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CHARACTERISTICS OF VEHICLE HEADWAY DURING RAINFALL AT NIGHT IN PONTIAN, JOHOR

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Abstract: The headway pattern of a traffic stream has a significant impact on the accident possibility of the road section. The aim of this study is to determine the impact of different rainfall intensities have on the headway pattern in Pekan Nenas, Pontian, Johor. In this study, the automatic traffic count system (ATC) is utilised to obtain vehicle headway on the site. Rainfall data were obtained from the Department of Drainage and Irrigation, Pontian. The rainfall data was categorised into three rainfall intensity categories which are light rain, moderate rain and heavy rain. The traffic data and rainfall data then were then embedded to analyse the headway pattern of road user on the road section during rainfall at night. The results from the analysis showed that the headway pattern at night time followed the gamma distribution model. It was found that the mean vehicle headway increases as the rainfall intensity increases.

Keywords: *headway, rainfall, night*

1.0 Introduction

Headway is the primary parameter when it comes to learning about the accident pattern for all road sections. Vehicles should be travelling with a safe time separation of headway in order to prevent accidents from happening. Malaysia is a country with monsoon seasons, with the Northeast Monsoon occurring from November to March. It could be concluded that during the end of the year, the number of rainy days will be more compared to any other time of the year. Weather plays a significant role in driver's performance on the road. During night time, visibility of vehicle drivers is negatively affected due to darkness. Rainfall at night, especially during heavy rain could lead to worse situation. These undesired traffic conditions will challenge the concentration and mental condition of drivers especially during long drives. These situations may also lead to unpleasant driving experience or the change in the mood of the drivers as the travel time will be longer than expected, both of which might increase the possibility of accidents due the loss of concentration. Headway is one of the criteria considered in road safety, capacity and the level of service for a road section.

The aim of this study is to determine the impact of rainfall at night has on traffic headway, one of the most important parameters in traffic characteristics. The results of this study can improve the understanding of road users on the road section during rainfall at night, therefore, the mitigation procedures can be considered to avoid bad situations such as road accidents.

2.0 Literature Review

2.1 Road User Behaviours

Headway is the primary data studied to determine the probability of accidents happening for a road section. It is one of the most fundamental traffic parameters (Li, 2011). If the headway value is smaller, it means that the vehicles are travelling closer to each other. Figure 1 illustrates the headway parameter between vehicles travelling in the same direction along the same road.

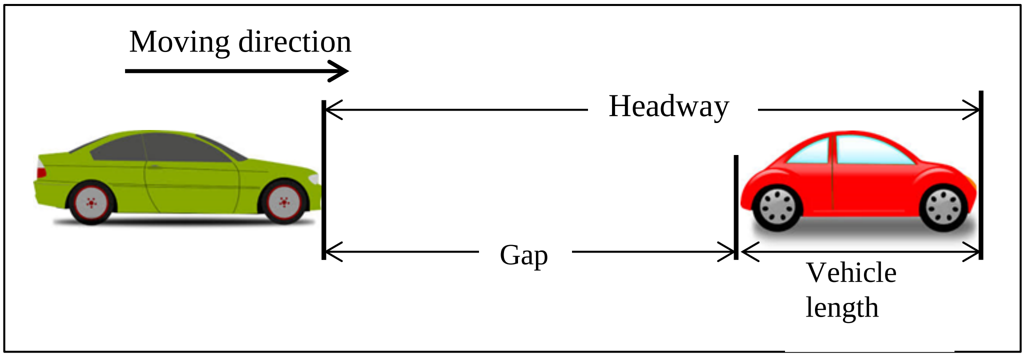

Figure 1: Vehicle Headway

As shown in Figure 1, headway is identified as the difference between the time when the front of a vehicle arrives at a point on the highway and the time the front of the next vehicle arrives at the same point (in seconds). To ensure the safety of all road users, all vehicles should be travelling with appropriate and safe headway separation between the vehicles. There is no a definite answer as to how long the headway should be to be considered as safe for all drivers, as a lot of factors should be considered (Zhang *et al*., 2007). Among the factors are vehicle performance, perception-reaction time of drivers and visibility.. The concept of a safe headway between vehicles is one that would allow the car to have enough time to stop before colliding with the vehicle in front. According to Strong *et al*. (2010), precipitation of any types reduces visibility and has no immediate effect on vehicle performance, but it leaves an impact on the driver.

