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Roundabout Capacity Model Case Study Tangier City

Marwane Benhadou
LTI (Laboratory of Innovative Technologies)
Abdelmalek Essaâdi University, Tangier, Morocco

Abstract:- Roundabout has been widely adopted, due to its convenience for improving safety at an intersection by reducing speed and conflicts points. This article presents a roundabout capacity model located in Tangier, Morocco. The study is based on regression analysis and roundabout delay simulation to determine level of service, LOS. Roundabout capacity model is determined by the relationship between entry flow and circulating flow. It's one of the parameters that determines the efficiency of the roundabout design, to facilitate the passage without conflicts and minimum delay. There are more parameters that affect roundabout capacity, as geometrical features, driver behaviour, weather conditions and pedestrian presence. In this work, we are interested in the hourly vehicles flow in different time interval during a day at the roundabout entrances and the circulatory lanes.

Keywords:- *Roundabout Capacity Model, Regression Analysis, Tangier City, LOS.*

I. INTRODUCTION

Intersections in cities are a very important transit point to regulate traffic and speeds control. There are two types, signalized intersections and unsignalized intersections, a roundabout is an unsignalized intersection where traffic travels counterclockwise around a central raised island, and entering traffic must yield to circulating traffic [1]. In terms of safety, roundabouts play a very important role than other intersections form [2]. Studies have shown that it's more efficient than controlled intersection [3], but when traffic increases especially at rush hour, roundabouts become inefficient to regulate traffic and cause congestion [4]. The operational evaluation of the roundabouts is done through, delays, Level of Service and capacity [5]. In this work, we are interested in the hourly vehicles flow in different time interval during a day at the roundabout entrances and the circulatory lanes.

Tangier has experienced a considerable urban expansion. Urban mobility is becoming more complex, causing an imbalance between supply and demand, in which urbanization can impede access to urban center [6]. The control of vehicular traffic becomes more complex, which insists the use of more efficient control elements. Since 2015 the authorities in Tangier have opted to replace 8 roundabouts, with 'roundabout and underground passageway' [7] to decongest traffic, as represented in figure 1. This new structure has demonstrated its effectiveness in streamlining traffic.

Fig. 1. Roundabout with underground passageway

Some roundabouts due to their location, the road geometry is fixed by surrounded buildings, and it's difficult to introduce geometric changes to solve congestion problem. In this work we will study a roundabout with geometrics constraints to develop a capacity model, delay and level of service. The capacity modelling varies according to the study precision, data collection and roundabout geometry. In the next paragraph, we introduce the different methods used to model roundabout capacity.

II. CAPACITY ESTIMATION: A REVIEW

Historically, William Phelps Eno, proposed in 1912 the first regulated roundabout. The modern roundabout was developed in the United Kingdom in 1966, which required entering traffic to give way, to circulating traffic [8]. Roundabouts are circular intersections with three or more legs, specific design and traffic control features, as shown in figure 2. These features include yield control of all entering traffic, and appropriate geometric curvature to ensure circulatory flow speeds less than 50 km/h [9]. The objective of a roundabout is to reduce speed between vehicles in conflict and decreases accident rate. One of the roundabout performance parameters is capacity estimation in order to determine the level of service, also the delay caused.

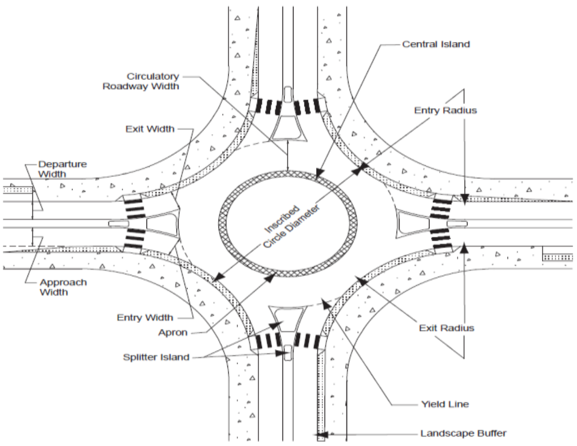

Fig.2. Roundabout geometric parameters

Earlier, the global capacity of intersection was discussed. The obvious way to increase capacity and avoid blocking, is to increase the length of each weaving section. Which leads to large diameters of the intersection. The formula developed by Wardrop, eq. 1, took into account the geometric roundabout characteristics [10].

$$Q_w = \frac{K.w.(l+\frac{e}{w})(l-\frac{p}{3})}{l+\frac{w}{l}} \qquad (1)$$

l, p, w , are access parameters and Q_w, entry capacity.

