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# Impact of Highway Darkness on Traffic Flow Characteristics

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## ABSTRACT

Most of previous research on the effects of darkness investigated the issues of night visibility and traffic safety. Only limited efforts have been made to investigate the effect of darkness on traffic flow characteristics. Based on the hypothesis that darkness may induce traffic stream characteristics in the presence of substantial traffic volume, darkness impact study was carried out in Pontian, Johor Malaysia. Flow rate, speed and density were evaluated from the collected data under external periods of darkness, nature light and artificial light during dry weather condition and compared. Result signifies that roadway capacity during darkness is estimated approximately 1768.21pcu/hr, while during artificial light the roadway capacity is 1719.24pcu/hr and during nature light the roadway capacity is 1358.12 pcu/hr. The 15th percentile speed during darkness is 76 km/hr, increasing to 79 km/hr during artificial light condition but decrease to 75 km/hr during nature light. The 85th percentile speed during darkness, artificial light and nature light are 82 km/hr, 77 km/hr and 65 km/hr respectively. Statistical test result shown that the difference of 85th and 15th percentile speed during darkness and artificial light and during darkness and nature light condition was statistically not significant. Optimum speed during darkness is 40.02 km/hr, while during artificial light and nature light are increased to 43.67 km/hr and 44.53 km/hr respectively . The paper concluded that under highway darkness the quality of service on the roadway is not affected significantly.
**KEYWORDS:** Highway Darkness, Speed, Highway Capacity

## 1. INTRODUCTION

Main traffic flow characteristics are speed, density, headway and flow. These are the factors that can be used to qualify the serviceability of the roadway segment. The capacity at which a highway can handle the traffic flow efficiently can be determined by observing such factors. In general, drivers as individuals, care about the comfort of the drive. As engineers, the design of various traffic facilities should be such that drivers do not face any discomfort. Among the common causes of discomfort to drivers are including excessive deceleration rates, excessive jerk and glare. If there is a darkness on the roadway, how the drivers will reduce the level of discomfort is a question that need to take into account. This is because during nighttime, if there is no road lights available along the roadway, the drivers might face some problems of interfering traffic contraction flow. Darkness can make drivers to go in slow speed compared in daytime. This is because during darkness there is not enough lights to illumine the whole area of the roadway. Only drivers depend on lights provided in their vehicles. So the vehicle's light does not seem much effective during nighttime on the road without the presence of road light. Therefore, this study will mitigate the impact of darkness on the level of service.

### 1.1. Previous Findings under External Periods

A proper highway makes it possible for user to ride safely and comfortably at the design speed. The quality of road surface and its facility will affect the performance evaluation, which traffic engineers can rate operating characteristics of individual section of roadway and facilities as a whole in relative terms as was mentioned in (Jahandaret al, 2012)[1]. In a low traffic volume situation, driver's selection of speed is usually influenced by such factors as the road geometry, lighting and weather condition (Aleksanteri Ekrias et al, 2008)[2].Therefore, in a straight segment of road, darkness plays the most significant part in driver's behaviour and their desirable speed. Studies have shown that road lighting has minor effect to the flow and roadway capacity under congestion condition. One reason is, in congestion condition, as the space headway decreased the speed of vehicles will be decreased for drivers to retrieve safe time headway. In this situation drivers have enough time to decide what to do when they are seeing an obstacle or changing the lane, while in high speed. Otherwise they might be surprised and not have enough time to man oeuvre smoothly and subsequently shock the entire traffic flow (Othman et al, 2004) [3]. However it can be argued that road lighting can promote discomfort to some drivers as the drivers profoundly subjected to glaring situation. This situation happens when there is too much of lighting make drivers effectively blinded for a small period of time and thus posing a big safety hazard. Therefore these kind of drivers prefer to drive in darkness condition compared in road lighting.

