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Research Article

Effect of Road Lighting on the Quality of Dual Carriageway Road Service

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Abstract: The study is exciting because it introduced a new quality of road service assessment approach. The study explored the effect of road lighting on the quality of dual carriageway road service. Based on the hypothesis that road lighting has no significant effect on the level of road service, an impact study was carried out in Skudai town, Malaysia. Twenty four hours continuous traffic volume, vehicle types and speeds data were collected during daylight, road lighting and dry weather conditions for two directional flows. Results show that travel speeds speed during daylight and road lighting periods did not differ significantly. The study concluded road lighting does not affect the quality of road service significantly.

Keywords: Density, highway, road lighting, road service, speed

INTRODUCTION

Globally, road use is a 24 h operation under daylight road lighting, darkness and other ambient conditions. Road lighting impact studies are rare. However, in a previous study (Van Goeverden and Botma, 1998) a significant increase in capacity of about 2.5% was found during nighttime (road lighting) whereas in this study, highway capacity change is considered to be insignificant. This is so because in order to compare capacity for daylight and road-lighting flow and speed must be observed within the same time frame, point and/or section. But this cannot happen within a 24 h day period because daylight is approximately between 7 am and 7 pm and road lighting between 7 pm and 7 am. If this line of thought is pursued, empirical road capacity for daylight and road lighting will occur at two separate periods, hence cannot be compared. It can be argued. Further, it is likely that capacity during road lighting will occur at off peak period; even if it doesn't, peak period data cannot be used because of the constraint inherent in it. Given the complexity of defining time frame for road lighting impact studies, it is reasonable to assess the effectiveness of highway traffic stream under daylight and road lighting conditions. The dominant parameter in qualitative assessment of highway service is travel speed (free-flow and 85 percentile). It can be measured. In the previous Dutch case study (Van Goeverden and Botma, 1998) on the impact of road lighting on the capacity of uninterrupted motorway sections; a capacity estimation method based on extrapolation of the free-flow rate and density was used. The method assumes that the density at capacity is not affected by illumination, which implies that capacity shifts are fully the result of speed changes. However, in the Malaysia case study, maximum flowrate was based on extrapolation from speed and density linearity function. The reasons for this approach are:

- Capacity for prevailing conditions are not dependent on the same time frame within a 24 h time cycle even though road lighting and daylight are with the same 24 h time frame;
- Speed normalization would allow maximum flow boundary to gyrate within the allowable speed variance. In any case, the concern of the study is to estimate the number of vehicles passing a road segment during daylight 7 am-7 pm, road lighting 7 pm-7 am, dry weather and off-peak conditions. Off peak periods are needed in order to eliminate the influence of peak traffic conditions on the observed highway traffic stream. Based on the hypothesis that road lighting has insignificant impact on the quality of dual carriageway road service, the remainder of the study has been divided into four sections. Section 2 is on literature review and in section 3 setup of impact study and data collection are discussed. Section 4 deals with results, analysis and findings. In section 5, conclusions are drawn.

LITERATURE REVIEW

Qualitative assessment of roadway service is a subjective yet scientific measurement of road providers and users perception of value derived from using the

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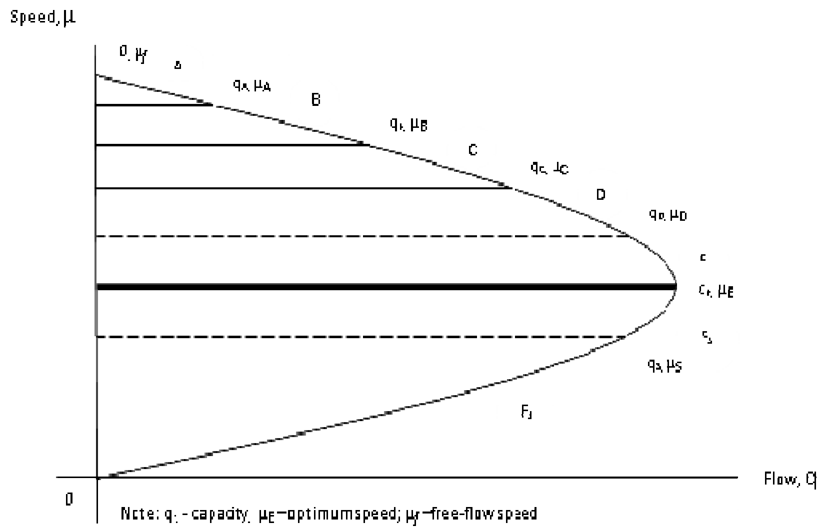

