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Influence of Darkness Dry and Darkness Rainfall on Malaysian Expressway for Traffic Characteristics using Greenshield's model

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ABSTRACT

The study is concerned on evaluating traffic performance during darkness time on expressways. The study aimed at comparing influence of dry and rainfall weather condition. In a threshold impact of darkness, traffic flow characteristics on expressway at two different locations in Malaysia were investigated. Based on the investigation, data for travel speed, traffic flow and density were obtained continuously for three weeks at the selected segment of expressway in Slim River and supplemented with dry and rainfall data culled from ProjekLebuhraya Utara Selatan (PLUS). Observation periods for nature light, darkness and artificial light for the selected sites are 24 hours including darkness rainfall and darkness dry weather condition. Results show that density appears to be sensitive to speed, although the scatter decreases at higher speeds during darkness condition. Average speeds in the region of the higher densities region or lowers densities region appears to be a linear relationship and show reasonable agreements with the typical Greenshield's hypothesis for both darkness dry and darkness rainfall as far as the range of the data allows. Study concluded that comparison between darkness dry and darkness rainfall for Greenshield's model has no or less significant effect on traffic flow characteristics at the respective sites.

KEYWORDS: Darkness, dry, rainfall, speed, density, flow, Greenshield

1. INTRODUCTION

The study is aimed at investigating the influence of darkness dry and darkness rainfall on expressway traffic flow characteristics. Traffic flow characteristics are useful parameter in evaluating expressway standard of facilities. Traffic speed, travel time, traffic volume and density are fundamental traffic characteristics. These traffic parameters are related. The impetus of revisiting the modeling of a speed–density relationship is driven by need to find a darkness dry and darkness rainfall which can achieve reasonable empirical accuracy without sacrificing its quality. Among the three 'pair-wise' relationships for speed–density, flow-density, and speed-flow, the speed–density relationship appears to be fundamental since it draws direct connection to everyday driving experience. For example how a driver's speed choice is influenced by the presence of other vehicles under various condition. Such an observation has motivated speed–density models for darkness dry and darkness rainfall condition compared with the first attempt by Greenshields 75 years ago under daylight condition (Greenshields, 1935)[1]. Nighttime visibility on distances depends on the driving behavior of individual drivers. However, darkness under weather condition such as rainfall condition would be a subject of interest in this study. Individual driving behavior may cause permanent fluctuations in capacity and speed/density relationship remains valid with conventional wisdom trend. On the other hand, rainfall factors may cause periodic fluctuations and speed/density relationship models may irrelevant with respect to conventional wisdom trend. Therefore, a comparison is made between the darkness dry and darkness rainfall on speed/density models.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 (Sundara, 2013)[2].In Malaysia, there are some premises on expressway where lightings on some segments are turned off. This application

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designed by traffic engineers on some expressway due to factor that darkness can promote very little effect on the traffic flow which at the same time can safe cost on electricity for lighting. Opponents argued that motorway segment darkness will heighten the probability of motorway accident at night. (Ben-Edigbe, 2013)[3]Apart from posturing, both sides are yet to substantiate their arguments with meaningful scientific proof. In Holland, motorways will be unlit between 23.00 and 05.00 h to save money (Dutch News, 2013)[4]. In the United Kingdom, stretches of roadways are plunged into darkness between midnight and 5 am to save money and carbon according to the telegraph newspaper (2013)[5]. Drivers are warned of driving on the motorways in the dark because of poor visibility. Most of drivers rely on headlights in their vehicles or expressway lighting or both for better visibility when driving. However darkness promotes responsive driver behavior and enhances alertness. To shed light on complacency critics warned by the road users, such move of darkness on expressway could put road safety at risk even though the extent of risk has yet to be sustained.