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### 1.2 Criteria of External Period Findings

In this study, data are collected in a condition that possible disturbances of which may lead to wrong estimation of capacity should be avoided. These disturbances are such as congestion in peak hours, vehicle breakdowns, bottleneck, emerging ramps and intersections and adverse weather since previous research shows that adverse weather condition has the same effect on traffic flow as congestion (Alhassan and Johnnie, 2011)[4]. Evaluation relies on measuring performance quality, often stated in level of service. Quality of service can be measured from speed – volume relationship. In essence, by comparing 85th and 15th percentiles of cumulative speed distribution of roadway under day light, darkness and road lighting condition, the quality of roadway service can be estimated. Activity of the people is not restricted only in daytime, but people still doing their tasks in night time. Night time driving can be particularly a problem because is in bond with visibility for road users which can influence drivers' behaviour. Some previous studies found no change in average speed when road lighting was introduced, while others show contrary (Anais Mayeur et al, 2010) [5]. Most of previous study of darkness usually related to traffic safety and accident prevention. Only limited studies have been done to investigate effect of darkness to the quality of roadway service (QRS). QRS should be considered under darkness condition to compare with the control QRS when it is under day light condition and QRS under artificial light condition. The aim of this study is to determine the extent of darkness impact on traffic flow characteristics and the effectiveness of highway service. Based on the hypothesis that highway darkness would have minimal influences on traffic flow characteristics, the remainder of the paper has been divided into four sections. Following section, section 2, focuses on literature review of highway darkness and traffic flow concepts. Section 3 describes the setup of impact study and data collection. Section 4 is findings and discussion. Conclusions are drawn in section 5.

## 2. Traffic Flow Characteristics Concept

Previous study focused on estimating capacity in numeric values in order to be use in design and transportation management purposes (Persaud and Hurdle, 1991) [6]. Highway capacity values vary between locations, number of lanes, time of day and segment type as reported by (Jiyoun, Sarah and Elefteriadou 2009)[7]. Bottlenecks act as a constraint which result in breakdown phenomenon prior to traffic flow reaches its capacity. This leads to capacity loses that resulting impact on performance (Chin et al, 2002)[8]. The fluctuation of capacity values obtained along a highway made Minderhoud et al (1997)[9] to consider capacity as a stochastic parameter after a comprehensive critic on the methods of capacity estimation. Wu (2002)[10] used the fundamental diagram approach to predict the capacity of highways without the need to measure it directly. Researchers are now focused on precise measurements and forecast of the capacity of highways to be used in performance evaluation, accident detection and prediction, as well as the production of counter measures for safe and efficient operation of highway. The fundamental diagram is an approach proposed by Greenshield and lately by Wu (2002) which could be used to estimate traffic condition on a highway section. In particular, Greenshield model is accurate in highway capacity prediction (Alhassan and Johnnie, 2011)[11]. 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 Greenshield'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. Fundamental equation of traffic is as follow:

$$q = uk \longrightarrow u = \frac{q}{k} \longrightarrow k = \frac{q}{u} \qquad (1)$$

Where "u" is speed (km/hr), "k" is density (veh/km) and "q" is flow (veh/hr). General form of quadratic relationship between flow and density is presented in below:

$$q = \beta_1 k - \beta_2 k^2 \qquad (2)$$

Where $\beta_1$ and $\beta_2$ are coefficients. Then with dividing the equation 2 by "k" and plugging equation 1 intoit, following equation can be derived. This equation should be used to estimate the speed of traffic flow.

$$u = \beta_1 - \beta_2 k \qquad (3)$$

Using equation 3, optimum speed can be derived by substituting the value "$\beta_1$" by free-flow speed (uf)and considering critical density, as shown in equation 4.

$$u_{opt} = u_f - \beta_2 k_{cr} \qquad (4)$$

Maximum volume can be calculated by differentiating equation 2 in term of k, and then setting theequation to zero to find the critical density (kcr) as follow:

$$\partial q / \partial k = 0 \; ; \; \beta_1 - 2\beta_2 k = 0 \; ; \; k_c = \frac{\beta_1}{2\beta_2} \tag{5}$$

