TRANSPORT
2009
24(4): 257–264

COMPARISON OF DIFFERENT CAPACITY MODELS FOR TRAFFIC CIRCLES

Pelin Çalışkanelli[1], Mustafa Özuysal[2], Serhan Tanyel[3], Nadir Yayla[4]

[1, 2, 3] Dept of Civil Engineering, Dokuz Eylül University, Tınaz Tepe Kamp 35160 Buca İzmir-Türkiye
[4] Dept of Civil Engineering, İstanbul Technical University, 34469 Maslak İstanbul-Türkiye
E-mails: [1]pelin.caliskanelli@deu.edu.tr; [2]mustafa.ozuysal@deu.edu.tr; [3]serhan.tanyel@deu.edu.tr; [4]nyayla@ins.itu.edu.tr

Received 16 January 2009; accepted 3 November 2009

Abstract. Traffic circles have been used in many countries all over the world. Traffic circles can be defined as intersections where traffic circulates around a center island where priority is given to the vehicles entering from branches and are designed considering weaving movements as the basic goal. There are two most common capacity analysis methods for traffic circles: the method of critical gap acceptance and the method of regression analysis. This study explains the methods of gap acceptance and regression analysis. Ashworth and Field method is investigated and the applicability of these capacity models in Turkey is discussed. The obtained results have shown that both methodologies give satisfactory results; however, the existing methods should be improved (modified) considering conditions.

Keywords: traffic circles, roundabouts, capacity, gap acceptance theory, regression analysis, origin-destination matrix.

1. Introduction

Traffic circles (or conventional roundabouts) can be defined as intersections where traffic circulates around a center island but unlike modern roundabouts priority is given to the vehicles entering from branches and are designed considering weaving movements as the basic goal (Stanić *et al*. 2005; Pratelli 2006; Balsys *et al*. 2007; Jakimavičius and Burinskienė 2007, 2009a, 2009b; Ziari *et al*. 2007; Daunoras *et al*. 2008; Niewczas *et al*. 2008; Matis 2008; Šelih *et al*. 2008; Antov *et al*. 2009; Paslawski 2009; Mesarec and Lep 2009). In such a case, the circles became very large with long distances between successive branches with relatively low speeds and circulating flows (Pratelli 2006). This type of traffic circles was built worldwide and particularly in the UK from the beginning of the 20th century to 1960's. The traffic circles designed according to the off-side priority rule (modern roundabouts) were introduced in Great Britain in November 1966 (Ashworth and Field 1973). Since then, roundabouts have approached throughout the world especially in France, Germany, Sweden, Australia, Switzerland, Denmark and recently, in the United States (Troutbeck 1991 and 1998; Hagring 1996 and 1998; Stuwe 1991; Worthington 1992; Highway Capacity Manual 2000; FHWA-RD-00-67 2000; Flannery *et al*. 1998).

In Turkey, traffic circles are used as one of the most common intersection types. Although they have been previously designed as unsignalized intersections, in recent years, due to capacity concern, most of them are either newly designed or converted into signalized traffic circles. However, there are a few of those operating as an unsignalized intersection and still provide high capacity. On the other hand, Turkish General Directorate of Highways (Karayolları Genel Müdürlüğü, KGM) has started to construct modern roundabouts and has changed design guides to traffic circles with modern roundabout design principles depending mostly on Federal Highway Administration's (FHWA) studies (Arıkan Öztürk *et al*. 2007).

As geometric design and operation rules have changed, capacity and performance analysis methods have also varied. As stated before, the capacity of a traffic circle was calculated by an assumption that the intersection consisted of a series of weaving areas. The capacity of traffic circles was calculated using the following equation (Ashworth and Field 1973; Worthington 1992):

$$Q = \left(108w\left(1+e/w\right)\left(1-p/3\right)\right)/\left(1+w/l\right), \qquad (1)$$

where: Q is practical capacity (pcu/h); w is the width of weaving section (m), e is the average entry width (m),

l is the length of weaving section (m) and p is the ratio of weaving traffic to total traffic in the weaving section (changes between 0.4 to 1.0).

Today, two calculation methods are mainly used in roundabout capacity analysis:

1. Theoretical approach or gap-acceptance theory
2. Empirical models mostly depend on regression analysis.

The gap-acceptance theory assumes that drivers in the minor-stream approach of a roundabout decide to join the major (circulating) stream according to the size of gaps between successive vehicles in the major stream. The most known models that depend on the gap acceptance theory are Tanner's (Tanner 1962; Akçelik 1998; Hagring 1998 and 2003) and Highway Capacity Manual (Highway Capacity Manual 2000; Flannery *et al.* 1998; Troutbeck 1998) models. Akçelik and Troutbeck (1991) and Akçelik (2007) have also suggested a new approach to the gap acceptance theory named as traffic signal analogy. He also used this model in one of the pioneer computer programs named as SIDRA (Akçelik 1998 and 2003). In recent years, Chevallier and Leclercq (2007) have improved this model to represent flow dynamics.

