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EFFECTS OF WEAVING, MERGING AND DIVERGING ON DRIVER REACTIONS AT MIDBLOCK U-TURN FACILITIES

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ABSTRACT

The paper is aimed at exploring the effects of weaving, merging and diverging at midblock U-turn facilities on drivers' reaction. Midblock U-turn facilities at signalised and priority intersections are very commonly found along federal highways in Malaysia. However, the introduction of midblock U-turn facilities along roadway segments has provoked fierce national debates about their benefits and risks. Often U-turn traffic movements at roadway segments are channelized and aided with splitting islands so that drivers can be on their desired trajectories. Drivers will have to keep to the right lane; decelerate when diverging, accelerate when converging. These dangerous manoeuvres beg the question; 'what are the induced traffic flow consequences when the lead vehicle decelerates or accelerates abruptly? Based on the hypothesis that u-turning facilities at roadway segments have significant impact on weaving, merging and diverging manoeuvres; impact studies were carried out at 2 locations, Malaysia during daylight and dry weather conditions. 24hr traffic volume, speed, and vehicle types' were collected continuously for eight weeks from January to March 2012 for both directional traffic flows. The survey data were supplemented with information culled from the Malaysian Public Works Departments highway design manual. Traffic shockwave velocity propagations were estimated for roadway sections with deceleration and acceleration midblock U-turn carriageway lanes and then compared. Results show that traffic shockwaves caused by deceleration and diverging are less severe than those caused by acceleration and merging. Significant traffic kinematic shockwave of about 21km/h occurred only when converging. Further, average critical gap on major road is 5.51s and average delay of about 8.5s/veh occurred at the exit lane. The paper concluded that weaving intensity is heightened around the midblock U-turn facilities. Further,induced traffic shockwaves triggered by vehicle merging may cause road accidents.

Keywords: U-turning, Midblock, Traffic Shockwave, Merging

BACKGROUND

Weaving, merging and diverging are traffic stream deft manoeuvres that are often laden with profound risk of accident occurring. Weaving occurs when vehicles crisscross the carriageway lanes often with a view to repositioning for traffic stream advantage. It is inherent because of drivers desire to position their vehicle along the appropriate carriageway lane. On approach to Midblock u-turning facilities, drivers alone must decide when it is safe to merge, diverge and accept emerging gaps. Misjudgement of ensuing gaps ia not an option. When exiting the facility, driver may reject gap on the major road and wait for a subsequent gap. Poor gap acceptance decisions have severe consequences. They may cause traffic shockwave and lead to accidents. In any case, the existence of traffic shockwave at the weaving area of midblock u-turning facilities is a clear indication of inherent road safety risk.

Weaving is often triggered on approach to highway ramps, intersections as well as midblock facilities among others. Some, midblock u-turning facilities are built to complement existing road geometric design; others are built as a complete replacement to existing facilities on the premises that they will reduce conflicts and ease congestion at adjoining intersections. That may be so, but there are road safety consequences that are often ignored. Although it can be argued that the presence of traffic shockwave cannot be associated solely with midblock u-turning facilities given that traffic shockwave can occur without their presence. That may be true, but the presence of midblock u-turning facilities may increase the probability of shockwave occurring.

A U-turn refers to vehicles performing a 180 degree rotation to reverse the direction of travel. Often u-turning movements at roadway segments are channelized and aided with splitting islands so that drivers can be on their desired trajectories. Nevertheless the movements are often accompanied with weaving, merging and diverging in the vicinity of the midblock u-turning facilities.So, it can be postulated that U-turning movements will inherently interfere with through traffic by encroaching on part or all of the through traffic carriageway lanes.

In Malaysia where the left hand driving rule is in place, drivers will tend to keep to the right lane; decelerate when diverging, accelerate when converging. These dangerous manoeuvres beg the question; ‘what are the induced traffic flow consequences when the lead vehicle decelerates or accelerates abruptly? It can be argued that when the lead vehicle decelerates abruptly in a traffic stream, shockwaves can be triggered. Therefore, it is not surprising that the issue of midblock u-turning facilities along a roadway segment have provoked fierce national debates in Malaysia. However, the debates are yet to be substantiated with empirical research evidences.

Malaysia consists of thirteen states and three federal territories and has a total landmass of 329,847m^2 separated by the South China Sea into two similarly sized regions, Peninsular Malaysia and Malaysian Borneo [IDRA 2011]. The capital city is Kuala Lumpur. In 2010 the population exceeded 27.5 million, with over 20 million living on the Peninsula. Malaysian highways are classified by the ministry of works as expressway, federal, state, municipal highways and others. State highways connect district headquarters and are normally single carriageway road. Municipal highways connect residential, commercial and other roads within their district of influence. The expressways are defined as high-speed routes with at least four lanes (2 lanes per carriageway) with full access control, grade-separated interchanges and high design speed limit of 120 km/h, allowing the maximum speed limit of 110 km/h. It has a total length of about 1,850km. Federal Highways connect all state capitals and city of Kuala Lumpur. It is the busiest highway. They are often built with 2 carriageway lanes in each direction and an operating speed limit of 90km/h. It is conventional wisdom that motorists are expected to travel faster when overtaking on right lane.

The paper reports on driver reactions to weaving, merging and diverging within the context of transport policy aimed at changing travel behaviour. When ascertaining the extent of drivers' reaction induced by weaving, merging and diverging at midblock u-turning facilities the paper focused on key parameters like, weaving intensity, kinematic shockwaves gap acceptance and delays at u-turning exit lane. Specifically, the paper explores associations between traffic flows and deft manoeuvresu-turning movements at midblock facilities in other to derive safety indicators or early warning signs that will assist practitioners and policy makers in determining the effectiveness of decision-making.Based on the hypothesis that u-turning facilities at roadway segments have significant impact on weaving, merging and diverging manoeuvres; the remainder of the paper has been divided into 4 sections. In the immediate section literatures on weaving, merging, diverging shockwave and delays are reviewed. Section 3 is on sample survey and data collection, while in section 4 findings from analysed sample data are presented. In section 5, conclusions are drawn.

