between 8pm to 12am. The road segment between the two curve sections is around 2570 m in length and the total site length is 241 m. The allowance for stopping sight distance (SSD) is approximately 205 m as shown in Figure 1.

As shown in Figure 1, the study site is located at one section of the Skudai-Pontian Highway. The road under investigation is single carriageway road with two-lane road. The vehicles under survey are travelling in the direction that passes through Site FT001. The ATC is set up in the middle of a straight road section with an approximate length of 2.5km. It fulfils the requirement of having the ATC set up within a 2 km length of straight road section. Some features of the road section under survey are shown in Table 3.

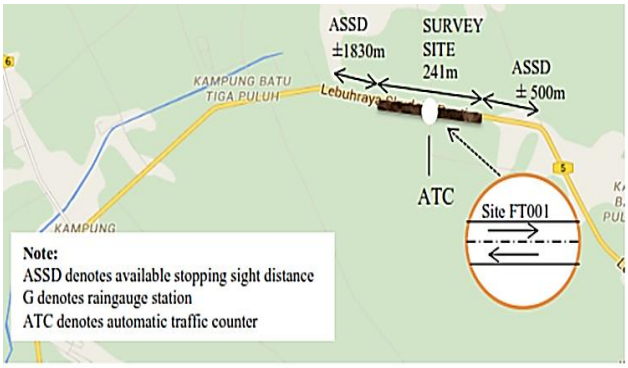


Figure 1 Site Location at Pengkalan Raja, Pontian

Table 3 Summary of feature of the survey site

Feature	Site FT001
Type of terrain	Flat
Speed limit (km/hr)	60
Site Length (m)	241
Segment Length (m)	± 2570
Lane Width (m)	3.8
Shoulder Width (m)	0.8
Surfacing Type	Asphaltic Concrete
Provision of Road Drainage Facility	Yes
Distance to Rain Gauge (km)	1.15
Rain Gauge Station Number	1534002
Station Name	PusatKemajuan Per. Pekan Nanas

Automatic Traffic Count (ATC) was used to collect the traffic data of the vehicles passing the road section. ATC Metro Count 5600 Series was utilised as it is the most convenient and safe method to collect the data under rain and dark situation. It is also reliable in terms of obtaining the flow and speed of vehicles continuously for the duration of few months. Two pneumatic tubes were laid parallel across the road section at Pontian with a gap of 1 metre apart as shown in Figure 2. Vehicle volumes, vehicle classification and speeds were captured continuously for three months period during monsoon season.

Figure 2 Pneumatic Tubes are 1 Metre Apart

The rainfall or hydrological data was acquired from the Department of Irrigation and Drainage, Pontian. The rainfall data obtained for this study is collected from the information on the rain gauge station number 1534002, which is located at 1.15km away from the site where the ATC is set up. The latitude of the station is 01° 30' 55" and the longitude is 103° 29 '40 ". The data obtained showed the day and time that rainfall occurs in this section of the road selected for this study. The rainfall data for the entire period of study from 6th November 2010 to 31st January 2011 was then divided into three categories according to the rainfall intensity such as light rain, moderate rain and heavy rain as shown in Table 4.

Table 4 Categories of Rainfall

Rainfall categories	Rainfall Intensity
Light rain	< 0.208 mm/5min
Medium rain	0.208 – 0.833 mm/5min
Heavy rain	0.833 – 4.167 mm/5min
Very heavy rain	>4.167 mm/5min

Table 4 above shows four categories of rainfall intensity. However, very heavy rainfall with intensity of more than 4.167 mm/5min was excluded from the analysis since very heavy rainfall is expected to cause flooding and vehicles would not be able to travel. The weather report data was then integrated with the traffic data for 5-minute interval. The traffic data and rainfall data were extracted for duration of 8pm to 12am for three consecutive monsoon months (6thNovember 2010 to 31stJanuary 2011).

