Extent of Highway Capacity Loss Resulting from Road Humps

J. Ben-Edigbe and N. Mashros

***Abstract*—Road humps are traffic calming devices placed across road widths solely as speed reduction mechanism. They include, speed cushions, junction tables, road humps. Whilst it is clear that 75mm deflection like road humps would reduce speed to 20km/h on average, determining their impact on traffic flow rate has often been poorly reported. Based on the hypothesis that on any route with humps mean stream flow will lie within highway capacity loss envelope; moving car observer survey method was used to determine mean stream flows as well as a volumes and speeds of 'with and without' road humps sections. The studies were carried out under day light and dry weather conditions so as to eliminate their effects. An important part of the study is employment of dynamic passenger car equivalent values for the road sections. Results show significant highway capacity loss and the mean traffic flows lying within capacity loss envelope. The study concluded that although road humps are effective mechanism for vehicle speed reduction, their resultant highway capacity loss is significant.**

***Index Terms*—Vertical deflection, road hump, flow, highway capacity, speed**

I. Introduction

Road humps are traffic calming (road safety) devices aimed are reducing vehicle speeds. Although they are effective deterrent to speeding motorists, nonetheless they give discomfort to drivers and their passengers because of the need to climb and descend at every installation. Since every road accident prevented is taken as savings, the traveling motorists have accepted albeit reluctantly the discomfort that comes with vertical deflection as a trade off for road safety. Speed cushions take the form of small plateau with gaps between them, making it easier for wider vehicles especially emergency services, trucks and buses to straddle and pass along a route with minimum discomfort.

Junction table on the other hand take the form of raised plateau across the entire intersection. They are designed to make it easier and safer for pedestrians to cross the road on the top of the table where speed is lowest.

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 [6]. However, the studies have focused mainly on speed reduction in isolation of fundamental parameters. Traffic flow, speed and density on any roadways are related; therefore any one parameter cannot be treated in isolation. Although the result of the studies is conclusive; the analytical approach is questionable.

Highway capacity is a central concept in roadway design and traffic control. Headway distribution, bimodal distribution, selected maxima and the direct probability methods are often used to estimate highway capacity. The choice of a particular method depends largely on the data collected and purpose of estimation. According to Highway Capacity Manual (HCM) the capacity of a facility is defined as the maximum hourly flow rate at which vehicles can reasonably be expected to traverse a point or section of a roadway under prevailing traffic, roadway and ambient conditions. Any alteration made to the roadway for example installing a road hump would result in highway capacity loss.

Since the highway capacity is an essential ingredient in the planning, design and operation of roadways, it is desirable for traffic analysts to predict fairly accurately the impact of road humps on highway capacity loss. Road humps are used mainly to reduce and control vehicle speeds. Though they are successful in achieving reductions in speed, their usage would trigger highway capacity loss, the extent of which the study is keen to establish. Although not a focus of the study, road humps have been linked to accidents and complaints received by local authorities concerning damage to vehicles and discomfort to motorists.

In any case, the study objectives are to; determine whether highway capacity loss will result from road humps and if so, the extent; establish mean stream flows on route with road humps and also whether such flows lie within the capacity loss envelope.

In or to achieve these objectives, 75mm road hump installed to TRL 2/96 [4, 5] specifications (see Table I) on a total stretch of 1.2km road was surveyed in Skudai town Malaysia. Skudai is a town is a suburb of the sprawling metropolitan area of Johor Bahru, Malaysia. It is located 16 km from Johor Bahru city centre and very close to Senai International Airport and the Port of Tanjung Pelepas, Malaysia. As often the case with new growth corridors, socio-economic developments also have downside effects, Skudai is no exception.

II. Road Humps

In many literatures, pavement distress is taken as potholes, edge subsidence, excessive cracking and un-even road surfaces, often road humps, speed cushions and junction tables are often not considered as pavement distress but vertical deflection. On the contrary, they are all pavement distress.

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Three parameters, road hump heights, spacing and road hierarchy are important when considering road hump as a road safety control device. Appropriate road hump heights and spacing needed to achieve mean 'after speeds are show below in Table I:

TABLE I: APPROPRIATE ROAD HUMP HEIGHTS

Road Hump Type	Mean 'Between Hump' Speed' 48km/h	Mean 'Between Hump Speed' 32km/h
Round Top		
Flat Top	50mm– 75mm	75mm
Raised	50mm 75mm	75mm
Junction	50mm100mm	75mm–100mm
Speed	60mm 75mm	N/A
cushion	35mm 45mm	N/A
Thump		

Culled from TRL Traffic Advisory Note leaflet 2/96[5]

Road humps are constructed as traffic barriers aimed at reducing vehicle speed. Unfortunately, they are often viewed negatively by local residents of affected routes, areas or spots and emergency services. Transport Research laboratory (TRL) and Department for Transport (D*f*T) have investigated the possibility that road humps cause increased wear and tear to vehicle components and injury to vehicle occupants. Concern has also been raised about whether the use of road humps might cause or exacerbate back or other injuries.