LITERATURE REVIEW

In Malaysia, some midblock u-turning facilities are built as complimentary facilities to existing infrastructure design, others are built as a complete replacement to existing facilities on the premises that they will reduce conflicts and ease congestion at adjoining intersections. The issue of open midblock u-turning facilities has provoked fierce national debates among road providers and users in Malaysia. Arguments have been advanced by some opponents of infrastructure modification projects that the increased numbers of u-turning facilities may compromise safety and exacerbate operational problems affected roadway. As contained many literatures [TRB 1997], midblock u-turning facilities are effective conflict-points reduction mechanism at intersections. An intersection without treatment has 32 conflict points (16 crossing, 8 diverge, 8 merge), however, at treated intersection conflict points are reduced to 8 (1 crossing, 3 diverge, 4 merge). The more common right turn treatments used on urban and suburban arterials are: flash median with one way right turn lane, raised curb median with alternating right turn bays, flush median with alternating right turn and undivided cross section as contained in NCHRP Report 395 [TRB 1997]. One potential treatment to combat congestion and safety problems at intersections is the installation of non-traversable medians and directional median opening has produced an increased number of U-turns on multilane divided roadways [IDRA2011]. The concern of this paper is weaving, diverging and merging associated with midblock U-turn facilities and driver reactions.Consequently, it is reasonable to assume that free-flow speed will decrease with relative decrease in density on approach to and on exit from midblock U-turn facilities. This is so because vehicles vying to turn right at the midblock section will most likely reduce approach speed on entry and may even force oncoming vehicles to slow down sometimes abruptly on exit from the facility.

Weaving, diverging and merging literature

Interaction between traffic streams on approach to midblock U-turn facilities has insignificant adverse effect on driver reactions and the absence of significant kinematic shockwaves also suggests that safety is not necessarily an issue here. Capacity and delays at midblock U-turn lane are moderate and somewhat acceptable; however, when a driver arrives at the exit lane and misjudge a gap in the major road traffic stream, the consequences could be fatal. Acceleration and merging is a deft manoeuvre becausethrough traffic flows have priority in the conflict sections, and vehicles attempting to enter the stream can only do so during larger gaps of successive vehicles in the fast lane. Merging is more difficult than diverging because through traffic flows are traversing along the faster lane. It is often a very dangerous manoeuvre that can trigger road accident. This is so because drivers along the overtaking lane are forced to either abandon the overtaking move in other to avoid collusion or ignore the risk altogether. In any case critical gap which is a threshold by which merging stream drivers judge whether to accept a gap or abandon it is an important variable. If the gap is larger than the critical gap, drivers accept it and enter the through traffic; otherwise drivers reject the gap and wait for the next gap. Since this is not a priority-controlled intersection the rule of critical gap fixed values or distribution does not strictly apply. It's up to drivers to get the merge-timing right.

As shown below in figure 1, four critical geometric variables have significant weaving effect on drivers' reaction and by extension the quality of road service, they are; length of weaving area, width of weaving area, number of lanes in the weaving area and of course lane configuration.

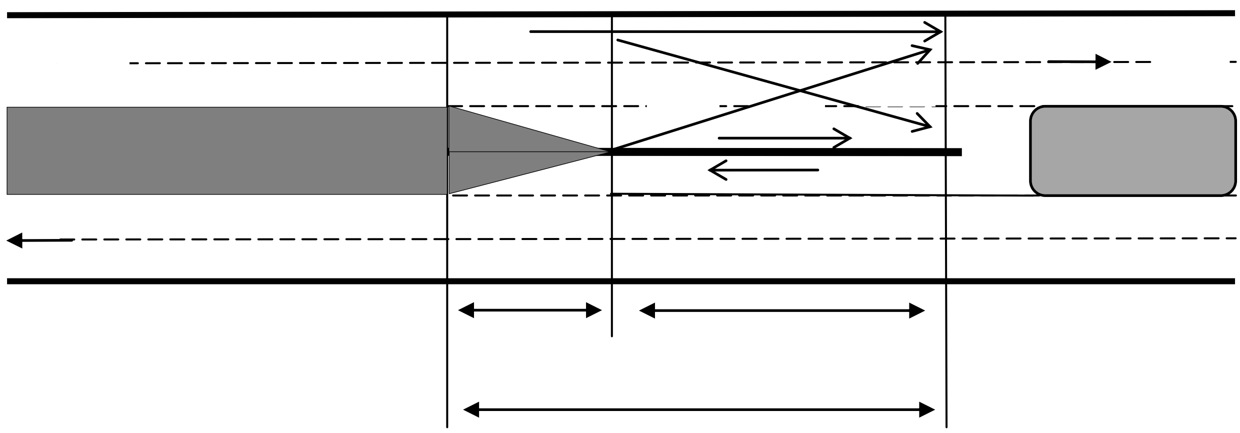


Figure 1Typical Weaving, Merging and Diverging Diagram

Consider figure 1 again and note that; Total flow per direction, $q_A = q_B + q_C$;
AC = Entry flow; and BC = Exit flow. In a typical weaving area, weaving and non-weaving flows exist. Now, let q_w be weaving flow and q_0 be non-weaving flow;
Total weaving flow (q_w) can be taken as $q_{w1}+q_{w2}$;
Total non-weaving flow (q_0) can be taken as $q_{01}+q_{02}$.

