A MODEL TO PREDICT CAPACITY OF MULTI-LANE ROUNDABOUTS UNDER HIGH DEMAND FLOWS IN BAHRAIN

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ABSTRACT
An exponential model is developed for capacity estimate of roundabouts with triple circulating lanes based on given circulating flows. The necessary data for the development of the model and for the comparison purposes between the model and other international models are gathered from 13 roundabouts in Bahrain. The geometric data were gathered from the actual drawings, scaled aerial photographs and from the field. The necessary traffic data were gathered during morning and evening peak periods. The developed model falls well in between the tested international models and matches the actual data reasonably well. Substantial differences in estimating capacities were observed between the various available international methods. Such variations make the judgment of accepting or rejecting the estimated capacities difficult. They will also make the gating strategies and traffic assignments unreliable. The methods with complicated input parameters, extensive equations and tedious calculations, such as aaSIDRA, UK RODEL, French and Indian methods, did not prove to be better than much simpler ones, such as HCM or FHWA methods, in estimating roundabout capacities when compared with actual data. The influence of most of the geometric parameters of roundabouts on capacity during rush hours is limited. The findings are quite essential for traffic planners in making judicious decisions regarding roundabouts' performance. There is a real need for a more consistent model for the capacity estimation of roundabouts.
Keywords: circulating or conflicting flow, roundabout capacity, triple circulating lanes, entry capacity.

1 BACKGROUND

Current roundabouts came as a replacement of traffic circles (rotaries) to overcome some of the practical deficiencies associated with circles such as locking up of the traffic and development of long queues in the circles. This is because of the right of way given to the vehicles entering the circles. In order to avoid such blocking queues, the entering traffic should yield, or give way, to circulating ones. This is the main principle of the current roundabouts. Roundabouts are quite popular in erstwhile British colonial countries. All the traffic circles in Bahrain were converted into conventional roundabouts, soon after Britain, in the 1960s. Roundabouts are widely spreading in many other countries because of their advantages over other types of intersection control. The principal reason was the profit of safety over other cross-roads [1]. Reduction in incapacitating crashes was observed in the USA, Denmark, France and Germany after adopting roundabouts in replacement to other types of intersection control [2]. This is due to reduction in approaching speeds, fewer conflict points and no direct left turning. Some of the other advantages include minimum maintenance cost and a nice landscape. However, they also carry several serious disadvantages, many of which are usually overlooked. Some of them are as follows: drivers frustration due to unpredictable long queues during rush hours, when compared with traffic signals [3], limitation of bicycle and pedestrian facilities, high construction cost, large land requirements, high tail end accidents, frequent rutting failures at approach entries of flexible pavements, limitation of the technological support or software compared with traffic signals and limitation of entry and circulating lanes.

1.1 History of roundabouts

Traffic circles or rotaries were part of the transportation system in the United States and in some of the European countries long back. High crash experience and congestion in the circles led to the rotaries

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falling out of favor in America since the mid-1950s. Internationally, the experience with traffic circles was equally negative, with many countries experiencing circles that locked up as traffic volumes increased [4]. The roundabouts were developed in the United Kingdom. It adopted a mandatory 'Give-Way' rule at all circular intersections, which required entering traffic to give way, or yield, to circulating traffic. Wardrop [5], Britain TRL researcher, developed some models related to roundabout capacity in 1957. The 'Give-Way' rule prevented circular intersections from locking up by not allowing vehicles to enter the intersection until there were sufficient gaps in the circulating traffic. The roundabout represents a substantial improvement, in terms of operations and safety [2], when compared with older rotaries. Therefore, many countries have adopted them as a common intersection form and some have developed extensive design guidelines and methods to evaluate the operational performance of modern roundabouts. Al-Madani [3] found that roundabouts perform better than traffic signals when the traffic demand is low. However, as the demand increases at a roundabout so does the queue length and the delays. Beside drivers' frustration due to the unpredictable delays at congested roundabouts, when compared with traffic signals, long queues are inevitable. The latter leads to police intervention in order to control the queues and direct the traffic flow. Such phenomena led governments of Bahrain and Qatar to convert most of the major roundabouts on the main roads into signalized intersections. Some were constructed during the 1960s. Akçelik [6] also observed roundabouts to perform well at low to medium flow conditions. Clear capacity reduction was observed at high demand levels.

