Research Journal of Applied Sciences, Engineering and Technology 7(22): 4656-4660, 2014
DOI:10.19026/rjaset.7.848
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: August 24, 2013 Accepted: September 03, 2013 Published: June 10, 2014

Research Article

Influence of Darkness on Motorway Traffic Flow Characteristics

Johnnie Ben-Edigbe
Universiti Teknologi Malaysia, UTM-Skudai, 81310 Johor, Malaysia, Tel.: + 6075532457, +60177520293; Fax: +6075532678

Abstract: The study is aimed at estimating the influence of darkness on motorways during dry weather. In a 'with-and-without' impact studies, motorway traffic flow characteristics at two different locations in Malaysia were investigated. Travel speed, traffic flow and headway data were obtained continuously for six weeks at selected sites and supplemented with darkness and daylight data culled from Malaysian Metrological Department website. Start of pitch darkness time was given as 19.45 pm. The study used 22:00 pm as start of pitch darkness. Results show that maximum flow rate, optimum travel speed, critical density and optimum headway did not differ significantly. The study concluded that motorway traffic flow characteristics are not influenced by darkness significantly.

Keywords: Darkness, flowrate, headway, motorway, travel speed

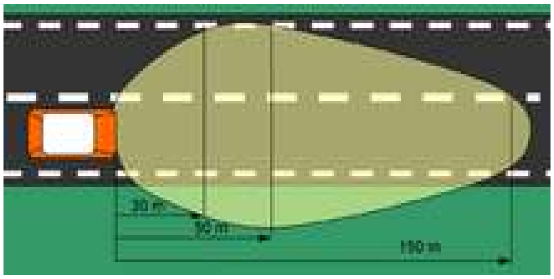
INTRODUCTION

The study is aimed at investigating the influence of darkness on motorway traffic flow characteristics. Traffic flow characteristics are useful performance pointer of motorway facilities. Traffic speed, travel time, traffic volume and density are fundamental traffic characteristics. They are related. For the purpose of measuring quantity of motorway performance, relationship between flow and density can be relied upon. For the purpose of determining the quality of motorway service, speed, flow and travel time can be used. In Malaysia, lightings on some segments motorway are turned off. Proponents of motorway darkness argue that the design of motorway is such that staggered segment darkness will have very little effect on the traffic flow. Opponents argued that motorway segment darkness will heighten the probability of motorway accident at night. 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). 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). Drivers are warned of driving on the motorways in the dark because of poor visibility. Do drivers rely on headlights or motorway lighting or both for visibility it can be queried. It is a common knowledge that darkness is prevalent on some highway segments on the premises that darkness promotes responsive driver behavior and enhances alertness. Critics warned that the move switch off lighting on motorways could put road safety at risk even though the extent of risk has yet to be sustained. Surely, if the postulation that motorway darkness has influence of traffic flow characteristics is to hold, maximum traffic flow, travel speed and density during daylight, lighting and darkness will differ significantly. The remainder of the study is based on the hypothesis that the influence of darkness on motorway in not significant. It can be argued.

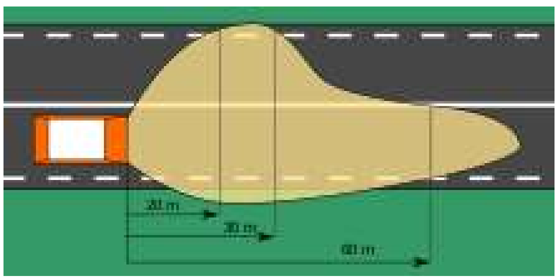
LITERATURE REVIEW

Motorways are capital intensive ventures untaken by governments. They are the highest ranking roadway in Malaysia, often designated expressway. Expressways in Malaysia are built to cope with allowable speed limit of 110 km/h; vehicles are equipped with headlamps, side, rear and brake lights. 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 Wikipedia, "typical low and high beam headlight coverage area" are illustrated in Fig. 1.