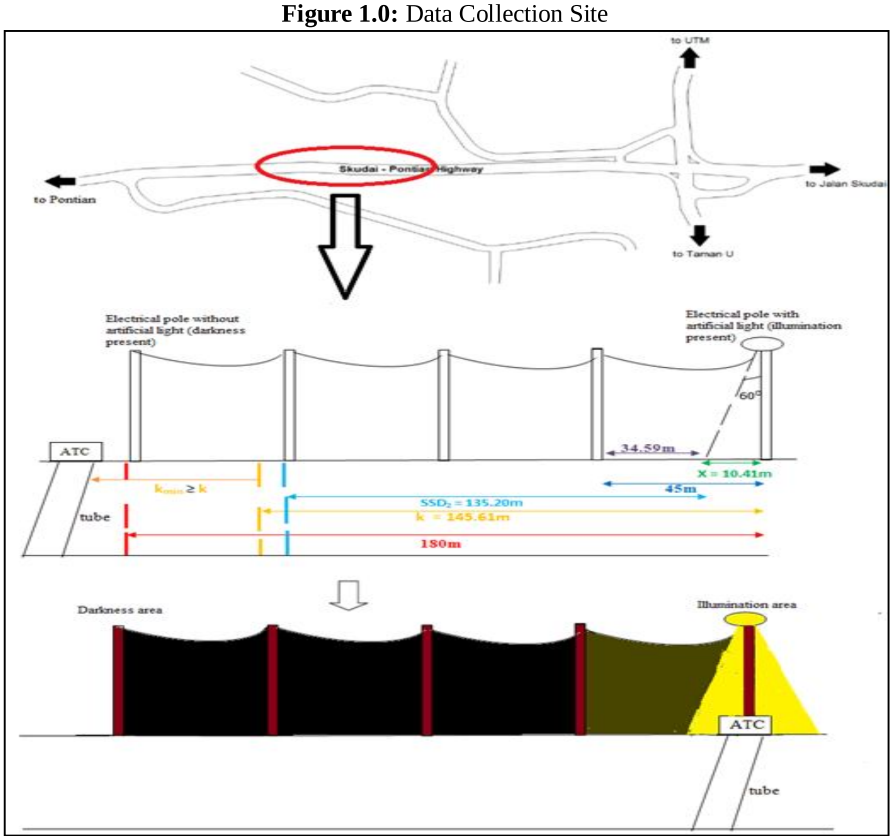
As a result, maximum flow can be derived by substituting critical density into equation 2.

$$q_{max} = \beta_1 k_c - \beta_2 k_c^2 \tag{6}$$

**3. Set up of Highway Darkness Impact Study and 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 condition is 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 Lebuhraya Skudai-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 60km/hr. 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 was 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 paper. 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 Figure 1.0.

**Figure 1.0:** Data Collection Site



## 4. FINDINGS AND DISCUSSION

### 4.1. Flow – Density Relationship

A fundamental diagram is the bivariate relationship between the macroscopic parameters of speed, volume and density. A fundamental diagram (FD) can thus be produced from any traffic condition for which these parameters are observable. In a similar way flow-density relationship can be used to construct fundamental diagrams to show darkness, artificial light and nature light conditions of a highway under dry weather. Three graphs, one representing darkness conditions, other representing artificial light condition and followed by nature light condition are drawn as shown in further figures. In this study, each hour was divided into 5-minute segments, which made 12 segments for every individual hour. Flow in terms of pcu/hr were calculated for every 5-minute segment. Having mean speed and flow, densities were computed using equation 2. Following tables; Tables 1, Tables 2 and Tables 3 represent the value of mean speed, flow and density for each 5-minute segments for the selected time, from 10:00 to 11:00 during weekday study for the three different conditions. In response to the objectives of the study, at first, it needs to establish the polynomial model which relates flow to density. Statistical analysis software was used to estimate quadratic model and regression as shown in Figure 2.0, Figure 3.0 and Figure 4.0 and its equations are as shown in (7), (8) and (9).