Rainfall intensity is the amount of rainfall per unit time. Smaller raindrops have the size of diameter smaller than 0.8mm, large raindrops collectively have the size larger than 7.5mm and the range of sizes in between are categorised as medium size rain particles. Sizes of rainfall drops could cause a short-term vision blur for drivers, which could lead to reduction in sight distance. The meteorological department categorises rainfall by their intensity, as shown in Table 1 below.

Table 1: Rainfall Intensity

Rainfall Category	Intensity (mm/hr)
Light rain	< 2.5
Moderate rain	2.5 - 10
Heavy rain	10 - 50
Very heavy rain	>50

(Source: Todd, 2000)

The most significant effect that rainfall has on traffic stream is it lowers the visibility of drivers and causes the loss of concentration. Rainfall is the greatest weather hazard among other meteorological element that causes disruption to traffic flow (Parameswary Sundara, 2012). Study done by Chung *et al*. (2005) clearly showed that accident rates are much higher during rainy weather. 1.5 accidents/hr is the rate during rainy hours but the average for all other times is only 0.85 accidents/hr. Since headway is the primary parameter for accident pattern study, the differences in the pattern of headway during different weather conditions have to be determined. Table 2 below shows the impact of rainfall intensity on the change of speed of travelling vehicles (U.S. Department of Transportation, 2004).

Table 2: Impact of rainfall intensity on vehicle speed change

Intensity of rainfall (mm/hr)	Impact	Speed Change (km/hr)
0 - 4	None	Negligible
5 - 10	Moderate	10 – 20
10 - 20	Intense	15 - 40
>20	Extreme	>40

Darkness is one of the more important factors when it comes to analysing traffic characteristics of road user's behaviour. Darkness reduces the visibility of the road user. In the dark, drivers could not see as far as they could during the daytime when there is sufficient sunlight. To help the drivers, road lights are usually installed along the roads to make sure that the drivers could see the traffic conditions clearly. When driving during night time or in the dark, the concentration level must be higher compared to when they are driving during day time. Since the margin of error is much smaller in the dark, drivers may get fatigue faster than they normally would. Long drives in the dark would really challenge the mental strength and concentration level of the drivers. It was proven by Pasetto and Barbati (2012) that darkness has an effect on drivers' behaviour due to the difficulties and challenges arise in the interpretation of volumes, spaces and distances when the perception of the road environment worsens.

Car following behaviour is the condition and distance measured of how close the drivers behind are following a specific vehicle under certain circumstances. During daytime, drivers focus more on traffic on the road, parked cars and traffic lights, hence the dwell time percentage is higher. At night, due to lower object-background contrast and ambient luminance, drivers are more aware and tend to focus on the rear middle and rear right. This shows that drivers at night tend to have a broader view on the rear front view whereas in the daytime it is more limited due to heavier traffic. During car following, the drivers' eye glance away from the road ahead was found to be at average 0.6 seconds with standard deviation of 0.46 seconds (Chung *et al*., 2005). The time of eye glance is not affected by the travelling speed of the vehicle, but the visibility and reaction time of the drivers. During night time, the visibility drops for all drivers.

2.2 Headway Distribution Models

In order to minimize vehicle delays and maximize roadway capacity, traffic engineers are required to carry out accurate modelling and analysis of vehicle headway distribution. A number of headway models have been developed and generally, these models are classified into two categories, single statistical distribution models or simple distribution and mixed distribution. Headway distribution models are evaluated based on three considerations: reasonability, applicability and validity. It is stated that traffic states are divided into three categories, namely low, medium and high flow conditions (Mathew, 2014):

1. Low volume flow

   (a) Headway follows a random process as there is no interaction between the arrivals of two vehicles.
   (b) The arrival of one vehicle is independent to the arrival of other vehicles.
   (c) The minimum headway is governed by the safety criteria.
   (d) A negative exponential distribution can be used to model such flow.

2. High volume flow
   - (a) The flow is very high and is near to the capacity.
   - (b) There is very high interaction between the vehicles.
   - (c) This is characterized by near constant headway.
   - (d) The mean and variance of the headway is very low.
   - (e) A normal distribution can be used to model such flow.