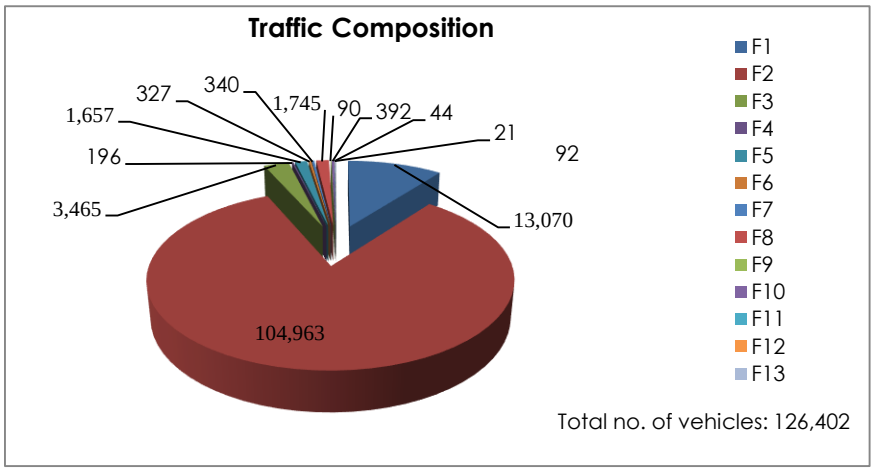
4.0 RESULTS

It was found that between 6th November 2010 and 31st January 2011 there were 126,402 vehicles travelled on the road section under investigation during the study period from 8pm to 12am. Vehicle composition on the road section at night is as shown in Figure 3.

Out of the total of 126,402 vehicles that pass the area during the observed hours, 83% of the vehicles are classified as passenger cars (Class F2) and 10% motorcycles (Class F1). Traffic on the site during the observed hours of three months period consists of more cars and motorcycles compared to the number of heavy vehicles such as bus, trucks, heavy trailers, etc. Then, the total number of hours accumulated based on different rainfall intensity is determined and is shown in Figure 4.

From Figure 4, an average of 95.6% of dry road section is recorded at night from 8pm to 12am within the three months monsoon season. Then, light rain intensity which is a total of 3.4% followed by medium and heavy rainfall, which is 0.4% (1.2 hours) and 0.6% (2.1 hours) respectively. November to January is considered as the monsoon season in Malaysia, however the occurrence of rainfall at night totals up to only 15 hours within the three months period and most drivers still travels on dry road pavement condition at night. This finding shows that the duration of heavy rainfall is very short, as compared to dry condition.

The actual number of vehicles travelling at different weather condition at night, which is under dry condition, light, medium and heavy rain intensity, was determined as shown in Figure 5.



Class of vehicle	Type of vehicle
F1	Motorcycle
F2	Passenger car
F3	Heavy pick up
F4	Bus
F5	Two-axle truck
F6	Three-axle truck
F7	Four-axle truck
F8	2S2, 3S1 (Heavy vehicles)
F9	3S2, five-axle combination 3S3, Six-axle combination
F10	2S1-2
F11	3S1-2
F12	seven (or more) axle
F13	combination

Figure 3 General Traffic Composition at Night inPengkalan Raja, Pontian

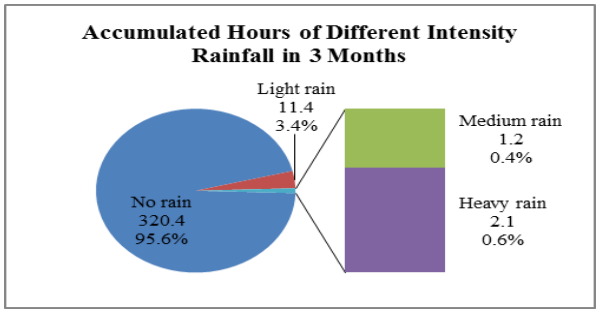


Figure 4 Accumulated Hours of Different Rainfall Intensity at Night in Pengkalan Raja, Pontian

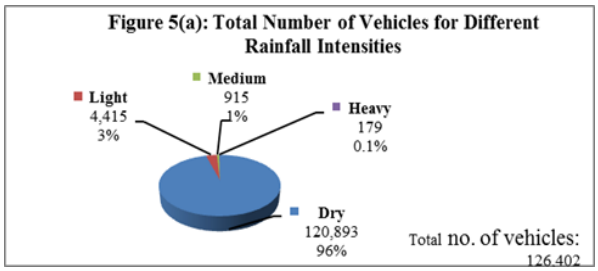


Figure 5 Traffic Volume at Night in Pengkalan Raja, Pontian

Based on Figure 5, in total there are 120,893 vehicles are travelling under dry condition, which consists of 96% of the vehicles travelsat night. During light, medium and heavy rainfall at night there are 3% vehicles (4,415 vehicles), 1% vehicles (915 vehicles) and 0.1% vehicles (179 vehicles) respectively.

