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Roundabout Optimal Entry and Circulating Flow Induced by Road Hump

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***Abstract*—**Roundabout work on the principle of circulation and entry flows, where the maximum entry flow rates depend largely on circulating flow bearing in mind that entry flows must give away to circulating flows. Where an existing roundabout has a road hump installed at the entry arm, it can be hypothesized that the kinematics of vehicles may prevent the entry arm from achieving optimum performance. Road humps are traffic calming devices placed across road width solely as speed reduction mechanism. They are the preferred traffic calming option in Malaysia and often used on single and dual carriageway local routes. The speed limit on local routes is 30mph (50 km/hr). Road humps in their various forms achieved the biggest mean speed reduction (based on a mean speed before traffic calming of 30mph) of up to 10mph or 16 km/hr according to the UK Department of Transport. The underlying aim of reduced speed should be to achieve a 'safe' distribution of speeds which reflects the function of the road and the impacts on the local community. Constraining safe distribution of speeds may lead to poor drivers timing and delayed reflex reaction that can probably cause accident. Previous studies on road hump impact have focused mainly on speed reduction, traffic volume, noise and vibrations, discomfort and delay from the use of road humps. The paper is aimed at optimal entry and circulating flow induced by road humps. Results show that roundabout entry and circulating flow perform better in circumstances where there is no road hump at entrance.

***Keywords*—**Road hump, Roundabout, Speed Reduction

I. INTRODUCTION

As an establishing intersection control type, roundabout becomes more popular through the world in the recent decades [1]. In the first design of traffic circle the central island was typically larger which emphasize higher speeds and give right of way to entry flow [2]. Therefore, traffic calming devices installed at the entry roundabout to increase safety and reduce speed. The offside priority guideline at modern roundabout was developed to reduce number of conflicting points and also operating speed which identified the entering vehicle flows should grant right of way to the circulating flows and also based on the appropriate gap to merge circulation length. Therefore, Modern roundabout involves lower risk than others types of intersection control and traffic signal for both pedestrian and vehicles [3].

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According to highway capacity manual (2000), the location of crossing walk for pedestrian should be at least retreat from the length of one private car. In addition the special geometric parameters such as splitter island and restriction circular roadway diameter decline the speed of vehicles at roundabout [4]. Speed hump is one of the practical devices to reduce speed and traffic calming which widespread all over the world. There are various road humps with a variety of geometry features design aid to reduce speed such as circular hump [5]. According to the UK department of transport (1999), the length of circular hump should be 3-7 meters with maximum 0.1 meter high over the width of the road to encourage vehicles to traverse vehicles up to 16 km/hr and based on the USA institute of transportation engineering pass safely through the road hump at 25 to 30 km/hr [5], [6].

The performance of speed humps at particular site should be examined that's because there are some conflicting views and also negative debates on the effect of road hump at specific location which results pain, disabilities and injury for drivers and vehicles, waste of fuels, increasing traffic noise, engine suspension and deterioration of tires and more anxiety at upper speed [7]-[11].In Malaysia like other developed countries, modern roundabouts have been used for several years and according to the Jabatan Kerja Raya (JKR) (1987), roundabout can hold higher traffic volume on the two-way [12]. In addition, on this guideline there is a lack of using traffic attribute and volume on each arm and only based on the weaving section.Part of this research investigates optimal relationship between maximum entry and circulating flow induced by road humps and also the function of speed hump in decreasing vehicle speeds on the main roundabout of Universiti Teknologi Malaysia (UTM), Skudai, Malaysia. The reminder of this study consists of four sections. Section 1 is based on the introduction and previous studies of parameters while section 2 is on the characteristics of study area and data collection. Section 3 focuses on results and analysis whereas section 4 is on the conclusion.

A. Passenger Car Unit (PCU)

Firstly Passenger Car Unit (PCU) presented in HCM-1965 to explain the effect of heavy vehicles on traffic stream [13]. The definition of PCU in most recent version of majority guidelines is the effects of mixed vehicles forms on traffic flow by transforming different vehicle types into an equal traffic stream which composed of passenger cars.

In Malaysia, Arahan Teknik Jabatan (ATJ) (13/86) guideline is used to convert all vehicle types into passenger cars [14].