3. Intermediate flow
   - (a)Some vehicle travel independently and some vehicle has interaction with other vehicles.
   - (b) More difficult to analyse, however, has more application in the field.
   - (c) Pearson Type III Distribution can be used which is a very general case of negative exponential distribution.

2.2.1 Negative Exponential Distribution

The negative exponential distribution can be used to analyse low flow traffic data. It is the inter-arrival time distribution of the Poisson process. Negative exponential distribution has the probability density function as shown below.

$$f(t) = \lambda e^{-\lambda t}, \quad t \geq 0 \qquad (1)$$

The shape parameter, λ will determine the shape of the distribution. The shape of negative exponential distribution for shape parameter of 0.5, 1 and 1.5 are shown in Figure 2.

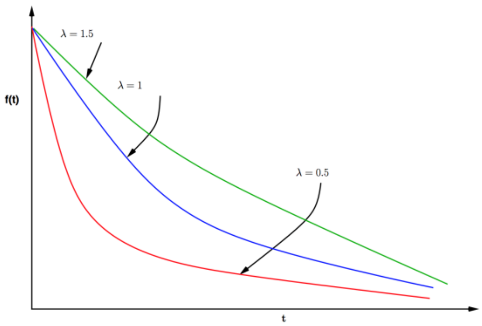

Figure 2: Shape of the Negative exponential distribution for various values of λ

The parameter estimation in negative exponential distribution is very straight forward as the traffic volume is the only information needed to proceed. It can be considered as the headway models for low flow traffic condition and some other applications that are not sensitive to the headway distribution shape.

2.2.2 Shifted Exponential Distribution

A phase with deterministic service time (τ) is added to negative exponential distribution to avoid extremely short headways. This process will shift the negative exponential distribution τ seconds to the right. With τ as a nonnegative constant and X as a random variate, headway will be considered as a random variate T = τ + X. The density function for shifted exponential distribution can be obtained by modifying the negative exponential distribution equation into:

$$f(t\,|\,\tau,\theta\,) = \begin{cases} \theta e^{-\theta(t-\tau)}, & \text{if } t \geq \tau \\ 0, & \text{otherwise,} \end{cases} \qquad (2)$$

where τ and θ are the location and scale parameters, respectively.

The reasonability factor for choosing shifted exponential distribution is the location parameter or deterministic service time (τ) eliminates the extremely short headways, which was a problem in negative exponential distribution cases. The properties of shifted exponential distribution are best under low flow traffic rates.

2.2.3 Gamma Distribution

In shifted exponential distribution, adding a service time constant (τ) to an exponential random variate helps avoid extremely short headway problem. A different approach can be used to reduce the probability of extremely short headway intervals, which is to put α exponential server in series. The resulting departure interval is a sum of α mutually exponential random variates:

$$S_\alpha = X_1 + X_2 + \cdots + X_\alpha, \qquad \alpha \in \{1,2,\ldots\}. \qquad (3)$$

The new random variate (Sα) is said to follow the α-phase Erlangian distribution. Erlangian distribution has a probability distribution as follows.

$$F(t \mid \beta, \alpha) = 1 - \sum_{j=0}^{\alpha-1} \frac{(\beta t)^j}{j!} e^{-\beta t}. \tag{4}$$

If the Erlangian distribution is allowed to have a non-integer number of phases (α > 0), the resulting generalization is called the gamma distribution. Introducing a location parameter (τ) will further adjust the proportion of short headways. The probability density function will be adjusted to:

$$f(t \mid \tau, \beta, \alpha) = \frac{\beta^{\alpha}(t-\tau)^{\alpha-1}}{\Gamma(\alpha)} e^{-\beta t}, \tag{5}$$

where

$$\Gamma(x) = \int_0^{\infty} y^{x-1} e^{y} dy \tag{6}$$

is the gamma function. It is a generalization of the factorial function

$$(x-1)! = \Gamma(x). \tag{7}$$

Location parameter (τ), the scale parameter (β) and the shape parameter (α) are required as parameters in this distribution. Figure 3 shows the result of a regular gamma distribution.

