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Determining the Impact of Darkness on Highway Traffic Shockwave Propagation

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ABSTRACT

During darkness visibility diminishes resulting in reduced sight distances and drivers are subjected to anxiety that may give way to anger and frustration. However, the study is concerned with traffic shockwave propagation that could be associated with darkness on highways. Based on the hypothesis that darkness may induce temporary traffic shockwave propagation in the presence of substantial traffic volume, darkness impact study was carried out in Pontian, Johor Malaysia. Data on traffic volume, speed, headway and vehicle types were collected for three weeks in darkness condition and another three weeks in artificial light condition and analysed. Results show that darkness shockwave velocity propagations is about 35.43 km/hr/ln of which the vehicle speed reduction is within variance limits. Consequently, the study concluded that the impact of darkness on highway traffic shockwave propagation is temporary and fairly insignificant when compared with nature light and also artificial light.

Keywords: Darkness, Shockwave, Traffic Flow, Temporary, Insignificant

1. INTRODUCTION

Often the impacts of darkness on traffic flowrate are taken for granted. It is a common knowledge that darkness is prevalent on some highway segments on the premises that darkness promotes responsive driver behaviour and enhances alertness. By information, during darkness it will generate less comfort among drivers as there is an uncertainty of a driver to behave emotionally and navigate tasks for example might break rule compliance of traffic or simply by unconfident with the information perceived by drivers. The potential problems here is the little consistency in specific threshold of darkness situation is the factor that governing speed and thus reducing sight distance due to poor visibility of drivers and that will often make drivers to behave in anxiety, anger and frustration. A driver who does not know what the road looks like under darkness condition will slow down. Therefore, it can be argued that darkness has an adverse effect on several elements of vision, including visual acuity. Visual acuity can be construed as an acuteness of vision. As mentioned in studies, colour vision deteriorates when the illumination level decreases below the sensitivity range of cones. Basically, highway segment having artificial lights are used to illumine the highway to give a better visibility to the road users compared with highway without artificial lights simply means by highway under darkness. It is believed that, road lights will help the road users to utilize roads efficiently and safely when in darkness and thus used as a leverage to propel drivers towards better travel decision. Hence, it is believed that the traffic flow can move smoothly because a good illumination is taking place. Although the design of highway facilities from illumination to darkness should be such that to provide different view of visibility to drivers so that drivers do not face any discomfort or boring when a continuous travelling of non-stop. However, it can be questioned, how would the traffic flow will react from illumination of articial light towards the approach of darknesswhen compared with

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traffic flow under daylight? Is the presence of darkness can make drivers to behave emotionally of which has a potentialto trigger traffic shock wave propagation due to variability in traffic kinematic movement under the condition changes from darkness, artificial light and nature light will become the vexing issue in this study.

1.1. Traffic Kinematic Concerning Shock Wave Velocity

1.1.1. Three Major Traffic Variables in Traffic Kinematic

Most of macroscopic analyses in traffic kinematic arebased on three major variables such as traffic volume denoted as q(vehicle per hour; vehicle/hr), space mean speed denoted as v (km per hour;km/hr) and traffic density represent as k (vehicle per km; veh/km). In a wide sense, (q) isdefined as the number of vehicles passing through a certain point or line during a specified time period, whereas (v)defined asthe average speed ofvehicles that exist in a segment of the road at an instantaneous time and finally (k) represents how many vehicles exist in a certain length of roadsection during a specified time period.As contained in many literatures, traffic flow which can be obtained after conversion of traffic volume to PCE units is actually denotes as speed multiply with density.