Currently, roundabouts began to be considered as a sum of "T" intersections, and the concept of global capacity is replaced by the capacity of each entrance [10]. Therefore, by definition, the capacity is: The maximum number of vehicles that can enter the roundabout from an access, during a period of time under certain traffic and geometry conditions [5,10].

Each country develops its own ‘culture’ regarding the use of roundabouts, and the capacity may increase as drivers become more familiar with this type of intersection [11]. According to the different studies, the capacity represents the relationship between circulating traffic and the maximum that could be incorporated into the entrance [10]. There are factors that affect the roundabout capacity, as geometry, which has a major impact on capacity and safety (accident rate), and small changes in geometric parameters produce significant changes in capacity. Also the presence of pedestrians crossing at the entrance of the roundabout can reduce significantly the access capacity [12].

There are methods used to estimate roundabout capacity, to find out the maximum hourly flow at the intersection access during a time interval. There are two methodologies, empirical and analytical (probabilistic) methods [13]. Most countries have adopted their capacity model based on one of these 2 methods, the regression basis (UK) and the gap acceptance theory (Australia).

A. *Empirical models*

Based on field data, which make a relationship between circulatory and entry flow, roundabout characteristics and performance measures.

➢ The English model

Based on the equation developed by Kimber in the United Kingdom in 1980 [14], it’s the most efficient method, given the long English experience in this field. All the experimental measurements indicate that the relationship between the capacity and the circulatory flow is linear (depending on roundabout geometry). Knowing the geometry and the flows of the different movements, the capacity can be predicted using eq. 2.

Kimber model:

$$C = k(F - f_c \, . \, Q_c) \qquad (2)$$

With:
C, entry capacity (vh/hr)
Q_c, circulating flow (vh/hr)
K, F, f_c = Depends on the roundabout geometry
In order to apply the Kimber formula, it’s necessary to have the O-D matrix of traffics at the intersection.

➢ German model

In Germany [15] they used the same English philosophy, but with exponential approximation, eq. 3, to describe the relationship between Q_c and Q_e:

$$Q_e = A.\exp(\frac{-B.Q_c}{10000}) \qquad (3)$$

Q_e, entry capacity (vh/hr)
Q_c, circulating flow (vh/hr)
A, B, geometric parameters as shown in table 1

TABLE I. PARAMETERS ESTIMATION

Number of lanes		A	B
Enter road	Circulatory road		
1	1	1089	7.42
1	2-3	1200	7.30
2	2	1553	6.69
2	3	2018	6.68

➢ French model

Similar to English model, but with some differences, as maximum entrance capacity is considered fixed at about 1500 vh/hr, with one entrance and one lane on circulatory road [16].

$$C_E = 1500 - k.[\frac{5}{6}.(Q_c + 0,2.Q_s)] \qquad (4)$$

C_E, entry capacity vh/hr
Q_c, circulating flow vh/hr
Q_s, volume exiting on the same leg as the entry
K, correction coefficient according to the access road geometry
For larger roundabouts, eq. 5, with a two entry lanes:

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$$C_E = 1{,}4\left[1500 - k.\left[\frac{5}{6}.(Q_c + 0{,}2.Q_s)\right]\right] \quad (5)$$

- Swiss model

Bovy et al. Formula, proposes an empirical linear relationship, eq. 6. Expresses the entrance capacity as a function of Q_g [17].

$$C_E = k.(1500 - 8/9.Q_g) \quad (6)$$
$$Q_g = \beta.Q_c + \alpha.Q_s \quad (7)$$

Q_c, circulating flow vh/hr
Q_s, volume exiting on the same leg as the entry
K, factor for adjusting entry capacity depending on the number of circulating lanes
β, factor for adjusting circulating flow depending on the number of circulating lanes
α, factor reflecting the impact of exiting traffic on entry capacity

B. Analytical models or the gap acceptance model

Based on driver's behaviour. This analytical method is based on the critical gap and follow-up time. The first is defined when a driver enter the roundabout, if the gap between 2 successive vehicles in circulatory road is greater than a minimum value (critical gap) [18,33], and the follow-up time is the wait time for second vehicle position in the queue entry, as depicted in figure 3.