If the total flow, $q = q_w + q_{0;}$

Volume ratio $VR = \frac{q_w}{q}$; (1)

Weaving ratio, $WR = \frac{q_{w2}}{q_w}$ (2)

Since each lane has an impact on the extent of lane changing and their ensuing intensity, the average speed of weaving and non-weaving vehicles can be taken as;

$$v_i = v_{min} + \frac{v_{max} - v_{min}}{1+w} \quad (3)$$

Where; v_{min} is the minimum speed in the weaving area; v_{max} is the maximum speed in the weaving area and Speed (v) is a function of density (k) and flow (q)

$$v = {}^{q}/_{k} \Rightarrow q = vk \quad (4)$$

When computing capacity, Greenshields [1935], derived speed and density linear relationship shown below:

$$v = v_f - \frac{v_f}{k_j} k \quad (5)$$

If equation 5 in plugged into 4, then

$$q = k\left(u_f - \frac{u_f}{k_j} k\right) \quad (6)$$

Where v_f is the free-flow speed, and k_j is the jam density . . . .

According to Ben-Edigbe/Ferguson [2005, 2009] where the flow / density relationship has been used to compute roadway capacity where critical density is reached at the apex point. Up till that point, traffic stream is operating under unconstrained conditions not free flow as often wrongly mentioned in many literatures. Beyond the apex point, traffic flowrate is operating under constrained condition. Since our interest is in estimating the traffic kinematic changes due to midblock right u-turning movement, the choice of precise value of critical density need not be very critical to the outcome of this study. Consider Equation 6above, for maximum flow;

$$\frac{\partial_q}{\partial_k} = u_f - 2\left(\frac{u_f}{k_j}\right) k = 0 \quad (7)$$

Then, critical density

$$k_c = \frac{u_f}{2\left(\frac{u_f}{k_j}\right)} \quad (8)$$

Where, k_c is the critical density.

If equation 8 is plugged into equation 5 then, optimum speed can be re-written as:

$$v_0 = \frac{u_f\left(\frac{u_f}{2\left(\frac{u_f}{k_j}\right)}\right) - \left(\frac{u_f}{k_j}\left(\frac{u_f}{2\left(\frac{u_f}{k_j}\right)}\right)\right)}{\left\{\frac{u_f}{2\left(\frac{u_f}{k_j}\right)}\right\}} \quad (9)$$

Let $v = v_i$, v_{min} = optimum speed (v_o) and $v_{max} = v_f$;So that equation 3 can be rewritten as:

$$v = v_o + \frac{v_f - v_o}{1 + w} \tag{10}$$

Then, weaving intensity is given by,

$$w = 1 - \left(\frac{v - v_o}{v_f - v_o}\right) \tag{11}$$

Note that Highway Capacity Manual [HCM 2000] suggests that weaving intensity can also be estimated where:

$$w = \frac{a(1+VR)^b \left({}^{q}/_{N}\right)^c}{L} \tag{12}$$

a = 0.15; b = 2.2, c = 0.97; d = 0.8 for weaving speeds and
a = 0.0035; b = 4.0, c = 1.3; d = 0.75 for non-weaving speeds

However, model equation 11 is preferred and applied in the paper because of the constraints inherent in equation 12

Delays at Midblock Exit Lane and Drivers Reaction

Many studies have been carried out with respect to capacities and delays at priority intersections, so there is no need to build a new model. The maximum traffic flow from the midblock U-turn carriageway according to Tanner [1962] can be estimated as;

$$q_{max} = \frac{q_1(1-\beta_1 q_1)}{\exp[q_1(\alpha-\beta_1][1-\exp(-\beta_2 q_1)]} \tag{13}$$

In addition Tanner derived an expression for average delay to minor road (midblock U-turn lane) shown below:

$$\overline{W_2} = \frac{\frac{1}{2}E(y^2)/Y\ exp(-\beta_2 q_1)[\exp(\beta_2 q_1)-\beta_2 q_1 - 1]/q_1}{1 - q_2 Y[1-\exp(-\beta_2 q_1)]} \tag{14}$$

For;

$$E(y) = \frac{\exp[q_1(\alpha - \beta_1)]}{q_1(1 - \beta_1 q_1)} - \frac{1}{q_1}$$

$$E(y^2) = \frac{2\exp[q_1(\alpha - \beta_1)]}{{q_1}^2(1 - \beta_1 q_1)^2} \{\exp[q_1(\alpha - \beta_1)] - \alpha q_1(1 - \beta_1 q_1) - 1 + \beta_1 q_{1-} {\beta_1}^2 {q_1}^2 + \frac{1}{2} {\beta_1}^2 {q_1}^2/(1 - \beta_1 q_1)\}$$

$$Y = E(y) + {}^{1}/_{q_1}$$

Where; q_1 is traffic flow from major road (veh/s); q_2 is maximum traffic flow from midblock lane; β_1 minimum time headway between vehicles on major through road;
β_2 minimum time headway between vehicles emerging from midblock U-turn lane; α average gap in the major road stream

In other to determine the number of vehicles waiting at the exit lane when the delay time per vehicle is known and Q is the mean rate of departure of vehicles, then;

$$E(n) = \frac{q_2}{Q}\left(1 - \frac{q_2}{Q}\right)/\left(1 - \frac{q_2}{Q}\right) \quad (15)$$

Steady state and deterministic theories have been used in previous studies. However, Kimber and Hollis [1979] developed an expression for queue length and delay that combined both steady-state and deterministic theory shown below.