2. Traffic Flow Characteristics Concept

Expressways are capital intensive ventures untaken by governments. They are the highest ranking roadway in Malaysia, often designated as motorway. Expressways in Malaysia are built to cope with allowable speed limit of 110 km/h. Some premises on expressway segment, road lighting was installed because of its ability to reduce night time accident and driver comfort (Holmes; 1997)[6]. Road lighting has function to illuminate adequately the road surface and objects on the road and its surrounding areas to be visible enough to ensure that the driving task is performed successfully (Aleksanteri E. *et al.*, 2008)[7]. From engineer's point of view, primary object of road lighting is to improve the safety of roads at night by providing good visibility conditions for all road users. However in some areas according to British Columbia Ministry of Transportation, nuisance lights such as bright lights or distracting lights are regulated and enforced under the Transportation Act. This is because nuisance lights are considered any light that would distract a motorist from the act of driving their vehicle. If the light is imposing a hazard to motorists or impairing a person's vision, the Ministry official has authority to ensure removal of the light as per Section 16 of the Transportation Act. The Ministry official may request the owner of the light to turn the light off, place dark covers around the light to direct the light away from motorists, reposition the light away from the highway or remove it entirely. Meanwhile according to Ontario Ministry of Transportation (OMT) Canada, Headlights enable drivers see the roadway in front of your vehicle when visibility is poor, as well as making your vehicle visible to others. Vehicle's headlights must shine a white light that can be seen at least 150 m in front and is strong enough to light up objects 110 m away. Vehicles must also have red rear lights that can be seen 150 m away and a white light lighting the rear license plate when headlights are on (OMT). Culled from OMT, typical low and high beam headlight coverage area are illustrated in Figure 1 and Figure 2.

Figure 1.0: Headlight using high beams during darkness

Figure 2.0: Headlight using low beams during darkness

When there is a rainfall, it has the tendency to distract the visibility. Rainfall is one of the meteorological elements that causes disruption to traffic flow and causes the greatest weather hazard to road traffic (Sundara, 2014)[8]. Drivers in the midst of rain can lose concentration when driving. Corresponding to poor visibility, the drivers normally drive their transport in a moderate slow speed in the rain. Unlike under dry weather, the drivers tend to go in speed because there is no contraction in visibility. Drivers caught up in rain have been known to reduce speed, increase headways with resulting contraction in flow. This has been supported by (Ben-Edigbe, 2010)[9] informing that reduction in flow during wet weather give impact to traffic flow parameters. However can this definition hold and spread the literacy to darkness rainfall on traffic expressway. This can be argued as this research will study the impact of darkness under rainfall on traffic characteristics in terms of speed, density and flow rate. Apart from that, under dry weather and good road surface conditions, HCM (TRB, 1994)[10] suggests that the speed/flow/density relationships should be based on the plots of a series of short period observations to consider the short-term fluctuations in traffic demand. However, there is no minimum time interval specified for the analysis. The relationships as they are traditionally understood, are illustrated in Figure 3.0 (a-c). This type of interpretation may be found from many traffic textbooks. Perhaps the most intuitive starting point for developing the basic traffic model is to focus on the relationship between speed and density. One possible representation of the process describing the change of speed from free flowing condition to jam condition might be the linear relationship indicated in Figure 3.(a), as suggested by Greenshields (TRB, 1975)[11]. The mathematical representation of the relationship is given as:

$$Vs = V_f - (V_f/Kj)K \qquad (1.0)$$

where, Vs is the space mean speed, V_f is the space mean speed for free flow conditions, K is the density and Kj is the jam density. Equation (1.0) is a simplification of various non-linear forms of the speed/density relationship which have been reported by a number of researchers since 30 years ago. Non-linearity in the speed/density relationship has been observed near free flow conditions and jam density. The linear representation of the speed/density relationship results in intuitive mathematical representations of traffic flow, speed and density interactions. A parabolic flow/density relationship can be derived by substituting Equation (1.0) into Equation (2.0) below which relates the three basic traffic variables:

$$Q = KVs \qquad (2.0)$$

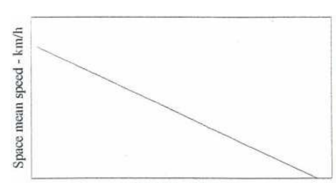
where Q is the flow and Vs and K are defined earlier. Hence, the flow/density relationship may be written as:

$$Q = K[V_f - (V_f/Kj)K] \qquad (3.0)$$

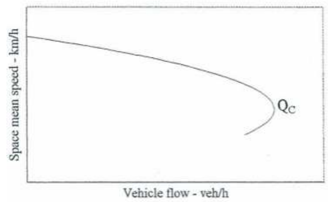
Similarly, a speed/flow relationship is obtained by rearranging Equation (1.0) for K and substituting the new equation of K into Equation (2.0) to give

$$Q = Vs[Kj - (Kj/Vf)Vs] \qquad (4.0)$$

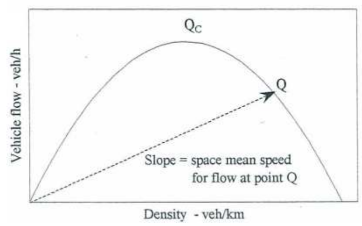
Two identical points on the parabolic curve descibing flow/density and speed/flow relationships, i.e Figures 3.0 (b) and 3.0 (c) respectively are worthy of note. The maximum flow rate, Qc, represents the highest rate of traffic flow that the section is capable of supporting. Speed for any flow may also be obtained from Figure 3.0 (c) by taking the slope of a line drawn from origin to a point on the curve as represented by a dotted line in the diagram.



(a) Speed/Density Relationship



(b) Speed/Flow Relationship



(c) Flow/Density Relationship

Figure 3.0: Speed/Flow/Density Fundamental Relationships

However, traffic stream is made up different types of conditions such as darkness dry and darkness rainfall; therefore traffic flow cannot be looked at in isolation of other daylight and dry weather condition which has been documented in HCM. This study compares darkness dry and darkness rainfall on traffic flow since the fundamental diagram of traffic flow encompasses expressway flow characteristics, it would be relied upon. This has been supported by (Parameswary, et.al 2013)[12]. The relationship between speed and density is such that as density increases speed decreases. These two parameters enable traffic engineers to relate travel demand directly to congestion on the freeway. The model used during analysis is Green shield's model as it is the most accurate model in predicting optimum speed and maximum volume. However, Greenshield's model is not reliable in computing jam density but this deficiency is beyond the need of this study. According to the principles of the study, only the data related to the off-peak hours and normal flow under the dry weather condition are necessary. Any oversaturated flow or interrupted flow data like congested condition, accident and/or car break downs should not be included in the analysis. Each pair of volume-speed data related to any unique observation should be used to determine the negative linear relationship between volume and speed. Using traffic fundamental relationship between speed, flow and density one can derive the second degree polynomial representing relationship between flow and density. Maximum volume can be easily calculated when differentiation of this equation equated to zero.

3. Set up of Highway Darkness Impact Study and Data Collection

As contained in many literatures, motorway capacity is constrained by factors associated with traffic, ambient and road conditions. Since the study is based on the influence of darkness dry and darkness rainfall on expressway traffic flow characteristics; the primary concern is measuring the number of vehicles passing a given point on the motorway segment under off-peak periods. Peak period counts are excluded in the analysis to remove peak traffic volume effect. Motorways are divided into three sections as shown in Fig. 4.

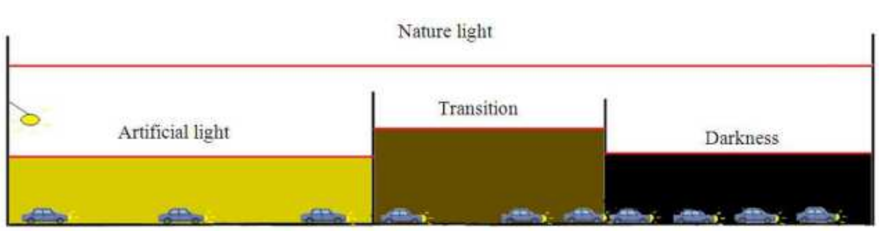


Figure 4: Hypothetical nature light, artificial light and darkness expressway segment in phases