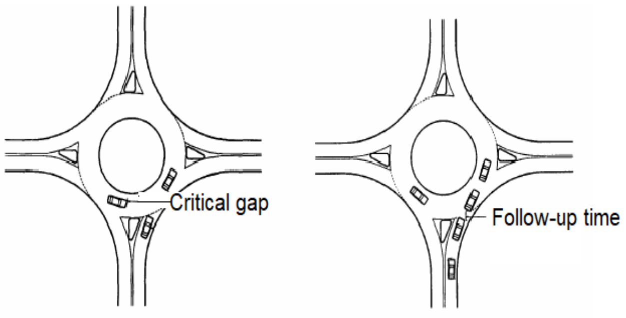

Fig. 3. Critical gap and follow up time

- Australian model

The development of analytical method was elaborated by Tanner (1962), eq. 8. Tanner analyse the major and minor stream delays at intersection [10].

Tanner's equation:

$$q_e = \frac{q_c(1-\delta.q_c).exp(q_c(T-\delta))}{1-\exp(-q_c.T_0)} \quad (8)$$

q_c, circulating flow in front of the entry approach
q_e, entry capacity
T, critical headway (3-4) seconds, Troutbeck [10].
T_0, follow-up time (s).
δ, the minimum headway between the circulating vehicles (1-2) seconds, Troutbeck [10].

The distance distribution between vehicles on the circulatory road, obeys Cowan M3 distribution [19]. Some modifications have been made to the Tanner formula by Troutbeck and Ning Wu [10,20]. There are different models developed and these models are based on driver's behaviour [10,20].

German model

Developed by Siegloch, Harders and Brilon, using Poisson distribution. This formula, eq. 9, is useful for multi-lane roundabouts [21].

Harders formula [22]:

$$C = F.e^{-\beta}.\frac{Q_g}{e^{\alpha}-1} \quad (9)$$

C, entry capacity
F, is a factor introduced by Harders, to correct the dispersion of the critical and follow-up time times.

Q_g, circulating traffic

$$\alpha = \frac{Q_g}{3600}.t_f, \beta = \frac{Q_g}{3600}.(t_g - t_f) \quad (10)$$

$t_g = 4{,}5(s)\ et\ t_f = 2{,}5(s)$, critical and follow-up times

- Swiss model

Ola Hagring 1998 [23], has studied the Swedish roundabouts, introducing the concept of circulating and main flow, also the near and far lane within circulatory road, has estimated the values of critical and follow-up time, eq. 11. With this simplified model it's possible to relate the critical gap with the roundabout size, length and width of the weaving section, as explained in figure 4.

T= 3.91 – 0.0278.L + 0.121.W + 0.592. $((N_L - 1)$. (11)
T, critical gap.
L, length of weaving section.
W, weaving section width.
N_L, number of lanes.

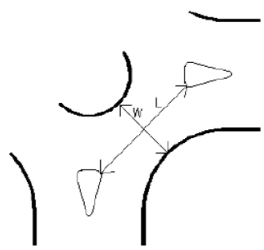

Fig. 4. Weaving section

Hagring formula, is based on the Cowan M3 distribution, depends on distribution flow in the different circulatory lanes, and the maximum capacity is obtained when the circulating flow is equally distributed between lanes [23].

- Methods in the United States

To predict capacity 'C' of a single lane, eq. 12:

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$$C = \frac{V_c . e^{-\frac{V_c . t_c}{3600}}}{1 - e^{-\frac{V_c . t_f}{3600}}} \quad (12)$$

V_c, circulating flow vh/hr
t_c, t_f, critical and follow-up time, t_c= 4.1-4.6 t_f= 2.6-3.1 seconds
The HCM 2010 formula [24], eq. 13:

$$C = f_{HV} . f_p . f_A . A . e^{-\left(\frac{B}{f_B}\right).Q_c} \quad (13)$$

f_{HV}, heavy vehicle factor
f_p, pedestrian factor
f_A, f_B, adjustment factor for A and B
Q_c, circulatory flow
A and B values for Single-lane circulating stream [24]

III. LITERATURE REVIEW

Researchers have studied the roundabouts capacity from 2 perspectives, using an empirical model or analytic method. The roundabout capacity is defined as the maximum number of entering flow under certain geometric conditions, driver's behaviour and weather conditions [9].