Fig. 1: Graphical illustration of hypothetical level of road service

highway. In many studies, speed/flow is often used for qualitative measurements. In the United States, observed speed/flow data are often superimposed on predetermined level of service chart in other to determine the prevailing LOS. Highway Capacity Manual (HCM) uses speed/flow as the control variables to describe six LOS experienced by road users. It can be argued that LOS describes the perception of road providers not users, after all there is nothing in LOS manual to suggest that road users experience was assessed. Rather, LOS divides the level of traffic flows into six levels ranging from level A to level F. where level A is the highest quality of highway service and level F the lowest. Level of service E denotes traffic operation at capacity. Capacity is taken as 2000 vehicles per hour per lane; optimum speed is approximately 80km per hour and critical density is 25vehicles per km (Ben-Edigbe, 2010; Anais *et al*., 2010). In Malaysia, the speed limit on principal roadways is 80 km/h. Consequently, it is difficult to visualize a traffic stream that's operating at 80 km/h on a two-lane highway in Malaysia as unstable and at critical stage. The vagueness of LOS assessment criteria makes it unsuitable for use in Malaysia even though it is in use at the moment. In any case, the concept has not gain significant traction in Europe, in the United Kingdom LOS is sparingly used in practice. The study recognises that quality of highway service hinges on two important assessment inputs; the service providers' (traffic class, traffic control and safety) and the road users' (travel time, comfort, delay and queues).

Quality of road service concepts: Quality of road service is a function of speed and volume/capacity ratio. In other to assess prevailing highway traffic class, there is need to have an assessment criteria that reflects

Table 1: Hypothetical level of road service criteria

LRS		Intervals Speed i = 1	Flow i = 2	Density i = 3
A		μ_f -μ_A	$\le q_A$	q_A/μ_A
B		μ_A-μ_B	$\le q_B$	q_B/μ_B
C		μ_B-μ_C	$\le q_C$	q_C/μ_C
D		μ_C-μ_D	$\le q_D$	q_D/μ_D
E		μ_D-μ_E	$\le q_E$	q_E/μ_E
F	F_s	μ_E-μ_S	$\le q_S$	q_S/μ_S
	F_J	μ_S-μ_J	$< q_J$	q_J/μ_J

i – order of LRS assessment; Fs –shockwave flow; Fj jam flow

traffic performance at peak under dry and daylight conditions. In the study the assessment criteria or if you like traffic control class is divided into six classes (A-F) (Fig. 1 and Table 1), where A is the highest and F is the lowest. Traffic flow oscillates between Class A and D. Class A describes traffic flow within the 15 percentile and free-flow speeds. It also shows that traffic flow is between zero and 15% of capacity. Class B describes traffic flow within the 15 percentile and 50 percentile speeds. It also shows that traffic flow is between 15 and 50% of capacity. Class C describes traffic flow within the 50 percentile and 85 percentile speeds. It also shows that traffic flow is between 50 and 85% of capacity. Class D describes traffic flow within the 85 percentile and optimum speeds. It also shows that traffic flow is between 85% of capacity and the capacity. Beyond capacity, traffic flowrate contraction sets in; class E describes flowrate contraction within the shockwave velocity propagation zone. It suggests that traffic congestion at this stage may be construed as 'temporary'; Class F describes traffic congestion where vehicle moves in lockstep with the vehicle in front of it. Additional vehicles entering the traffic stream may trigger traffic jam.

