Malaysian Journal of Civil Engineering 25(2):168-176(2013)

PREVALENCE OF TRAFFIC KINEMATIC WAVE AT PRIORITY JUNCTION WITH ENTRY HUMP

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Abstract: The presence of traffic shockwave on any roadway irrespective of the causation is an indicator of inherent safety problem. Priority T-junction with road hump on one major arm was investigated for kinematic waves. Automatic traffic counters were installed at each lane of the T-junction for six weeks. Traffic volume, headway, vehicle type and travel speed data were collated and analysed. Results show that right turn movement from the minor will trigger positive traffic shockwave of about 20km/h, whereas the other turning movements are merely subjected to rarefaction waves. The paper concluded that road hump at the major road can be partly held accountable for the prevalence of traffic shockwave associated with right turn movements.

Keywords: *Kinematics, rarefaction, shockwave, hump, volume, speed*

1.0 Introduction

Indeed, road junctions are intended to operate where vehicles often must share space with other road users. During operation, many simultaneous decisions, such as selection of the proper lane; manoeuvring for position; need to decelerate, stop, or accelerate; and need to select a safe gap are filtered through the mind of drivers approaching a junction. Simply put a priority junction is an intersection where drivers on the major road are given definite priority over the others. The minor road will usually be controlled by some form of sign marking, such as stop or yield sign; thus ensuring that priority vehicles incur virtually no delay. Drivers on minor road are always seeking entry gaps on the major road. In order to minimise reckless entry into major roads, humps are often installed at a distance on the minor road to ensure speed reduction and reasonableness. In some cases road humps are installed on all arms in order to reduce travel speed at the intersections. In Malaysia, priority junctions are often preceded with rumble strips and 75mm humps are usually installed at the entry section of all arms. The Humps are placed at distances between 30 and 50m from the centre of the priority T-junction. The paper is aimed at determining the prevalence and type of traffic kinematic waves present at priority T-junction with road humps. The primary objective is to determine the extent of kinematic wave and type if at all. The contemptuous issue of road humps is gradually become loud. It can be argued that hump installations at priority junction may infringe upon drivers priority right and erode the delay minimisation advantage of major roads. As for drivers on the minor road, they may misjudge gap acceptance and entry timing into the major road with severe consequence. Whilst the road humps are used for speed reduction, it is debatable whether the benefits offered by the humps in terms of speed reduction can be offset by the inherent safety issues associated with kinematic waves. The presence of kinematic wave in the traffic stream is not the big issue, but its transformation from rarefaction to shockwave would signal looming road accident at the intersection.

2.0 Traffic Kinematic Wave Concepts

Kinematic wave is a family of parallel characteristics in the x-t plane. Drivers experience 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. Should the lead driver brake abruptly due to changes in traffic, roadway, weather or ambient conditions the resultant kinematic wave will be along lines C,A and B as shown below in figure 1. According to Ben-Edigbe [1], the critical density is reached at the apex point of the curve shown in figure 1. 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 flow is operating under constrained condition. Since our interest is in estimating the traffic kinematic wave, the choice of precise value of critical density need not be very critical to the outcome of this study. Note that shockwaves are by-products of traffic congestion and queuing [4] whereas rarefaction waves are merely the kinematic effects that thin out over time. In order words rarefaction faction (Rw) will operate between C and A; hence

$$R_w = \frac{q_c - Q_A}{k_c - k_A} \qquad \text{For } k_A \geq k \geq 0.85q\text{; Else } R_w \rightarrow S_w \qquad (1)$$

Note that 0.85 is commonly taken as traffic flow (q) benchmark. Shockwave speeds will operate between A and B; as shown in figure 1. Therefore care should be taken when expressing wave in traffic in order not to misrepresent one for another.. The area of traffic shockwave (S_w) in figure 1 can be taken as:

$$S_w = \int_{k_A}^{k_B} f(k)\,\partial k = ak^2 + bk - c \qquad (2)$$

For $k_A < k \geq 0.85q$; Else $S_w = 0$

If the interest is shockwave, the traffic flow pressure must such that road capacity is exceeded momentarily. Should that fail to happen, the traffic stream will only experience rarefaction especially in cases where traffic flow is operating in excess of 85 percent of capacity. It can be argued. If the study interest is road safety it would advisable to investigate traffic kinematic wave ABC in figure 1. By investigating the presence of kinematic wave in the first instance, one is merely stating the obvious; that the outcome of the study could be rarefaction and/or shockwave. Kinematic wave can be computed as:

$$K_w = \frac{q_c - Q_B}{k_c - k_B} \qquad (3)$$

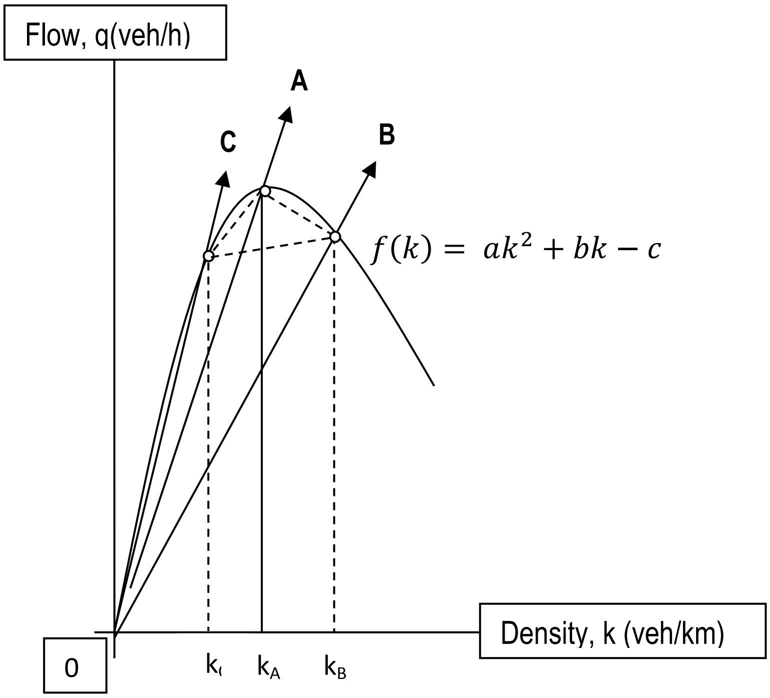

Figure 1: Flow-density curve with kinematic wave ABC

In any case, kinematic model is made up of three components: the fundamental diagram, the conservation equation, and initial conditions. Where density is defined as $\rho\ (x, t)$ and flow is $q\ (x, t)$ then, $x_2 > x > x_1$:

Integrating over an arbitrary time interval, $[t_1, t_2]$

$$\int_{x_1}^{x_2} \left(\rho(x,t_2) - \rho(x,t_1)\right) dx = \int_{t_1}^{t_2} \left(q(x_1,t) - q(x_2,t)\right) dt$$

This is equivalent to $$\int_{t_1}^{t_2}\int_{x_1}^{x_2} \left(\frac{\partial \rho}{\partial t} + \frac{\partial q}{\partial x}\right) dxdt = 0$$

Therefore the integrand shown below as equation 4 is the Conservation Law. It is the fundamental law governing the kinematic Wave Model.

$$\frac{\partial\rho}{\partial t} + \frac{\partial q}{\partial x} = 0 \qquad (4)$$

The relation between q and ρ is assumed to be $q = Q(\rho)$

Then $\rho_t + c(\rho)\rho_x = 0,\ \ c(\rho) = Q'(\rho)$

Plug discontinuities into the solution by a simple jump in q and ρ

Assuming q and ρ are continuous; $x_1 > x > x_s(t), x_s(t) > x > x_2$

Then,

$$q(x_{2,}t) - q(x_1,t) = \frac{d}{dt}\int_{x_2}^{x_s(t)} \rho(x,t)\,dx + \frac{d}{dt}\int_{x_s(t)}^{x_1} \rho(x,t)\,dx \qquad (5)$$

$$= \rho(x_s^-,t)s - \rho(x_s^+,t)s + \int_{x_2}^{x_s(t)} \rho_t(x,t)\,dx + \int_{x_s(t)}^{x_1} \rho_t(x,t)\,dx$$

Where: $\rho(x_s^-,t), \rho(x_s^+,t)$ are the values of $\rho(x,t), x \to x_s(t)$

Now, let S be shock velocity, so that, $q_2 - q_1 = S(\rho_2 - \rho_1)$,

Then, $S = \frac{Q(\rho_2) - Q(\rho_1)}{\rho_2 - \rho_1}$ (6)

Lighthill and Whitham postulated that there exists some functional relationship between flow and density that may vary with location but not with time. Where location is x and time is t; then

$$k\,(x,t) = k\,(q(x,t),x) \qquad (7)$$

If it assumed that there is no vehicle entering or exiting the traffic stream, then the equation of continuity can be applied to equation 7 to give a partial differential equation 6 for q (x, t).

$$\frac{\partial k\ (x,t)}{\partial t} + \frac{\partial k\ (x,t)}{\partial t} = 0 \qquad (8)$$