In the research article [10], Troutbeck, develops the different methods used to estimate the roundabout capacity, and how these methods vary according to various points of view of traffic, experience and the philosophy of dealing with the problem. The studies carried out since then allow a comparison between the different models, through simulations, and developing other models, as E. Chung et al. works [25], where evaluate gap-acceptance models used with Sidra software simulation. A. Akçelik discuss in a research article [26] the reliability of UK linear regression for low and high circulating flow. Ola Hagring et al. investigates a two-lane roundabout, such critical gap, entry capacity, delay and follow-on times in Copenhagen, Denmark [27]. Al Masaeid and Faddah [28] developed a capacity model in Jordan for roundabout using empirical method. Al-Madani & M. Saad develops capacity models for roundabouts under saturated traffic demands in Bahrain studying 13 major roundabouts using regression models [29]. Also researchers developed capacity model using conflict theory studying 2 different roundabout [30], comparing the result with Wu model. 21 roundabouts geometric characteristic is studied in Beijing using regression models [31]. in Baghdad City, authors developed roundabout capacity model in function of influence traffic and geometrics parameters using empirical model though regression analysis [32]. Capacity model and other parameters evaluated using HCM 2000 [34]. In Sarajevo, capacity levels compared using different gap acceptance [35]. The E. Macioszek model developed in Poland is applied to estimate roundabout capacity in Tokyo, Japan [36].

IV. APPLICATION

C. *Study area*

The roundabout is located at the intersection, Habib Bourguiba, Sidi Amar and El Ouchak avenues. Situated between two intersections, one controlled intersection with traffic light and the second intersection controlled with yield signs, as depicted in figure 5.

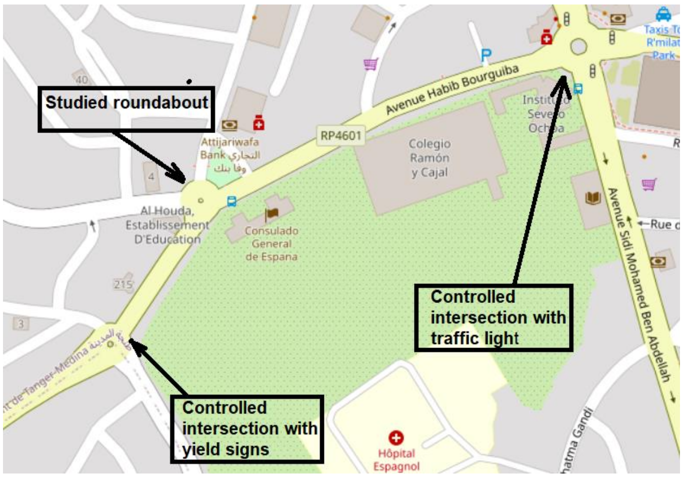


Fig. 5. Study area

The peculiarity of this roundabout is the central aspect, where traffics stream converges, as illustrated in figure 6. Also, near to the intersection there are a primary school and two hospitals, which requires a clean environment, noise and emissions.

Fig. 6. Roundabout localisation

Which leads us to analyse vehicular flow at the roundabout, developing a capacity model and level of service. For 4 entry lanes and 2 circulating lanes, each entry identified with numbers 1, 2, 3, 4 and a central island 5, as shown in figure 7.

Fig 7. Roundabout model

Modelling facilitates data collection and data processing. As shown in table 2, the O-D matrix and circulating flow for each entry lanes. The O-D matrix reflects the distribution of each entry flow between the 4 entry lanes of the roundabout.

D. Data collection

Analysis of the existing condition (carry out a first diagnosis, the traffic load, analyse the context of the roundabout, analysis of the nearby urban environment as: schools, parks, malls), constraints and objectives (urban structure) demand or traffic flow. The data collected refers to the entry flow Q_e and circulating flow in front of it Q_c , as explained in figure 8.

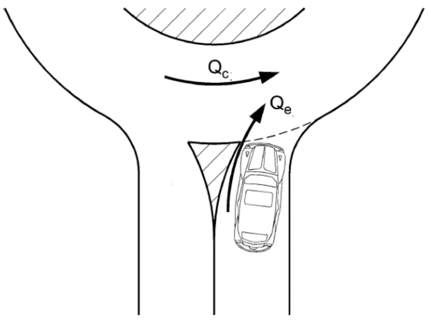


Fig. 8. Entry flow Qe vs circulating flow Qc.