Rain gauge station is deemed necessary in selecting for a suitable location in expressway since it stands as a reference point. The Projek Lebuhraya Utara-Selatan Department (PLUS) is having their owned rain gauge station which is located in the vicinity of study site at E1 371.35 whereby the distance is 0.35 km from E1 371.7 and 1.15 km from E1 372.5. It is located along the roadway whereby Site 3: DDS724003 is located within the radius range of rainfall capture which is to say less than 1 km from location of rain gauge station at E1 371.35. Rain data obtained from PLUS department will be used for analysis of traffic data study. Automatic traffic counters are positioned at each section. Figure 5.0 illustrates location of study site where darkness exists at the location of E1 371.7 and artificial light exists at the location of E1 372.5. PLUS rain gauge is stationed at the location of E1 371.35.

Figure 5: Illustration of Study Area with Rain Gauge Station

Section 1 and 3 is set at distance greater than the applicable sight distance; Section 2 is the transition length. The set distance was based on stopping distance SSD Eq. (5). It is assumed that the roadway has 0% Gradient (G), 2.5 sec reaction time (t), deceleration is taken as 3.4 m/sec2:

$$SSD = 0.278 v_t + 0.039\ v^2/a \qquad (5.0)$$

Three classes of vehicles (passenger cars, large goods vehicle and heavy goods vehicle) were investigated. Twenty four hour traffic volume, travel speed, headways and vehicle types are continuously recorded for 3 weeks. This information is processed in a variety of ways to generate traffic flow parameters of interest to this study. Data collected under darkness dry and darkness rainfall conditions were considered for inclusion in the analysis stage.

4. FINDINGS AND DISCUSSION

4.1Comparison of Speed/Density, Flow/Density and Flow/Speed Model on Expressway under Dry condition with Greenshield's Model

To compare with Greenshield's hypothesis of linear relationship model for speed/density and flow/density, Figure 5 and Figure 6 illustrate the external period of traffic at Site 3 and Site 4 on expressway for both speed/density and flow/density model under dry condition associate with Greenshield's model of equation. The predicted dry speed/flow model on expressway of various external periods in Figure 7 was compared with the regression model form and trend from Greenshield's speed-flow function that was fitted to the Chicago Data (Drake et al. 1967)[13]. The model is $q = 126.02v - 2.15v^2$ which shows the speed/flow function resulting from Greenshield's hypothesis of a linear speed-density relationship.

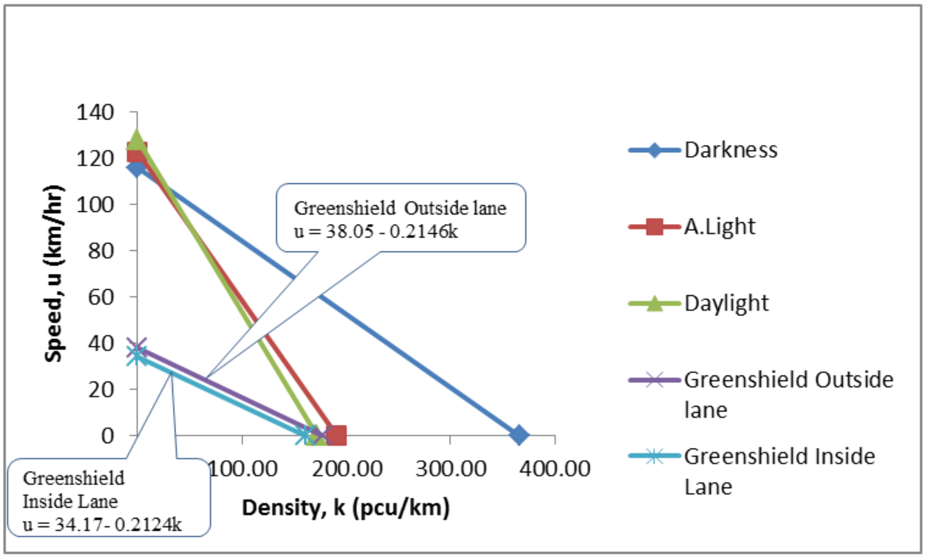


Figure 5: The Compared of Traffic Speed versus Traffic Density on Expressway under Dry Condition with Greenshield