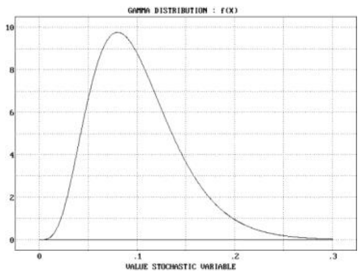

Figure 3: Gamma distribution

3.0 Methodology

The traffic data at night-time was collected between 8pm to 12am. The vehicles travelling across this road section after midnight was not considered. This is because the number of vehicles travelling after 12am is very small. When the vehicles travelling on the road is minimal, the traffic parameters and characteristics may differ quite significantly from the results during the period between 8pm to 12am.

The study was conducted at Pekan Nenas, Pontian, Johor. Automatic Traffic Counter (ATC) was used to obtain traffic data. The ATC should not be located too close to a junction or a curve section of the road. It is preferred that the ATC is set up in a location within a 2km length of straight road section.

Two rubber pneumatic tubes were used to collect the data of the passing vehicles. The rubber tubes were placed one meter apart on the road section. One end of the rubber tubes were tied into knots and pinned to the side of the road using some nails. The end of the tubes must be firmly pinned to the road to prevent movement of the tubes which may lead to inaccurate results. The tubes were placed one meter apart to obtain the travelling speed of the vehicles passing through. The other end of the tubes was connected to the ATC. Once the tubes and the system were set up, the ATC system was left at the side of the road. The ATC system was locked in a box and chained to a signboard or a tree, whichever is available at the side of the road to prevent the loss of the system.

After the three month period of collecting traffic data, the data were analysed using Microsoft Excel. The rainfall data were acquired from Department of Drainage and Irrigation, Pontian. The rainfall data has been classified into 4 classes which are light rain, moderate rain, heavy rain and very heavy rain. Upon acquiring the rainfall data for the period of study, the data were combined with the traffic data collected from the ATC system for further analysis. Traffic data were divided into four different categories according to the rainfall intensity. The data for the time period that are not considered for this study were eliminated, leaving only the traffic data from 8pm to 12am for each day. Figure 4 shows an example of the data being divided into different rainfall intensity categories.

	A	C	D	E	F	H	I	J	K	L	M	N
1	~~~	Tid	eda ~~~ JP	S Ampang 29-MAR-2011 1(		light rain		I < 0.208 mm/5 min			0.1-0.2	
2	~~~	~~~				moderate rain		0.208 ≤ I < 0.833 mm/5 min			0.3-0.8	
3	Sou	s 5	minit.mtd	Site 1534002 PUSAT KEMAJUAN PER. at F		heavy rain		0.833 ≤ I < 4.167mm/5 min			0.9-4.1	
4	1	IN	CREMENTAL	From 20101101 000000 to 20110131 2400(		very heavy rain		I ≥ 4.167 mm/5 min			≥ 4.2	
5		ain	Date	Time								
6		mm										
7												
8		1	20101031	240000	0.1							
9		1	20101101	500	0.1							
10		1	20101101	1000	0.1							
11		1	20101101	1500	0.1							
12		1	20101101	2000	0.1							
13		1	20101101	2500	0.1							
14		1	20101101	3000	0.1							
15		1	20101101	3500	0.1							
16		15	20101101	4000	1.5							
17		1	20101101	4500	0.1							
18		0	20101101	5000	0							
19		0	20101101	5500	0							

Figure 4 Traffic data categorized according to rainfall intensity

After obtaining the complete traffic data for the whole three months, the headway data is analysed. All the results were divided according to the weather and rainfall intensity.

4.0 Results and Discussion

4.1 Headway Analysis Result

The data collected were filtered so that only data from 8pm to 12am for each day were considered. The total number of vehicles passing through the site of this study is 127995. The number of data for each weather conditions, dry, light rain, moderate rain, and heavy rain are 122445, 4402, 927 and 181 respectively.

Data for all four weather conditions were analysed separately. The frequency graphs and cumulative frequency percentage graphs were obtained for each weather condition and the results were being compared with each other. Figures 5, 6, 7 and 8 show the headway analysis results at night for dry weather, light rain, moderate rain and heavy rainfall condition.

