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Modelling the Quality of Service at Multilane Midblock U-Turn Facilities

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Abstract

Often highway quality of service (HQS) and level of service (LOS) are presented incorrectly as interchangeable in many studies. LOS relates traffic service quality to a given flow rate of traffic whereas HQS measures how operating conditions are perceived by road users and providers. In context, LOS is a road segment estimation method based travel speed whereas HQS is based on travel time and travel speed. In this paper, the quality of traffic service at highway midblock U-turn zone is investigated. Traffic volume, speed, headway and vehicle type data for both directional flow were recorded continuously for six weeks, analyzed. Travel time and travel speed for road sections with and without midblock U-turn zone were estimated and compared. On approach to the midblock U-turn zone entrance, results show that average travel time increased by 8%, average travel speed reduced by 9 km/h and quality of traffic service reduced from grade C to D. There were no significant travel time and speed changes at the exit section of midblock facilities. The paper concluded that midblock U-turn zone can reduce the quality of traffic service on approach to a midblock U-Turn facilities.

Keywords: Quality of service; travel time; capacity; travel speed; highway; LOS; traffic volume.

INTRODUCTION

Median opening facilities are provided to aid U-turning movements and are often designed to accommodate all vehicle types. In some countries, they are located midway along a multilane highway (midblock facilities) as effective conflicts reduction mechanism at intersections. While some are built as complimentary facilities to existing road geometric designs, others are built as a complete replacement to existing facilities on the premises that they will reduce conflicts and ease traffic congestions at adjoining intersections. In Malaysia, midblock U-Turn opening facilities are constructed on multilane highways to facilitate U-turn movements along road segments. For assessing highway quality of service, previous studies used speed percentile differentials, level of service and discrete model choice. Often assessment is based on either drivers or road providers' perception of quality of service. There is the need to develop an assessment method that considers both drivers and road providers' perception of quality. In any case, the paper is interested in determining the extent of quality of traffic service reduction at midblock median U-turn facilities. Rather than present, highway quality of service and level of service as interchangeable, the paper will describe a method that can be used to determine travel speed and travel time relative to traffic flow rate. Travel time is used as proxy for road users' perceptions of the quality of highway traffic service.

LITERATURE REVIEW

In Malaysia, a persistence problem of traffic conflicts and congestion at multi-lane highway intersections forced the government to invest in midblock U-Turn opening facilities as traffic conflict reduction mechanism. In Arahan Teknik (Teknik, 1986) design manual, the width of the highway, including the median should be sufficient to allow the U-Turn to be made without going beyond the outer of the pavements. On a multilane highway with midblock U-Turn facilities for example, prior to the point where the roadway diverges into three lanes, motorists weave and jockey for vantage midblock entry position. As expected, U-turning vehicles lower their speeds on approach to the facilities entry lane. It begs the question, how is the follow-up traffic stream affected? Merging from the facilities is often a deft maneuver because of through traffic stream on the farside lane. So, it is not surprising that the issue of midblock u-turning facilities has provoked fierce national debates in countries where they are installed midway along the road segment. Proponents of midblock facilities argue that their installation has brought succor to motorists plagued with conflicts and congestions at adjoining intersections. Whereas, opponents argued that the road safety problems associated with midblock facilities far outweigh the benefits of direct midblock facilities. In this paper the primary concern is quality of traffic service delivery.

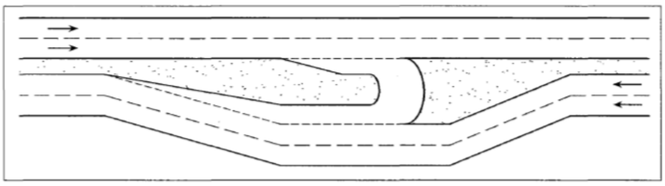

Figure 1: Typical Midblock Median U-turn Opening Facilities

The ability of the roads to carry out their design function is often verified periodically by road providers. If the road provider is interested in quantitative performance traffic flow is used as a function of density. However, if the road provider is interested in qualitative performance travel speed is measured against traffic volume. Since level of service (LOS) is a measure of effectiveness based only on speed/flow relationship (HCM 2010) it can be construed as a measure of road providers' perception of quality of traffic service. Since design speed and traffic volume among others are criteria used for designing highway. It makes sense to measure effectiveness based on these design parameters. LOS ascribes A to the best traffic stream and F to the worst. Speed percentiles are also tools used to measure effectiveness of highway service. The 15th, 50th and 85th percentile speeds show speed distributions relative to drivers' population. The 85th percentile is often defined in many literatures as the speed at or below which 85 percent of vehicles moving (Brewer 2006, Hewson 2008, Voigt 2008). The 15th percentile is the speed at or below which 15 percent of vehicles are travelling. A nonparametric double bootstrapping and the quantile regression are typical method used for comparing percentiles. Both speed percentile and level of service based quality of traffic service estimation on travel speed. In this paper, travel time is also considered.