1.2. Conventional Theory of Macroscopic Shockwave

Macroscopic shockwave caused by an unstable traffic stream or traffic shockwave degrades the performance of road transportation networks. Yi and Horowitz (2006). So what are shock waves? Shock wave can be denoted as discontinuous change in the characteristics of the traffic kinematic. In previous researchers by Lighthill and Whitham (1955) reported that wave velocity changes according to vehicular density and it is possible to have differentwaves traveling through a vehicular stream. It is a case of a section of road with low-density flow immediately followed by a section with higher-density flow. According to Lighthill and Whitham (1955) thiscase might be caused by an accident, a reduction in number of lanes, an entrance ramp, or other constricted circumstances. The wave in the lower-density traffic will travel forward(relative to the road) at a higher speed than the wave in the higher-density flow. When thesewaves meet there will be a change in flow and a new wave will form. Both the original wavesand new wave will move forward relative to the road and the new wave has been termed as a shock wave. Ben-Edigbe and Mashros (2011) reported that when traffic stream is moving at a speed in close proximity and lead vehicle driver step on the brake follow up by driver behind lead car loose his/her nerves on sighting the brake lights carry abrupt braking will trigger shock waves. So, it can be postulated that an abrupt slowdown in concentrated traffic stream can trigger shock wave along the line of cars, either downstream (in the traffic direction) or upstream, or it can be stationary. Is the presence of darkness condition, artificial light condition and nature light condition could trigger potential of shock wave would be discussed in this study as shown in **Fig. 1**.

Any discontinuity in a state variable of flow, speed and density due to changes in condition such as darkness, artificial light and daylight can potentially set up shock waves that travel through the traffic stream. Previous researcher by (Ekrias *et al*., 2008) indicated that in a low traffic volume situation or in a free flow situation, driver's selections of speed are usually influenced by such factors of the road geometry, lighting and weather condition. Let us consider a traffic conditionas illustrated in **Fig. 1** that vehicles are approaching from artificial light to darkness along a straight segment of road. Driver's selection of speed is usually influenced by illumination area for example under nature light and artificial light compared in nighttimes due to consequence of high visibility. Therefore low visibility under darkness plays the most significant part in driver's behaviour and their desirable speed. Two conditions in which any one or more of the speed, density and flow are different from the corresponding value in the other condition are separated by a wave front or shock wave that will define as travelling with speed. The equation of shock wave velocity can be represented as:

$$Usw = \frac{q_b - q_a}{k_b - k_a} \qquad (1)$$

Where:

Usw = Propagation velocity of shock wave (km/h)
q_a = Flow prior to change in conditions (veh/h)
q_b = Flow after change in conditions (veh/h)
k_a = Traffic density prior to change in conditions (veh/km) and
k_b = Traffic density after change in conditions (veh/km)

1.3. q-k Curve and Macroscopic Shockwave

In this study, shockwave for traffic states under darkness, shockwave for traffic states under artificial light and shockwave for traffic state under nature light will be determined and the corresponding value would be compared with darkness and artificial light and darkness with nature light in order to check whether the confluence give rise to the shock wave under the darkness condition.

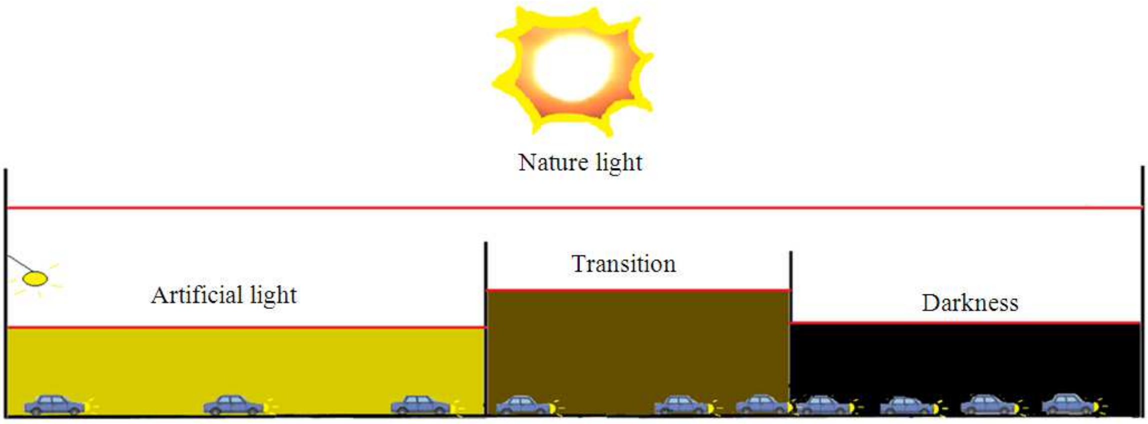

Fig. 1. Darkness condition, artificial light condition and nature light condition