Delay per unit time,

$$D = \frac{1}{2}\left\{(F^2 + G)^{1/2} - F\right\} \quad (16)$$

Where;

$$F = \frac{(1-\rho)(Qt)^2 \;\; - 2(Lo-1)Qt - 4(1-C)(Lo+\rho Qt)}{2\{Qt + 2(1-C)\}}$$

$$G = \frac{2(Lo+\rho Qt)[Qt - (1-C)(2Lo+\rho Qt)]}{Qt + 2(1-C)}$$

And, Queue length,

$$L = \frac{1}{2}\left\{(A^2 + B)^{1/2} - A\right\} \quad (17)$$

$$A = \frac{(1-\rho)(Qt)^2 \;\; + 2(1-Lo)Qt - 2(1-C)(Lo+\rho Qt)}{Qt + (1-C)}$$

$$B = \frac{4(Lo+\rho Qt)\{Qt - (1-C)(Lo+\rho Qt)\}}{Qt + (1-C)}$$

For; C = 1 for random arrivals and service: C = 0 for regular arrivals and service
Q = capacity; $\rho = q/\mu$; q = demand flow; t = time interval (t=0.25 if time interval is 15mins)
Lo = length of queue at start of time arrival

In any case an analytical approach to delay is used in the paper. An indication of likely values of β_1 (1s) β_2 (3s) and that of α varies between 4s and 12s according to intersection layout and speed. Delays at exit midblock carriageway lane can trigger erratic driver reaction especially in circumstances where the critical gap on the major road is smaller than reaction time. Safe road crossing is a complex perceptual-motor task that requires accurate perception of the gap sizes in a dynamic stream of traffic and fine coordination to synchronize the onset of movement with the approaching gap. Gap is very similar to headway minus the vehicle length. It is a measure of the time that elapses between the departure of the first vehicle and the arrival of the second at the designated test point.

Gap acceptance plays a crucial role in safe driving. At the exit carriageway lane of midblock facilities, cautious drivers are more likely to reject small gaps than erratic drivers who may misjudge critical gap. Critical gap is usually considered as a fixed value or to follow a certain distribution. It is the threshold by which drivers judge whether to accept a gap or retain holding position. If the critical gap is larger than reaction time, drivers are more likely to enter the traffic stream on the major road. However, where gaps are well below reaction time, it can be assumed that the probability of accident occurring would be profound. Gap can be written as;

$$g = h - \left(\frac{l}{v} \right) \tag{18}$$

Where, *h* is headway (s), *l* is length of vehicle (m), *v* is vehicle speed (m/s) q is flow (pcu/s).

$$h_m = \left(\frac{3600}{q_m} \right) \tag{19}$$

Modification of passenger car equivalent values

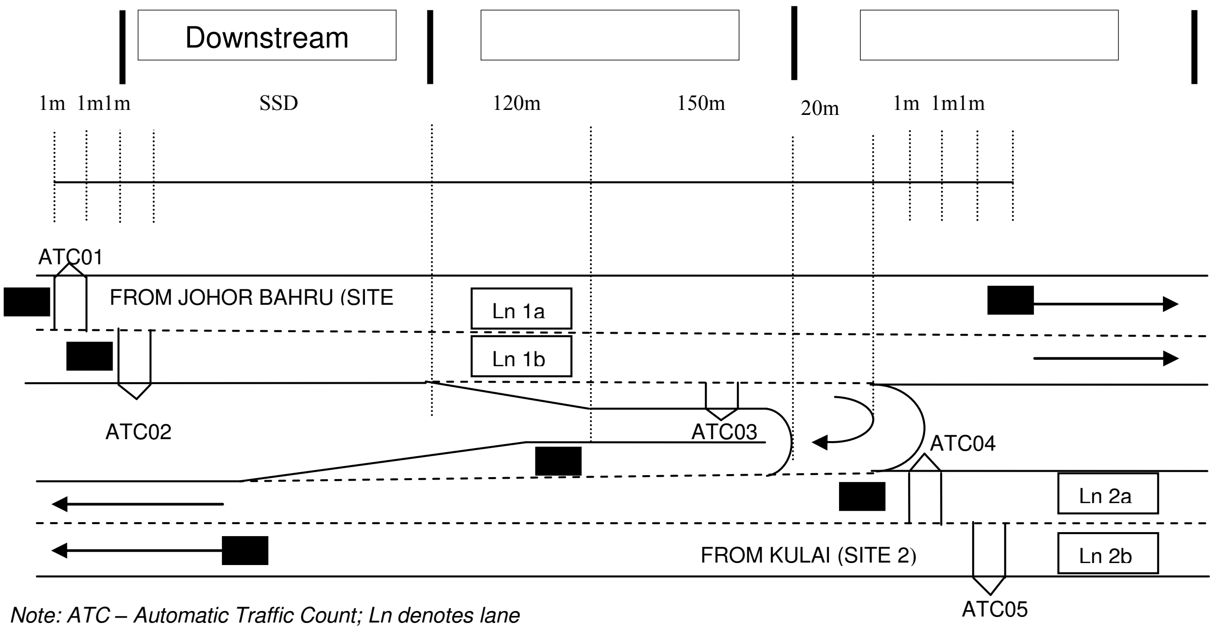
The passenger car equivalent values being an instrument of highway traffic flow computation must also be modified to take into account weaving, diverging and merging.Ignoring PCE modifications could lead to grossly inaccurate traffic estimates.Since PCE measures the impact that a mode of transport has 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. Therefore traffic flow modelequations must be modified accordingly. The term ‘passenger car equivalent’ was defined in Highway Capacity Manual [HCM 2000] as ‘the number of passenger cars displaced in the traffic flow by truck or a bus under the prevailing roadway and traffic conditions’. This definition still holds today and the use of such equivalents is central to road capacity analysis where mixed traffic stream are present. The headway evaluation criteria could be applied to many traffic situations such as at intersection and basic highway segments or mid-block sections. Whereas headway data can be obtained in the field with relative ease, other evaluation criteria such as delay, density and speed are expensive as such methods based on these adopt the simulation approach. The passenger car equivalency method used in this study is the headway method. The method was first proposed by and involves the following equation;

$$PCE_i = \frac{H_i}{H_c} \tag{20}$$

Where:PCE_i is the passenger car unit of vehicle class *i*. H_i is the average headway of vehicle class *i* and H_c is the average headway of passenger car.