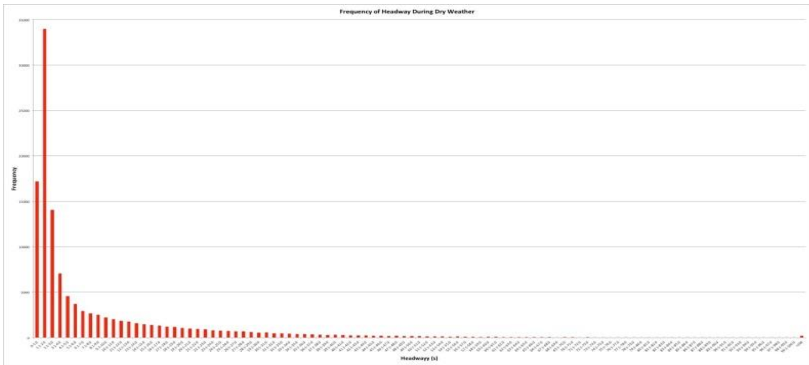

Figure 5: Frequency of Headway during Dry Weather at Night

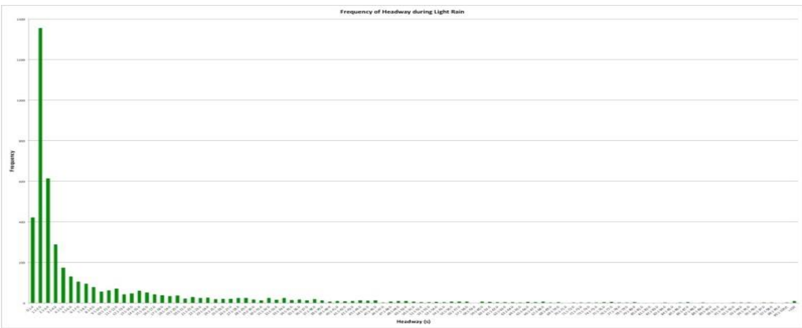

Figure 6: Frequency of Headway during Light Rain at Night

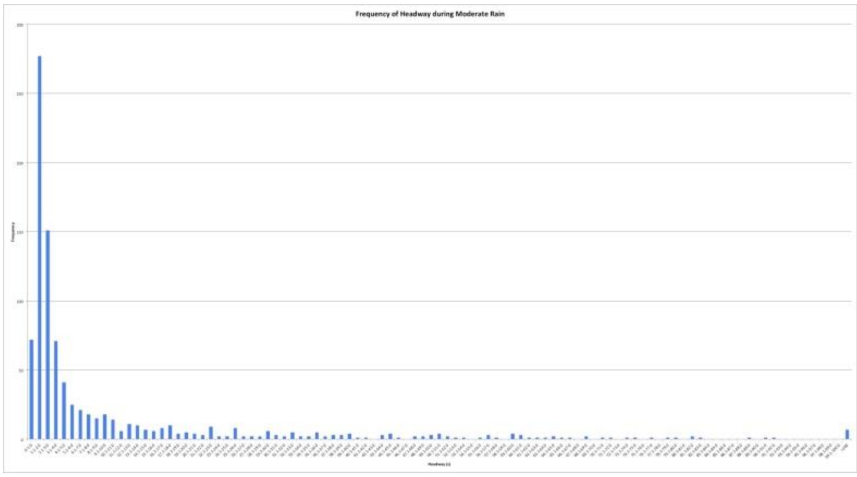

Figure 7: Frequency of Headway during Moderate Rain at Night

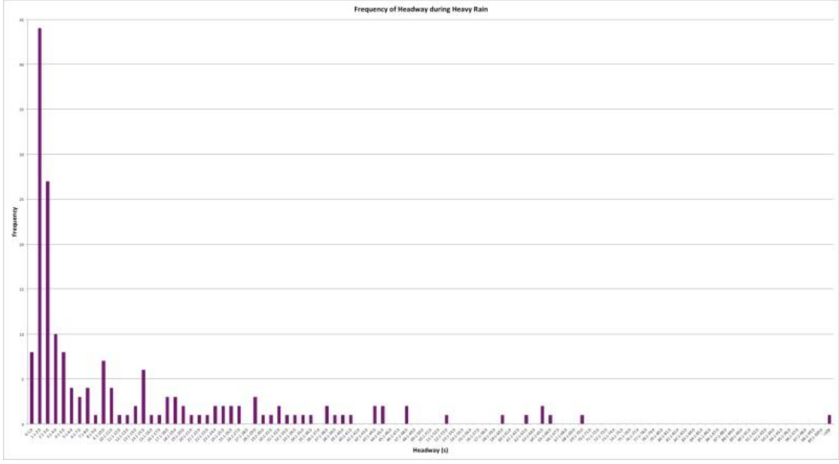

Figure 8: Frequency of Headway during Heavy Rain at Night

For all four weather conditions, headway with the highest number of occurrence frequency was between 1-2 seconds. The number of occurrence then gradually decreases as the time headway increases. Wang and Song (2009) found out that during dry weather, over 70% of vehicles will travel with headway of less than 10 seconds for a straight road section. This percentage could be applied to this study as 90920 out of 122445 vehicles (74.3%) of vehicles were travelling with 10 seconds or less headway during dry weather.

The mean headway increases as the rainfall increases. During dry weather, the mean headway obtained is 8.84s. It increases to 9.14s during light rain condition, while the mean headway for moderate rain and heavy rain are 10.3s and 12.98s respectively. This shows that the vehicles are generally travelling with a