Quality of service concepts

Highway quality of service (HQS) premised on the idea that drivers and road providers' perceptions of quality are key assessment parameters. Transportation quality of service is defined in Florida State Transportation Handbook as how well the transportation facility has performed based on road user's perception (FDOT, 2013). It can be argued that level of service and quality of service are not the same. It cannot be used interchangeably. Sakai et al, mentioned that quality of service should be evaluated from perspectives of both the service provider and the customer (Sakai et al, 2011). Kita and Kouchi proposed a discrete choice model for measuring the perceived quality of service of a driver. The method characterizes a driver's perception of the quality of traffic service as based on the microscopic traffic conditions that the driver faces (Kita and Kouchi, 2011). Road providers' perception of quality of service was not included in the study. Travel time measurements can be classified into direct and indirect measurements. In the paper travel was measured indirectly as a function of link distance and travel speed. As shown in previous studies prevailing travel time can be computed with equations 1 (Ben-Edigbe 2013).

$$T = t_f\left\{1 + a\left(\frac{v}{Q}\right)^b\right\} \qquad (1)$$

Where; q = traffic flow, k = density; T = travel time, t_f = free-flow time; v = traffic volume, Q = capacity; $^V/_Q$ = degree of saturation; a, b are model coefficients

Stochastic normalized travel times can be expressed in terms of its standardized distribution Fosgerau and Karlström (2010):

$$T = \mu T + \sigma TX \qquad (2)$$

"μ_T" is the normalized mean, "σ_T" the normalized standard deviation and "X", a standardized version of the random travel time, with mean 0 and variance 1. With these assumptions and notation, and given a fixed travel time distribution, (Fosgerau and Karlström, 2010) shows that the first order condition for the driver utility maximization is given by:

$$\varphi_x\left(\frac{D-\mu_\tau}{\sigma_\tau}\right) = 1 - \frac{\beta}{\beta+\gamma} \qquad (3)$$

Where, φ_x is the perceived cumulative distribution function for the standardized travel times, and therefore "$\beta/(\beta + \gamma\ )$" is the optimal lateness probability.

Capacity is pertinent to LOS and HQS methods. HCM defines capacity as the "maximum sustainable flow rate at which vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time under prevailing conditions." Any change in prevailing conditions results in capacity change. The application of quadratic function shown below as equation 3 has been used previous studies by Ben-Edigbe (2013, 2016) to estimate capacity. Speed is known to have a linear relationship with density as shown below in equation 4.

$$q = -ak^2 + bk - c \qquad (4)$$

Where; q denotes traffic flow; k is density; u = speed, u_f = free-flow speed, a, b, are model coefficients and c is constant; for maximum flow,

$$\frac{\partial q}{\partial k} = -2ak + b = 0 \ \rightarrow \ k = -\frac{b}{2a};$$

Capacity $\quad Q = -\,b\left({}^{a}/_{2b}\right)^2 + a\left({}^{a}/_{2b}\right) - c \qquad (5)$

Speed at Q, $v_Q = \frac{\left(a({}^{a}/_{2b}) - b({}^{a}/_{2b})^2 - c\right)}{({}^{a}/_{2b})} \qquad (6)$

The paper argues that there is no need to build a new LOS, what is needed is a slight modification of LOS that considers travel time as well as travel speed. Just like LOS criteria table, HQS must develop a criteria table. HQS criteria table based on peak traffic performance takes into account free-flow time-t_f, free-flow speed-v_f; traffic capacity-C, travel speed at capacity-v_c, volume/capacity ratio, and travel time at capacity-t_c. Volume/capacity ratio depicts the proportion of traffic flow traversing a roadway and used to predict its effectiveness.

Traffic volume is the parameter most often used to quantify traffic demand.

Insert equation 5 into equation 1 and rewrite as:

$$T = \frac{1}{u_f}\left\{1 + 0.2\left(\frac{v}{-a\left(-\frac{b}{2a}\right)^2 + b\left(-\frac{b}{2a}\right) - c}\right)^{10}\right\} \tag{7}$$

In the US Highway Capacity Manual, (HCM 2010), a high value of *b* causes speed to be insensitive to degree of saturation until it gets close to 1.0; then the speed drops abruptly. Hence, HCM 2010 recommended 'a' = 0.20, and 'b' = 10 for equation 5 when predicting travel time where the degree of saturation is less that 90 percent. Note that '*a'* determines the ratio of free-flow speed to the speed at capacity and '*b'* determines how abruptly the curve drops from free-flow speed. Since the paper is interested in predicting travel time where degree of saturation is less than 0.90, then a = 0.20, and b = 10, there is no need to build a new model.