The conversion of each vehicle for different area is as follow:

TABLE I
CONVERSION FACTORS TO PASSENGER CAR UNIT

Type of Vehicle	EQUIVALENT VALUE IN P.C.E			
	Rural Standards	Urban Standards	Roundabout Design	Traffic Signal Design
Passenger Cars	1.00	1.00	1.00	1.00
Motorcycle	1.00	0.75	0.75	0.33
Light Vans	2.00	2.00	2.00	2.00
Medium Lorries	2.50	2.50	2.80	1.75
Heavy Lorries	3.00	3.00	2.80	2.25
Buses	3.00	3.00	2.80	2.25

B. Entry-Circulating Flow Relationship

The entry capacity of a roundabout considers the changeability of vehicles dealing at entry arm and is based on the maximum number of vehicles can enter into the circular length from an entry approach. Kimber (1980) developed the linear regression between entry and circulating flow based on the geometric parameters such as number of legs, roundabout diameter (D), entry radius (r), flare length (l'), entry width (e), approach width (v) and entry angle (M) [15]. In 1989, he announced that empirical method has better performance than gap acceptance method to estimate capacity of roundabout and identified gap acceptance has a good performance only for single-lane entry that's because when additional entry lane added to roundabout, analytical method cannot increase capacity accurately [16]. Figure 1 shows the geometric parameters of roundabout. The following formulas recognize the empirical relationship between entry and circulating flows.

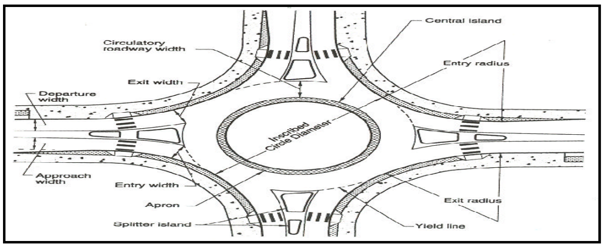

Fig. 1 Geometric elements of a typical urban roundabout
Source: (an informational guide, 2000)

$$Qe = k\,(F - FcQc) \quad (1)$$

C. Speed

Speed is one of the most significant variables that affects on the real-time traffic control, safety and finances of the motorway [17]. Time mean speed is the average instantaneous speed at a known point. Spot speed is closely associated link with speed and highway alignment, and also determines the effectiveness of speed limits [18]. Speed percentile which is based on the cumulative speed frequencies used to consider the effects of speed, minimum and maximum speed on the motorway where 15th, 50th and 85th percentile speed recognized minimum speed, mean of vehicles speed and speed limit of vehicles on motorway.

Based on the normal distribution of speed, Standard Deviation is a statistical assesses of distribution of speed about the mean and is outcome by square root of variance.

The formula is used to determine the standard deviation; S= Standard deviation of the distribution, $\sum fi(Vi - V)^2$= Square of the sum of the mean frequency

$$S = \sqrt{\frac{\sum fi(Vi-V)^2}{\sum fi-1}} \quad (2)$$

Where:

II. STUDY APPROACH

Data for this study was collected on a standard roundabout at Universiti Teknologi Malaysia, Skudai, Malaysia. The site is located in between the UTM guard post and UTM main gate. This roundabout was selected as the study site because it is one of the standard roundabout that have the combination of 2 entry arm with road hump and 2 entry arm without road hump which are become an ideal location for this study. The geometric design of the roundabout was measured by using trumeter as well as measuring tape

In the term of traffic data, four automatics traffic counters (ATC) installed at each side of study location, two pneumatic tubes were laid in parallel 1 meter apart and linked to ATC. Figure 2 shows the installation layout of the ATC machines. Therefore, 2 ATC machines were set up at arm A where the first one put at least 50m away from the road hump to eliminate the effect cause by this clamming facility so that free flow speed can be obtained. The second ATC machine was installed just before the road hump to determine the vehicle speed that passed through the road hump. Meanwhile, another 2 ATC machines were placed at arm D where the first ATC machine was installed at least 50m away from the yield line to get the free flow speed of the vehicles. In addition, second ATC machine was used to determine the vehicle speed when entering the roundabout. Then the traffic manual counting can be established on the working day. This includes the recording of entry and circulating flow as well as the vehicles type. The traffic volume was taken at 15 minutes intervals for 1 hour and 30 minutes that the former15 minutes and later 15 minutes is assigned the before and after peak hour respectively. The exact location and geometry parameters of speed hump are shown in figure 3.