Determining the coordinates of speed/flow curve: In the study traffic flow is synonymous with

volume/capacity ratio. Volume/capacity ratio depicts the proportion of traffic flow traversing a roadway and used to predict its effectiveness. The ultimate value is 1.00. The ratios are classified in the study into four main groups; ≤0.15, 0.15 to 0.50, 0.50 to 0.85 and >0.85 to 1.00. Volume/capacity critical ratio is often taken in many studies as 0.85, therefore, traffic flow at and beyond 0.85 is considered to be approaching capacity. There is no need to suggest otherwise. The general concept in the United Kingdom is that, the maximum speed limits should be based primarily on an established 85th percentile speed. The 85th percentile is an important descriptive statistic in evaluating road safety. The general concept is that maximum speed limits should be based primarily on an established 85th percentile speed under good traffic conditions. Hence, most cumulative speed distribution curves indent at around 15 percentile and 85 percentile of the total number of vehicle observations. In many studies, 85% is considered as critical volume/capacity ratio and 15% ascribed to free-flow speed distribution, consequently cumulative speed distribution curves indent at around 15 percentile and 85 percentile of the total number of vehicle observations. There is no reason to suggest otherwise in this study. Consequently, the upper section of the speed/flow curve can be divided into four classes (A, B, C and D) and the lower section into two (E and F) (Fig. 1). The speed/flow curve has two corresponding speeds for every traffic flow apart from capacity where the optimum speed is reached. From the discussion so far it has shown that a simplistic approach can be used to classify traffic stream performance. Quantitative and qualitative assessments of highway traffic are intrinsically linked by the fundamental diagram of flow. In any case, flow, density and speed have often been used in many studies to describe highway traffic.
where,

$$q = uk; \Rightarrow \nu = \frac{q}{\kappa}; \Rightarrow \kappa = \frac{q}{u} \tag{1}$$

It has been shown in previous studies (Anais *et al*., 2010; Ben-Edigbe and Ferguson, 2005) that roadway capacity can be estimated with Eq. (2).
So that, capacity

$$Q = -c + (u_f)\frac{u_f}{2\left(\frac{u_f}{k_j}\right)} - \frac{u_f}{k_j}\left(\frac{u_f}{2\left(\frac{u_f}{k_j}\right)}\right)^2 \tag{2}$$

Since flow, density and speed are related as shown in Eq. (1), the function for speed/flow curve shown below as equation 3 can be considered as a subordinate of Eq. (2):

$$Q_s = -c + (u_f)\frac{u_f}{2\left(\frac{u_f}{k_j}\right)} - \frac{u_f}{k_j}\left(\frac{u_f}{2\left(\frac{u_f}{k_j}\right)}\right)^2 \tag{3}$$

where,
u_f = Free-flow speed
k_j = Jam density
c = A constant

It has been shown that maximum flow estimation problem consists of a series of essential points of interest that include among others; Type of Data To Be Collected, Location Choice for Observations, Choice for Appropriate Averaging Interval, Needed Observation Period, Required Traffic State and Lane (Minderhoud *et al*., 1997). According to Minderhoud *et al*. (1997) capacity from empirical studies that can be estimated using various methods that include the followings:

- Estimation with headways
- Estimation with traffic flows (Bi-Modal Distribution Method, Selected Maximal method, Expected Extreme Value Method)
- Estimation with traffic flows and speeds using Product limit Method
- Estimation with traffic flows, speed and density relationship (fundamental diagram). Only the headway and estimation with traffic flows, speed and density methods can be used for off-peak capacity modeling. Since the study is interested in off-peak traffic stream characteristics on road section under daylight, road lighting and dry weather conditions, Eq. (3) can be used (Eckenrode *et al*., 2007). The use of fundamental diagram offers four advantages that other methods lack. First the traffic state can be determined at any point required; this gives full information required to assess traffic performance. Secondly, data need not be acquired at a bottleneck location to see the state of traffic at capacity. And thirdly, two variables suffice to construct the fundamental diagram. The third parameter is derived from the continuum theory of traffic flow and finally the fundamental diagram approach could be used to model different conditions of the flow. As shown in previous studies, Greenshield speed/density linear model is useful in accuracy of highway capacity prediction (Ben-Edigbe and Ferguson, 2005; Ben-Edigbe, 2010) The relationship between speed and density is such that as density increases speed decreases:

$$u_s = u_f - \frac{u_f}{k_j}k \tag{4}$$

where,
u_s = The space mean speed
u_f = Free flow speed
k = The density
kj = The density at jam