1.2 Roundabout capacity

Roundabout capacity is the main determinant parameter for the performance measure of many other parameters such as delay and queue length. It is the maximum sustainable entry flow rate that an approach can accommodate during a specific period under prevailing traffic, geometric and control conditions. Capacity is service rate and is different than maximum volume that an intersection can handle [6], which is the practical capacity under high demand volume, not under prevailing conditions.

Most of the capacity models are either analytical ones based on gap acceptance, with no actual observations, or empirical regression ones based on observed geometric and flow parameters (Fig. 1). Both techniques are considered to be macroscopic ones. Kimber [7] stated that capacity estimates based on gap acceptance models are not suitable for application in England. This was due to the problems related to human behavior. Russell and Rys [8] also questioned the validity of gap acceptance models at near capacity conditions. On the other hand, Fisk [9] finds regression models to be difficult for frequent application due to large number of data requirements. Microscopic models typically simulate traffic system on a vehicle-by-vehicle basis by updating position, speed, acceleration, lane position and other variables on small time steps such as a one-second interval or less [10]. Stanek and Milan [11] recommended use of macroscopic methods, such as FHWA, RODEL and aaSIDRA, for the capacity use for unsaturated conditions. For oversaturated conditions microscopic methods such as Paramics and VISSIM are preferred. However, Stanek and Milan [11] placed their recommendations based on very limited tested roundabouts. Furthermore, they utilized two famous macroscopic models, RODEL and aaSIDRA, for the comparison purposes.

The maximum flow rate that can be accommodated at a roundabout entry depends mainly on the following factors: the circulating flow on the roundabout that conflicts with the entry flow, exiting flow and the geometric elements of the roundabout. When the circulating flow is low, drivers at the entry are able to enter the roundabout without any significant delay. The larger the gaps, i.e. the headways, in the circulating flow, the more useful they are for the drivers entering the roundabout. In fact, more than one vehicle may enter in each gap. As the circulating flow increases, the size of the gaps in the circulating flow decreases, and the rate at which vehicles enter the roundabout

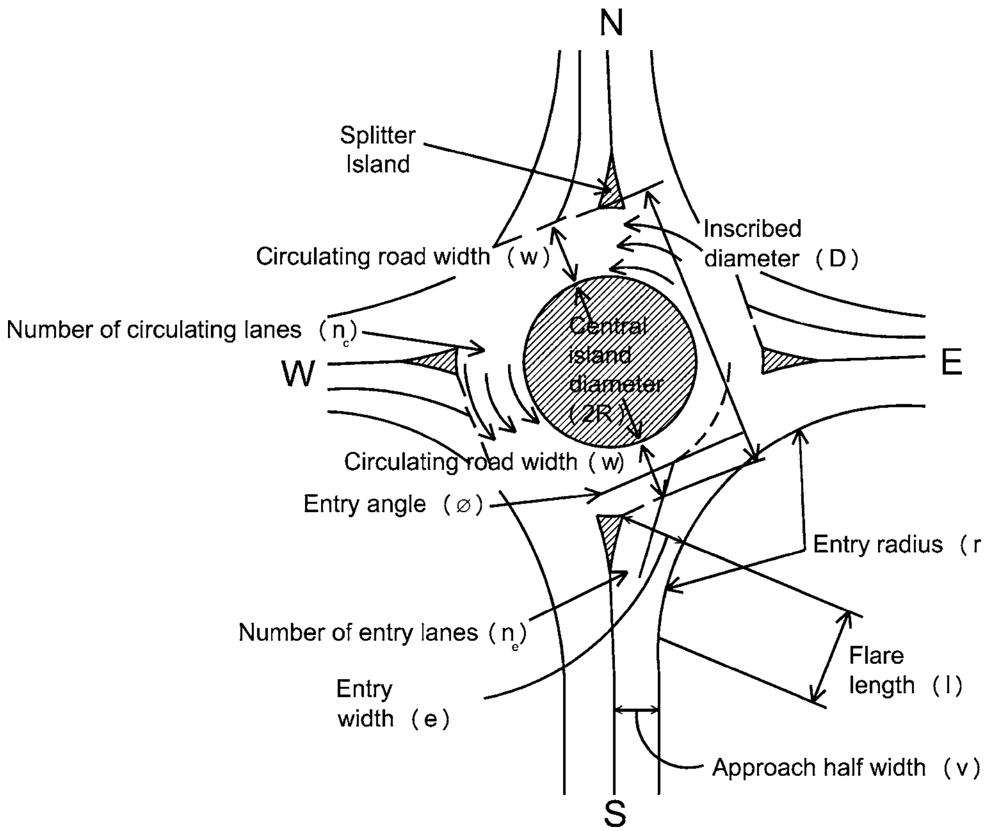

Figure 1: Geometric parameters needed for the roundabout capacity models.