This is an exaggerated assumption nonetheless;

$$S_{w\ (q(x,t),x)} \frac{\partial k\ (x,t)}{\partial t} + \frac{\partial k\ (x,t)}{\partial t} = 0 \qquad (9)$$

$$S_w(q,x) = \frac{\partial k(q,x)}{\partial q} \qquad (10)$$

For; $\frac{1}{S_w}$ is traffic shockwave velocity propagation

If the assertion that, 'traffic shockwaves are by-products of traffic congestion' is to hold, then q_1 and k_1 must be congested flow and density respectively. Therefore, a threshold capacity must be estimated in other to ascertain whether traffic shockwave has indeed occurred. Where the threshold capacity has been exceeded the passenger car equivalent values being an instrument of capacity computation must also be modified. Ignoring PCE modifications could lead to grossly inaccurate road capacity estimates with consequences for road transportation modeling. In any case, three primary measures namely: flow, speed and density characterise the operational state of any given traffic stream. Non-signalized junction capacity calculation can be divided into two groups: i; simple queuing system with two streams: one major stream and one minor stream; ii, comprehensive queuing system with more than two streams of different rank in the priority regulation. In the group "queuing systems with one major stream and one minor stream", a large variety of calculation methods which yield the corresponding accuracy depending on the assumed traffic conditions exists. In the group "queuing systems with more than two streams", only one pragmatic procedure exits for practice uses.

The paper is focused on the one major and one minor queuing system; hence the procedure for the determination of capacity is based on the calculation of the distribution of gaps in the major stream and on the calculation of the number of vehicles which can depart during a gap within the major stream. Gap acceptance is one of the most important components in microscopic traffic characteristic. The gap acceptance theory commonly used in the analysis of uncontrolled intersections based on the concept of defining the extent drivers will be able to utilize a gap of particular size or duration. A driver entering into or going across a traffic stream must evaluate the space between a potentially conflicting vehicle and decide whether to cross or enter or not. One of the most important aspects of traffic operation is the interaction of vehicles with in a single stream of traffic or the interaction of two separate traffic streams. This interaction takes place when a driver changes lanes merging in to a traffic stream or crosses a traffic stream. Inherent in the traffic interaction associated with these basic manoeuvres is concept of gap acceptance.

The critical gap t_{cx} for movement “x” is defined as the minimum average acceptable gap that allows intersection entry for one minor or major road. The term average acceptable means that the average driver would accept or choose to utilize a gap of this size. The gap is measured as the clear time in the traffic stream defined by all conflicting movements. Thus, the model assumes that all gaps shorter than t_{cx} are rejected or unused, while all gaps equal to or larger than t_{cx} would be accepted or used. The adjusted critical gap t_{cx} can be computed as follows.

$$t_{cx} = t_{cb} + t_{cHV}PHV + t_{c,G}G - t_{c,T} - t_{3,LT} \qquad (11)$$

Where,
t_{cx} = critical gap for movement “x”,
t_{cb} = base critical gap (see HCM2010)
t_{cHV} = adjustment factor for heavy vehicles,
PHV = proportion of heavy vehicles
t_{cG} = adjustment factor for grade, G = percent grade divided by 100,
t_{cT} = adjustment factor for each part of a two-stage gap acceptance process
$t_{3,LT}$ = critical gap adjustment factor for intersection geometry

The follow up time t_{fx} for movement “x” is the minimum average acceptable time for a second queued minor street vehicle to use a gap large enough admit two or more vehicles. Base critical gaps and follow up times can be adjusted to account for a number of conditions, including heavy - vehicle presence grade, and the existence of two stage gap acceptance. Adjusted Follow up Time computed as:

$$t_{fx} = t_{fb} + t_{fHV}PHV \qquad (12)$$

Where, t_{fx} = Follow-up time for minor movement x,
t_{fb} = Base follow-up time (see HCM 2010)
t_{fHV} = Adjustment factor for heavy vehicles,
PHV = Proportion of heavy vehicles for minor movement

3.0 Setup of Impact Study

The setup of empirical study is illustrated below in figure 2. Note: ATC denotes automatic traffic counter