If Eq. (1) is plugged into Eq. (1), the flow-density function can be written as:

$$q_m = -c + ak - bk^2 \tag{5}$$

The draw back with flow-density estimation method lies with determining the critical density. It can be derived, estimated or assumed as appropriate or extrapolated mathematically (Hou *et al*., 2012) Since our interest is in estimating maximum flow, the choice of precise value of critical density need not be very critical to the outcome of this study. By computing maximum flow for each road segment, it is recognized that capacity varies per road section. In any case, for maximum flow:

$$\frac{\partial q}{\partial k} = a - 2\left(\frac{a}{k_j}\right)k \implies critical\ density, k_o$$

$$k_o = \frac{a}{2\left(\frac{a}{k_j}\right)} \tag{6}$$

$$then, u = a - \frac{a}{k_j}\left(\frac{a}{2\left(\frac{a}{k_j}\right)}\right)$$

Maximum flow:

$$q_m = ak - \frac{a}{k_j}\left(\frac{a}{2\left(\frac{a}{k_j}\right)}\right)^2 \tag{7}$$

Optimum speed:

$$v_o = \frac{ak - \frac{a}{k_j}\left(\frac{a}{2\left(\frac{a}{k_j}\right)}\right)^2}{\frac{a}{2\left(\frac{a}{k_j}\right)}} \tag{8}$$

Since traffic theory is dependent on fundamental diagram, it follows that:

$$ak - \frac{a}{k_j}\left(\frac{a}{2\left(\frac{a}{k_j}\right)}\right)^2 = \frac{ak - \frac{a}{k_j}\left(\frac{a}{2\left(\frac{a}{k_j}\right)}\right)^2}{\frac{a}{2\left(\frac{a}{k_j}\right)}}\ x\ \frac{a}{2\left(\frac{a}{k_j}\right)} \tag{9}$$

The critical volume to capacity ratio $\left(\frac{\varkappa}{q}\right)$ is often taken in many studies as 0.85 (Ben-Edigbe and Ferguson, 2005) When road space is under-subscribed ($q \leq 0.85$) oscillation movements within the free-flow section of the curve would indicate that quality of highway service is good. However, when road space is oversubscribed, the oscillation movements will stop; flow rate contraction will commence in the congested section of the curve suggesting that the quality of service is poor. Assuming that $\left(\frac{\varkappa}{q}\right) = 1$; it can be argued that traffic flows within ±0.15 of $\left(\frac{\varkappa}{q}\right)$ are neither free- nor congested flows. Since roadway capacity is dynamic and speed/flow function hinges on roadway capacity model equation, it can be postulated that the resultant speed/flow curve is dynamic. Although it is not the focus of this study, nonetheless, it can be mentioned in passing that all associated instruments of capacity computations must be dynamic. Since passenger car equivalent (*pce*) values or units (*pcu*) are the convertor from volume to flow, it makes sense to assume that they are dynamic. The calibration of the PCE values can have a significant impact on capacity analysis computations where the presence of commercial vehicles is significant. PCE has been defined as the ratio of the mean lagging headway of a subject vehicle divided by the mean lagging headway of the basic passenger car (Seguin, 1998). A simplistic passenger car equivalent calculation method based on headway was used in the study.
where,

$$pce_{ij} = \frac{h_{ij}}{h_{pcj}} \tag{10}$$

where,
pce_{ij} = P*ce* of vehicle Type *i* under conditions *j*
h_{ij}, h_{pcj} = Average headway for vehicle type *i* and passenger car for conditions *j*’

Mean speed and cumulative speed distribution statistical tests: The cumulative percentiles are two descriptive parameters that are commonly used to compare different traffic conditions. The 85th and 15th percentiles are two parameters that are commonly used to evaluate the effectiveness of highway service. In many studies nonparametric double bootstrapping, the quantile regression, averaging 85th percentile methods or using the binomial test have been used to assess the statistical difference between two percentile samples. Bootstrapping is a method of resampling existing data by using simulation. Often the focus is on sampling distribution of the mean instead of the sampling distribution of the percentile. Because there is a lack of statistical test for percentiles that can be easily applied and theoretically sound in many literatures. Statistical test based on Crammer’s theory of asymptotic sample distribution has also been suggested (Hou *et al*., 2012) where the random variable can be used to as the standard normal test statistics for examining the difference between two population percentiles. Where; $X_{(n0.85)}$ and $Y_{(n0.85)}$ are 85th percentile random variables, n_x, n_y are random sample sizes and S_x and S_y are sample variances:

$$\frac{(X_{([n0.85]+1)} - Y_{([n0.85]+1)}) - 0}{1.530\sqrt{S_x^2/n_x + S_y^2/n_y}} \tag{11}$$