decreases. The geometric elements of the roundabout also affect the rate of entry flow. The most important geometric elements are the width of the entry, the width of the circulatory roadway or the number of lanes around the central island. Wider circulatory roadways allow vehicles to travel alongside, or follow, each other in tighter bunches and so provide longer gaps between bunches of vehicles. The flare length also affects the capacity. The inscribed circle diameter and the entry angle have minor effects on capacity. In fact, TRL invented mini roundabouts that performed better than some larger ones in terms of capacities [12].

There are several analytical and empirical models for the capacity estimations. Some are very well known and others are less popular. Many countries utilize models developed by their own researchers to meet their needs. However, capacities estimated through these models widely differ from one model to another. Some are very simple and require minimum data entry as the Swiss, the US Highway Capacity Manual (HCM) and Federal Highway Administration (FHWA) models, others are far more complicated requiring extensive data gathering and tedious calculations such as UK RODEL, Australia aaSIDRA, French GIRABASE and Indian models. The UK RODEL and the Australian aaSIDRA models are the most famous ones. The question of how good the capacity estimate of each model is requires further investigations. Pratelli [13] found clear differences in capacity estimates when he used French and Swiss models as compared with actual data in Italy. Overestimation of 25–79% was observed in the capacity estimates. The need for capacity evaluation developed through the various models and software programs, available worldwide, was stressed by Jacquemart [14].

1.3 International roundabout capacity models

Most of the capacity models are developed in the West European countries and in Australia. There are several models currently used by both the researchers and the operators. Some are widely used, others are not. Stanek and Milan [11] stated that most of the known capacity models can be calibrated by modifying the intercept values, as in RODEL model, and follow up headway, as in aaSIDRA model.

1.3.1 UK model (RODEL)

It is based on the work carried out by Kimber and Hollis [15] and Kimber [12] for TRL. This method has been incorporated into a software packages widely known as RODEL [16]. The model involves extensive geometric requirements. The basic model is as follows:

$q_{e,max} = k*(F - f_c*q_c)$ for $q_e > 0$ else $q_e = 0$

$F = 303x_2$; $f_c = 0.21T_D*(1+0.2x_2)$; $S = (e - v)/l'$

$x_2 = v+((e - v)/(1 + 2*S))$; $T_D = 0.5/(1 + \exp((D_i - 60)/10))$

$k = 1 - 0.00347(\varphi - 30) - 0.978\ (1/r - 0.05)$

1.3.2 Australian model (aaSIDRA)

Detailed capacity expressions published in Australia are available in studies carried out by Akçelik [17, 18], and have been incorporated into a widely known software called aaSIDRA. Many parameters are employed in aaSIDRA [6] for sensitivity analysis to count for driver behavior.

$q_{e,max} = (\max f_{od}\, q_g, q_m)$

$q_g = (3600/\beta)*(1 - \Delta_c\ (q_c/3600)) + 0.5\beta*\varphi_c(q_c/3600)*\exp(-\lambda*(\alpha - \Delta_c)/3600)$

$q = \min(q_e, 60n_m)$, $f_{od} = 1 - f_{qc}\ (P_{qd}P_{cd})$

$\lambda = (\varphi_c q_c/3600)/(1 - \Delta_c q_c/3600)$ for $(q_c/3600) \le (0.98/\Delta_c)$

$= (49\varphi_c/\Delta_c)$ Else

$\varphi_c = \exp(-3.0*q_c/3600)$ for $n_c = 2$ or 3, for $0.01 < \varphi_c < 1.0$

$q_c = q_{cr} + q_{co}$ = flow on inner and outer circulating flow, $r_{ds} = q_d/q_s$