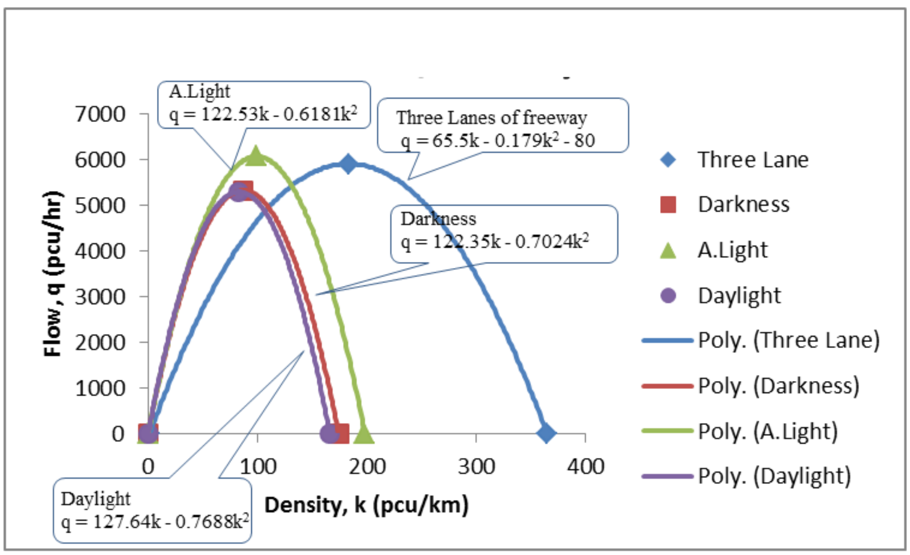


Figure 6: The Compared of Traffic Rate of Flow versus Traffic Density on Expressway under Dry Condition with Greenshield

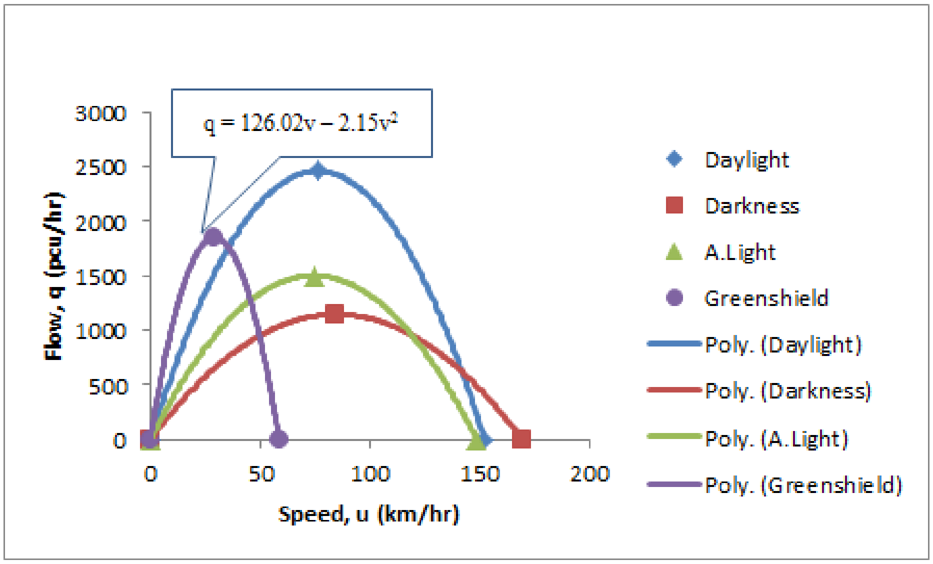


Figure 7: The Compared of Traffic Rate of Flow versus Traffic Speed on Expressway under Dry Condition with Greenshield