Speed trend of vehicles for dry condition and each of rainfall intensity at night was then analysed. Figure 6(a) to 6(d) below show the number of vehicles for each of the speed class under different weather conditions at night.

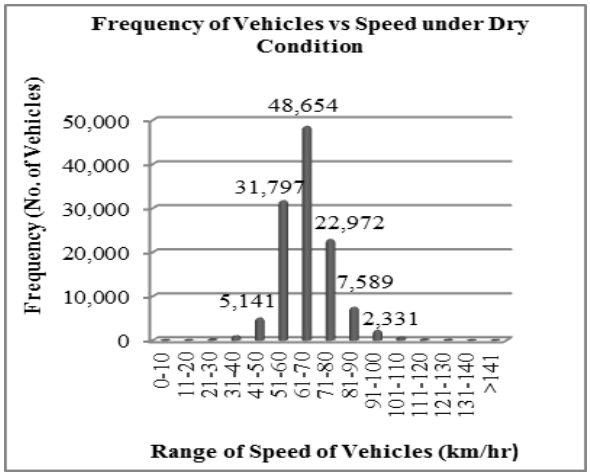


Figure 6(a) Frequency of Vehicles vs Speed under Dry Condition at Night

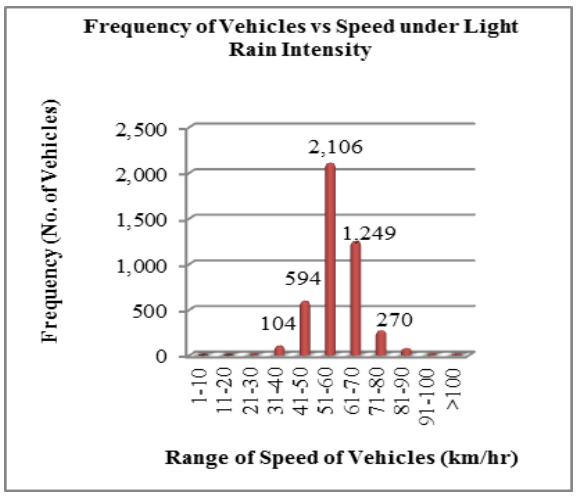


Figure 6(b) Frequency of Vehicles vs Speed under Light Rain Intensity at Night

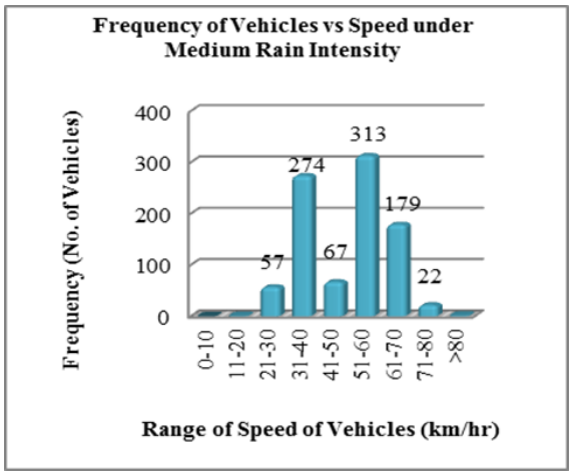


Figure 6(c) Frequency of Vehicles vs Speed under Medium Rain Intensity at Night

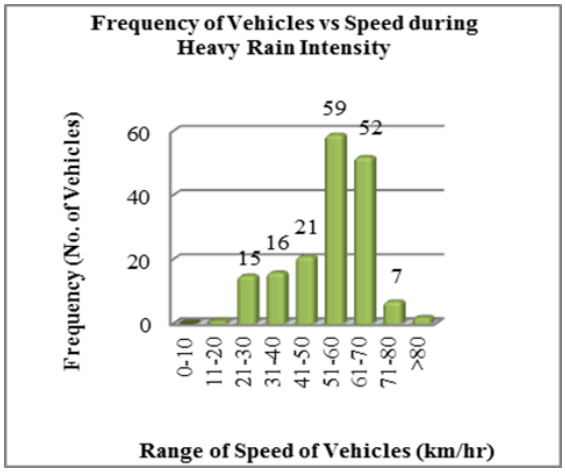


Figure 6(d) Frequency of Vehicles vs Speed under Heavy Rain Intensity at Night

From the histogram in Figure 6(a) above, most vehicles travels at speed between 61 km/hr to 70 km/hr under dry condition at night. As the weather change from dry condition to rain regardless of the rainfall intensity, most of vehicles travelled within the speed range of 51 km/hr to 60 km/hr as shown in Figure 6(b) to (d). Table 5 below shows the descriptive analysis of speed of vehicles for different weather conditions at night.