Notwithstanding, road humps are largely the most effective traffic calming device currently available and are likely to be in common use for some time although speed cushions are widely accepted as replacement. Because of induced levels of discomfort to vehicle occupants travelling at overprescribed speed, drivers are persuaded to slow down. The concerns of this study are two folds; to present the extent of highway capacity loss resulting from road humps and determine whether traffic stream flow on road stretch with humps would lie within highway capacity loss envelope. Highway capacity loss envelope has a polygon that is shaped like a trapezium, hence the terminology 'trapezoidal flow contraction-TFC' which is a function of highway capacity loss [2, 3].

III. EMPIRICAL CAPACITY ESTIMATION

Although the definition of highway capacity can be easily understood in theory, misinterpreting the derived value can easily occur because there are different approaches to expressing the capacity of a roadway. The paper is concerned with operational capacity based on direct-empirical method using observed volumes and speeds to derive densities.

In the fundamental relationship between speed (u), flow (q) and density (k);

$$q = uk \implies u = \frac{q}{k} \text{ and } k = \frac{q}{u} \quad (1)$$

A. Flow / Density Curve

In the flow / density relationships, density was used as the control parameter and flow the objective function. The capacity theory underlying the model dictates that concavity in the flow – density curve must be present for validity [7, 9]. Therefore the coefficients signs in equation 2, must be appropriate in order not to violate the concavity requirement of the flow-density curve. If it is assumed that the straight line that represents the flow-density relationship ($k < k_c$) is tangent to the quadratic curve at $k = k_c$ it can be argued that c must also return a negative or zero sign. Hence the 2^0 polynomial equations can now be re-written as:

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

In theory, where the flow / density relationship has been used to compute roadway capacity, the critical density is reached at the apex points as shown in Fig. 1 below. At point Q_1 the traffic is free flowing and at Q2 traffic stream is in congestion, and one could expect that to happen on road sections or points with road humps, peak hour traffic and other forms of adverse conditions.

The draw back with this method lies with determining the critical density; it can be derived, estimated or assumed as appropriate, but how, it may be queried. It is quite possible to extrapolate mathematically till the maximum of the q-k function is reached but would such theoretical values so computed compare with the actuality of traffic operation. It may even be the case that such calculated capacities are unrealistically high and questionable. It can even be argued that capacities derived in such a way may have very little resemblance to traffic actuality. Since our interest is in estimating the capacity change due to road humps, the choice of precise value of critical density need not be very critical to the outcome of this study. By maximising flow, critical density can be reasonably estimated.

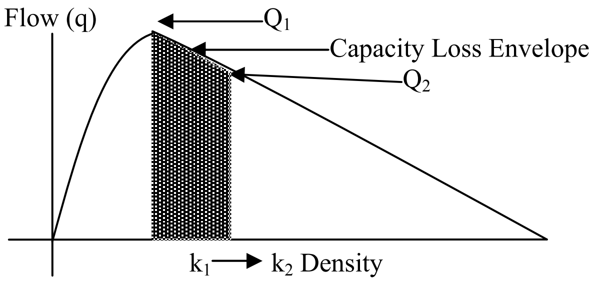

Fig. 1. Hypothetical flow/density

Traffic flow can be categorized into uncongested and congested state. Uncongested traffic state is usually found when the traffic demand is less than the roadway capacity and vehicle speeds are within optimum and free flow speed limits. Congested states are often triggered by adverse conditions and are characterized by forced flow operating at or greater than roadway capacity. When capacity is over sub-subscribed, additional vehicles in the traffic stream will trigger perturbation, vehicle speeds become unpredictable, oscillation movement between free flow and optimum speeds terminates, quality of service is significantly reduced, vehicles are herd and synchronized, flow contractions set in [3]. The roadway is now in congestion mode. In any case, should highway prevailing road conditions improve, traffic disturbances are removed, and optimum speed reached then the curve reverts back to the free flow optimum speed and starts to oscillate again.