$\beta = \beta_d = \beta'_o - 3.94*10^{-4}*q_c$ for $1.2 < \beta < 4.0$

$\beta'_o = 3.3 - 0.0208D_i + 0.889*10^{-4}D_i^2 - 0.395n_e + 0.388n_c$ subject to $20 < D_i < 80$

$\alpha = (3.6135 - 3.137*10^{-4}*q_c - 0.339*e' - 0.277*n_c)*\beta$ for $q_c \le 1200$

$= (3.2371 - 0.339*e' - 0.2775*n_c)*\beta$ Else

subject to $3.0 \ge \alpha/\beta \ge 1$ and $2.2 \le \alpha \le 8.0$

$f_{qc} = 0.04 + 0.00015*q_c$ for $q_c < 600$

$= 0.55$ for $q_c > 1800$

$= 0.00035*q_c - 0.08$ for $600 \le q_c \le 1800$

1.3.3 Australian model (NAASRA)

The NAASRA model was developed earlier than SIDRA model. The model is summarized as follows [19–21]:

$$q_{e,max} = n_c*q_c*\exp(-q_c*T/3600)/(1 - \exp(-q_c*T_0/3600)),$$

where T = 6 and $T_0 = 3$.

1.3.4 German model

The German Highway Capacity Manual has officially introduced in 2001 [22] the Tanner-Wu capacity equation [23]. The formula for entry flow [24, 25] is as follows:

$$q_{e,max} = (3600/t_f)*(n_e^{nf/(nf+1)}S)*(1 - (\Delta_c*q_c/3600)/n_c)^{nc}*\exp(-(q_c/3600)*(\alpha - (t_f/2) - \Delta_c))$$

Utilized default values: $\alpha = 3.3$s, $t_f = 3.1$s, $\Delta_c = 1.8$s, $n_f = 1.4$ vehicles.

1.3.5 French model

The model is based on the work carried out by Louah [26] which was later incorporated into a model known as GIRABASE [27].

$$
\begin{array}{lll}
q_{e,max} & = A*\exp(-C_B*q_g) & \\
q_g & = q_a k_a(1 - (q_a/(q_c+q_a))) + q_{ci}k_{t,i} + q_{ce}k_{t,e}, & A = 3600/t_f(\mathrm{e}/3.5) \\
q_{ci} & = \text{conflicting flow on inner lane (default } 0.4*q_c) & \\
q_{ce} & = \text{conflicting flow on outer lane (default } 0.6*q_c) & \\
C_B & = 3.525 \text{ for urban area,} & \\
L_{i,max} & = 4.55\sqrt{}(R+(w/2)) & \\
K_a & = (R/(R+w_1)) - (L_i/L_{i,max}) \quad \text{for } L_i < L_{i,max}, & K_a = 0 \quad \text{Else} \\
k_{t,i} & = \mathrm{Min}((160/(w*(R+w)) & \text{Else} = 1 \\
k_{t,e} & = \mathrm{Min}((1 - ((w-8)/w)*(R/(R+w)^2))) & \text{Else} = 1
\end{array}
$$

1.3.6 US HCM model

There are two methods currently found in the US literature. The first is found in the Highway Capacity Manual – HCM [28]. The second is a simplified British linear regression method cited in the Federal Highway Administration (FHWA) Roundabout Guidebook [29]. The former is as follows:

$$q_{e,max} = 1230*n_c*\exp(-0.0009*q_c) \qquad \text{for multi-lanes}$$

1.3.7 US FHWA model

US FHWA model is as follows [29]:

$$q_{e,max} = 2424 - 0.71*q_c \qquad \text{for } n_e = 2; \qquad D_i > 50 \text{ m}$$

1.3.8 Indian model

The basic concept of the model was based on Wardrop literatures of the late 1950s. The modified equations are as follows [30]:

$$
\begin{array}{ll}
q_{e,max} & = ((280*w)*(1 + (e/w))*(1 - (p/3))/(1 + (w/l)) \\
\text{Average e} & = (e + e_2)/2, \qquad p = q_c/(q_c + q_e) \\
\multicolumn{2}{l}{\text{Subject to } 0.1 < e/w < 0.4; \quad 0.1 < w/l < 0.4; 0.4 < p < 1.0; \quad \text{and } 18 < \mathrm{l} < 90}
\end{array}
$$

1.3.9 Simulation models

Simulation techniques cover modeling of complicated traffic operation [10]. Simulation has not yet been used much in studying roundabout performance. However, not many simulation software are flexible enough to allow the user to model roundabouts [31]. Multi-lane simulations are very limited because procedure for setting out priority rules for roundabouts entry are quite complicated [31]. Cube Dynasim and VISSIM have been used to simulate many urban network including some roundabouts.