larger headway value when the weather condition deteriorates. Drivers were more careful when driving in the rain to reduce the possibility of accidents. The impact of rainfall intensity can be seen clearly in Figure 9 below.

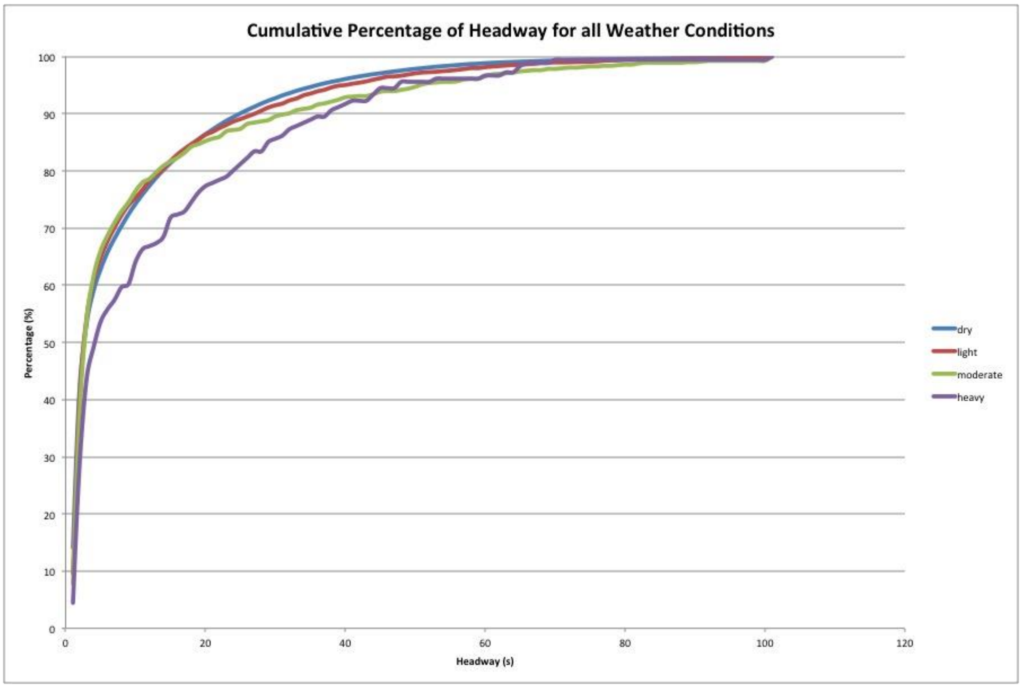

Figure 9: Vehicle Headway at Various Rainfall Intensities at Night

As shown in Figure 9 above, the graph for each weather condition has a different gradient of slope with one another. It can be seen clearly that for heavy rain condition, the gradient of the curve was the lowest, indicating that percentage of vehicles travelling with low value of headway is much lower than the other three weather conditions. Besides, it was shown from the graph that nearly 90% of vehicles under dry conditions were travelling with headway value of under 30 seconds. This percentage was the highest among the four conditions, followed by light rain and moderate rain, while heavy rain has the lowest percentage of vehicles travelling under 30 seconds headway. This proves that the drivers were not as aggressive when rain intensity increases as they normally would under dry condition. Table 3 below shows the descriptive data of headway for four rainfall intensities at night time.