SETUP OF IMPACT STUDY AND DATA COLLECTION

In order to collect traffic stream data, 24 h automatic traffic counters were installed at two sites in Skudai, Malaysia for 8 weeks. Three classes of vehicles (passenger cars, large goods vehicle and heavy goods vehicle) were investigated. Typical setup of road lighting impact study site is shown below in Fig. 2. Since passenger car equivalent (*pce*) measures the impact that a mode of transport has on traffic variables compared to a passenger car under prevailing conditions, it follows that changes in prevailing conditions will have relative effect on pce values. In essence *pce* values are dynamic; consequently, pce values were estimated using a simple model Eq. (13). So, there is no need to build a need model. In any case, the study pce values though useful have not affected the study outcomes significantly. Note that PCE is usually the terminology employed in the United States and Canada, while PCU is commonly used in the United Kingdom. As for the typical study site layout, it is important that influences from intersection and other attraction on collected data are minimised. Intersections are kept at distances greater than an estimated stopping sight distance for each observed road segment. The intersection Stopping Distance (SSD) was based on Eq. (12) below, with assumptions of 5% road gradient, 2.5 sec reaction time and 0.3 coefficient of friction:

$$SSD = 0.278v_t + 0.039\frac{v^2}{a} \qquad (12)$$

FINDINGS AND DISCUSSION

Aggregated data collected at road sections were analysed for each prevailing condition using a stepwise procedure.

Step 1: Determine traffic flow and time profile for the road segment under observation. Typical volume-density scatter plot for Skudai road segment is shown in Fig. 3.

Step 2: Estimate traffic flows using appropriate *pce* values.

Step 3: Estimate vehicle speeds variances and associated errors per road section. then divide flow by speed to compute density. Compute free-flow headways using Eq. (4).

Step 4: Develop a model for speed/density relationship, test for validity and

Step 5: Then, derive flow/density functions, or as an alternative.

Step 6: Skip steps 4 and 5, model flow/density relationships directly and test for validity.

Step 7: Estimate critical densities, hence maximum flow and optimum speeds; Compute congested headways using Eq. (4).

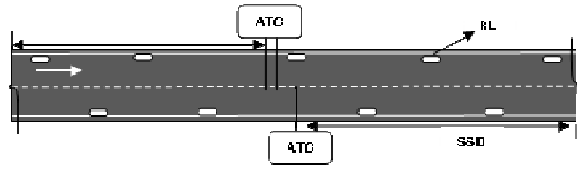

Fig. 2: Typical setup of impact study site; ATC-automatic traffic counter; SSD-stopping sight distance; RL-road lighting

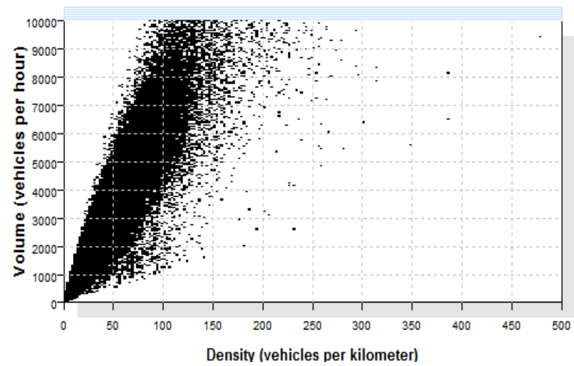

Fig. 3: Typical volume-density scatter plot

Table 2: Level of Roadway Service Criteria

LRS		Intervals: Speed-km/h i = 1	Flow-veh/h i = 2	Density-veh/km i = 3
A		85 km/h	≤650 veh/h	≤10 veh/km
B		70 km/h	≤1300 veh/h	≤20 veh/km
C		55 km/h	≤1950 veh/h	≤35 veh/km
D		50 km/h	≤2200 veh/h	≤45 veh/km
E		40 km/h	≤2600 veh/h	≤65 veh/km
F	F_s	30 km/h	≤2200 veh/h	≤75 veh/km
	F_J	<30 km/h	> 2200 veh/h	> 75 veh/km

i-order of LRS assessment; Fs-shockwave flow; Fj jam flow

Step 8: Compare headway, speed and maximum flow Outcomes

Step 9: Determine capacities for the road segment in order to make sure that computed traffic flows occurred at off-peak periods (Table 2).

