

Original Research Article

Traffic Kinematic Wave Caused By Road Hump: Perceptions and Analysis

Aims: The paper is aimed at investigating the extent and type of kinematic waves caused by road hump.
Study design: Impact study.
Place and Duration of Study: The study was carried out at locations along Jalan universiti, Skudai, Johor Malaysia, between April 2012 and October 2012.
Methodology: Volume, speed, headway, gaps and types of vehicles collected continuously for eight weeks. Data were supplemented with design data supplied by ministry of works. Data were collated and compared.
Results: Kinematic waves may be compressive and/or expansive. Results show that road humps are effective speed reduction barriers irrespective of discomfort caused to vehicle occupants. Although speed reductions were recorded, traffic shockwaves were not recorded in all cases. There is no significant kinematic wave at road section with humps.
Conclusion: The paper concluded that road hump cannot be held solely accountable for traffic flow abruptness that will lead to shockwaves. Traffic flow abruptness is more likely to be caused by the led driver's approach not the barrier itself.

Keywords: *hump, road, kinematic rarefaction, shockwave*

1. INTRODUCTION

Road humps are constructed as traffic barriers aimed at reducing vehicle speed. Three parameters namely; hump heights, spacing and road hierarchy are important when considering road hump as a speed reduction device. They are largely the most effective speed reduction mechanism currently available and are likely to be in common use for some time. Drivers traversing road segments with humps are persuaded to slow down because of induced levels of discomfort to vehicle occupants travelling at overprescribed speed. Road hump that is of interest to the study was first introduced in 1970s by Transport Research Laboratory England. Initial research comprised of numerous designs; flat top, round top, heights (12mm – 150mm) and lengths (50mm to 3600mm), as to be expected many failed expectations and dashed hopes. Eventually initial design standards of circular profile hump (3.6m by 100mm height) were installed at trial sites in 1983 and evaluated. Results showed that road humps are effective traffic calming measures. However, the studies have focused mainly on speed reduction only. Whilst it is clear that 75mm road humps would reduce speed, their influence on traffic kinematic waves is yet to be fully studied. Also the components of traffic kinematic waves and their unique characteristics have often been ignored. Kinematic is the geometry of motion without cause consideration. Since force consideration is not needed, traffic kinematic wave can be construed as a function of density. In traffic analysis traffic, three parameters drive traffic operation, namely; flow, speed and density. Density drives speed and flow. As contained in man literatures, flow/density curve has two sections (constrained and unconstrained). The constraint is capacity. The two

sections behave differently. Speed oscillates in the unconstrained section whereas flow contracts in the constrained section. Since rarefaction wave is merely an expansive density loss, it would be restricted to the constrained section. Traffic shockwave is an abrupt and compressive limited motion that can only happen at the constrained section of the flow/density curve. Kinematic wave which is the overall motion will may cut across the two sections of the curve. Therefore it would be misleading to describe a wave across the two sections for flow/density curve as shockwave. The paper will address the components of traffic kinematic waves as well as determine the type and extent of kinematic wave that may be triggered by 75mm road hump.

2. TRAFFIC KINEMATIC CONCEPTS / DATA COLLECTION

A wave is the propagation in time (t) and space (x) of a disturbance in a medium. Kinematic wave is a family of parallel characteristics in the x - t plane. By investigating the presence of kinematic wave in the traffic stream, one is merely stating the obvious; that the outcome of the study could be rarefaction and/or shockwave. 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. 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, $[t_1, t_2]$

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

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

Therefore the integrand shown below as equation 1 is the Conservation Law [6]. It is the fundamental law governing the kinematic Wave Model.

$$\frac{\partial \rho}{\partial t} + \frac{\partial q}{\partial x} = 0 \quad (1)$$

If q and ρ is assumed to be $q = Q(\rho)$; Then $\rho_t + v(\rho)\rho_x = 0$, $v(\rho) = Q'(\rho)$
Plug discontinuities into the solution by a simple jump in q and ρ assuming q and ρ are continuous;
 $x_1 > x > x_2(t)$, $x_2(t) > x > x_2$ Then;

$$\begin{aligned} q(x_2, t) - q(x_1, t) &= \frac{d}{dt} \int_{x_2}^{x_2(t)} \rho(x, t) dx + \frac{d}{dt} \int_{x_2(t)}^{x_1} \rho(x, t) dx \\ &= \rho(x_s^-, t)s - \rho(x_s^+, t)s + \int_{x_2}^{x_2(t)} \rho_t(x, t) dx + \int_{x_2(t)}^{x_1} \rho_t(x, t) dx \end{aligned}$$