4.2Comparison of Speed/Density, Flow/Density and Flow/Speed Models on Expressway under Rainfall Condition with Greenshield's Model

To compare with Greenshield's hypothesis of linear relationship model for speed/density and flow/density, Figure 8 and Figure 9 illustrate the external period of traffic at Site 3 and Site 4 on expressway for both speed/density and flow/density model under rainfall condition associate with Greenshield's model of equation. The predicted rainfall speed/flow model on expressway of various external periods in Figure 10 was compared with the regression model form and trend from Greenshield's speed/flow function that was fitted to the Chicago Data (Drake et al. 1967). The model is $q = 126.02v - 2.15v^2$ which shows the speed/flow function resulting from Greenshield's hypothesis of a linear speed/density relationship.

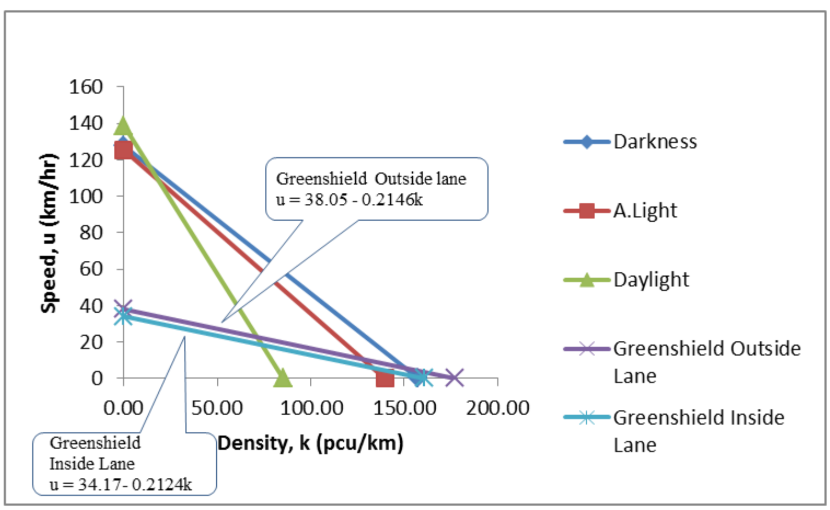


Figure 8: The Compared of Traffic Speed versus Traffic Density on Expressway under Rainfall Condition with Greenshield

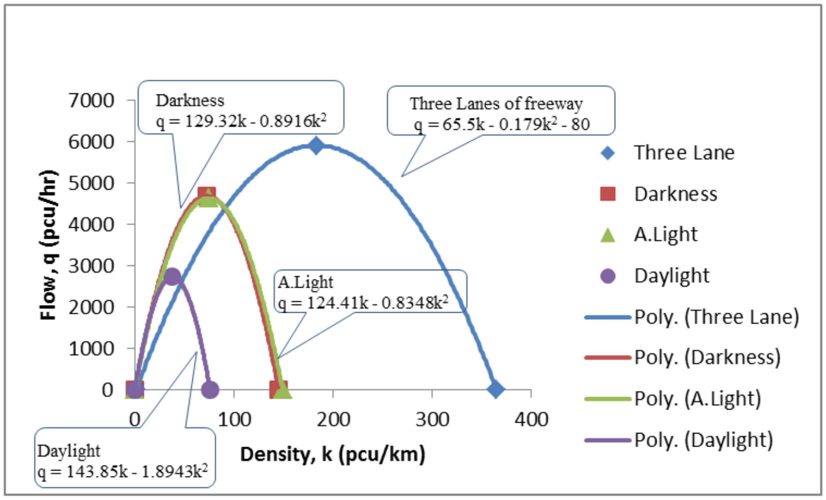


Figure 9: The Compared of Traffic Rate of Flow versus Traffic Density on Expressway under Rainfall Condition with Greenshield