Table 5 Descriptive Analysis of Speed of Vehicles for Various Weather Condition at Night

Descriptive Analysis	Dry	Light	Medium	Heavy
Mode (km/hr)	64.5	56.9	57.0	58.9
Median (km/hr)	65.2	58.2	54.2	57.9
Mean (km/hr)	66.2	58.7	49.5	54.6
Standard Deviation	11.2	9.1	13.6	13.3
Count (vehicle)	120,893	4,415	915	179
Reduction of Mean Speed (%)	0	11.4	25.0	18.3

Based on Table 5, vehicle speed during dry and light rainfall at night is pretty much constant approximately around 65 km/h and 57 km/hr respectively. During medium rainfall, the most speed travelled by vehicles is 57 km/h higher than the mean speed of 49.5 km/hr. Similarly, during heavy rainfall, the most speed travelled by vehicles is 58.9 km/hr higher than the mean speed of 54.6 km/hr.

There is a reduction in vehicle's speed when rainfall intensities getting higher. The most speed reduction occurs during medium rainfall at night (25% reduction), followed by heavy rainfall (18.3% reduction) and then light rainfall (11.4%). Note that the reduction of speed is measured by comparing the mean speed of dry condition to the mean speed of each of the rainfall intensity. During heavy rainfall at night, the results in Table 5 shows that the mean speed of vehicles is higher compared to mean seed of vehicles during medium rainfall at night which is 54.6 km/hr and 49.5 km/hr respectively.

Further investigation was conducted to determine the underlying reason of why the vehicle speed during heavy rainfall at night is higher compared to the vehicle speed during medium rainfall at night. Figure 7 shows average speed for different types of vehicles at night in Pengkalan Raja, Pontian.

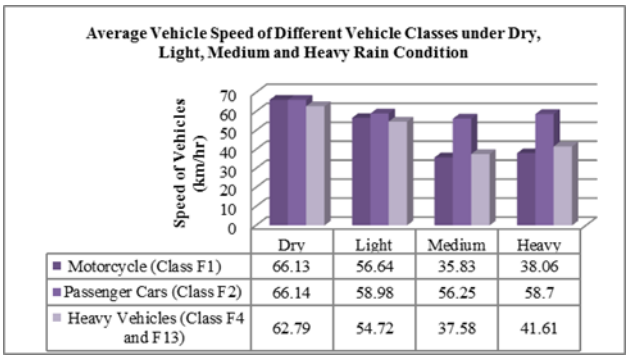
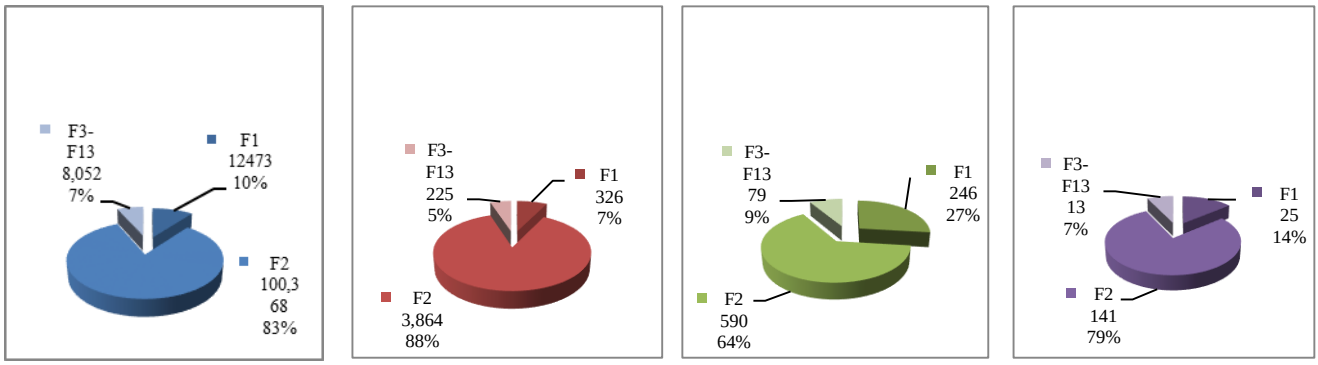