Assuming dry weather and good road surface conditions, typical stopping distance for an average vehicle (4 m) traveling at 112 km/h is about 96 m (Mashros and Ben-Edigbe, 2013), suggesting that headlamp high beam distance is greater than stopping distance. However, traffic stream is made up different types of vehicle and driver behaviors; therefore traffic flow cannot be looked at in isolation of other vehicles



(a) Symmetrical high beam



(b) Asymmetrical low beam

Fig. 1: High and low beam headlamp (wikipedia)

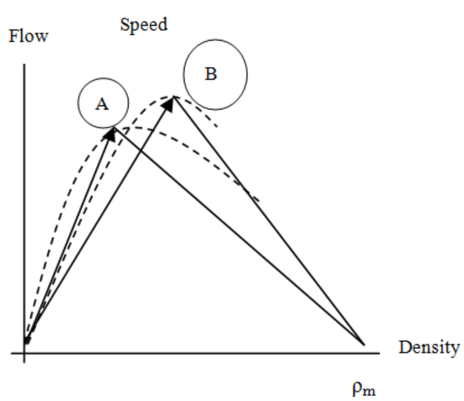


Fig. 2: Hypothetical flow v density curves

on the motorway. Three variables, density (ρ), flow (q) and speed (u) can be used to describe traffic streams on a motorway segment. They are related as written in Eq. (1):

$$q = u\rho \;\Rightarrow u = {}^{q}/_{\rho} \;and\; \rho = {}^{q}/_{u} \quad (1)$$

$$u = u - \vartheta\rho \;\Rightarrow q = u - \vartheta\rho^2 \quad (2)$$

In traffic flow, critical density (k_c) and jam density (k_j) are important indicators of maximum number of vehicle per segment length achievable under free flow is k_c, while k_j is the maximum achieved under congestion. The study is not concerned with traffic jam. As shown in Fig. 2, shift from A to B indicates that flow has contracted relative to external influence. According to Minderhoud *et al*. (1997) and Alhassan and Ben-Edigbe (2011) empirical traffic capacity can be estimated using relationship between flow and density; where speed changes will affect density as shown in Fig. 2 and Eq. (2). A simple speed and density linear model shown below in Eq. (3) is still relevant today:

$$v\,(\rho) = v_f\,(1 - \frac{\rho}{\rho_m}) \quad (3)$$

Where the effect of gradual speed reduction takes place in response to kinematic wave propagated by darkness, then Eq. (3) can be modified as:

$$v\,(\rho) = v_f\left(1 - \frac{\rho}{\rho_m}\right) - \frac{D}{\rho}\left(\frac{\partial\rho}{\partial_x}\right) \;for\; D = \tau v_r^2 \quad (4)$$

where,

v_f = Free flow speed
τ = Response parameter
v_r = Random speed
ρ_m = Jam density

Bando *et al*. (1995) proposed optimal speed model shown below as Eq. (5) and (6):

$$\frac{\partial^2 x_i}{dt^2} = a\left\{v(\Delta_{xi}) - \frac{\partial x_i}{\partial t}\right\} \quad (5)$$

where,

$v(\Delta_{xi}\,(t))$ = Optimal speed
$x_i(t)$ = Vehicle *i* position at time *t*
$\Delta_{xi}(t)\begin{pmatrix}= x_i + 1^{(t)} \\ - x_i(t)\end{pmatrix}$ = Headway of the i^{th} vehicle at time *t*
a = The sensitivity of a driver and given the inverse of delay time τ
$v(\Delta_{xi}\,(t))$ = Often given by:

$$v(\Delta x_i) = \frac{v_{max}}{2}[\tan h(\Delta x_i - x_c) + \tan h(x_c)] \quad (6)$$

where,

v_{max} = The maximal speed
x_c = The safety distance between vehicles

Equation (4) raises a very serious question about motorway segment darkness; can it propagate shock or rarefaction waves? Drivers travelling along a lit motorway may experience some abrupt acuity discomfort on entering the dark segment of the motorway (Wanvik, 2009). This is not like adjusting to room lights going off and on in an environment without secondary lights. In such circumstances, there is split second blindness before the human sight is adjusted to the new lighting conditions. However, on the motorway it is totally different because of the presence of headlamp. Headlamp provides secondary lighting, so