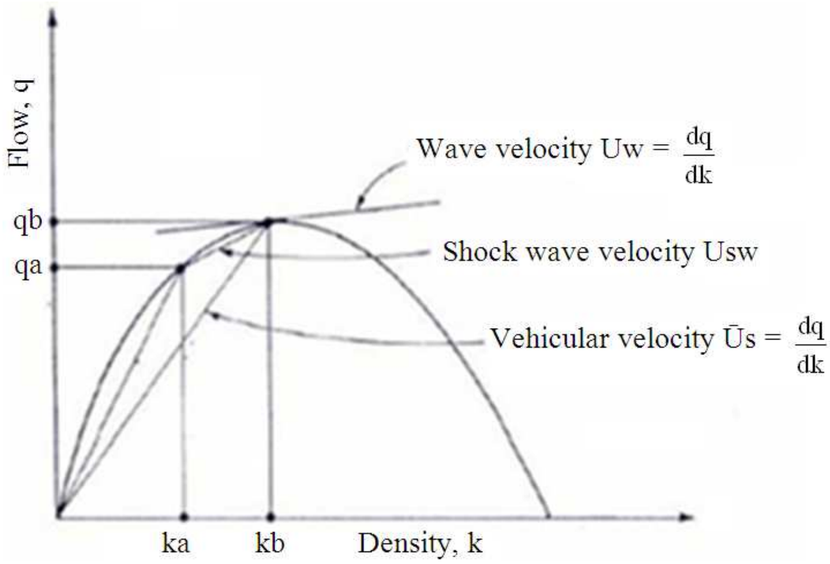

Fig. 2. Conventional q-k curve and the shockwave speed

It is noted that the above equation for the speed of the shock wave can also be obtained using simple graphical interpretation as shown in **Fig. 2**. As shown in the figure, it states that the speed of the shock wave is given by the slope of the line joining the points representing the two conditions (on a q-k graph) whose confluence gives rise to the shock wave.

1.4. Formulating Propagation Shockwave Speed

In general, q-k curve would give quadratic function as is shown in Equation 2 below:

$$q_b = \beta_1 k - \beta_2 k^2 \tag{2}$$

If quadratic function in Equation 2 is plugged into Equation 1, desired shock wave velocity can be obtained as in the Equation 3 below:

$$Usw = \frac{\left(\beta_1 k - \beta_2 k^2\right) - q_a}{k_c - k_a} \tag{3}$$

where, q_b represent as maximum flow rate which can be determined by differentiation and when the differentiation is equated to zero, k_c can be obtained and then this k_c will plug into Equation 2 in order to get the maximum flow rate. Meanwhile, β_1 and β_2 are coefficients.

1.5. Data Collection

Traffic flow measured quantitatively during daylight condition was seemed to be obvious in previous research. However traffic flow measured quantitatively attributable to darkness conditionis seems to be unknown. Therefore an attempt was made to identify these variables of darkness towards traffic flow movement. The darkness traffic states was selected based on dry condition for this study, therefore data for darkness was collected for a period of twenty-four hours and was observed for about three weeks on uninterrupted roadway section which is on highway road in Johor state of Malaysia. The darkness's data was collected in year 2010. The site is located about 23 km from Universiti Teknologi Malaysia along Skudai-Pontian highway. The highway link along the way from Skudai to Pontian is named as LebuhrayaSkudai-Pontian with assign number route 5 and is owned by federal government. The highway is a link between the southern city of Johor and the north-western part of peninsula Malaysia. In addition, it has features such two lane facility that is well maintained, marked and all traffic regulatory; guidance and warning devices are properly installed. Apart of that, the section has a posted speed limit of 60 km h^{-1}. Data been collected on a straight section along this highway whereby the straight segment is about 2km in length. However in order to compare darkness with artificial light state, therefore data for artificial light is required in this study. The artificial light data was collected for about three weeks in year 2011 along the same section of the road which having darkness at some distance. After considering Stop Sight Distance factor (SSD) between both desired locations, automatic traffic counter was installed for year 2010 representing data for darkness and subsequently after that, in year 2011, automatic traffic counter was installed again but this time at another location which representing data for artificial light. Detailed vehicular information logged in by the counters were retrieved and processed into macroscopic parameters. Traffic data of day light, darkness and artificial light during darkness time have been used in this study. All traffic volumes were converted to PCE units prior to analysis using the standard Malaysia PCE values.The site of the study as shown in **Fig. 3**.