Figure 7 Average Vehicle Speeds of Different Vehicle Classes under Different Rainfall Intensities

From Figure 7, it can be seen that all vehicle types reduce their speed as weather conditions at night change from dry to rain regardless of the rainfall intensity. The count of vehicles travelling at night between 8pm and 12am shows that there are 915 and 179 vehicles travelling during medium rainfall and heavy rainfall at night respectively (see Figure 5). Findings in Figure 7 revealed that heavy vehicles travelled at the most slowest speed during medium rainfall at night which is 37.58 km/h. Investigation was then conducted on the traffic composition at night in Pengkalan Raja, Pontian as shown in Figure 8.



(a) Dry Condition at Night (b) Light Rainfall at Night (c) Medium Rainfall at Night (d) Heavy Rainfall at Night

Figure 8 Traffic Compositions at Night for Different Weather Condition at Night in Pengkalan Raja, Pontian

It has been shown in Figure 5 that passenger cars dominated the traffic composition at night in Pengkalan Raja, Pontian. It is shown in Figure 8(a) to (d) that for each of weather conditions at night (dry, light rainfall, medium rainfall and heavy rainfall), most of vehicles travelling through the area are passenger cars (Class F2).It can be seen from Figures 8(c) that there are more heavy vehicles (class F3-F13) travelling during medium rainfall at night (79 vehicles) compared to heavy rainfall at night (only 13 vehicles). More heavy vehicles travel at the slowest speed during medium rainfall at night compare to during heavy rainfall at night (79 heavy vehicles travelling at an average speed of 37.58 km/h during medium rainfall at night as in Figure 8(c) and Figure 7 respectively).The presence of higher volume of heavy vehicles during medium rainfall at night with the slowest speed is perceived to increase the tendency of drivers to increase the gap between vehicles for safety precaution, hence the slower speed of all vehicle types during medium rainfall compared to heavy rainfall at night (see Figure 7).

Statistical analysis using SPSS was conducted to test the significant difference of vehicle speed for various weather conditions at night. Kolmogorov-Smirnov test was used to assess the normality of the data before testing on significant differences was conducted. With 95% confidence level, it was found that the speed data were not normally distributed. Therefore, Mann-Whitney U test as in Table 6 and Table 7 below was used to assess the significant difference of vehicle speeds during dry and rainfall conditions at night.

A Mann-Whitney U test in Table 6 and Table 7 revealed there is a statistically significant difference in the vehicle speed of dry condition at night (Median = 65.2, N = 120893) and light rainfall condition at night (Median = 58.2, N = 4415), U = 1.528E8, z = -48.337, p = 0.00 (significance level < 0.05) in which the vehicle speed in dry condition is higher compared to light rainfall condition at night. Similarly for other rainfall intensity at night such as medium rainfall and heavy rainfall, a Mann-Whitney U test revealed that there is a statistically significant difference in the vehicle speed between dry condition and medium rainfall at night (U = 1.959E7, -z = 33.712, p = 0.00) and between dry condition and heavy rainfall at night respectively (U = 5368080.500, z = -11.079, p = 0.00), in which vehicle speed during dry condition at night is higher than vehicle speed during medium and heavy rainfall at night.

Table 6 Significant differences for vehicle speed during dry and various rainfall intensities at night

	Dry and Light Rainfall at Night	**Dry and Medium Rainfall at Night**	**Dry and Heavy Rainfall at Night**	**Light and Medium Rainfall at Night**	**Medium and Heavy Rainfall at Night**
Mann-Whitney U	1.528E8	1.959E7	5368080.500	1337689.000	62732.500
Wilcoxon W	1.626E8	2.000E7	5383131.500	1756759.000	481802.500
Z	-48.337	-33.712	-11.079	-16.111	-4.224
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000

Table 7 Ranks of Mann-Whitney U Test for vehicle speed during dry and rainfall condition at night