Table 3: Descriptive Analysis of Vehicle Headway for Various Rainfall Intensities at Night

	Dry	Light Rain	Moderate rain	Heavy Rain
Number of vehicles	122445	4402	927	181
Min. Headway (s)	0	0	0	0
Max. Headway (s)	943.2	185.9	135	121.1
Range (s)	943.2	185.9	135	121.1
Mean Headway (s)	8.84	9.14	10.3	12.98
Median (s)	2.7	2.6	2.7	4.2
Mode (s)	1.1	1.4	1.3	1.4
Standard Deviation	15.37	14.9	17.94	17.7
Flow Rate (/min)	6.8	6.57	5.79	4.53

From Table 3, it is shown clearly that rainfall intensity had a significant impact on headway data on a road section. Another impact of rainfall intensity on the traffic data is it reduces the traffic flow rate as rainfall intensity increases. When the flow rate decreases, the distance between vehicles to vehicle is larger, thus contributing to the increase of headway value.

The results from this study were supported by several previous researches in the similar field. Wang and Song (2009) found out that the vehicles headway decreases as rain intensity increases. The results of Chung *et al*. (2005) also showed that rainfall intensity will affect the travel demand on roads, causing the flow rate to decrease as rainfall intensity increases. Meanwhile the hypothesis that rainfall intensity will cause the vehicle headway to increase and the traffic flow to decrease is also supported by Saberi and Bertini (2009).

4.2 Gamma Distribution Model

Gamma distribution model is produced for comparison with the headway data collected on site for all weather conditions. For this study, the shape parameter (α) of 2 and the scale parameter (β) of 2 are selected to produce the optimum shape for the gamma distribution graph. The probability of each headway value ranging from 1 second to 100 seconds occurring is being plotted and shown in Figure 10 below.

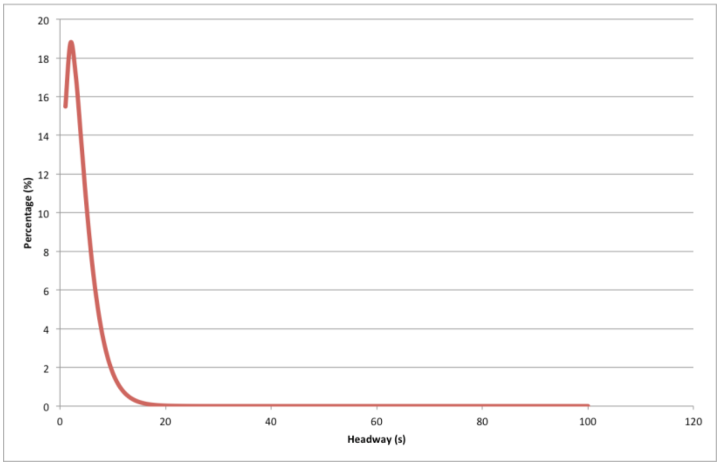

Figure 10: Gamma distribution model with shape parameter of 2 and scale parameter of 2

As shown in Figure 10 above, the majority of the headway data obtained should be smaller than 10 seconds. This gamma distribution model is being used for comparison for all four weather conditions to determine if the traffic pattern has the criteria to be considered as a gamma model. Figure 11 to 14 show the data of headway collected compared to the gamma distribution obtained as shown in Figure 10 above.

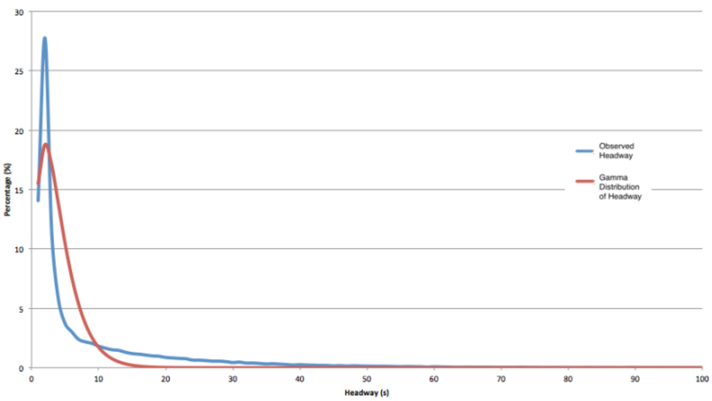

Figure 11: Graph of gamma distribution model and headway data for dry weather at night