B. Speed / Density Linearity

The speed-density relationship serves as the basis to understand system dynamics in various disciplines. If speed and density equation 3 is plugged into 1; the resultant second degree polynomial equation 4 can then be used to estimate roadway capacity.

$$u = a - bk \tag{3}$$

Speed - density curve has negative linear function. Consider equations 1 and 2 discussed earlier. By plugging equation 3 into 1, flow equation can also be written as:

$$q = ak - bk^2 \tag{4}$$

Let equation 2 = equation 4, hence,

$$\mathrm{ak} - \mathrm{bk}^2 = -\mathrm{c} + \mathrm{ak} - \mathrm{bk}^2 \tag{5}$$

Therefore, constant, c = 0

The maximum value for flow is attainable when density is at zero, and of course when maximum density is reached, flow is at zero or jam. Note that;

$$b = \frac{a}{k_j} \implies U = a - \frac{a}{k_j}k : q = ak - \frac{a}{k_j}k^2$$

$$\frac{\partial q}{\partial k} = a - 2\left(\frac{a}{k_j}\right)k$$

$$\implies critical\ density, k_c \qquad k_c = \frac{a}{2\left(\frac{a}{k_j}\right)}$$

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

$$capacity, Q = ak - \frac{a}{k_j}\left(\frac{a}{2\left(\frac{a}{k_j}\right)}\right)^2 \tag{6}$$

Thus, roadway capacity was estimated using equation 6. By computing roadway capacity for each link section, it is recognised that capacity varies per road section as contained in many literatures.

IV. Setup of Impact Study

The purpose of the study is to determine the extent of highway capacity loss resulting from road humps. Study sites were divided into three sections with Section **A** as the upstream end and Section **C** the downstream end, while Section **B** was the transition part allowing for possible congestion flow upstream of the distressed section. Section B was set at 130m from the baseline of section A. Section C has road humps, section B is the transition while section A is free from the influence of road hump.

Volume and speed data were collected for road section with and without road humps. Automatic traffic count was used to capture 24hr traffic at sections A, B and C for 4 weeks. It is assumed that the roadway has 5% gradient (G), 2.5seconds reaction time (t), 0.3coefficient of friction (f), and stopping distance (SSD);

$$SSD = 0.278v_t + 0.039\frac{v^2}{a} \tag{7}$$

where: SSD = stopping sight distance ≈130m;

V = design speed, (km/h),

t = brake reaction time, 2.5 s;

a = driver deceleration, (m/s^2)

V. Results and Analysis

Pre-determined passenger car equivalency values are usually applied to traffic volumes when converting from vehicles per hour. The study will use a simplistic approach based on vehicle headways from our survey database. The effects of road humps on passenger car equivalent values are taken into account when determining flow at road sections.

Three classes of vehicles (passenger cars, large goods vehicle, and heavy goods vehicle) were investigated. Although not the central focus of the paper; a simplistic passenger car equivalent (PCEs) calculation method based on headway was explored [8]. In any case PCEs may be estimated as:

$$PCE_{ij} = H_{ij} / H_{pcj}$$

Note that: Headway = Spacing / Speed

Where: PCE_{ij} is the PCE of vehicle Type i under Conditions j, and H_{ij}, H_{pcj} is the average headway for vehicle Type i and passenger car for Conditions j.

The stepwise procedure used for estimating road capacities and trapezoidal flow contractions in the studies can be stated as follows:

Step 1 Estimate traffic flows using appropriate PCE

Step 2 Estimate vehicle speeds and variances

Step 3 Derive densities from speed/flow relationship

Step 4 Determine variances and standard errors

Step 5 Derive flow/density equations from speed density linear equation and skip step 4, or

Step 6 Use flow/density relationships to determine flow/density model coefficients

Step 7 Test model equations for validity

Step 8 Estimate critical densities

Step 9 Determine highway capacities

Summary of findings are shown in Tables II and III. However sample calculation of highway capacity loss is illustrated below where the computed percentage of highway capacity loss, is;

(1037-808) / 1037 = 22.1%

Without Road Hump

$H_A = -11.99k^2 + 339.07k - 1359.7$

$R^2 = 0.58$

$\partial q / \partial \kappa = 2(-11.99k) + 339.07 = 0$

$k_c \cong 14$ veh/km, Plug k into H_A

$H_A = -11.99(14)^2 + 339.07(14) - 1359.7$

$H_A = 1037$veh/hr

With Road Hump

$H_A = -0.657k^2 + 46.03k - 2.11$

$R^2 = 0.64$

$\partial q / \partial \kappa = 2(-1.314k) + 46.03 = 0$

$k_c \cong 34$ veh/km, Plug k into H_A

$H_A = -0.657(34)^2 + 46.03(34) - 2.11$

$H_A = 808$veh/hr,

The methods used for estimation of the model coefficients are ordinary and constrained least square regressions. For each case capacity was estimated for a fixed critical density. The data in Table III suggest that if critical densities increases because of pavement distress capacity loss will occur. In all cases, capacities at road sections with pavement distress were substantially higher than those at section without for all investigated locations.