Where: $\rho(x_s^-, t), x \rightarrow \rho(x_s^+, t)$ are the values of $\rho(x, t), x \rightarrow x_2(t)$ (2)

2.1 Shockwave. It is a formation of an abrupt change in traffic stream with compressive characteristics that trigger temporary congestion. Lighthill and Whitham [4] 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

$$k(x, t) = k(q(x, t), x) \quad (3)$$

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

$$81 \quad \frac{\partial k(x, t)}{\partial t} + \frac{\partial k(x, t)}{\partial t} = 0 \quad (4)$$

82 This is an exaggerated assumption nonetheless;

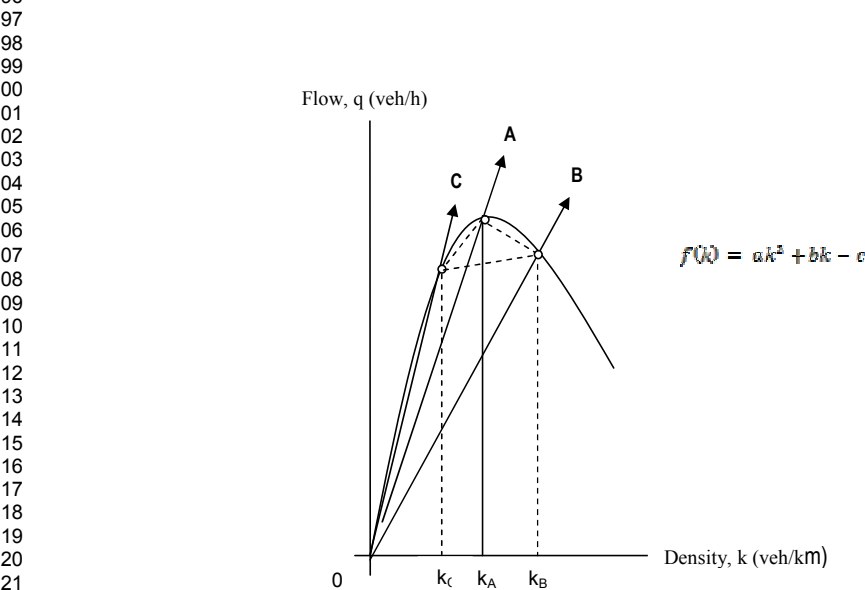
$$83 \quad S_w(q(x, t), x) \frac{\partial k(x, t)}{\partial t} + \frac{\partial k(x, t)}{\partial t} = 0 \quad (5)$$

$$85 \quad S_w(q, x) = \frac{\partial k(q, x)}{\partial q} \quad (6)$$

86
87 Should the lead driver brake abruptly due to changes in traffic, roadway, weather or ambient conditions the resultant
88 kinematic wave will operate along lines C, A and B as shown below in figure 1. However, traffic shockwave speeds will
89 operate between A and B; as shown in figure 1. So care should be taken when expressing traffic kinematic so as not to
90 misconstrue it as traffic shock wave propagation. They are clearly not the same thing. The area of traffic shockwave (s_w)
91 in figure 1 can be taken as:

$$92 \quad s_w = \int_{k_A}^{k_B} f(k) dk = ak^2 + bk - c \quad (7)$$

94
95 For $k_A < k \leq 0.85q$; Else $S_w = 0$



124 **Figure 1** Flow-density curve with kinematic wave ABC

126 **2.2 Rarefaction wave.** It is the effect that the kinematic profile with diverging characteristics has thinned out over time. In
127 essence rarefactions are post shockwave formations, keep in mind that shockwave is a post capacity kinematic wave.
128 Rarefaction can occur in circumstance where traffic change is spread across the stream simultaneously, for example at
129 the onset of rainfall or snow. Rarefaction expansion will be limited to pre-capacity section of the flow/density curve shown
130 below in figure 1. 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

$$R_w = \frac{Q_c - Q_A}{k_c - k_A} \quad \text{For } k_A \geq k \geq 0.85q; \text{ Else } R_w \rightarrow S_w \quad (8)$$