Formulating a criteria table - As shown below in table 1, speed (u), degree of saturation ($_{V/Q}$), capacity (Q), traffic volume (v) and travel time (t) are the key parameters needed to draw a highway quality of service assessment criteria table. Peak period traffic volume, speed and vehicle type data are used to construct speed/degree of saturation criteria curve. Capacity is an important variable that can be estimated in many ways. It is reached when the degree of saturation is at 1. Degree of saturation is divided into six classes; 0.25, 0.50, 0.75, 0.85, 1.0.

DATA COLLECTION

As shown below in figure 2, selected multilane highway links were divided into three zones (diverging DZ, and free-flow FZ) going from east to west and (merging MZ, and free-flow FZ) going from west to east. Note that surveyed sites in Malaysia are under the left-hand drive rule where midblock facilities are built exclusively for U-turning vehicular movements. Both directional traffic volume, speed, headway and vehicle type data were recorded continuously for six weeks at each section.

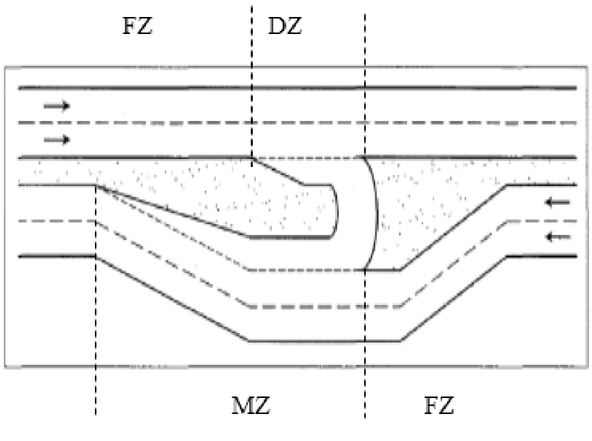

Figure 2: Typical survey setup

ANALYSIS AND FINDINGS

A stepwise results and analysis procedure has been adopted for the ease of explanations and can be summarized as:

Step 1: convert traffic volume to traffic flow using appropriate *pce* values.

Step 2: Compute capacity, using equation 5 and test for statistical relevance of the model equation. For example;

$$q = -0.592k^2 + 74.53k \quad R^2 = 0.95 \tag{8}$$

For maximum flow,

$\frac{dq}{dk} = 1.184k - 74.53 = 0 \rightarrow k \approx 63$ Veh/km

Capacity, Q = -0.592(63)^2 + 74.53(63) = 1600 veh/h;

Speed, U_Q = 1600/63 = 25 km/h;

Where $q = uk \rightarrow u \approx 75 - 0.59k$ and

Free-flow speed = 75km/h;

It can be seen form equation 7 that all model coefficients have the correct sign with R^2-value more than 50 percent, suggesting that a strong relationship between flow and density. F-test at 5% significance level is higher than F-critical (4.25) suggesting that the relationship did not occur by chance. Student t-test at 5% significance level is higher than t-critical (1.38) suggesting that density is an important variable.

Step 3 Estimate travel time and construct criteria table as illustrated below:

Table 1: HQS criteria table

Grade	v/c ratio	travel time s	speed km/h	flow veh/h	density veh/km	headway (s)
A	0.25	45	>80	550	9	7
B	0.50	50	80	1100	16	3
C	0.75	60	70	1650	24	2
D	0.85	65	50	1870	37	1.9
E	1.00	80	30	2200	73	1.6
F	>1.0	<80	<30	>2200	>73	<1.6

Where t_f = time at free-flow speed; t_Q = time at capacity Note that travel time is not a function of volume capacity ratio. Information in the criteria curve is used to draw a criteria table 1.

Step 4 Use observed off-peak data to compute prevailing travel time, for example: site 01 free-flow zone (FZ) travel speed (U_f) is 82 km/h equates free-flow travel time (T_f) 43.9s; V/Q is approximately 0.7 then: T = 43.9 {1+0.2(0.7)^{10}} = 44s. From table 1, HQS = A. Likewise, at site 01, midblock zone, (MZ) T=48.65(1+0.2(0.85)^{10} = 51s; HQS = B. The results for all surveyed sites at shown in tables 2 and 3.