1.6. Findings and Discussion

Data collected was graphically summarized on weekly bases. Daily and hourly summaries at 15 min intervals and these daily and hourly are separated into darkness time before sunrise and after sunset. At the location of study site, the sunrise appeared to be at 7.30 am and the sunset happened to be at 7.45 pm. In order to get darkness time, daylight time or nature light time were excluded. The volume and density captured in darkness and artificial light under darkness were graphically presented as shown in **Fig. 4 and 5** respectively. **Figure 6** displays volume and density for nature light only for the weeks of observation. This graphical which was obtained directly from the counter's software, allow accurate sampling from the data pool.

Similar data processing was carried out for darkness, artificial light and nature light data for one hour at 5 min interval. The one hour data of traffic flow parameters are tabulated separately in **Table 1-3** for the 3 various conditions denoted as darkness, artificial light and nature light. The data processing described under method of observed volume, speed and densities. In this study, each hour was divided into 5 min segments, which made 12 segments for every individual hour. Flow in terms of pcu/h were calculated for every 5 min segment. Having mean speed and flow, densities were computed using fundamental equation q = uk. Following tables represent the value of mean speed, flow and density for each 5 min segments for the selected time, from 10:00 to 11:00 during weekday study:

H_o = No significance difference of shock wave velocity between darkness and artificial light
H_1 = Have significance difference of shock wave velocity between darkness and artificial light

From the observation in **Fig. 7-9**, darkness, artificial light and nature light condition resemble the same pattern of traffic flow characteristics. However, there are some changes in traffic parameters when traffic condition changes as shown in **Table 4**. This is because when darkness condition compared with artificial light, the difference in shock wave speed is about 0.29 km/hr/ln and this means that since t-Test obtained for artificial lightis less than darkness, therefore H_1 hypotheses is rejected and H_o hypotheses is accepted whereby there is no significance difference of shock wave velocity between darkness and artificial light:

H_o = No significance difference of shock wave velocity between darkness and nature light
H_1 = Have significance difference of shock wave velocity between darkness and nature light

Table 1. Traffic flow parameters of darkness

Time (hr:min)	Mean Speed (km/h)	Flow (pcu/min)	Flow (pcu/hr)	Density (pcu/km)	Density (pcu/km)
10: 00 10: 05	72.94	48	576	0.658	7.9
10: 05 10: 10	76.14	59	708	0.775	9.3
10: 10 10: 15	67.82	74	888	1.092	13.1
10: 15 10: 20	74.15	57	684	0.767	9.2
10: 20 10: 25	66.82	57	684	0.850	10.2
10: 25 10: 30	68.06	38	456	0.558	6.7
10: 30 10: 35	71.31	42	504	0.592	7.1
10: 35 10: 40	68.24	33	396	0.483	5.8
10: 40 10: 45	82.80	49	588	0.592	7.1
10: 45 10: 50	84.69	29	348	0.342	4.1
10: 50 10: 55	73.16	59	708	0.808	9.7
10: 55 11:00	69.64	34	408	0.492	5.9
Constant	0.00	0	0	0.000	0.0