SETUP OF IMPACT STUDY

The setup of midblock u-turning impact study is illustrated below in figure 2. Note that for the ease of referencing, the survey site has been coded as follows: Site 001: lane 1a and 1b are influenced by diverging; Site 002: (lanes 2a and 2b are influenced by merging. The dual carriageway Federal Highway FT001 Senai, Kulai in the Johor State of Malaysia has been selected for the study after careful considerations. The survey data were supplemented with highway design information culled from the Malaysian Public Works Departments manual. 24hr traffic volume, speeds, vehicle types, headways and gaps were recorded continuously for 8 weeks (January – March 2012) for both directions. Over 500,000 vehicles per roadway direction were captured on the data logger. Study was carried out under dry weather and daylight conditions.



Note: ATC – Automatic Traffic Count; Ln denotes lane

Figure 2 Typical layout of Survey Site

As shown above in figure 2, the roadway was divided into three sections (downstream, transition and upstream) in both directions. Motorists traveling along lane 1a and crossing the automatic traffic counter (ATC01) are assumed to be travelling at free flow speed, whereas motorists crossing ATC02 are within the SSD influence area and they are assumed to be influenced by midblock U-turn facilities. Motorists at upstream section are assumed to be driving at free flow speed. Motorists intending to use the midblock U-turn facilities would decelerate on approach to the entry lane and accelerate on exit from the U-turn lane.

The downstream section was set at a distance greater than stopping sight distance (SSD) so as to minimise the influence of weaving and deceleration/acceleration on the carriageway lanes.SSD is the length of the roadway ahead that is visible to the driver. The distances are derived for various design speeds based on assumptions for driver reaction time, the braking ability of most vehicles under wet pavement conditions, and the friction provided by most pavement surfaces, assuming good tires. It is also influenced by both vertical and horizontal alignment. However, the study was carried out on flat terrain and straight road segment. The set distance was based on stopping distance (SSD) equation 21 with assumptions of 5% road gradient, 2.5seconds reaction time and 0.3coefficient of frictionNote also that, SSD = driver perception/reaction distance (d_1) + braking distance (d_2). Based on the results of many studies, 2.5 seconds has been chosen for a perception-reaction time and deceleration rate of 3.4 m/s^2 used to determine stopping sight distance. These values are within most drivers' ability to maintain safe vehicle control.

$$SSD\ (m) = \left\{(0.278vt) + \left(0.039\frac{v^2}{a}\right)\right\} \tag{21}$$

Where;t = perception time; v = approach speed; a = deceleration time

FINDINGS

Weaving and merging interaction between traffic streams on approach to the facility, queues and delays at the facility and also, gaps and merging at exit of the facility were analysed and presented below using a step wise procedure:

Step1: Aggregated traffic data as shown below in figure 3 were disseminated and fitted into peak and off peak period under day light and dry weather conditions. Peak data were used for further analysis. Traffic volumes were converted into flows using appropriate passenger car units.

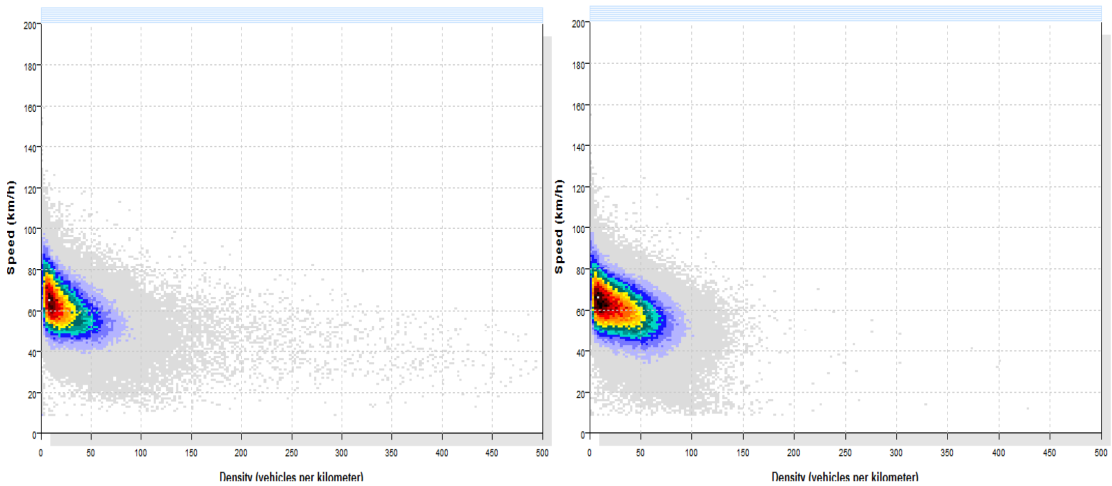


Figure 3a: Lane 1a

Figure 3b: Lane 1b

Figure 3: Typical Speed v Density Scatter plots Carriageway Lanes

This study is exciting because it has been able to link speed reductions and weaving intensity to traffic kinematic waves and by extensionroad safety on dual carriageway roads.Traffic flow, speed and density data were extracted from figure 3 and shown below in tables 1 and 2. Traffic flows were estimated from observed volume using modified passenger car equivalent values; traffic densities were computed from travel speed and traffic flow using equation 4. From the observed data in tables 1 and 2, increase in traffic flow triggers decrease in travel speed and increase in traffic density.