Table 2: HQS & LOS (Diverging Road Section)

Sites	Travel Time (s)	Travel Speed km/h	v/c	HQS	LOS
01FZ	47	78	0.78	B	D
01DZ	51	73	0.83	C	D
02FZ	49	74	0.68	B	C
02DZ	52	70	0.69	C	C
03FZ	48	75	0.69	B	C
03DZ	54	67	0.75	C	D
04FZ	40	93	0.80	A	D
04DZ	50	74	0.82	B	D

Table 3: HQS & LOS (Merging Road Section)

Sites	Travel Time (s)	Travel Speed km/h	v/c	HQS	LOS
01FZ	45	87	0.83	B	D
01MZ	49	75	0.73	B	D
02FZ	52	72	0.83	C	D
02MZ	52	70	0.77	C	D
03FZ	50	74	0.83	C	D
03MZ	54	67	0.77	C	D
04FZ	38	91	0.65	A	C
04MZ	43	76	0.66	A	C

DISCUSSION

At all surveyed sites, both the percentile distribution and HQS methods show similar trends in travel speed reduction at midblock zone, although not by the same percentage. A key aspect of the paper is the development of an assessment criteria table based on the traffic properties of the assessed roadway. Traffic flow, speed and density fundamental relationships were used to estimate the variables in the HQS assessment criteria table. The table has in-built flexibility because road capacity has no fixed value and the model coefficients in travel time model equation 5 are sensitive to volume/capacity ratios. In any case, the HQS assessment criteria table developed in this paper considers drivers and road providers' perceptions of highway quality of service. As shown in tables 2 and 3, travel time fluctuates at free flow zone, suggesting that drivers were not constrained by midblock facilities. However, travel time trends at midblock facilities zone are nearly flat, suggesting that drivers were constrained by midblock zone induced conditions. It was observed that travel time changes can be gradual or abrupt at the merging section of the midblock facilities. Abrupt travel time changes could have been triggered by merging drivers who misjudged or simply ignored an unsafe gap in the through traffic stream. Average travel time increase at the diverging section is about 17% and at the merging section about 14%. The lowest travel time increase is 5.9% at the diverging section of surveyed site 02 compared to 15.9% at site 01, 14.3% at site 03 and 30.8% at site 04. Site 04 has the largest population of trucks making U-turn at the facilities. That probably explains why the site has the highest travel time increase of 30.8%. The presence 14.4% (highest) motorcycle population with 9% (highest) making U-turn at site 02 may have contributed to the lowest travel time increase. At the other surveyed sites motorcycles accounted for only 4%. Passenger cars accounted for 80% of the vehicle population and the proportion making U-turn is about 12%. Based on the synthesis of evidence in this paper, the study has shown that directional midblock median opening has significant negative impact on quality of highway service. Directional midblock median opening has negative impact on traffic operation because drivers respond to the median opening zone by lowering their operational speeds often because of weaving, follow-up drivers' response to lead vehicles attempting to enter the midblock facilities. Through drivers at the exit end of the midblock facilities approach the merging zone cautiously at lower speeds mindful that drivers at the exit lane may merge forcefully. In sum, the paper has shown that travel time increase and travel speed decrease would be induced by midblock U-turn facilities irrespective of directional flow.

CONCLUSIONS

Midblock facilities are not to be confused with median opening facilities that are built to allow right turn and U-turn under left hand drive rule. Midblock facilities are built midway along road segment exclusively for U-turn movements. Often drivers approach the midblock zone at reduced speed. Drivers wait at Midblock U-turn exit lane for gap in through traffic flow before joining the through traffic stream. In this paper, two assessment procedures were used; HQS and percentile distribution. Each method acted not only as control but also as validity check on outcomes. The following conclusions can be drawn from this study;

- Midblock U-turn facilities are built exclusively along multilane road segments to reduce junction conflicts and not the same as intersection median U-turn opening zone.
- Highway quality of service assessment has three key parameters; travel time, travel speed and degree of saturation
- Prevailing highway quality of service based on drivers and road providers' perceptions of quality can be assessed for any roadway using the novel approach in this paper.
- Highway quality of service assessment criteria table can be developed for any roadway.

- Travel time is the key highway quality of service parameter
- Travel time increase would result from midblock U-turn facilities
- Travel speed reduction would result from midblock U-turn facilities

The conclusions drawn in this paper are based on multilane highways, it is quite possible that when the surveyed data are expanded to highways with three or more carriageway lanes, findings could be different from those observed in this study. So, further studies are needed. Further studies are needed to determine additional factors that can be used to optimize traffic operations at midblock U-turn zones.

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