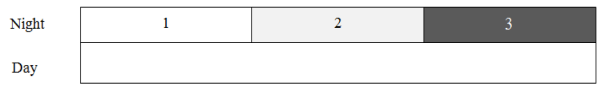


Fig. 3: Hypothetical day and night motorway segment light phases

that the effect of darkness on motorway segment is minimised. Consequently, it can be postulated that human sight adjustment to motorway darkness is partial not total. It is partial because of the presence of headlamp. As illustrated above in Fig. 3, motorists would experience natural light during daylight and three light phases during night time. During the day, drivers would experience natural lights albeit variable intensities; however at night, motorist may experience full artificial lighting from headlamp and road lights at phase 1, partial road light and headlamp at the transition phase 2 and finally headlamp only at phase 3 being the dark segment of the motorway. In order to establish that motorway flow characteristics have been influenced by darkness, traffic flow-rate must contract significantly especially at phase 3 of Fig. 3. With regard to the question raised earlier, it is doubtful that motorway segment darkness can be called to account for shock or rarefaction waves without assistance from other sources. Hence Eq. (4) to (6) will not be appropriate in solving the problem in this study.

Papers on the effect of lighting (artificial) on motorways have been written by many authors, consequently this study compare darkness and natural light traffic flow-rate contraction if at all. Since the fundamental diagram of traffic flow encompasses motorway flow characteristics, it would be relied upon. As shown in Eq. (1) and (2), flow is a function of speed and density. If traffic flow is differentiated with respect to speed and density, critical density can be estimated; where the critical density is plugged into Eq. (2), maximum flow-rate can be computed. Where daylight is the control flow-rate, significant changes in flow-rate between natural light and darkness would suggest that darkness has influence on motorway flow characteristics. Consider Eq. (2) again:

$$Let\ \vartheta = \frac{a}{\rho_j}\ ; differentiate\ q\ wrt\ \rho$$

$$\frac{\partial q}{\partial \rho} = a - 2\left(\frac{a}{\rho_j}\right)\rho \implies critical\ density, \rho_c = \frac{a}{2\left(\frac{a}{\rho_j}\right)}$$

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

Maximum Traffic flow:

$$Q = a\rho - \frac{a}{\rho_j}\left(\frac{a}{2\left(\frac{a}{\rho_j}\right)}\right)^2 \tag{7}$$

Optimum speed:

$$\cup_o = \frac{a\rho - \frac{a}{\rho_j}\left(\frac{a}{2\left(\frac{a}{\rho_j}\right)}\right)^2}{\frac{a}{2\left(\frac{a}{\rho_j}\right)}} \tag{8}$$

The draw back with flow-density estimation method lies with critical density. It can be derived, estimated or assumed as appropriate, or extrapolated mathematically. It can be argued that maximum traffic flow derived in such a way may be unrealistic. Nonetheless, the choice of precise value of critical density need not be very critical to the outcome of darkness impact studies.

Setup of darkness impact studies: 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 on motorway traffic flow characteristics; the primary concern is measuring the number of vehicles passing a given point on the motorway segment under dry and off-peak periods. Peak period counts are excluded in the analysis to remove peak traffic volume effect. Motorways are divided into three section as shown in Fig. 3. Automatic traffic counters are positioned at each section. 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. (10). It is assumed that the roadway has 5% Gradient (G), 2.5 sec reaction time (t), deceleration is taken as 3.4 m/sec^2:

$$SSD = 0.278v_t + 0.039\frac{v^2}{a} \tag{9}$$

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 contnously recorded for 6 weeks. This information is processed in a variety of ways to generate traffic flow parameters of interest to this study. Note that only data collected under dry weather conditions were considered for inclusion in the analysis stage.