Maximum flows were also higher at road sections without pavement distress for all investigated sites. As shown in Tables II and III, at road sections with road humps, maximum speed is somewhat less than the optimum speed at road sections without road humps.

Allowing for 10% deviation, mean traffic stream flow estimated by moving observer method at 835 veh/hr is within trapezoidal flow contraction envelope (1037, 808) and mean vehicle speed of 45km/hr is within 74km/hr and 24km/hr.

More importantly, it can be concluded that on roadways with humps, mean traffic flow would be outside the free flow roadway capacity. It can be averred that, road humps would lead to highway capacity loss. The methods used for estimation of model coefficients are ordinary and constrained least square regressions.

In order to find the significance of the capacity differences, t-values and F statistics were computed. Tabulated results show that the model equations did not happen by chance and are acceptable for predictions. In any case, the remainder of the study findings is summarized below in Tables II and III below.

Table III shows the results, from which it can be seen that capacities and optimum speeds at road sections with humps are significantly lower than those of road sections without humps. Further densities at road sections with humps are significantly higher than the sections without humps, and also that trapezoidal flow contraction is a function of highway capacity loss.

The results that road humps lead to capacity loss and speed reductions are indicative of Transport Research Laboratory, England (TRL) correct qualitative and qualitative assessments that impact of road hump installation on traffic safety is a much more important consideration for implementation. Introduction of road hump thus decreases roadway capacity.

TABLE II: ESTIMATED MODEL COEFFICIENTS

Site No. RH		Estimated Coefficients +β1k	-β2k2	R2	t-value	F
1	w	46.03	0.447	0.52	3.3	11
	wt	100.68	1.40	0.53	3.4	11
2	w	48.01	0.685	0.57	3.2	11
	wt	105.8	2.514	0.70	4.9	24
3	w	52.57	0.805	0.73	5.3	28
	wt	130.99	4.247	0.78	5.9	35
4	w	60.22	0.943	0.72	5.1	26
	wt	108.72	2.936	0.58	3.7	14
5	w	45.89	0.583	0.52	3.2	10.
	wt	95.32	2.243	0.51	3.3	11.
6	w	44.98	0.680	0.61	3.3	29
	wt	101.72	2.474	0.53	4.0	16.
7	w	59.83	0.930	0.51	3.2	10
	wt	112.80	2.315	0.54	3.4	11

Note: w-with; wt-without; RH-Road Hump

TABLE III: ESTIMATED HIGHWAY PARAMETERS

Site No. Road Hump		Parameters Capacity pcu/hr	Critical density	capacity loss %
1	with	1185	52	34.5
	without	1810	36	0
2	with	841	35	24.5
	without	1114	21	0
3	with	858	33	15.0
	without	1010	15	0
4	with	961	32	4.5
	without	1007	19	0
5	with	903	39	10.8
	without	1013	21	0
6	with	744	33	28.9
	without	1046	21	0
7	with	962	32	30.0
	without	1373	24	0

This study is a first attempt to look into the extent of capacity loss resulting road humps or vertical deflection and it is organised in a way, which offers results based on a synthesis of aggregate roadway capacity and road hump data. Its significant is in its attempt to show that by mapping out specific areas where action is needed roadway capacity loss can be avoided.

VI. CONCLUSIONS

This study is based on the hypothesis that significant highway capacity loss would result from road humps. The aim behind this exercise is to establish the extent of roadway capacity loss. For the purpose of estimating road capacity the relationship between flow and density in a situation of free flow was relied on.

Two sets of Passenger Car Equivalent (PCE) values (the standard values and the modified values) were used. Within the purview of the study objectives, we set out two road sections: one with road humps and the other without (control section). Both sections were surveyed and the empirical results investigated.

In the light of evidences obtained from the examination of survey data. The analytical findings for both road sections were compared. Based on the synthesis of evidences obtained from the relationship between roadway capacity and road hump, and also bearing in mind that the study did not take into consideration the impacts of road lighting, darkness and rainfall, it is correct to conclude that:

- Empirical road densities are finite and cannot be exceeded; therefore flows and densities relationship can be relied on in the study to estimate roadway capacity.
- There is a significance change in vehicle speed between the 'with' and without road hump sections. There are no other factors other than road humps that affected speed reductions between both road sections.
- Highway capacity loss was attributed to road humps spaced at 60m interval.
- The estimated capacity loss is substantial, the reason being that capacity was estimated rather than measured directly.
- Notwithstanding, the hypothesis that highway capacity loss would result from road humps remains valid.

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