Table 1: Flow, Speed and Density data for Site 1

Lane 1a			Lane 1b		
Speed km/h (±10)	Flow veh/hr	Density veh/km	Speed km/h (±5)	Flow veh/hr	Density veh/km
61	888	14.56	57	744	13.05
57	1362	24.12	60	528	8.80
54	1560	28.87	52	804	15.46
49	2112	43.17	57	642	11.26
47	1896	39.92	50	936	18.72
36	2526	70.41	45	1224	26.90
41	2358	57.98	50	1242	24.94
39	2352	60.86	46	1230	26.45
39	2556	65.10	43	1302	30.28
34	2694	79.08	45	1152	25.60
31	2574	82.52	55	816	14.84
38	2736	72.31	50	1194	23.93

Table 2: Flow, Speed and Density data for Site 2

Lane 2a			Lane 2b		
Speed km/h (±13)	Flow veh/hr	Density veh/km	Speed km/h (±7)	Flow veh/hr	Density veh/km
62	228	3.68	58	1218	20.87
18	1500	83.33	62	1356	21.87
44	1224	27.82	56	1776	31.89
48	1050	21.88	45	1992	44.27
33	1260	38.18	41	2352	57.37
53	792	14.94	49	1866	38.08
58	660	11.38	40	2226	55.65
60	564	9.40	50	2178	43.56
55	708	12.87	47	2328	49.53
60	456	7.60	56	1908	34.11
57	570	10.00	50	1866	37.32
60	594	9.90	51	1752	34.35

Step 2:Estimate traffic flow, speed and density. The model equations for sites 001 (diverging lanes) and 002 (merging lanes) shown below in table 3 were computed from traffic flow,

speed and density data in tables 1 and 2 above using equations 4, 5 and 6. Speed and density linearity equations were computed: for example lane 1a; u = 66.17–0.42k using equation 5; then traffic flow was estimated using equations 6 and 4; $q = 66.17k – 0.4203k^2$.

Step 3:Test model equations for validity. As shown below in table 3, the coefficient of determination (R^2)is greater than 0.5 suggesting that the equation is useful for modeling.

Step 4: Determine the threshold road capacity (Q) as shown below in table 3. Note that the threshold capacity has to be exceeded before traffic kinematic waves can occur; after all kinematic wavesareproducts of traffic congestion. In spite of weaving at site 001, travel speed for the two lanes are the same, however, there are significant differences in jam and optimum densities. Motorists weaving and jockeying for position at the entry lane of the midblock U-turn facilities may be called to account for the differences. At site 002, it is important to note that travel speed difference is significant mainly because of motorists deft exit manoeuvres.

Table 3: Estimated Flow Speed and Density

Site	Model Equation		R^2	v_f	k_j	v_o	k_o	Q
Site 001	Lane 1a	U = -0.4203k + 66.17	0.98	66	157	-	-	
		$q = 66.17k – 0.4203k^2$	0.98	-	-	34	79	2604
	Lane 1b	U = -0.7289k + 65.48	0.93	65	90	-	-	
		$q = 65.48 – 0.7289k^2$	0.93	-	-	33	45	2509
Site 002	Lane 2a	U = -0.5889k + 62.984	0.94	63	107	-	-	
		$q = 62.984k – 0.5889k^2$	0.94	-	-	32	54	2353
	Lane 2b	U = -0.5485k + 71.847	0.91	72	131	-	-	
		$q = 71.847k – 0.5485k^2$	0.91	-	-	36	66	2098

Note:v_f is free-flow speed;v_o is optimum speed; k_j is jam density and k_o is optimum density

Step 5: Determine weaving area and associated parameters. Total traffic flow (q), non-weaving traffic flow (q_o), weaving traffic flow (q_w) were extracted from figure 3; volume ratio and weaving ratio were computed as shown below in table 4.

Table 4: Estimated volume ratio and weaving ratio

Site	q_{o1}	q_{o2}	q_o	q_{w1}	q_{w2}	q_w	q	VR	WR
001	985	801	1875	187	225	412	2287	0.180	0.546
002	933	755	1688	193	339	532	2036	0.262	0.637

Note: Total flow, $q= q_w + q_o$; Volume ratio, $VR = q_w / q$; Weaving Ratio, $WR = q_{w2} / q_w$

Note that traffic flow weaving to left (q_{w1}) is smaller that traffic flow weaving to the right (q_{w2}); this is so because traffic flows weaving to the right are vying for the midblock U-turn entry lane. Traffic volume ratio for the entry section of the midblock U-turn facilities (site001) is smaller than the exit section (site002). The paper can only suggest that it may be indicative of the complexity inherent in merging with major roadway as opposed to diverging from it. It would be useful to estimate the weaving intensity in order to shed more lights on the behaviour of drivers at the midblock U-turn facilities.

Step 6: Determine weaving intensity using equation 11 as shown below in table 5.

$$PD = v_f t \text{ and } BD = \frac{(v_f)^2}{2a}$$

Where; PD is perception distance; BD is braking distance; *v* is speed, t is perception time (2.5s); and *a* is deceleration time (3.4m/s^2)

Table 5: Weaving intensity

Site	v	v_o	v_f	total	w	PD(m)	BD(m)	SSD(m)
001	57.3	34	66.2	0.72	0.28	45.97	47.73	93.7
002	50.5	36	71.8	0.41	0.59	49.86	58.47	108.3

Note: v (km/h) PD-perception distance, BD-braking distance, SSD-sight distance = PD+BD; 66.2km/r=18.39m/s also 71.8km/h=19.94m/s

Sight time (s) for site 001 (deceleration/midblock exit lane) = 93.7/18.39 = 5.09s
Sight time (s) for site 002 (acceleration/midblock exit lane) = 108.3/19.94 = 5.43s

If the average gap in the major road adjacent to the exit lane is greater than 5.43s, then it can be postulated that drivers can exit safely. However, if the average gap is less than 5.43s it can be postulated that drivers' exposure to collision is heightened. So, we need to determine delay, gap and headway along the major roadway adjacent to the exit lane

.