However, some scientists stated that the gap acceptance theory could not be easily applied to roundabout entries. They declared that in some cases, move-up times were greater or equal to the critical gap and it was difficult to define the correct major streams at multi-lane roundabouts with multi-lane entries (Stuwe 1991; Kimber 1980). Kimber (1980) was one of the leading researchers who used regression analysis to predict roundabout capacity and performance. This model is known as the TRL (Transportation Research Laboratory) method (Kimber 1980).

Various studies investigating the applicability of the gap acceptance theory were made in Turkey (Tanyel *et al.* 2005 and 2007; Tanyel and Yayla 2003).

In the following section of this study, the observation areas (intersections) and data collection procedures are introduced. In the third part of the article, the capacity calculation model introduced by Ashworth and Field (1973) for the first time is explained and its applicability is discussed. In the fourth part of the paper, the results obtained in the third part are compared with other capacity methods like National Cooperative Highway Research Program (NCHRP) – NCHRP Report 572 (2007), Highway Capacity Manual (2000) methods and the results of regression analysis.

2. Observations and Data Collection

Observations have been made at four approaches of four multi-lane and seven approaches of five single-lane traffic circles in İzmir, Turkey. Multi-lane traffic circles are named as Alsancak Gar, Lozan, Montrö and Cumhuriyet; single-lane traffic circles are named as Gündoğdu, Bostanlı, Sanayi, Aegean University and Soğukkuyu. Geometric variables are given in Table 1. These intersections were chosen because no signalization system was established during the observation period; they were all located on the main arterials of İzmir so that the interaction between high entry and circulating flow rates could be observed (which is quite important for capacity analysis). All observations were carried out using video cameras from a higher building near the intersections during peak hours on weekdays under dry and open weather conditions. The observations disclosed the following data:

- circulating (major) traffic volume (veh/h and veh/min);
- entering (minor) traffic volume (veh/h and veh/min);
- headway values in the major flow (sec);
- follow-up times between vehicles in the minor flow (sec);

Table 1. Geometric variables of the observed traffic circle approaches

Intersection name	Inscribed diameter (D_i) (m)	Number of entry lanes (n_e)	Entry lane width (w_e) (m)	Number of exit lanes (n_{exit})	Exit lane width (w_{exit}) (m)	Median width (w_{median}) (m)	Number of circulating lanes (n_c)	Width of circulating Area (w_c)	Conflict angle (ϕ)
Alsancak Gar	55.00	2	3.00	2	3.00	10.00	3	15.00	45.00
Cumhuriyet	140.00	1	5.00	1	5.00	8.00	2	7.00	47.00
Montrö	65.00	2	3.00	-	-	-	3	20.00	46.00
Lozan	67.00	2	3.00	2	3.00	9.00	3	20.00	54.00
Gündoğdu 1	20.00	1	3.20	1	4.60	5.73	1	5.70	27.50
Gündoğdu 2	20.00	1	4.80	1	4.51	9.05	1	4.87	16.60
Sanayi	30.00	1	4.00	1	4.10	7.80	1	5.50	25.00
Egean Univ.	15.00	1	4.90	1	5.66	8.09	1	4.47	32.70
Bostanlı 1	14.00	1	5.20	1	4.02	1.25	1	5.91	25.30
Bostanlı 2	14.00	1	3.90	1	3.70	0.70	1	5.47	36.10
Soğukkuyu	15.00	1	3.30	1	3.40	1.86	1	4.68	33.20

- accepted gaps (sec);
- rejected gaps (sec);
- types and percentages of heavy vehicles;
- service (minimum) delays (sec) for minor stream vehicles;
- queue lengths (m).

Although there are 3 circulating lanes at Montrö and Lozan intersections, two lanes have been effectively used for circulation. This is mainly due to the fact that at both intersections, short periods of parking and stopping are allowed. Especially at Montrö intersection, there is a bus stop that is frequently occupied by public transit buses. For this reason, both of these intersections will be assumed to have two circulating lanes in analysis.

Troutbeck (1998) has stated that the best way to estimate capacity is the direct measurement of the average of maximum throughput. However, to obtain an acceptable regression equation, there should be a constant queue of vehicles the drivers of which are waiting in a suitable gap to enter the traffic circle at least for a 30 min period. Thus, flows for a number of 1 and 5 min periods should be used to calibrate regression equations. In this study, 1 min period traffic flows are used throughout all analysis. 49 min data set was obtained from Lozan, 53 min data set was collected from Montrö, 84 min data set was obtained from Cumhuriyet and 82 min data set was gathered from Alsancak Gar intersection at which continued queues existed. On the other hand, in total, 521 one-minute traffic flow data have been obtained from all single-lane traffic circles.