However, no clear simulation program has yet been utilized for roundabouts during congested conditions [10]. Simulation models require more input data and are more time consuming when compared with macroscopic ones.

Further to the earlier mentioned models Al-Madani and Saad [32] have developed a capacity model for roundabouts in Bahrain with triple entry and circulating lanes. The model is as follows:

$$q_e = 2952.9e^{-0.0007Qc}$$

The model fall within the earlier mentioned models, but is much simpler than many of them, and matched the actual data reasonably well.

2 OBJECTIVES

The main objective is to develop a capacity model for roundabouts with triple circulating lanes under the saturated traffic demands in Bahrain. The developed model is compared with eight international capacity models.

3 METHODOLOGY

The capacity model is developed using data from 13 existing major roundabouts, out of 15 selected ones, in Bahrain. These cover triple circulating lanes by either dual or triple entry lanes. The roundabouts in Bahrain are designed to high international standards. The model is developed based on the maximum entry flow, i.e. actual capacity, and the corresponding circulating flow. The former will be used as the dependent variable while the latter as the independent one. The data are collected during the peak hours to ensure higher saturation flows necessary for the development of capacity models. Furthermore, they provide better basis for comparison [33] with other models. Least square regression models are used to develop the model. The data will be regressed based on linear, logarithmic, polynomial, power and exponential methods. The model with best fit in terms of highest R^2 values will be selected to represent the data.

All the necessary traffic and geometric data are carefully gathered and properly considered to avoid misinterpretations of the parameters, which are used in the various models, as they may vary from one method to another. These parameters are unified and given the same abbreviated letters. Afterward, the roundabouts' maximum entry flows are determined for each approach of the selected roundabouts for nine international methods. These are determined using the advanced EXCEL features. The estimated maximum entry flows are based on the equations stated earlier. None were produced through the developed software corresponding to the earlier mentioned methods, in case there are any. This is to avoid unrealistic assumptions and default values utilized in the software for simplification purposes. The maximum entry capacity is analyzed per approach entry flow, not per individual lane, since most of the considered models utilize the traffic per approach entry. This is just not to add further complications to the models that are already complex. Furthermore, researchers prefer them over individual lane determination [33]. The calculated capacities are compared with that determined for the developed model.

The circulating and exiting flows are quite difficult to measure. Therefore, they are measured indirectly. The circulating flow for the South approach in Fig. 1, for example, consist of through traffic flowing from the West approach, left turning traffic flowing from the North approach and the U-turning traffic from the East approach. The latter is usually very limited during rush hours. Exiting traffic is considered in the same way, as well. Data from both a.m. and p.m. traffic are considered for the development of the capacity model.

4 DATA GATHERING

A total of 15 roundabouts were first selected across Bahrain for the investigation. The selected roundabouts carried saturated traffic flows during peak periods, relatively large inscribed diameters, i.e. over 60 m, and similar approaching lane widths. These were short-listed to 13 roundabouts based on the following requirements: multi-entry lanes, multi-circulating lanes, either four or five approaching legs, being on the main roads, and minimal approaching grades. These are meant to lead to better consistency in the results and fair comparison between the considered models. The geometric parameters require careful attention and high caliber to measure them as to fulfill the needs for the various international methods. Many are very tedious to acquire. The process of gathering the geometric parameters was not an easy one. The geometric parameters of the roundabouts were gathered from actual drawings of the roundabouts, GIS maps with scale of (1:2000), scaled aerial photos and actual field measurements. These were necessary to cross-check the data extracted from one source with another, to measure the missing geometric parameters from the original drawings and to compare the proposed drawings with the actual ones. The traffic flow counts during both morning and evening peaks were gathered for each approach.

The range of measured geometric parameters for the considered roundabouts, along with the averages, are presented in Table 1. Majority of the parameters fall within the recommended values by the UK Ministry of Transport, as has been discussed by Salter [34].