Condition at night	**Mean**	**N**	**Std. Deviation**	**Median**
Dry	66.2420	120893	11.23327	65.2000
Light rainfall	58.6536	4415	9.11926	58.2000
Medium rainfall	49.4961	915	13.63679	54.2000
Heavy rainfall	54.5711	179	13.26735	57.9000

A comparison made between light and medium rainfall intensity at night using Mann-Whitney U test shows that the difference of vehicle speed between light and medium rainfall at night is statistically significant with z = -16.111 and p = 0.00 with the vehicle speed during light rainfall at night is higher than during medium rainfall at night. Similarly for medium and heavy rainfall at night, the difference of vehicle speed is statistically significant (z = -4.224, p = 0.00) with the vehicle speed is higher during heavy rainfall compared to medium rainfall at night.

Cumulative speed distributions were then plotted for different rainfall intensities at night: dry, light, medium and heavy as shown in Figure 9(a) to (d).

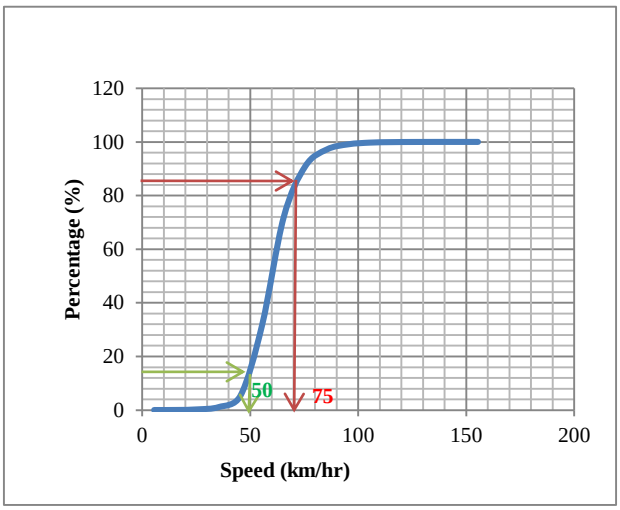


Figure 9(a) Cumulative Speed Distribution for Dry Condition at Night

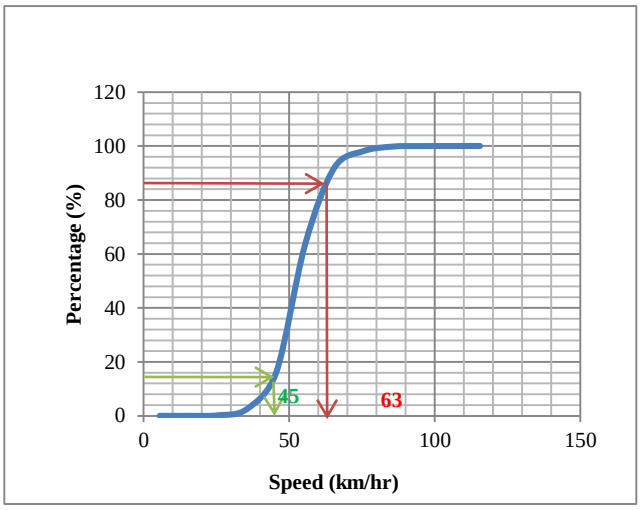


Figure 9(b) Cumulative Speed Distribution for Light Rain Intensity at Night

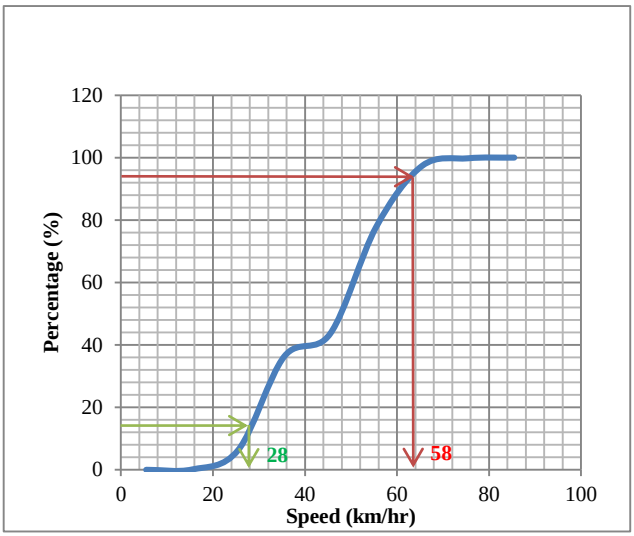


Figure 9(c) Cumulative Speed Distribution for Medium Rain Intensity at Night

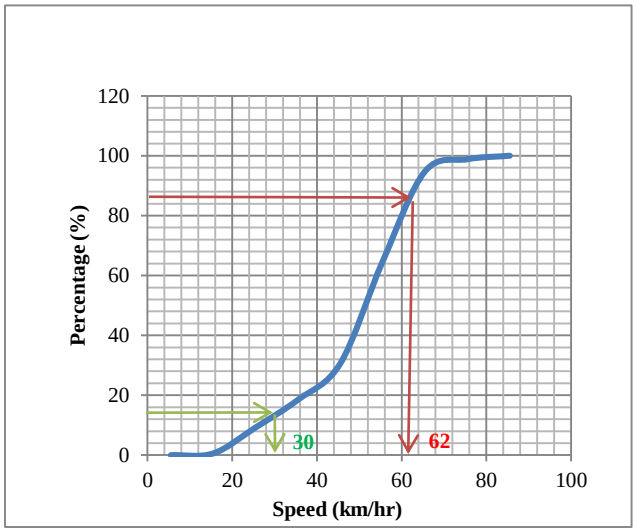


Figure 9(d) Cumulative Speed Distribution for Heavy Rain Intensity at Night

The 85th percentile speed is a speed below 85 percent whereby drivers at the given location is considered travelling at the maximum safe speed for that particular location. Based on Figure 9(a) to (d), the maximum safe speed during dry condition is 75 km/hr, followed by 63 km/hr for light rainfall, 58 km/hr for medium rainfall and 62 km/hr for heavy rainfall intensity. Any speed lower than 15th percentile value would have high probability of causing slow moving traffic thus affecting density of traffic. From the values in Figure 9(a) to (d), it is suggested that 60 km/hr is a safe speed limit under heavy rainfall condition on the road section at Pengkalan Raja, Pontian. Due to poor visibility under heavy rainfall conditions at night, it is advisable not to drive faster than 60 km/hr to maintain safety of drivers and other road users.

5.0 CONCLUSION