Step 7: Determine delay to vehicles exiting midblock U-turn lane; Based on equation 14, average delay to vehicles at midblock U-turn exit lane; $\overline{w_2} = 8.55s/\text{veh}$

Where;q_1 is traffic flow from major road =0.223 veh/s
β_1 minimum time headway between vehicles on major road =1.53s
β_2 minimum time headway between vehicles on minor road =3.1s
α average gap in the major merging roadway = 5.51s
q_2 is maximum traffic flow from midblock lane =0.0875 or 5.25pce/min or 315pce/hr
Q = capacity; $\rho = q/\mu$; = 1/8.55 ≈ 0.12

The number of vehicles waiting at the exit point is;

$$E(n) = \frac{0.0875}{0.12}\left(1 - \frac{0.0875}{2x0.12}\right) \Big/ \left(1 - \frac{0.0875}{2x0.12}\right) = 0.73 \cong 1$$

The average delay to vehicles along dedicated midblock U-turn lane is 8.55s per vehicle.As shown below in figure 6;the sight time for approaching vehicle = 5.43s
The safe gap on the major merging roadway; g = 170/19.94 = 8.52s
The average gap in the major merging roadway = 5.51s

The number of vehicle waiting at the exit lane to join the through traffic flow is one and the expected delay is 8.55s. As illustrated below in figure 4, the sight time for drivers approaching midblock facilities is 5.43s and the average gap on the major merging roadway is 5.51s.

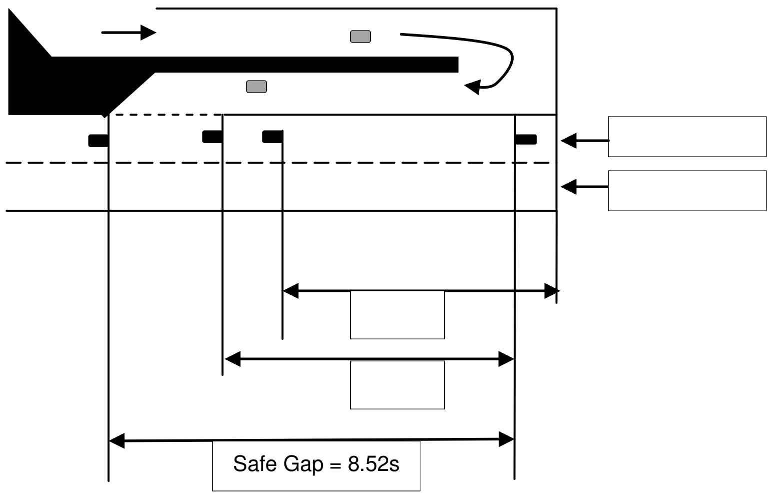


Figure 4 Gaps on Major Merging Roadway

Based on the configuration of the midblock facilities, the estimated safe gap time is 8.52s. The difference between safe gap and average gap is 3.01 which is grated that than the assumed drivers reaction time of 2.5s. Therefore for a safe merge, an approaching vehicle traveling at 19.94m/s on the major must be at least 170m away from the exit lane, in order to permit the merging driver a safe passage. Probably that explains why delay per vehicle of 8.55s is a high. Should the gap time be violated or misjudged, the lead vehicle on the major roadway may break abruptly, sometimes violently.It's up to the drivers at the exit lane to get the timing right. Merging is more difficult than diverging because the through traffic flows are traversing along the faster lane. It is often a very dangerous manoeuvre that can trigger road accident. This is so because drivers along the overtaking lane are forced to either abandon the overtaking move in other to avoid collusion or ignore the risk altogether. In essence a driver experiences kinematic wave whenever he/she adjusts his/her speeds in accordance with the behaviour of the car or cars in front, on observing a brake light, or an opportunity to overtake. So, it would be useful to test the exit lane area for traffic shockwave.

Step 8: Test for the presence of traffic shockwave. As illustrated in Figure 5, site 1 has two lanes 1a (slower lane) and 1 b (overtaking lane). Considering that traffic stream operation was at off peak period, the influence of peak traffic flow was minimised. Speed distributions on both lanes are the same. It thus suggests that vehicle traversing along lane 1b would have a torrid time trying to overtake vehicle along lane 1a. The reason is not farfetched. At the transition section of the carriageway, there is a dilemma zone where drivers must decide whether to stay in lane or move to the right. The drivers moving to the right include those detouring as well as those making U-turns. There are evidences from the findings to suggest that about 43% of drivers along lane 1b are U-turners. Since, the midblock U-turn has a decelerating lane at this section of the roadway, it is obvious that the deceleration effect would be transmitted along lane 1b, thus contributing to inability of drivers to overtake. As illustrated above in Figure 5, site 2 has two lanes 2b (slower lane) and 2a (overtaking lane). Considering that traffic stream operation was at off peak period, the influence of peak traffic flow was minimised. Speed distributions on both lanes are the same. It thus suggests that vehicle traversing along lane 2a would have a torrid time trying to overtake vehicle along lane2b. The reason is not farfetched. At the transition section of the carriageway, there is a dilemma zone where drivers must decide whether to stay in lane or move to the right. The section enveloped by midblock U-turning would experience weaving, acceleration, deceleration and critical gap acceptance impediment. Drivers emerging from the midblock U-turn facilities must wait to gap to appear along lane 2a before accelerating into that lane. It is often a dangerous manoeuvre that can trigger road accident. This is so because drivers along the overtaking lane 2a are forced to abandon the overtaking move in other to avoid collusion with vehicles emerging from the midblock U-turn facilities. This is clearly a safety issue that can be predicted with traffic shockwave computation.