3. Capacity Analysis Methods

As stated before in this study, the capacity of traffic circles is tried to be discussed using Ashworth and Filed (1973) method and its results are compared with those of gap acceptance and regression analysis techniques. This chapter of the paper is organized as follows:

Initially, the method suggested by Ashworth and Filed (1973) is presented. Next, the gap acceptance method used in analysis is described. Finally, the principles of regression analysis are explained.

3.1. Ashworth and Field Method

The method suggested by Ashworth and Field (1973) mostly depends on the studies by Tanner (1962) and Wohl and Martin (1967). In his study, Tanner (1962) showed that the maximum number of vehicles able to cross one-directional major road traffic from a minor road with a single lane approach could be found using the following equation:

$$q_{ecap} = \frac{q_c\left(1-\Delta q_c\right)}{e^{q_c(T-\Delta)}\left(1-e^{-q_c T_0}\right)}, \tag{2}$$

where: q_c is the volume of the major flow (veh/h); Δ is the minimum headway between the vehicles in the major flow (seconds); T is the critical gap value of drivers in the minor stream; T_0 is the minimum follow-up headway between entering vehicles from the minor stream approach and q_{ecap} is the capacity of the minor stream approach.

If traffic on the major road is considered as random, then Δ can be set equal to zero and equation (2) is simplified to:

$$q_{ecap} = \frac{q_c}{e^{q_c T}(1-e^{-q_c T_0})}. \tag{3}$$

Equation (3) is also used in Highway Capacity Manual (2000) to calculate the capacity of unsignalized intersections and roundabouts. Wohl and Martin (1967) considered q_c and q_e could represent circulatory and entering weaving flows respectively at a traffic circle and for simplicity, they assumed that $T = T_0 = t$ where t is the average headway between the major road vehicles. This simplifies equation (3) to:

$$q_{ecap} = \frac{q_c}{e^{q_c t}-1}. \tag{4}$$

In equation (4), if R is defined as the total entering the weaving section of traffic circle ($R = q_c / q_{ecap}$), the equation may turn into:

$$q_c = \frac{1}{t}\ln(R+1). \tag{5}$$

Ashworth and Field (1973) made observations on two-lane roundabouts and modified equation (5) for two lane traffic circles is:

$$q_c = \frac{1}{t}\left(2R+1\right)\big). \tag{6}$$

By taking ln(2R + 1) as a dependent variable, they fitted regression lines to their observed data for each of the weaving section. Their calculations resulted in very low intercept values they decided to neglect. As a result, they obtained the following equation for traffic circles having two entry lanes:

$$Q_{ecap} = \frac{2Q_c}{(e^{Q_c/1100}-1)}, \tag{7}$$

where: Q_c is the hourly circulating flow (veh/h) and Q_{ecap} is the hourly capacity ratio of the traffic circle minor approach (veh/h).

3.2. Gap Acceptance Method

As mentioned before, gap acceptance is one of the most preferred methods of the capacity and performance analysis of unsignalized intersections. This study presents a simple capacity calculation procedure. More detailed information about the capacity and performance analysis of traffic circles in Turkey can be found in Tanyel *et al.* (2005 and 2007); Tanyel and Yayla (2003).

In capacity analysis, it is assumed that headways between the major (circulating) road vehicles can be defined using Cowan's M3 distribution:

$$F(t) = 1-\alpha e^{-\lambda(t-\Delta)} \quad \text{for } t \ge 0, \tag{8}$$
$$F(t) = 0 \quad \text{for } t<0,$$

where: α is the proportion of free vehicles in the major flow; Δ is the minimum headway between vehicles in the major flow (sec) and λ is a decay constant that can be found using the following formula:

$$\lambda = \frac{\alpha q_c}{1 - \Delta q_c}. \quad (9)$$

According to this assumption, the capacity of single and multi-lane traffic circles can be found using the following formulas suggested by Troutbeck (1991) and Hagring (1998) respectively:

Single-lane traffic circles

$$q_{ecap} = \frac{q_c \alpha e^{(-\lambda(T-\Delta))}}{1 - e^{-\lambda T_0}}; \quad (10a)$$

Multi-lane traffic circles

$$q_{ecap} = \Lambda \prod_i \frac{\alpha_i q_{ci}}{\lambda_i} \frac{e^{-\Lambda T}}{e^{-\Lambda\Delta}(1 - e^{-\Lambda T_0})}, \quad (10b)$$

where: T is the critical gap acceptance value of minor flow drivers (sec); T_0 is the minimum follow-up time of entering vehicles from the minor approach (sec); α_i is the proportion of free vehicles in the i_{th} circulating lane, q_{ci} is traffic volume (in veh/sec) in the i_{th} circulating lane; λ_i is the decay constant for the i_{th} circulating lane and Λ is $\sum_i \lambda_i$.