For the road segment under observation the flow-density model equation is:

$$q = -1.96 + 84.9k - 0.67k^2 \quad R2 = 0.95 \qquad (13)$$

$\partial q/\partial \kappa = 2(-0.67k) + 84.9 = 0$; Critical density, $k_c \cong$ 63.4 veh/km.

Then plug k_c into Eq. (13) so that $q_m = -0.67(63.4)^2 + 84.9(63.4) - 1.96$.

Capacity, Q = 2688 veh/h., Optimum speed, u_o = 2688/63 = 42 km/h

Note that the t-values and F results indicate that the model equations are valid for further analysis and useful for predictions.

Table 3: Model coefficients and level of road service (LRS)

Site	Prevailing conditions	LRS	Flow/density Flow-c	Speed λk	Density-λk²	R^2	Speed/density Speed λk	Density -λk²
1	Daylight	A	-47.78	92.3	-0.99	0.95	92.3	-0.99
	Road-lighting	A	-76.8	92.9	-0.94	0.94	92.9	-0.94
2	Daylight	A	-28.01	88.8	-0.91	0.90	88.8	-0.91
	Road-lighting	A	-28.13	85.1	-0.76	0.97	85.1	-0.76

Table 4: Summary of traffic stream characteristics

Site	PC	q_m	$U_{f\,km/h}$	$U_{o\,km/h}$	$k_{c\,veh/km}$	Hwy (s)	$U_f\,\Delta$	HwyΔ	$q_m\Delta$	Tab χ^2 = 3.14
	DL	2103	92	44.7	47	1.7	3 km/h	0	1.6%	Cal. χ^2 = 0.57<3.14
1	RL	2138	89	45.4	49	1.7				
	DL	2218	93	45.4	49	1.6	8 km/h	1	5.8%	Cal. χ^2 = 7.8>3.14
2	RL	2354	85	43.9	56	1.5				

PC denotes prevailing conditions; DL-daylight; RL-road lighting; Hwy-headway; Δ-change

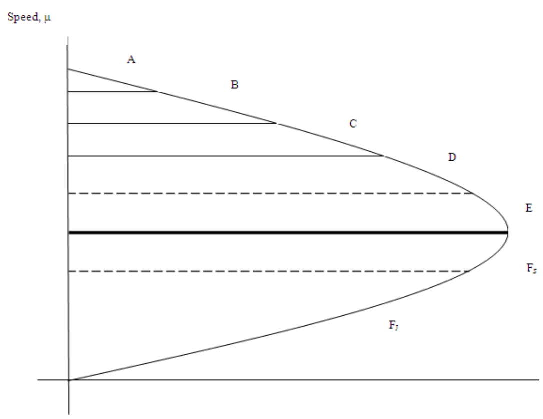

Fig. 4: Graphical illustration of level of road service

Summary of findings from the road lighting impact study are shown in Table 3 and 4 (Fig. 4).

Estimated model coefficients in Table 3 were then used to compute maximum flow and optimum speeds. The model coefficients in equations have the expected signs and the coefficients of determinations (R^2) are much greater than 0.85; so it can be suggested that a strong relationship between flows and densities exists and the model could be used to estimate roadway capacity for the link sections. The F-observed statistics at 10º of freedom is much greater than F critical (4.94) suggesting that the relationship did not occur by chance. Also the t- observed statistic at 10º of freedom tested at 5% significance level is much greater than 2 thus suggesting that density is an important variable when estimating flow. The statistics were taken directly from the spreadsheet output.

Typical highway maximum flow calculations from the model coefficients in Table 3 are shown below and the remainder results are shown in Table 4:

Where flow and density quadratic function is used:

$$q = -47.78+92.3\,k-0.99\,k^2 \tag{14}$$

$\partial q/\partial \kappa = 2(-0.99k) + 92.3 = 0$; Critical density, $k_c \cong$ 47.07 veh/km.