This study aims to determine the speed characteristics of vehicles during dry and rainfall condition at night for different rainfall intensities. In this study, night was considered for a period of 8pm to 12am. Therefore, three months data during monsoon season from 8pm to 12am were recorded continuously using automatic traffic counter road section at Pengkalan Raja, Pontian. It was observed that passenger cars were dominant vehicles during this study period. Results have shown that during this three months monsoon season (6 November 2010 to 31st January 2011), dry weather still dominates at night the total days that are raining are still much less compare to dry condition.

From this study, it was found that there is a vehicle speed reduction from the dry condition regardless of

rainfall intensities at night. At night, vehicles mean speeds generally reduce by 11.4%, 25% and 18.3% for light rainfall, medium rainfall and heavy rainfall respectively. Statistical testing using Mann-Whitney U test has revealed that the difference of vehicle speed between dry condition and rainfall at night is statistically significant regardless of rainfall intensity. The difference of vehicle speed between light rainfall and medium rainfall at night also shows a statistically significant. Similar finding was obtained for vehicle speed differences between medium rainfall and heavy rainfall at night.

The highest average speed of vehicle at night is recorded during dry condition at night. During dry condition at night, drivers have a clearer viewpoint and can estimate a nearer distance with the upfront vehicle, hence giving a high confidence level in drivers to drive at a higher speed. Under light rain, there is a decrease about 11.4% in the speed of vehicles. Sudden changes in weather would initiate vehicle users to reduce speed in order to minimise risks especially in a poor visibility condition. This reduced vision may also be another factor to the 25% and 18.3% further reduction of vehicle speed during medium and heavy rainfall intensity at night respectively.

The mean speed, 15th percentile and 85th percentile of vehicles decrease with the increase in rainfall intensity at night. It shows that environmental condition has some impact on traffic operations on road. Rainfall at night can reduce visibility, thus affect driver's perception reaction time to drive under that situation especially aged drivers. Findings from this study can be used to help local authorities and transport planners in planning an efficient traffic management system for a safer travel experience to road users in Malaysia. Further research can be done to investigate relationship between headway and speed of vehicles for similar conditions at night to determine car-following behaviour of drivers during rainfall at night.

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