Table 2. Traffic flow parameters of artificial light

Time (hr:min)	Mean Speed (km/h)	Flow (pcu/min)	Flow (pcu/hr)	Density (pcu/km)	Density (pcu/km)
10: 00 10: 05	80.60	47	564	0.583	7.0
10: 05 10: 10	82.18	102	1224	1.242	14.9
10: 10 10: 15	76.19	49	588	0.642	7.7
10: 15 10: 20	66.01	91	1092	1.375	16.5
10: 20 10: 25	66.93	97	1164	1.450	17.4
10: 25 10: 30	76.26	82	984	1.075	12.9
10: 30 10: 35	70.80	62	744	0.875	10.5
10: 35 10: 40	71.87	82	984	1.142	13.7
10: 40 10: 45	75.99	86	1032	1.133	13.6
10: 45 10: 50	68.17	108	1296	1.583	19.0
10: 50 10: 55	69.93	87	1044	1.242	14.9
10: 55 11:00	66.28	86	1032	1.300	15.6
Constant	0.00	0	0	0.000	0.0

Table 3. Traffic flow parameters of nature light

Time (hh:min)	Mean Speed (km/h)	Flow (pcu/min)	Flow (pcu/hr)	Density (pcu/km)	Density (pcu/km)
10: 00 10: 05	75.88	62	744	0.817	9.8
10: 05 10: 10	77.18	73	876	0.950	11.4
10: 10 10: 15	71.05	60	720	0.842	10.1
10: 15 10: 20	73.33	67	804	0.917	11.0
10: 20 10: 25	76.63	91	1092	1.192	14.3
10: 25 10: 30	64.65	58	696	0.900	10.8
10: 30 10: 35	67.87	99	1188	1.458	17.5
10: 35 10: 40	53.04	76	912	1.433	17.2
10: 40 10: 45	63.44	101	1212	1.592	19.1
10: 45 10: 50	73.72	66	792	0.892	10.7
10: 50 10: 55	74.20	74	888	1.000	12.0
10: 55 11: 00	69.50	89	1068	1.283	15.4
Constant	0.00	0	0	0.000	0.0

Table 4. Comparison of shock wave velocity between darkness and artificial light

Conditions	t-Test	F	df	$p<0.05$	R^2
Darkness	19.79	392.89	11	2.201	0.973
A/Light	16.7	278.92	11	2.201	0.962
Conditions	q_a (pcu/hr)	k_a (veh/km)	q_b (pcu/hr)	k_c (veh/km)	Usw (km/hr/ln)
Darkness	348	4.1	1768.21	44.18	35.43
A/Light	588	7.7	1719.24	39.37	35.72

Table 5. Comparison of shock wave velocity between darkness and nature light

Conditions	t-Test	F	df	$p< 0.05$	R^2
Darkness	19.79	392.89	11	2.201	0.973
N/Light	10.52	110.50	11	2.201	0.909
Conditions	q_a (pcu/hr)	k_a (veh/km)	q_b (pcu/hr)	k_c (veh/km)	Usw (km/hr/ln)
Darkness	348	4.1	1768.21	44.18	35.43
N/Light	804	11	1358.12	30.51	28.40