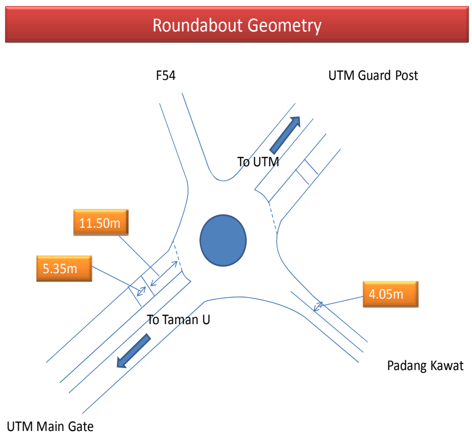

Fig. 2 Speed hump geometry

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TABLE II
GEOMETRIC DATA FROM UTM ROUNDABOUT

Arm	Approach half-width, v (m)	Entry width, e (m)	Effective flare length, ℓ (m)	Entry radius, r (m)	Inscribed circle diameter, D (m)	Entry angle, Ø (°)
A	3.10	5.20	10.00	12.00	33.00	40.00
B	6.20	7.90	20.00	20.00	33.00	50.00
C	3.20	5.00	10.00	12.00	33.00	40.00
D	6.10	7.20	20.00	20.00	33.00	50.00

TABLE III
ENTRY FLOW AND CIRCULATING FLOW DURING PEAK HOUR

Arm	Entry Flow (Qe) (pcu/hr)	Circulating Flow (Qc) (pcu/hr)
A	2126	2954
B	1227	2284
C	1985	2869
D	1231	2287

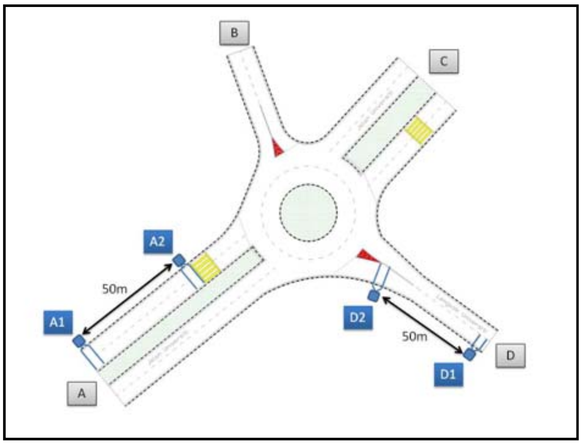

Fig. 3 Location of ATC machines

A. Geometric and traffic data

Based on the study approach, number of vehicles passing at each entry arm and circulating width is important. Therefore, geometric parameters, traffic flows and also the circulating flows of study area were identified in the following tables.

III. STATISTICAL ANALYSIS

The statistical analysis was used to identify the relationship between entry and circulating flows which developed the relations of vehicle-vehicle interaction that occur at the entry. Linear regression which was built up by the Kimber was used to identify the performance of vehicle on the entry and circulating flows in arm A with speed hump and arm D without speed hump at peak hour. Therefore the relationships between them were derived as follows:

$$QeA = -0.719QcA + 2126 \quad (3)$$

$$QeD = -0.538QcD + 1231 \quad (4)$$

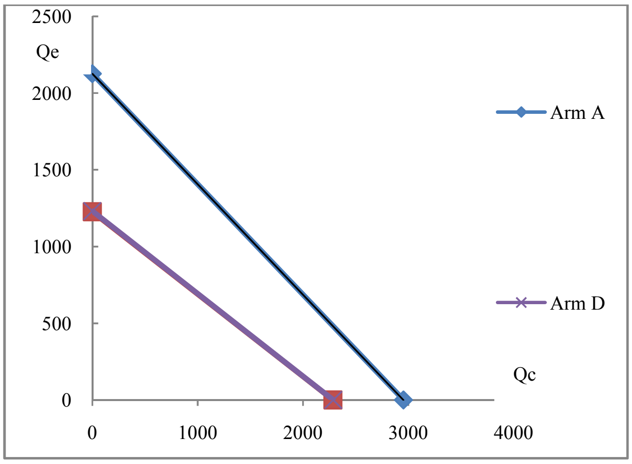

Fig. 4 Entry capacity versus circulating flow

Due to the scatter plot, the entry capacity of arm A (with speed hump) achieved from the regression equation was compared to the entry capacity of arm D (without speed hump). The slop rate of arm A and arm D are 0.8 and 0.4 respectively. Therefore, there is a steep decline in the arm A. That means from every 2 vehicles that entry the circulating length in arm D, only one vehicle is able to entrance in arm A. This is resulted in long queue at entry flow of arm A and caused delay for drivers, increasing the probability of accident and also waste of fuel of vehicles. Thus, roundabout entry and circulating flow perform better where there is no road hump at entrance.

A. Speed

Based on the MetroCount software, the percentiles of speed were derived for two arms with and without speed humps. Tables 4 and 5 recognize speed statistics for both arms A and D.

TABLE IV
ARM D SPEED STATISTICS

SPEED CLASS (KM/HR)	CLASS MID VALUE, VI	CLASS FREQUENCY (NUMBER OF OBSERVATION IN CLASS), FI	PERCENTAGE OF OBSERVATION IN CLASS	CUMULATIVE PERCENTAGE OF ALL OBSERVATION
				N
10_20	15	168	0.22	0.22
20_30	25	2157	2.89	3.11
30_40	35	25022	33.49	36.6
40_50	45	42812	57.29	93.89
50_60	55	4486	6.00	99.89
60_70	65	80	0.11	100
	∑ TOTAL	74725	100	

Based on the software, posted speed limit is 60 km/h while maximum speed is 67 km/hr and minimum speed is 10.3 km/h. The mean speed is 41.6 km/h whereas 85% Speed is 46.8 km/h. Variance and Standard deviation are 34 and 5.8 kilometer per hour respectively. Therefore, majority speed of this arm is as follow:

$$U\ (km/hr) = 46.8 \pm 5.8 \quad (5)$$

TABLE V
ARM A SPEED STATISTICS

Speed Class (km/hr)	Class Mid Value, vi	Class Frequency (Number of Observation in Class), fi	Percentage of Observation in class	Cumulative Percentage of All Observation
10_20	15	10029	7.92	7.92
20_30	25	73624	58.11	66.03
30_40	35	41108	32.45	98.47
40_50	45	1873	1.48	99.95
50_60	55	66	0.05	100.00
60_70	65	0	0.00	100
	$\sum$ TOTAL	126700	100	

In the same condition, the most significant parameters for entry roundabout with speed hump were shown in table VI.

TABLE VI
SPEED PARAMETERS FOR ARM A WITH SPEED HUMP

Posted Limit (km/hr)	Max. Speed (km/hr)	Min. Speed (km/hr)	Mean Speed (km/hr)	85% Percentile Speed (km/hr)	Variance (km/hr)	Standard Deviation
60	61.8	10	27.8	33.1	30.9	5.56

Thus, majority speed of this arm is 33.1± 5.56 (km/hr).

Based on the data in table IV, entry width and deflection at roundabout caused majority of vehicles couldn't traverse roundabout at speed more than 50 km/hr. As mentioned before, cumulative speed frequency of arm A and D are 126700 and 74725 vehicles respectively. Therefore, number of vehicles in arm A is 1.6 times more than that in arm D. Thus, existing of speed hump on arm A resulted in highly speed reduction as recognize in the above table. Thus, majority of vehicles should pass roundabout at speed less or 33 k/hr. Therefore, it resulted in decreasing safety level and increasing rate of accident especially for poor drivers that haven't appropriate reaction time. Deteriorating of tires and increasing anxiety are other causes of extra delay. As above discussion, speed function at roundabout perform better in circumstances where there is no road hump at entrance.

IV. CONCLUSION

Modern roundabout is a type of intersection control with particular design and physical geometry to control driver activities such that maximum entry flow rate relies on circulating flow. Some of these features such as yield control at entrance and splitter island guarantee vehicles traverse roundabout safely and comparatively with slower speed. Speed hump is a type of traffic control calming that encourages vehicles to pass motorway safely. On the other hand speed hump at roundabout may lead to poor drivers timing and delayed reflex reaction that can probably cause accident. Based on the statistical analysis, from every 2 vehicles at entry arm without speed hump only one vehicle at entry arm with speed hump can entry the roundabout.