RESULTS AND DISCUSSION

Since the study is concerned with the influence of darkness on traffic flow characteristics, it may be appropriate to look at the speed/time graph shown in Fig. 4 and volume/time/speed graph in Fig. 5. Travel speed is shown in blue; note that the trend is nearly

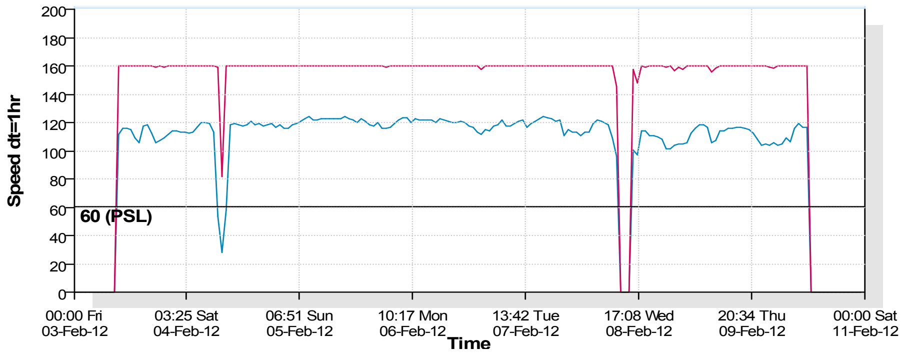


Fig. 4: Typical observed 24 h speed/time graph

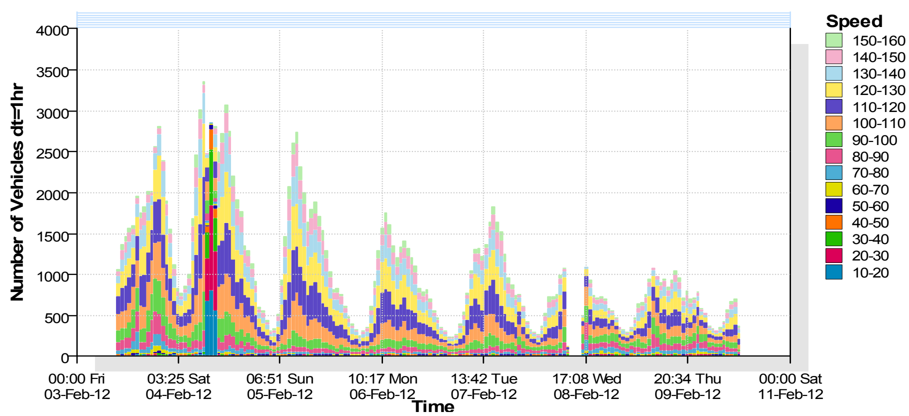


Fig. 5: Typical observed volume/time graph

Table 1: Typical darkness/daylight traffic flow characteristics

	Darkness				Daylight			
Period	Q veh/h	V_o km/h	ρ veh/km	Φ (sec)	Q veh/h	V_o km/h	ρ veh/km	φ (sec)
1	1053	77	13.7	3.42	1578	76	20.8	2.28
2	1280	77	16.6	2.81	1536	79	19.4	2.34
3	1279	74	17.3	2.81	1401	80	17.5	2.57
4	1060	80	13.3	3.40	1448	78	18.6	2.49
5	1130	76	14.9	3.19	1445	79	18.3	2.49
6	1096	78	14.1	3.28	1285	78	16.5	2.80
7	1154	80	14.4	3.12	1459	75	19.5	2.47
8	1111	75	14.8	3.24	1432	76	18.8	2.51
9	1100	74	14.9	3.27	1548	76	20.4	2.33
10	1113	74	15.0	3.23	1465	78	18.8	2.46
11	1123	74	15.2	3.21	1368	77	17.8	2.63
12	1082	77	14.1	3.33	1453	77	18.9	2.48
85 percentile speed		79				79		

Q: Denotes traffic capacity; V_o: Denotes optimum speed; ρ: Denotes critical density; φ: Denotes critical headways

constant over a 24 h period. For example, from 06.5 am 5 February to 13.42 pm 7 February 2013, average travel speed is around 120 km/h irrespective of daylight light or darkness. The behavioral pattern is repeated at all sites, thus suggesting that darkness has insignificant impact on travel speed. The sudden dip in travel speed shown in Fig. 4 may indicate that some other factors could be called to account for the speed lost. The cyclic patterns in Fig. 5 also suggest that darkness has minimal influence on traffic flow and travel speed. Consequently, it is pertinent that maximum flow-rate be analyzed.