It is quite essential to mention that many methods require measurement of many tedious parameters such as flare length, entry angles splitter width and weaving length. Accuracy in measuring them may vary between one reading and another for over one meter, no matter how accurate your measurement is even when digital tools are utilized. This is because of difficulties in locating the beginning and the end of the measured parameter. However, such differences did not affect the estimated entry capacity much.

5 MODEL DEVELOPMENT

Various types of models are regressed for the estimated maximum entry flows as being the dependent parameter versus the circulating flows as being the independent one. The models best fitting the gathered maximum entry flow versus circulating flow data along with their corresponding R^2 values are presented in Table 2. These covered the following five main types: linear, logarithmic, exponential, quadratic and power regression models. The exponential model fits the tested data best when

Table 1: Geometric parameters of the roundabouts used in the study.

Parameter	Minimum and maximum measured values	Averages of measured values
Number of circulating lanes	3	3
Number of entry lanes	2 and 3	2 and 3
Inscribed diameter (m)	63–150	105
Entry angle	8–32.5	19
Entry radius from edge (m)	11.5–120	45
Flare effective length (m)	10–55	21
Approach half width of lanes (m)	6–10	7.6
Entry width all lanes (m)	6.5–16	9.3
Width of non-weaving (m)	9–14	6.1
Width weaving section or circulating width (m)	7.5–20	11
Length weaving section (m)	24–99	61
Radius of central island (m)	24–64.5	40
Width of splitter island (m)	18–82	31

Table 2: Developed models for roundabout capacity.

Model type	Developed models	R^2
Exponential	$2768e^{-0.0007Qc}$	0.559
Quadratic	$2534.9 - 1.1216Q_c + 0.0001Q_c^2$	0.536
Logarithmic	$6323.1 - 714.45\ln Q_c$	0.501
Linear	$2142 - 0.5785Q_c$	0.480
Power	$146{,}510Q_c^{-0.7076}$	0.415

compared with the other models because it holds the highest R^2 value (0.56). However, the quadratic relationship does not differ much from the exponential model in terms of R^2(0.54). The R^2 values for the models though being insufficiently high, they look fine for such dispersive nature of data and relatively large number of data points. It is quite interesting to mention that as the extreme data points, i.e. those beyond 1.8 of the standard deviation around the model, are removed the R^2 value improves to around 0.68 with little change in the model's constant values.

The maximum entry flow rates predicted from the developed model is compared with eight other international models. As can be seen from Figs 2 and 3 the following observation can be made regarding the developed model:

1. The model falls well in between the tested international methods.
2. The model fairly matches the Australian NAASRA model at low circulating flow rates but clearly falls above it at medium and high circulating flow rates. In fact, the NAASRA model falls below all the other models.
3. The Australian aaSIDRA model falls far above the developed models, the actual data and most of the other models.
4. The UK RODEL model clearly showed higher maximum entry flows when compared with the developed model.
5. The German model matched the developed model quite well. It is quite interesting to mention that German roundabouts showed actual capacities less than that found in Britain [35]. This match well with the results found here.
6. The French model falls above the developed model, especially for circulating flows below 2800 veh/h per approach, and above most of the actual data. The two match well beyond 2800 veh/h. The French model falls below the aaSIDRA and the RODEL.
7. The US HCM model matches the developed model quite well. However, it showed slightly lower predictions at medium to high circulating flows.
8. The US FHWA method also showed quite close match with the model developed here. However, one may observe higher estimated entry flow values using FHWA at medium circulating flow rates.
9. The Indian model showed far high estimations of entry flows compared with all the other models and with the actual data.