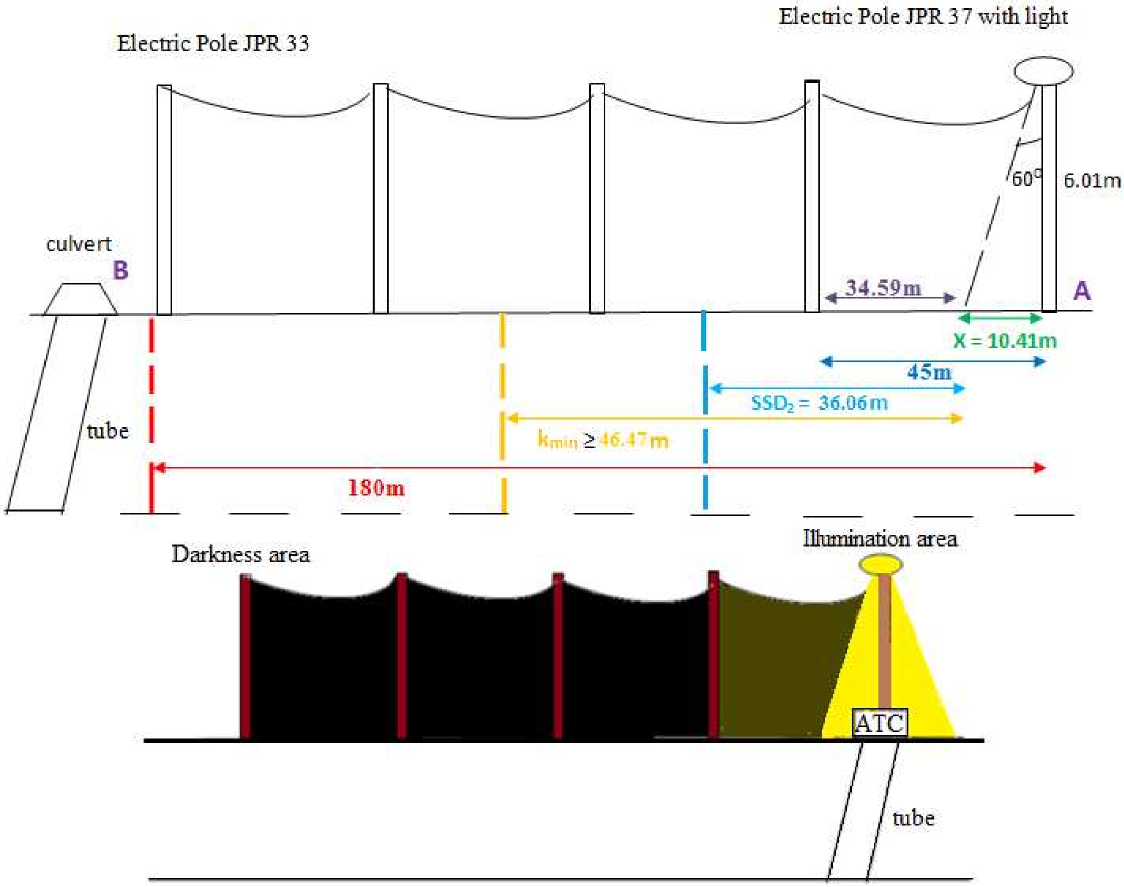

Fig. 3. Data collection site

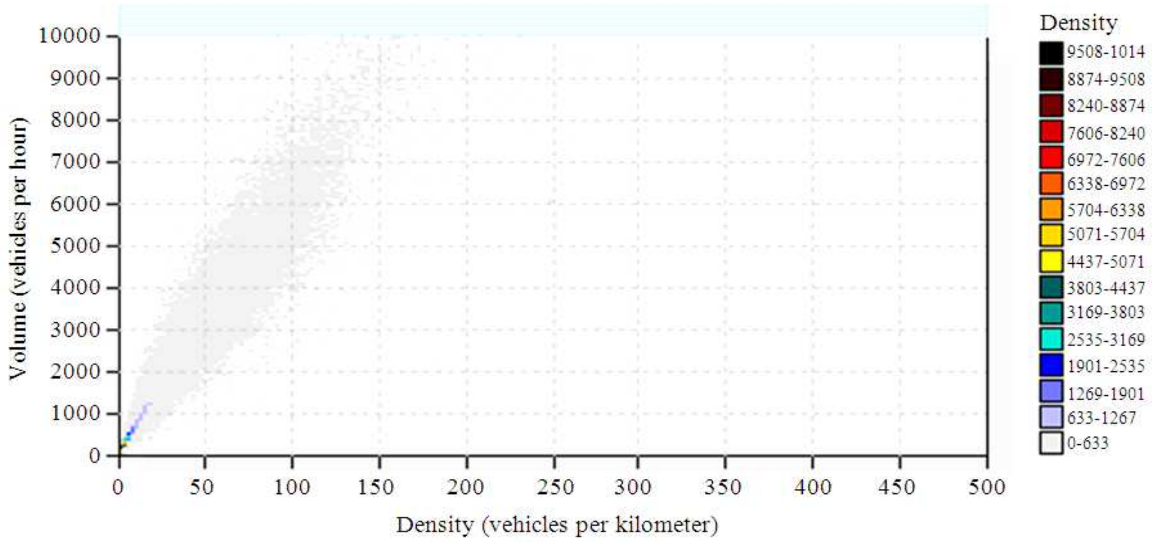

Fig. 4. Volume-density of darkness

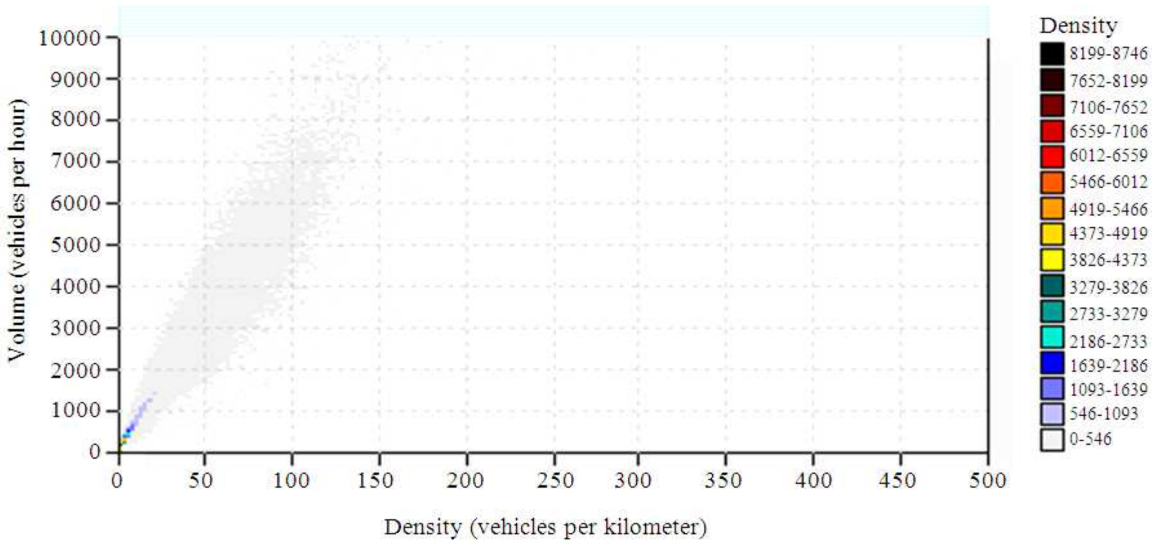

Fig. 5. Volume-density of artificial light

In **Table 5**, the result obtained resemblance as in **Table 4** whereby no significance difference of shock wave velocity between darkness and nature light because the t-Test for nature light which represents10.52 is less than t-Test for darkness. Therefore null hypothesis is accepted. In respect to that, darkness has 35.59% of resultant shock wave speed among the three conditions observed of which 19.84% less when compared with nature light and 0.82% less when compared with artificial light. The conclusion drawn that darkness has fairly minor impact on shock wave velocity for temporary.