Then plug k_c into equation 14 so that $q_m = -0.99\,(47.07)^2+92.3\,(47.07) - 47.78$.

Maximum flow, q_m = 2103veh/hr., Optimum speed, u_o = 2103/47.07 = 45 km/h

where, speed and density linearity is used:

$$v = 92.3 - 0.99k;\ \text{then}\ q = 92.3k-0.99k^2 \tag{15}$$

$\partial q/\partial \kappa = 2(-0.99k) + 92.3 = 0$; Critical density, $k_c \cong$ 47.07 veh/km.

Then plug k_c into equation 15 so that $q_m = -0.99(47.07)^2+ 92.3(47.07)$.

Maximum flow, q_m = 2151veh/hr., Optimum speed, u_o = 2151/47.07 = 46 km/h

where, calculated $\chi^2 = (2151-2103)^2/2151 = 1.07 <$ Tab $\chi^2 = 3.14$ it can be postulated that there is no significant difference in computed maximum flows. Therefore either empirical capacity computation method can be used in the study. It can be seen from Table 4 that free-flow speeds for daylight and road lighting are within speed variance of 12%; hence they cannot be construed as significant.

All tabulated maximum flows and their corresponding critical densities are lower than the estimated road capacity of 2688 pcu/h/lane and the corresponding critical density of 63 vehs/km; thus suggesting that the estimated traffic flows occurred at off-peak periods. Note also that all computed optimum speeds are inside the free-flow section of the flow-density curve.

At site 1, the change in maximum flow is insignificant (Table 3); however the change in maximum flow at site two is significant even though it did not occur as a result of road lighting. Since there is nothing in the study to suggest that change in maximum flow occurred because of road lighting, it can be postulated that increase in demand flow is responsible. Take note that capacities for day light and road lighting conditions can be computed but cannot be compared. The changes in headways are negligible. The study has shown that traffic stream characteristics for daylight and road lighting conditions can be computed and compared. Given that findings from the Malaysia study is different from that of the Dutch study, there is need for further research on the impact of road lighting on traffic flowrate.

CONCLUSION

Based on the synthesis of evidences obtained from the assessment of traffic stream characteristics under daylight and road lighting conditions, the study concluded that:

- The relationship between flows/densities as well as speeds/densities can be relied on upon when modeling capacity for road segment
- There is no significant difference between traffic stream characteristics in the level of roadway service under daylight and road lighting conditions
- Although empirical road capacities can be computed for daylight and road lighting conditions, they cannot be truly compared
- The hypothesis that capacity loss would result from road lighting is not valid

REFERENCES

Anais, M., B.J. Roland and M.C. Bastien, 2010. Effect of the viewing context on target detection, implications for road lighting design. J. Appl. Ergon., 41(3): 461-468.

Ben-Edigbe, J., 2010. Assessment of speed, flow and density functions under adverse pavement conditions. Int. J. Sust. Dev. Plan., 5(3): 238-252.

Ben-Edigbe, J. and N. Ferguson, 2005. Extent of capacity loss resulting from pavement distress. Proceedings of the Institution of Civil Engineers-Transport 158 Issues TRI, pp: 27-32.

Eckenrode, R.T., W.A. Sarasua, J.H. Mattox, J.H. Ogle and M. Chowdhury, 2007. Revisiting the use of drone radar to reduce speed in work zones: South Carolina's experience. J. Transp. Res. Board, 2015: 19-27.

Hou, Y., C. Sun and P. Edara, 2012. A statistical test for 85th and 15th percentile speeds using the asymptotic distribution of sample quantiles. The 91st Annual Meeting of the Transportation Research Board of the National Academies, Washington D.C.

Minderhoud, M., H. Botma and P.H. Bovy, 1997. Assessment of Roadway Capacity Estimation Methods. Transportation Research Record 1572, National Research Council, Washington DC, pp: 59-67.

Seguin, E.L., 1998. Passenger Car Equivalents on Urban Freeways Interim Report. DTFH61-C00100, Institute for Research (IR), State College, Pennsylvania, USA.

Van Goeverden, C.D. and H. Botma, 1998. Determining the impact of road lighting on the motorway capacity. Trans. Res. B., 1646: 1-8.