As contained in main literature, the flow/density curve is made up of two sections (pre and post capacity). Travel speeds oscillate between free-flow and capacity ($0 \leftrightarrow Q$) at the pre-capacity section, oscillation stops at capacity and it is followed by traffic contraction till jam is reached. Where 0.85 is assumed as the bench mark for traffic flow it can be postulated that rarefaction and shockwave will operate between ± 0.85 of the road capacity. Rarefaction wave may be mild before 0.85 whilst shock wave will be in congestion after 0.85 it can be argued. According to Ben-Edigbe [2, 3], the critical density (k_A) 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 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 study outcome. So, it may be postulated that road hump can cause traffic kinematic waves. The waves may be strong enough to send shock through the traffic stream else it may be rarefaction wave. If the assertion that, 'traffic shockwaves are post capacity products as suggested in the paper is to hold, then congested flow and density must be in temporary congestion. 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. Therefore care should be taken when expressing wave in traffic in order not to misrepresent one for another. Kinematic wave (k_w) can be computed as:

$$k_w = \frac{Q_c - Q_B}{k_c - k_B} \quad (9)$$

2.3 Data collection. Sites are divided into two sections A and B as shown below in figure 3. Section A is set 110m from the hump. Note that section A must be set at a distance greater than SSD so as to minimise the influence of road hump on drivers' reaction as they approach the barrier. The distance is computed from stopping sight distance (SSD) equation 10; assuming reaction time to be 2.5s and deceleration rate to be 3.4m/s^2 . Automatic traffic counters (ATC) were installed on the road sections as shown in figure 2. It recorded speed, volume, headway and vehicle type as they traversed the observation points. Roads wereare designed to Malaysian specifications[5].

$$SSD = 0.278vt + \frac{0.019v^2}{a} \quad (10)$$

Comment [u1]: Expand the section on data collection to include the type of data you collected! E.g. [1] Traffic stream peak data was collected for road section without hump (state reliability of data also.... was it just one data set or five data sets and then you got an average?) I can see only one data st represented as B. [2] Traffic stream peak data was collected for road section with hump(how many data sets?). I can see two data sets represented as 1 and 2. These information are very important for the readers and will provide connection to the results and discussion section !

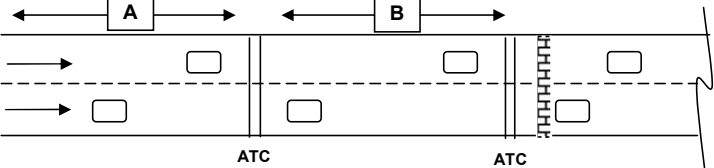


Figure 2 Typical layout of impact study site

3. RESULTS AND DISCUSSION

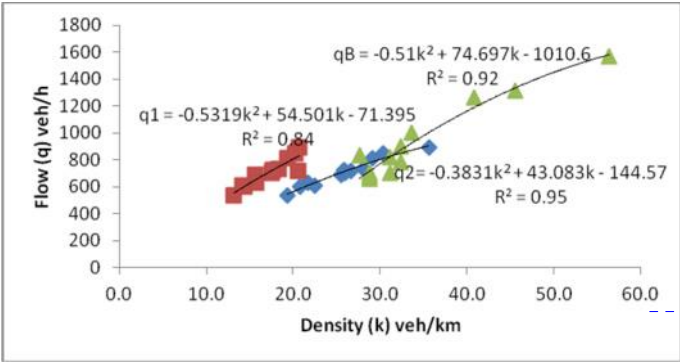
Traffic stream peak data for road section without hump were analyzed in order to estimate the base traffic flow and density performance criteria of the road section under observation. The method used for estimating empirical maximum flow relied on flow, speed and density relationship [1], Where flow is related to density, it is assumed that speed is the resultant slope. The paper used off peak traffic data for comparative assessment of kinematic waves so as to remove the effect of peak travel from the estimated outcomes. As shown below in figure 3 and illustrated in figure 4, the base traffic flow data (q_B) was computed as:

q_B = -0.51k²+74.6971k-1010.6 (11)

∂q_B/∂k = -1.02k + 74.697 = 0; hence k = 73

Plug k into the model equation11,

Capacity Q_B = 1725pcu/h.



Comment [u2]: Insert legend in the plot, stating what red square ; green triangle and blue diamond stand for !