Data has been recorded for 1 hour at peak hours (12:00, 2:00, and 6:00 p.m), from Monday to Thursday, with video camera, under good visibility conditions.

TABLE II. MATRIX FOR DATA COLLECTION

	4	5	3	2	1	Circulating flow
4						Q_4
3						Q_3
2						Q_2
1						Q_1

E. Development of capacity model, delay simulation and LOS

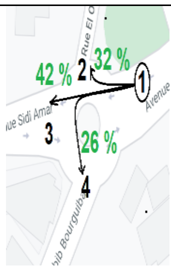
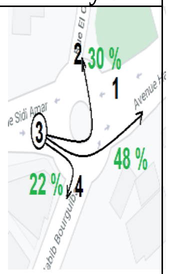
The models developed test the mathematical relation between the maximum entry flow and circulating flow based on regression analysis [37]. The best selected model based on the highest coefficient of determination R^2. According to the models represented in table 3, Power model shows best fit compared with the other models with $R^2 = 0{,}700$ and the inverse function showed the lowest capacity estimates.

TABLE III. REGRESSION MODELS DEVELOPED

Model Type	Regression models	R^2
Linear	$C = 8{,}311 + 0{,}989.Q_c$	0,43
Logarithmic	$C = -3{,}344 + 10{,}311.Ln(Q_c)$	0,529
Inverse	$C = 25{,}568 - \frac{32.717}{Q_c}$	0,359
Quadratic	$C = 0{,}232 + 2{,}342.Q_c - 0{,}44.Q_c^2$	0,527
Cubic	$C = -5{,}138 + 4{,}076.Q_c - 0{,}176.Q_c^2 + 0{,}03.Q_c^3$	0,555
Power	$C = 1{,}607.Q_c^{0{,}988}$	0,700
Exponential	$C = 5{,}785.e^{0{,}082.Q_c}$	0,428

We have also calculated the demand and distribution of entry flows between the different roundabout legs, the result is summarized in table 4, the flows percentage distributed according collected data, and shows the selected destination by each driver.

TABLE IV. DISTRIBUTION OF ENTRY FLOW

Entry 4	**Entry 1**	**Entry 2**	**Entry 3**
			

Using GLORIETA mobile application software, for simulating roundabout delay and level of service LOS, as depicted in figure 9, introducing geometrics parameters and entry flow.

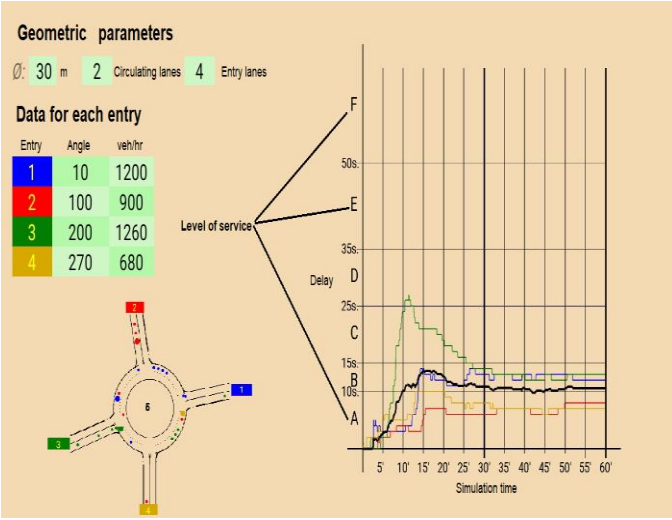


Fig. 9. Delay and level of service for 1min simulation for each entry lane

The entry lane 3, express the longest delay at the first 30 seconds of measurement, as shown figure 9. The Level of Service for vehicles based on delay [38], which roundabout LOS for this case is B.

V. CONCLUSION

In this article a review has been made for different concepts related to the study of roundabout capacity, such as analytical and empirical methods. As an application a roundabout located in the center of Tangier city, is studied using entry and circulatory flow data to develop capacity model based on the regression analysis. To determine the best predictive equation by using coefficient of determination. Power model shows best fit compared with the other models. Also using GLORIETA application mobile software for roundabout delay simulation, to determine the level of service. As a future work, developing a more general entry-capacity model including more roundabouts in data collection, and compare the result with international models.

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