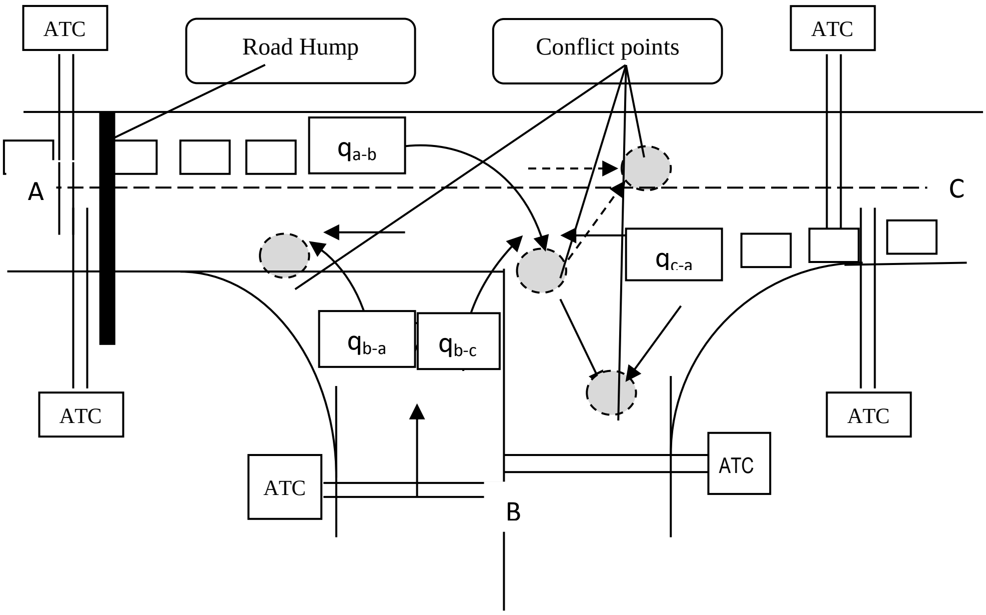

Figure 2: Typical Layout of Site

Note that in figure 2, the priority T-junction Arm has single lane in each direction although the minor road has provision for two exit lanes. Arm A has road hump installed from kerb to kerb whereas arms B and C are devoid of humps. The road hump at arm A is flat top 75mm height from carriageway surface. Traffic volume, speeds, vehicle types, headways and gaps were recorded continuously for 6 weeks for all directions. Only data taken during day light and r weather conditions are investigated Survey information was supplemented with data culled from Malaysia design manual, Ministry of works and the Universiti Teknologi Malaysia library. Follow-up travel times were measured directly by observing traffic flow. Stopping sight distance (SSD) was used to identify the location of the automatic traffic counter based on the premise that drivers behaviour will change once the junction was visible.

4.0 Findings and Discussion

Based on observation, four traffic flow conflict movements were clearly identified at the priority T- junction: q_{a-c} / q_{b-c}, q_{c-a} / q_{b-a}, q_{b-c} / q_{a-c} and q_{c-a} / q_{a-b}. Barring extraordinary circumstances at arm B, traffic kinematic wave is not expected to occur at this arm because it is the minor road. However, it was assumed that arm B being the minor road can only trigger kinematic waves on the major road partly because of poor gap judgment. Therefore, the first computation was the extent of adjusted gap acceptance at the major road using equation 11 and 12. Critical gap for arm A is 3.3s and arm C is 2.2s. Assuming maximum flow is same as capacity, Q_A = 3600/3.3 and Q_C = 3600/2.5; then capacity for the major road is 1440pcu/hr. Where 85%ile denotes 85 percentile speed; Q=flow; k=density; Sw=shockwave; Rw=rarefaction; Kw=kinematic wave. Based on the conditions in equations 1, 2 and 3 traffic waves were computed and shown below in table 1.

Table 1: Kinematic, Shock and Rarefaction Waves at Priority T-Junction

Arm		85%ile km/h	q_n veh/h	Q_1 veh/h	Q_c veh/h	k_n veh/h	k_c veh/h	k_1 veh/h	K_w	R_w	S_w
A	q_{a-c}	**35**	**937**	**1174**	**1440**	**26**	**41**	**33**	**33**	**33**	**0**
C	q_{c-a}	**41**	**1152**	**1302**	**1440**	**28**	**41**	**37**	**17**	**22**	**0**

Note that kinematic wave along arm A is greater than Arm C. Arm A has ramp installed whereas arm C is without ramp, it would appear that road hump could have accounted for the rarefaction wave at Arm A. One simple explanation is that drivers from the minor road (arm B) misjudge gap allowance at arm C because of the fluctuating speeds at arm C. Interestingly, there is no evidence of traffic shockwave at the junction partly because road humps would have taken out the sting by way of speed reduction.

5.0 Conclusions

As shown in the paper traffic kinematic encompasses rarefaction and shockwaves. On approach to priority junctions, drivers traversing from the minor road ma trigger kinematic waves that may or may not be laden with aggressive wave that can send shock through the line of travel. Drivers may misjudge gaps at the major road or simply irresponsible and reckless. Nonetheless, the installation of road hump at a selected arm contributed to bigger gaps and higher rarefaction waves at arm A; consequently, the paper concluded that:

- Road hump will induce traffic rarefaction wave of about 30km/h
- Priority junction will induce intermittent rarefaction waves of about 15 km/h along the major arms

- In spite of complexity associated with maneuvering at priority junction , there is no evidence in the paper to suggest that the intersection can be called upon to account for traffic shockwave on approach
- Typical critical gap at the major arms is about 2.5s
- Although road hump may aggravate traffic kinematic waves at the major road, the hypothesis that the waves will be strong enough to trigger shock along the major is not valid

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