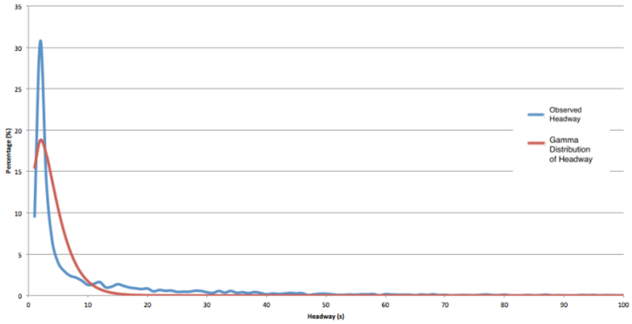

Figure 12: Graph of gamma distribution model and headway data for light rainfall at night

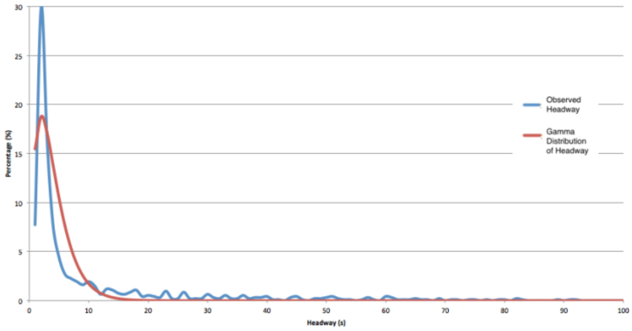

Figure 13: Graph of gamma distribution model and headway data for moderate rainfall at night

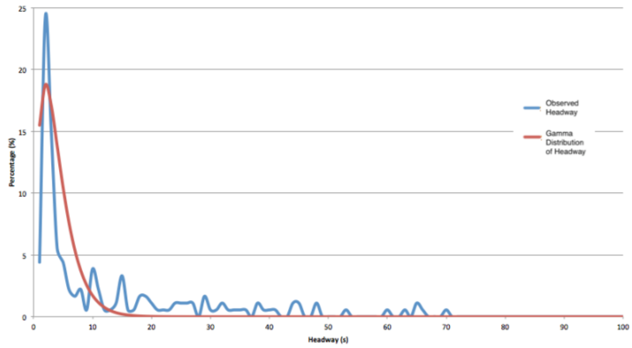

Figure 14: Graph of gamma distribution model and headway data for heavy rainfall at night

The shape of the headway data graph for all four weather conditions is similar to each other and consistent with the gamma distribution model. The results of the headway data reflect the property of gamma distribution models, where the majority of the headway value concentrates near the mode data value. Meanwhile, the percentages of high headway value were very low for all weather conditions, similar to the gamma distribution model as well.

Luttinen (1996) stated that the data being studied under gamma distribution models should not be too sensitive to the shape of the headway distribution. Even though the gradient of the headway distribution collected has some significant differences with the gamma distribution model, the shape and pattern of the headway distribution follows the graph of the gamma model.

Other than that, the headway distribution models were expected to be more skewed when the flow rate increases. During the lowest flow rate of these four weather conditions, which is under the heavy rain condition, the headway distribution is less skewed than others. The peak value or the highest percentage value of headway is less than 25%, compared to others which are around 30%.

5.0 Conclusion

The mean headway increases as the rainfall intensity increases. Vehicles were travelling with a higher headway value when the weather is not favourable to drivers such as during heavy rainfall. The majority of the vehicles were travelling within headway of 1 to 2 seconds, regardless of the weather condition, but the percentages of vehicles travelling at higher value of headway (more than 20 seconds) was higher when it rains, especially during heavy rain.

The headway characteristics of vehicles at night time was found to be consistent with the gamma distribution model, which states that majority of headway values will be close to the mode headway value. The headway values for vehicles travelling during rainy condition were found to be larger than the headway values during dry weather. Higher rainfall intensity leads to lower flow rate of traffic, which then contributes to the larger headway values. Gamma distribution models were generally used for lower volume flow, which was the case for this study as well, with the average flow rate of 6.8 vehicles per minute during dry weather.

6.0 Acknowledgement

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