6 COMPARISON BETWEEN THE INTERNATIONAL MODELS

The results for the various roundabout capacity methods versus circulating flows, for the different roundabouts, as shown in Figs 2 and 3, clearly show the Indian method to be highly overestimating the entry capacity for given circulating flow and corresponding geometric characteristics when

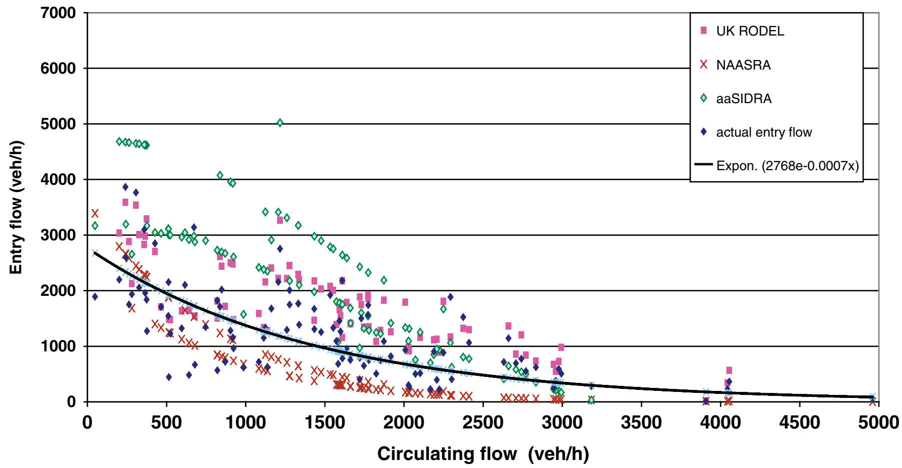

Figure 2: Developed capacity model for multi-lane roundabouts along with UK, NAASRA and aaSIDRA models.

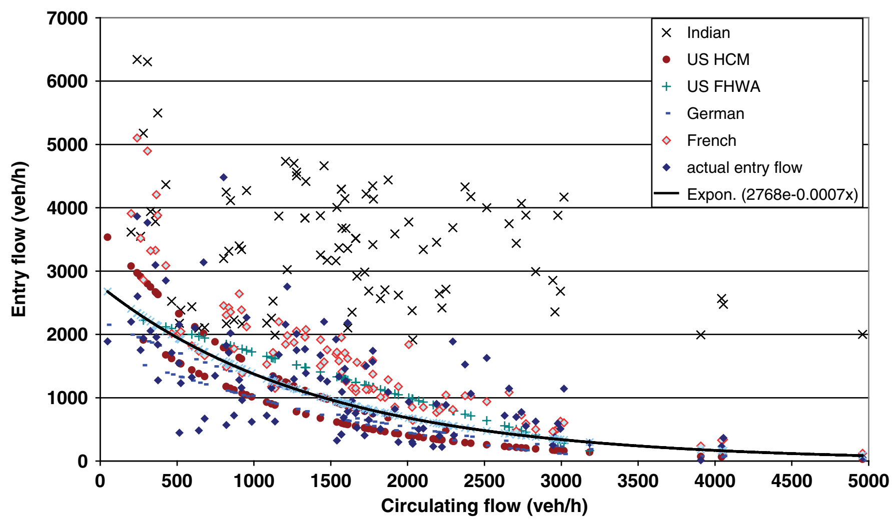

Figure 3: Developed capacity model for multi-lane roundabouts along with HCM, FHWA, German and French models.

compared with the actual demand and with those estimated from other tested methods. The results also indicated wide variations in capacity estimates of roundabouts among the various international methods. Some showed to be more reasonable than others when compared with the actual demand during rush hours. Such differences confuse the practicing engineers and consultants in properly assigning traffic to the various routes. Gating policies will also suffer just decisions.

The Australian NAASRA method showed the lowest capacity estimates compared with other international methods and compared with the actual data. The Australian aaSIDRA method, on the other hand, showed the highest capacity estimates, excluding the Indian method, for circulating flows up to 2300 veh/h. In other words, the maximum entry flows estimated by the two methods showed two extreme sides of predictions. One on the far high side and the other on the low side. It is also interesting to mention that very high estimates of entry capacities are observed for low circulating flow values when either the Australian aaSIDRA or the French methods are considered. They may require careful calibration and threshold limits for low circulating flows. Similar to the two Australian methods, i.e. NAASRA and aaSIDRA, the two US methods FHWA and HCM also showed a high and a low estimate of maximum entry flows, respectively, for the various given parameters when compared with the actual data. In general, the estimated entry flows using both methods fall between the envelopes of the two Australian methods, especially when the circulating flows falls are less than 2700 veh/h. The estimated roundabout entry capacity through the US HCM method showed to be closely matching that determined through the German method. Both tend to show low capacity estimates for given circulating flows when compared with the UK RODEL, the US FHWA, the French and the aaSIDRA methods. The maximum entry flows estimated through the French method falls below that estimated through the UK RODEL method.