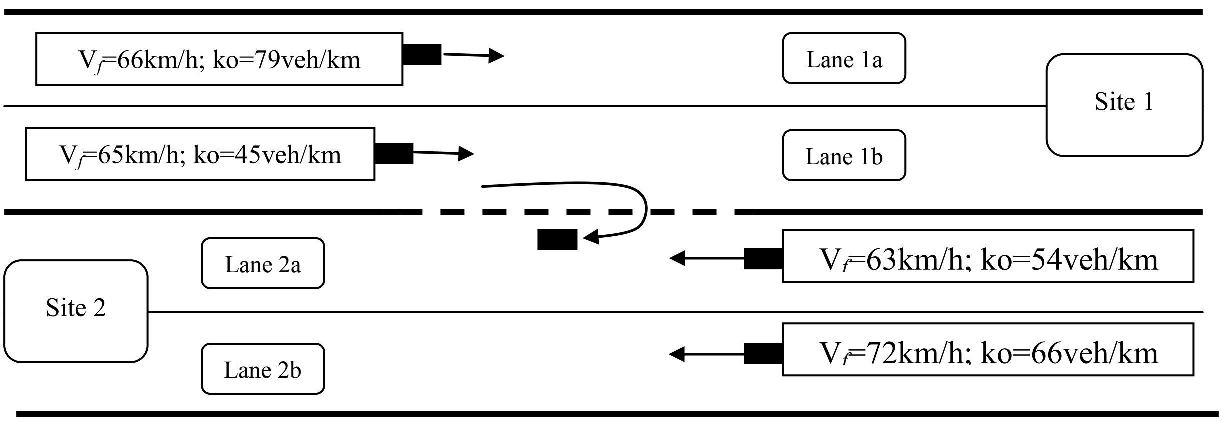


Figure 5: Operating Speed per Lane

Shockwaves are one of the major safety concerns because the sudden change of conditions drivers' experience, they can be derived as;

$$v_w = \frac{q_2 - q_1}{k_2 - k_1} \tag{22}$$

Where; v_w = propagation velocity of shock wave (km/h)
q_2 = flow before (veh/h); q_1 = flow after conditions (veh/h)
k_2 = density before (veh/km); k_1 = density after (veh/km)

As summarised below in table 6, predicted traffic shockwave of about 20km/h occurred when converging and 2km/h when diverging at the midblock u-turning facilities. Traffic shockwaves of about 20km/h at the exit carriageway lane were positive, suggesting that they were when travelling in same direction as traffic stream. Although vehicles may have difficulty in overtaking and weaving because of deceleration effect, kinematics of traffic flow suggest that weaving of vehicles at decision zone area has not led to shockwave. This is partly because drivers following the lead vehicle are able to appraise traffic stream and control mechanism positively. This has not been the case at the exit lane.In sum, traffic volume, speed, vehicle types collected at four strategic sites in Johor, Malaysia were analysed in order to identify impacts of midblock U-turn facilities on weaving, merging and diverging on driver reactions. Tanner [1962] derivations were employed to estimate delay. In addition Tanner derivation for maximum discharge for minor road was also relied upon. A case for dynamic passenger car equivalent values was made on the premise that, ignoring their modifications could lead to grossly inaccurate estimates with significant consequences for study outcomes. In any case, the presence of significant traffic shockwave on the major traffic stream lends credence to the hypothesis that midblock u-turning facilities have inherent safety problem. If the gap is larger than the critical gap, drivers accept it and enter the through traffic; otherwise drivers reject the gap and wait for the next gap. Since this is not a priority-controlled intersection the rule of critical gap fixed values or distribution does not apply. Vehicles priority lane can run into conflict sections without giving way, and vehicles attempting to enter the stream can only do so during larger gaps of successive vehicles in the fast lane.

Table 6: Traffic Flow Shockwave

Drivers' Behaviour	Lane	q_1 pcu/h/ln	k_1 veh/km	Q pcu/h	q_2 pcu/h/ln	k_2 veh/km	q_1-q_2	k_1-k_2	v_w Km/h
Deceleration & Diverging	1a	985	21	2604	1471	45	-486	-69	0
	1b	933	33	2509	1043	86	-110	-53	2
Acceleration & Merging	2a	801	21	2353	1684	66	-883	-45	20
	2b	755	39	2098	1263	72	-508	-33	15

Source: Survey Data Note: v_w – shockwave;

CONCLUSIONS

The weaving, diverging and merging at midblock u-turning impact studies gave an insight into some of the problems associated with midblock u-turning facilities in Malaysia. While it is recognised that midblock u-turning design must be appropriate to the specific needs of a particular country, it can be argued that the depth of understanding and experience gained from this study is more relevant to traffic control and management decision making in Malaysia than readily transferable solutions from other countries.Based on the hypothesis that u-turning movement at midblock facilities will heighten weavingintensity and inherent traffic safety, the paper concluded that:

- There is correlation between traffic safety and midblock u-turning facilities
- Weaving intensity on approach to the Midblock u-turning facilitiesis significant andcharacterised by speed fluctuation among others.
- There is no evidence in the paper to suggest that the presence of traffic shockwave at the entry lane is significant. However, significant positive shockwaves of 20km/h were found at the exit lane probably due to erratic driving and critical gap misjudgement
- Estimated delay of about 8.55s per vehicle can be expected at exit lane
- The hypothesis that u-turning movement at midblock will induce shockwave at the exit lane is valid

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