**Table 1.0:** 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** | 82.8 | 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 | 0 | 0 | 0 | 0 |

**Figure 2.0:** Flow-Density Plot for Darkness

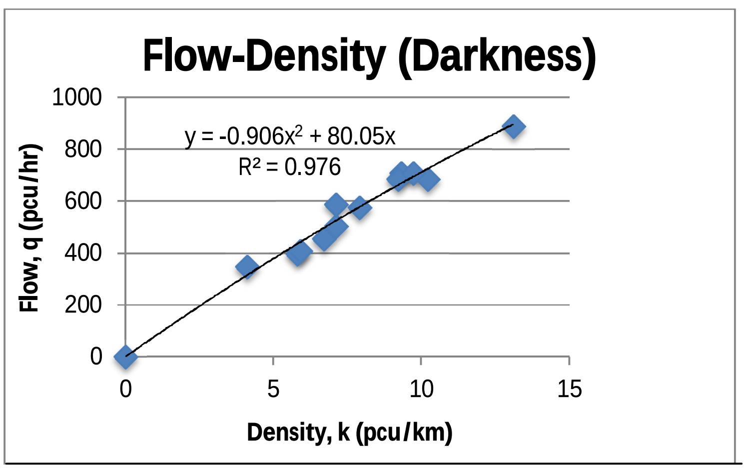



**Table 2.0:** Traffic flow parameters of Artificial Light

| Time (hr:min) | Mean Speed (km/h) | Flow (pcu/min) | Flow (pcu/hr) | Density (pcu/km) | Density (pcu/km) |
|---|---|---|---|---|---|
| **10: 00 –10: 05** | 80.6 | 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** | 70.8 | 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 | 0 | 0 | 0 | 0 |

**Figure 3.0:** Flow-Density Plot for Artificial Light

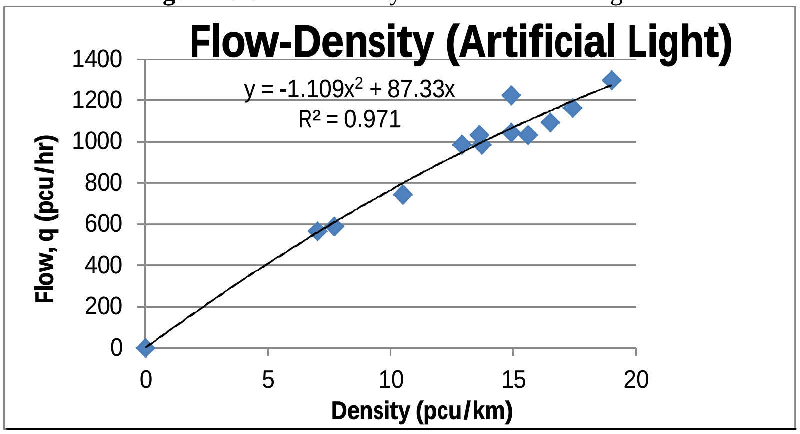
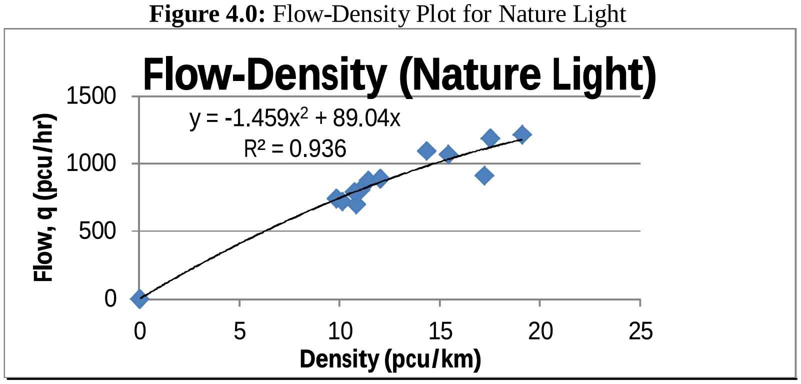