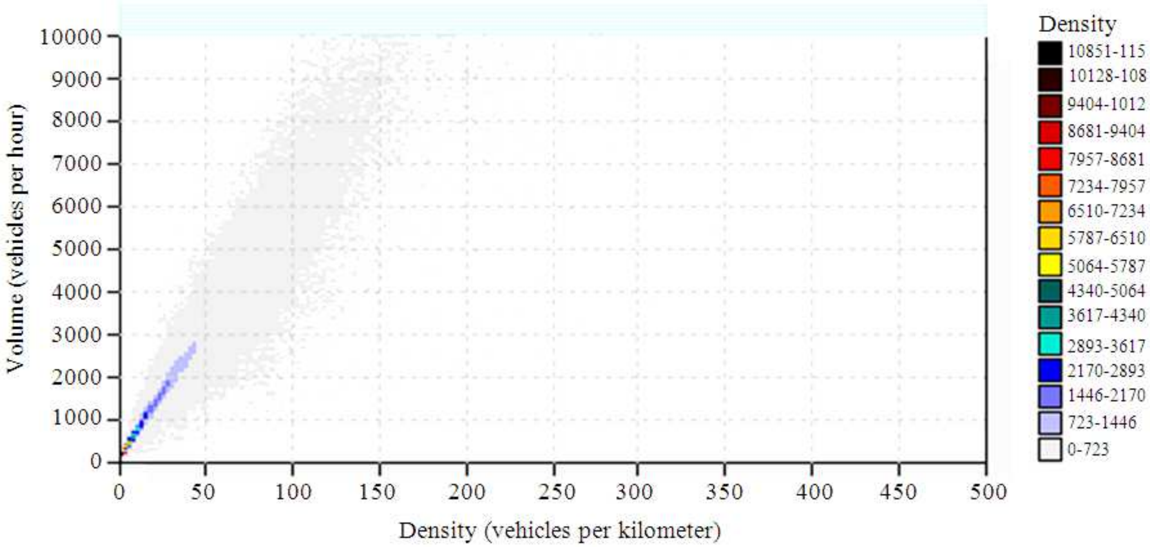

Fig. 6. Volume-density of nature light

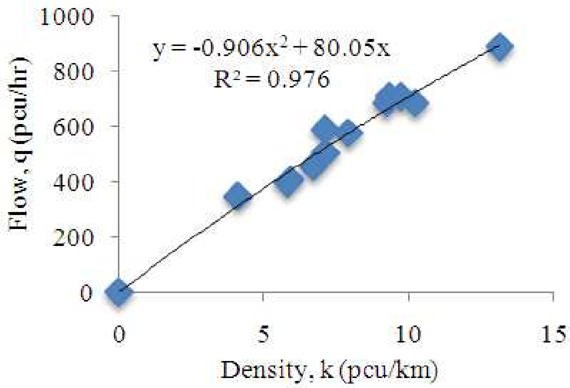

Fig. 7. Flow-density plot for darkness

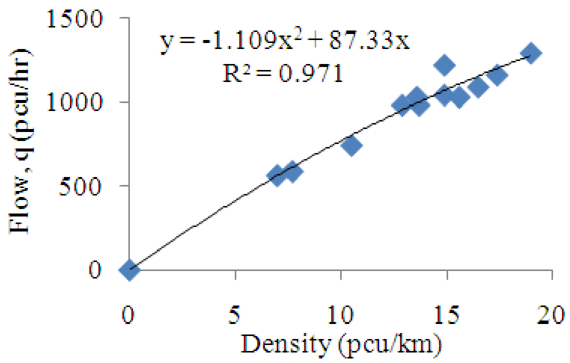

Fig. 8. Flow-density plot for artificial light

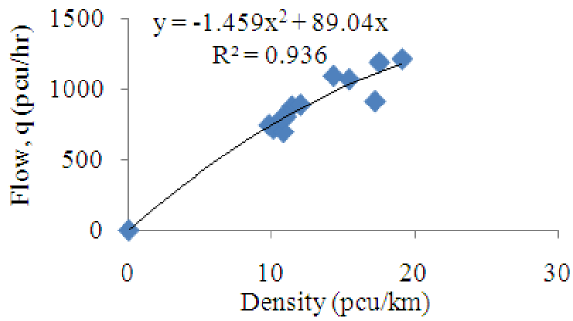

Fig. 9. Flow-density plot for nature light

2. CONCLUSION

Based on the synthesis of evidences obtained from the shock wave velocity under the denoted conditions of darkness, nature light and artificial light, it is correct to conclude that darkness did not bring much significance difference in resultant shock wave speed. The difference of resultant shock wave speed maybe due to drivers adjusts to new driving conditions from daylight to darkness time or from artificial light to darkness time. Based on the findings of the study, results show that traffic shockwaves only occur at the onset of darkness and the impact of darkness on highway traffic shockwave propagation is temporary and insignificant.

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