In addition, speed hump resulted in highly speed reduction at entry that majority of vehicles should pass roundabout at speed less or 33 km/hr where the safety speed at roundabout is approximately 50 km/hr. Therefore it caused extra delay for drivers, increasing the probability of accident especially for elderly, waste of vehicles fuel, demolishing of tires.

REFERENCES

[1] Robinson, B. W., L. Rodegerdts, W. Scarbrough, W. Kittelson, R. Troutbeck, W. Brilon, L. Bondzio, K. Courage, M. Kyte, J. Mason, A. Flannery, E. Myers, J. Bunker, and G. Jacquemart. "Roundabouts: An Informa- tional Guide". Report FHWA-RD-00-067. FHWA, U.S. Department of Transportation, June 2000. 2.

[2] Mohamed A. Aty, Yasser Hosni, "ROUNDABOUTS DESIGN, MODELING AND SIMULATION". STATE-OF-THE-ART. Department of Civil & Environmental Engineering University of Central Florida. March 2001.

[3] Shashi S. Nambisan, Venu Parimi (March 2007). "A Comparative Evaluation of the Safety Performance of Roundabouts and Traditional Intersection Controls". Institute of Transportation Engineers

[4] Highway Capacity Manual (2000). National Research Council Washington, D.C. United State Customary Units.

[5] G.R. Watts. "Road Humps for the Control of Vehicle Speeds". Crowthorne, United Kingdom: Transport and Road Research Laboratory Report 597, Department of the Environment and Department of Transport, 1973.

[6] ITE Technical Council Task Force on Speed Humps. "Guidelines for the Design and Application of Speed Humps". Washington, D.C., USA: Institute of Transportation Engineers (ITE), 1993.

[7] Corbridge C "Vibration in vehicles: its effect on comfort," PhD Thesis University of Southampton, 1987.

[8] X.H. Tao, X.M. Huang, "Three-mass vehicle model of people-vehicle-road interaction," J. Traffic Transport Eng. 4(3), 11-15(2004).

[9] C. S. Xu, H. H. Yi and C. X. Huang, " Experimental Study of Vehicle Modelling and Ride Comfort Simulation based on the Topology," Structure Analysing Intelligent Systems Design and Applications, ISDA '06 Sixth International Conference, Ji'an, China, 197-201(2006).

[10] E. Khorshid, M. Alfares, "Model refinement and experimental evaluation for optimal design of speed humps," International Journal of Vehicle Systems Modelling and Testing 2(1), 80 – 99(2007).

[11] David Bowrey, Rhys Thomas, Rupert Evans, Peter Richmond, Road humps: "accident prevention or hazard?", J Accid Emerg Med;13:289-29 1 (1996).

[12] Jabatan Kerja Raya Malaysia (1987) Arahan Teknik (Jalan) 11/87 – "A Guide to the Design of at-Grade Intersections", Cawangan Jalan, Ibu Pejabat J.K.R.

[13] Highway Research Board (1965), "Highway Capacity Manual", National Research Council. Department of Traffic and Operations, Special Report 87, Committee on Highway Capacity, Washington, DC.

[14] Jabatan Kerja Raya Malaysia (1986) Arahan Teknik (Jalan) 13/86 – "A Guide to the Design of at-Grade Intersections", Cawangan Jalan, Ibu Pejabat J.K.R.

[15] Kimber, R.M. "The Traffic Capacity of Roundabouts." TRRL Laboratory Report 942. (1980).

[16] Kimber, R.M. "Gap-Acceptance and Empiricism in Capacity Prediction." Transportation Science, Vol. 23, No. 2. May 1989.

[17] Cuthbert, T. (2006). "Flow, Speed and Capacity". PTRC London Lecture Series. Retrieved 20 may 2010.

[18] Robertson, Douglas H., Et. Al., "Spot Speed Studies", CH.3 of Manual of Transportation Engineering Studies, Institute of Transportation Engineers, 1994, pp 33-51.