The complicated methods, i.e. those requiring many parameters and involving several tedious equations, such as the aaSIDRA, the UK RODEL, the French GIRABASE and the Indian methods, did not show better capacity estimates than much simpler ones, such as the US FHWA or the HCM methods, when compared with the actual demands during peak periods. The latter match the demand flow reasonably well. The probable explanation is that motorists will be approaching and crossing the roundabouts at relatively low speeds during the forced flow of the rush hours. This makes the influence of many of the geometric parameters, such as the entry angle, flare length, entry radius and lane width, on capacity very limited, simply because motorists have limited space for maneuvering. The influence of geometric parameters might be more crucial to the motorists during nonforced flow conditions, through the vehicles being forced to slow down. The motorists have better approaching and crossing choices compared with congested conditions during rush hours.

7 CONCLUSIONS AND RECOMMENDATIONS

An exponential model for the capacity estimates for triple circulating lanes' roundabouts is developed here. The model predicts the maximum entry capacity of an approach knowing the circulating flow. The model matches the actual demand during the peak periods reasonably well and falls well in between the international models. Substantial differences in the capacity estimations were observed among the various available international methods. Such differences make the judgment of accepting or rejecting the estimated capacities very difficult. They also cause confusion to practicing engineers. While the capacities estimated through the Australian NAASRA method showed to be the lowest among those tested, that determined through the Australian aaSIDRA method showed to be among the highest. The US FHWA and HCM also showed a high and a low estimated entry flows, respectively, compared with the actual data and with the other tested methods. The aaSIDRA and the French methods showed nonrealistic high capacity estimates at low corresponding circulating flows. The estimated capacities through the HCM method matched that determined through the German method closely. However, they tend to show low estimated values when compared with UK RODEL, aaSIDRA and USFHWA methods. The French method falls below the UK RODEL method.

The complicated methods, those involving measuring many parameters and extensive calculations, such as the aaSIDRA, the RODEL, the French, and the Indian methods, did not necessarily show better capacity estimates than those much simpler ones as the HCM or the FHWA methods. This is probably because of the low speed of vehicles during rush hours, which make the influence of the geometric parameters minimal.

The findings are quite essential for the traffic planners in making judicious decisions regarding roundabouts' performance. There is a real need for a more consistent model for the capacity estimation of roundabouts. Such a model should utilize parameters that can easily be measured and comprehended by the users.

NOMENCLATURE

$q_{e,max}$	maximum entry flow for an entry lane (veh/h)
q_g	minimum entry flow (veh/h)
q_c, Q_c	conflicting flow (veh/h)
q_{ci}	conflicting flow on inner lane (default $0.4q_c$) (veh/h)
q_{ce}	conflicting flow on outer lane (default $0.6q_c$) (veh/h)
q_e	entry arrival flow (veh/h)
q_a	exiting flow (veh/h)
n_m	minimum entry flow (veh/min)
n_e	number of entry lanes
n_c	number of lanes in circulating (conflicting) flow
r_{ds}	ratio of dominant and subdominant flow in the entry
f_{od}	origin-destination adjustment factor
P_{cd} P_{qd}	proportion of total circulating flow 0.5–0.8 (0.6 used)
Δ_c	minimum headway in circulating traffic (s)
α	critical headway (s)
t_f	follow-up time (2.05 s in French model, 3.1 s in German model, 2.6–3.1 in HCM model)
λ	arrival headway distribution factor (veh/s)
φ_c	proportion of unbunched conflicting vehicles in circulatory stream
β	follow-up headway (s)
D_i	inscribed diameter (outer diameter of the roundabout) (m)]
R	radius of central island (m)
e	width at entry all lanes (m)
e'	average entry width per lane (m)
e_2	width of non-weaving section (m)
w	width of circulating lanes (m)
l	length of weaving section between the ends of the channelized islands (m)
r	narrowest radius of the right edge at the entry (m)
l'	effective length of the funnel-shaped flare (m)
v	width of the lane on the approaching street (m)
L_i	width of the splitter island (m)
n_f	short lane length (veh)
S	measure of the degree of the flaring (°)
φ	angle between ring and entry (°)
p	proportion of conflicting (weaving) traffic

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