**Table 3.0:** Traffic flow parameters of Nature Light

| Time (hh:mm:ss) | 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 | 74.2 | 74 | 888 | 1.000 | 12.0 |
| 10: 55 – 11:00 | 69.5 | 89 | 1068 | 1.283 | 15.4 |
| Constant | 0 | 0 | 0 | 0 | 0 |

**Figure 4.0:** Flow-Density Plot for Nature Light




$$q = 80.05k - 0.906k^2 \quad (7)$$

Where; q is flow (pcu/h) and k is density (pcu/km)

In order to determine apex point in Figure 2.0,the derivation of the model equated to zero which gives the critical density, then by substituting this value, maximum value of flow or capacity of roadway facility under darkness time condition is obtained which is 1768.21 pcu/hr. Maximum value of the flow is calculated as follow:

$\partial q / \partial k = 80.05 - 1.812k = 0$; hence, critical density, $k = \frac{80.05}{1.812} = 44.18$ pcu/km

Capacity, $q = 80.05(44.18) - 0.906(44.18)^2 = 1768.21$ pcu/hr

Relationship between flow and density during nature light condition is as follow:

$$q = 89.04k - 1.459k^2 \qquad (8)$$

Maximum value of flow or capacity of roadway facility under nature light condition is 1358.12pcu/hr. Maximum value of the flow is calculated as below:

$\partial q / \partial k = 89.04 - 2.918k = 0$; hence, critical density, $k = \frac{89.04}{2.918} = 30.51$ pcu/km

Capacity, $q = 89.04(30.51) - 1.459(30.51)^2 = 1358.12$ pcu/hr

Relationship between flow and density during artificial light condition is as follow:

$$q = 87.33k - 1.109\,k^2 \qquad (9)$$

Maximum value obtained for capacity of roadway facility under artificial light condition is 1719.24 pcu/hr. Maximum value of the flow is calculated as below:

$\partial q / \partial k = 87.33 - 2.218k = 0$; hence, critical density, $k = \frac{87.33}{2.218} = 39.37$ pcu/km

Capacity, $q = 87.33(39.37) - 1.109(39.37)^2 = 1719.24$ pcu/hr

**Figure 5.0:**Flow – Density Relationship with Darkness and Artificial Light

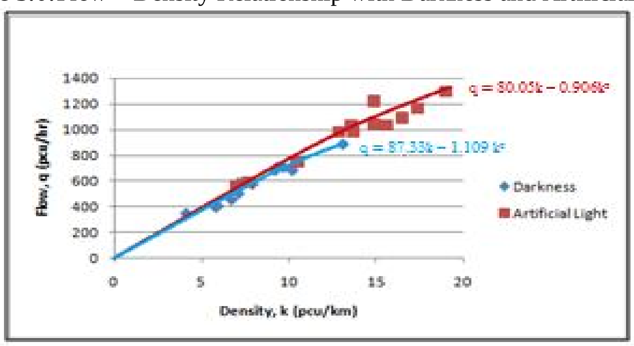
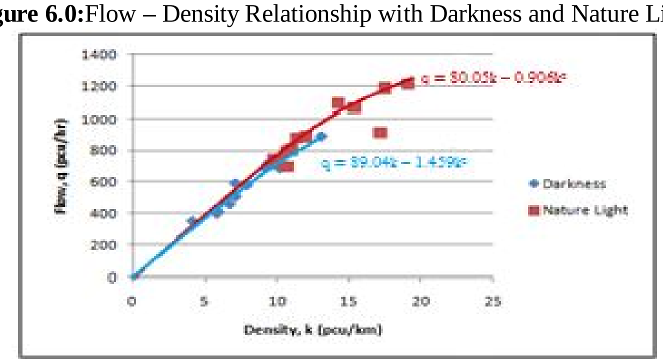



**Figure 6.0:**Flow – Density Relationship with Darkness and Nature Light




**4.2. Speed – Density Relationship**

In equation (7) calculated free-flow speed is 80.05 km/hr for darkness. Therefore optimum speed during darkness can be computed as:

$Uo = 80.05 - 0.906k_{critical}$

$= 80.05 - 0.906(44.18)$

$= 40.02$ km/hr

Same procedure applied for nature light condition. Let free-flow speed equals to 89.04 km/hr in equation (8), optimum speed can be calculated as:

$Uo = 89.04 - 1.459\,k_{critical}$

$= 89.04 - 1.459(30.51)$

$= 44.53$ km/hr

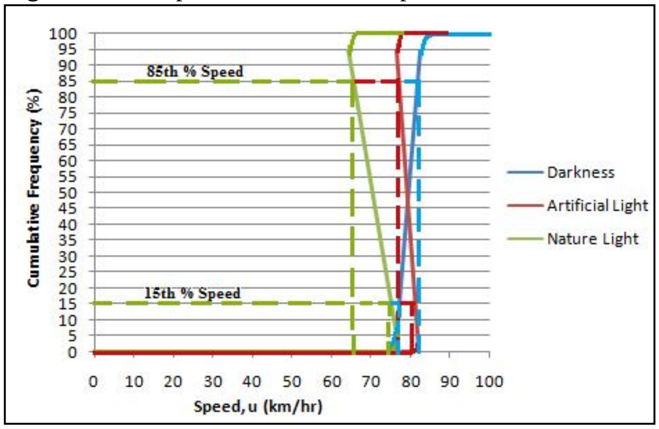
Optimum speed for nature light condition is 44.53 km/hr which is higher than that of darkness condition. Same procedure applied for artificial light condition. Let free-flow speed equals to 87.33 km/hr in equation (9), optimum speed can be calculated as:

$U_o = 87.33 - 1.109\, k_{critical}$
$= 87.33 - 1.109(39.37)$
$= 43.67$km/hr

### 4.3. Effectiveness of Highway Darkness

Other approach to measure the quality of roadway service in a qualitative manner is to investigatespeed variation along the facility by having a critical view to recognize the trend of movement under darkness, nature light and artificial light condition. Therefore, the 85th and 15th percentile of speed could play a substantial role to achieving this goal. The 85th and 15th percentile speed can be determined using cumulative speed distribution curve as shown in Figure 7.0.

**Figure 7.0:** Comparative Cumulative Speed Distribution Curves




The percentage of cumulative number of vehicle alongside speed was plotted. Therefore, the sample is used to determine the total trend of distribution and any parameters could be obtained. Beside median speed and mean speed, the 85th percentile speed is used to measure the speed limit of highway and the 15th percentile speed is used to estimate minimum speed of highway. The 85th percentile speed for darkness condition is 82 km/hr, for artificial light condition is 77 km/hr and finally for nature light is 65 km/hr. Similarly, the same trend is applied for the 15th percentile of speed which is 76km/hr, 79 km/hr and 75km/hr for darkness, artificial light and nature light conditions respectively.

Mean speed for darkness is 72.98 km/hr whereas this value slightly reduced to 72.60 km/hr for artificial light condition and reduced to 70.04 km/hr for nature light condition with respect to standard deviation of 5.80 for darkness, 5.56 for artificial light and 6.99 for nature light condition. Difference of 85th speed between darkness and artificial light is 5 km/hr while on the other hand difference of 85th speed between darkness and nature light is 17 km/hr. Result throughout the statistical analysis, showed P-value is 0.98 which is much more than 0.05 indicating null hypothesis is accepted and there is no significant difference between darkness and artificial light and no significant difference too between darkness and nature light**.** Similarly, the same approach goes to analyze of 15th speed for both scenarios. P-value states 0.99 which is more than 0.05 indicating null hypothesis is accepted and there is no significant difference between darkness and artificial light and no significant difference too between darkness and nature light.

## 5. Conclusions

This study was carried out to determine the extent of highway darkness impact on traffic flow characteristics. Based on the synthesis of evidence from the study, it can be inferred that highway darkness although discomfort for night visibility has no significant effect on traffic flow characteristics. The paper concluded that under highway darkness the quality of service on the roadway is not affected significantly.

**Acknowledgment**
The authors declare that they have no conflicts of interest in this research.

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