Fig. 3. Typical flow/density model coefficients

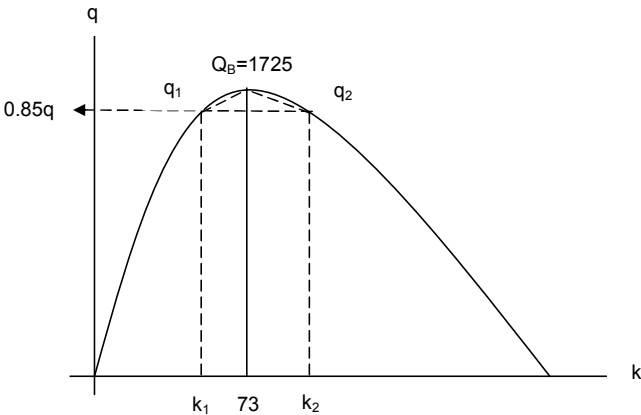


Fig. 4. Estimated Base Parameters

Table 1. Model Coefficients and coefficients of determination

Case	q_1	R^2	q_2	R^2
1	$-0.5319k^2+54.501k-71.395$	0.84	$-0.3831k^2+43.083-144.57$	0.95
2	$-0.4226k^2+35.042k-22.851$	0.91	$-0.5905k^2+48.545k-22.698$	0.96
3	$-0.6519k^2+54.071k-41.607$	0.75	$-0.3692k^2+41.752k-120.67$	0.93
4	$-0.7137k^2+48.86k-169.255$	0.96	$-0.4232k^2+46.944k-6.9547$	0.97

The model equations have the correct signs, and for each case study model coefficients shown above in table 1 were statistically tested for reliability. Coefficients of determination R^2 shown that equations are acceptable for prediction, t-test (>3) results show that the independent parameters are useful and the F-Statistics > 5, show that the model equations did not happen by chance. Typical results from the model coefficients are shown below in table 2. Note that the base criteria for traffic flow is 1725pcu/h with corresponding critical density of 73veh/km meaning that the critical density of 73veh/km must be exceeded for traffic shockwave to occur on the road sections. It has been mentioned earlier that traffic shockwave can be construed as temporary congestion, further that in the flow/density curve and indeed its subordinate speed/flow curve, speed oscillate at the unconstrained section often called free flow of the curve. Whereas traffic flow contraction and expansion occur at the constrained section of the curves and it is this behavioural change that will trigger shock in the traffic stream. In all cases shown below in table 2, there is no evidence of traffic kinematic, rarefaction or shock waves whatsoever. That can be attributed to two factors namely; sufficient forward visibility and pre-hump warning signs.

Table 2. Traffic kinematic, shock and rarefaction waves

Case	q_1	Q_B	q_2	k_1	k_B	k_2	K_w	S_w	R_w
1	1325	1725	1063	51	73	57	0	0	0
2	1267	1725	976	42	73	42	0	0	0
3	1069	1725	1074	45	73	58	0	0	0
4	672	1725	1298	35	73	56	0	0	0

Note - $K_w = q_2 - q_1 / k_2 - k_1$; $S_w = q_2 - Q_B / k_2 - k_B$; $R_w = Q_B - q_1 / k_B - k_1$;
 Provided $k_2 > k_B$, Else $K_w = S_w = R_w = 0$;

4. CONCLUSION

Based on hypothesis that 75mm road hump cannot be called solely to account for traffic kinematic wave; traffic flows and densities for road sections with and without hump were computed and compared. The synthesis of evidence from the study show that road hump did not trigger kinematic in all four case studies; consequently the paper concludes that the hypothesis that road hump will trigger traffic shockwave is null and void; it is more likely to be driver's error, poor judgement or sheer recklessness.

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COMPETING INTERESTS

Author has declared that no competing interests exist

REFERENCES

1. Alhassan, H.M. and Ben-Edigbe, J. Effect of Rainfall Intensity Variability on Highway Capacity, European Journal of Scientific Research, 2011: 49(1):117-126
2. Ben-Edigbe, J. Assessment of Speed-Flow-Density Functions under Adverse Pavement Condition' International Journal of Sustainable Development Planning 2010:5(3):238-252

282 3. Ben-Edigbe, J. and Ferguson, N. Extent of Capacity Loss Resulting from Pavement Distress' Proceedings of the
283 Institution of Civil Engineers 2005:158;27–32.
284 4. Lighthill M.J and Whitham G, B On kinematic waves, I: Flood movement in long rivers. II: A theory of traffic flow on
285 long crowded roads, proceedings royal Society, 1955: A229, 281-345
286 5. IDRA Road layout Design Blueprint for Iskandar Malaysia” Iskandar Development Regional Authority (IDRA), Johor
287 Bahru, Malaysia ISBN 9 78-967-5626 2011:23(4)15
288 6. Newell, G.F. A simplified theory of kinematic waves in highway traffic, part I: General theory Transportation Research
289 Part B: Methodological 1993: 27(4); 281–287
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