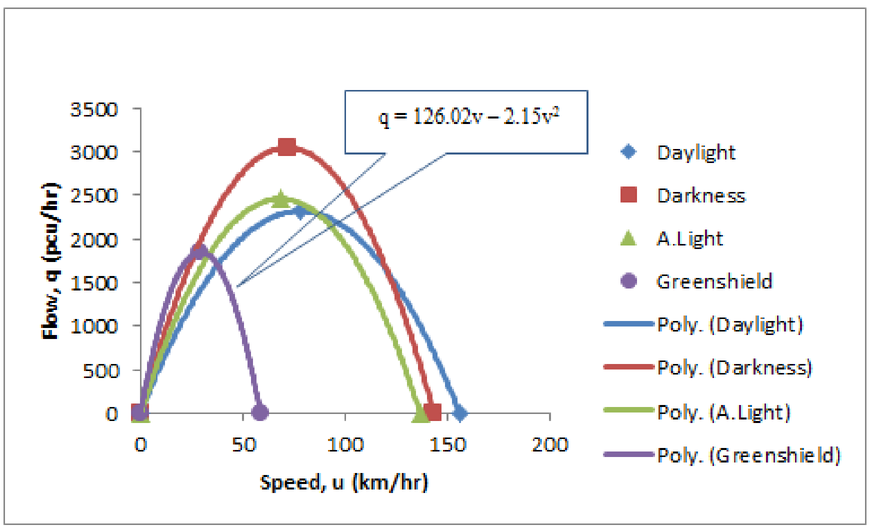


Figure 10: The Compared of Traffic Rate of Flow versus Traffic Speed on Expressway under Rainfall Condition with Greenshield

4.3 DISCUSSION

In relation to conventional interpretation, those figures shown could be interpreted to be consistent with the standard HCM using Greenshield hypothesis of a linear speed-density relationship with the development of traffic analysis model resulting from external period. Density appears to be sensitive to decrease speed for the external period of darkness, daylight and artificial light especially on expressway. For expressway under dry condition, Figure 5 represents the density increase with the presence of high speed when compared with Greenshield's model. However, the trend was slightly the same with Greenshield's model for the expressway under rainfall condition. Although the speed was obviously high, but the densities during rainfall daylight was slightly affected and the rest of periods seems to be the same with Greenshield's model. The rationale of this situation is because during daylight rainfall period, less vehicles travel on the road and thus lead to decrease in density and increase in speed on highway. On the other hand, the trend was indifferent for the three lanes expressway for MHA's speed/density model where density was increased to the sensitive increased speed for artificial light period and density was reduced to the sensitive slightly decrease speed during darkness. One rationale reason for this situation is that, to identify the nature linearity in operation, considerably more days of data are required. The size of the data set and analysis of 15-mins data traces unconfident in the trend and provide inadequate and inconsistent scatter region in the speed/density relationship for the external periods of darkness and artificial light condition. Density appears to be sensitive to speed, although the scatter decreases at higher speeds. Mainly for illustration, these figures represent the relationships among the average speed and average density over the observed periods and significantly from most speed-density models in which the average speed generally decreases linearly with the increase of density were observed. However, in this case the observable effect on darkness behavior, average speeds in these regions of the higher densities region or lowers densities region appears to be a linear relationship, which in medially region would obviously be a strong linear relationship. Those figures show reasonable agreements with the typical lines as shown in Greenshield's hypothesis as far as the range of the data allows.

5. Conclusion

Results show that density appears to be sensitive to speed, although the scatter decreases at higher speeds during darkness condition. Average speeds in the region of the higher densities region or lowers densities region appears to be a linear relationship and show reasonable agreements with the typical Greenshield's hypothesis for both darkness dry and darkness rainfall as far as the range of the data allows. Study concluded that comparison between darkness dry and darkness rainfall for Greenshield's model has no or less significant effect on traffic flow characteristics at the respective sites.

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