The method used for estimating empirical maximum flow-rate hinges on fundamental diagrams as mentioned earlier in Eq. (1) and (2). Where flow is related to density, it is assumed that speed is the resultant slope. Model coefficients were analyzed using Eq. (7) and (8) then they are tested for reliability. F-statistics, coefficients of determination R^2 and t-test results show that the model equations did not happen by chance, they are acceptable for predictions and all the parameters are useful for predictions. Typical results are shown below in Table 1 where the 85 percentile speed for darkness and day light is 79 km/h. the

Table 2: Differential traffic flow-rate characteristics

Sites	Condition	Q	V_o	ρ	φ
1 federal highway	Daylight	1602	38	42	2.25
	Darkness	1507	31	48	2.39
	Δ	95	7	6	0.14
3 expressway	Daylight	1901	73	26	1.89
	Darkness	1768	63	28	2.03
	Δ	133	10	2	0.14

Q: Denotes maximum flow-rate; V_o: Denotes optimum speed; ρ: Denotes critical density; φ: Critical headways

remainder of traffic flow characteristics are shown in Table 2. Note that estimated maximum flow-rate are for off peak periods only. The critical densities are below 17 vehicles/km with an average headway of about 3.2 sec during darkness period. The critical densities are below 21 vehicles/km with an average headway of about 2.5 sec during daylight period. Based on the hypothesis that no significant difference exist between headway for darkness and daylight as well as critical densities for darkness and daylight period, chi square test was carried out. Results confirmed that estimated chi square values are less than tabulated values, hence the hypothesis is accepted. With regard to Table 2, the difference in traffic flow is inconsequential because both scenarios occurred at off peal periods. For both the federal highway and expressway, the difference in optimum speeds is within the speed variance of 10% plus 2 km/h standard error. Likewise, the difference between critical densities is insignificant. Interestingly, there is no difference between the critical headways.

CONCLUSION

Based on findings obtained from the empirical studies on the influence of darkness on motorway traffic flow characteristics carried out under dry weather conditions, it is correct to conclude that:

- Empirical road densities are finite; therefore the relationship between flows and densities can be relied on when modeling travel speed.
- There is no significance change in travel speed during daylight and darkness at motorway sections under observation.
- Travel speed will not change significantly under darkness conditions on the motorway.
- The hypothesis that darkness has significant influence on motorway traffic characteristics significantly is rejected.

ACKNOWLEDGMENT

The authors would like to thank Public Work Department Johor Malaysia, Local Authority of Kulaijaya and Police Diraja Malaysia Kulaijaya for their invaluable assistances during data collection. The study is part of an ongoing PhD research work at Universiti Teknologi Malaysia.

REFERENCES

Alhassan, H. and J. Ben-Edigbe, 2011. Highway capacity prediction in adverse weather. J. Appl. Sci., 11(12): 2193-2199.

Bando, M., K. Hasebe, A. Nakayama, A. Shibata and Y. Sugimaya, 1995. Dynamical model of traffic congestion and numerical simulation. Phys. Rev., 51(2): 1035-1042.

Dutch News, 2013. Motorway Lights to be Turned Off at Night to Save Money" Available from: http://www.dutchnews.nl/news/archives/2012/09/roadmaintenancecutsupdates.php#sthash.iQTJJib2.dpuf (Accessed on: June16, 2013).

Mashros, N. and J. Ben-Edigbe, 2013. Determining the impact of rainfall on the quality of roadway service. P. I. Civil Eng-Transp., 166(3).

Minderhoud, M.M., H. Botma and P.L. Bovy, 1997. Assessment of roadway capacity estimation methods. Transportation Research Record: J. Transport. Res. Board, 1572: 59-67.

The Telegraph Newspaper, 2013. Motorway lights to be turned off to save cash and carbon. Retrieved from: http:// www.telegraph.co.uk/ motoring/news/ 7929223/Motorway-lights-to-be-turned-off-to-save -cash-and-carbon.html (Accessed on: June 16, 2013).

Wanvik, P.O., 2009. Effects of road lighting on motorways. Traffic Inj. Prev., 10(3): 279-289.