Literature shows that several models for α are suggested by different researchers like Akçelik and Chung (1994), Akçelik (2003), Troutbeck (1991), Plank (1982), Hagring (1998). In this study, a model suggested by Tanyel and Yayla (2003) is used in the analysis of multi-lane traffic circles:

$$\alpha = 1.25 - 1.13\Delta q_c \quad \text{if } \Delta q_c \geq 0.22 \quad (11)$$

$$\alpha = 1.0 \quad \text{otherwise.}$$

For single-lane traffic circles, a new model is suggested using headway data used in Tanyel *et al.*'s (2007) study. The obtained results have shown that although negative exponential distribution represents the observed headway values more accurately than Cowan M3 distribution, capacity models derived from Cowan M3 distribution give the best results. The parameters of Cowan M3 distribution are estimated using the method of moments. Δ is assumed as 2 sec and α and λ are found according to this assumption. The estimated a values are taken as α depended variable and regressed with Δq_c values. From regression analysis, the following model is obtained:

$$\alpha = 1.11 - 1.47\Delta q_c \quad \text{if } \Delta q_c \geq 0.07 \quad (12)$$

$$\alpha = 1.0 \quad \text{otherwise}$$

Fig. 1, different models of α are compared with single-lane traffic circles. The Fig. 1 also indicates that a new model gives close results with Plank model for low circulating flows and with Akçelik and Chung (1994) and Akçelik (1998, 2003, 2007) models for high circulating flows. The results show that Turkish drivers choose travelling more independently under light traffic conditions. This is probably because drivers feel more insecure under heavy traffic conditions at single-lane traffic circles. This is found to be an important point that may affect the capacity of the minor flow.

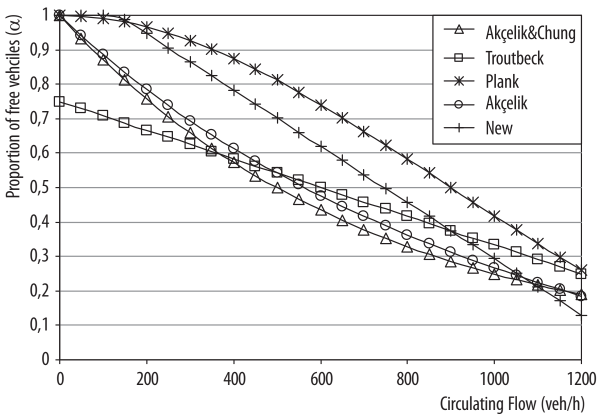

Fig. 1. Comparison of different models for the proportion of free vehicles in single-lane traffic circles

The other important parameters of capacity calculations determine the acceptance of the critical gap and follow-up time values. For simplicity, the models suggested by Troutbeck (1991) are used in this study (Equations 13 and 14).

$$T_{0dom} = 3.37 - 0.000394Q_c - 0.0208D_i + 0.0000889D_i^2 - 0.395n_e + 0.388n_c; \quad (13)$$

$$T_{osub} = 2.149 + 0.5135T_{0dom}\frac{Q_{dom}}{Q_{sub}} - 0.8735\frac{Q_{dom}}{Q_{sub}}; \quad (14)$$

$$T_i = (3.6135 - 0.0003137Q_c - 0.3390w_e - 0.2775n_c)T_{0i}. \quad (15)$$

In the equations, T_{0dom} is follow-up time between vehicles in the dominant minor approach lane, T_{osub} is follow-up time between vehicles in the sub-dominant minor approach lane; Q_{dom} is traffic flow in the dominant minor approach lane; Q_{sub} is traffic flow in the sub-dominant minor approach lane, T_{0i} is the follow-up time of i_{th} approach lane; T_i is the critical gap acceptance value of drivers entering from i_{th} approach lane. D_i, w_e, n_e and n_c are the same as given in Table 1.

3.3. Regression Analysis Method

As mentioned before, TRL method is the leading capacity analysis method that depends on regression analysis. On the other hand, to properly calibrate the model, the geometric characteristics of traffic circles should be proper and between certain limits (Akçelik 1998). However, this may not be possible for all traffic circles that should be analyzed. For example, in most cases, no flare is designed at traffic circles in Turkey. For this reason, in this study, simpler models for single and multi lane traffic circles are investigated.

Researchers in some previously conducted investigations in Germany used exponential functions reflecting relations between minor and major flows. This study examines linear and exponential functions for a similar purpose. More detailed results are presented in the following sections of this paper.

4. Analysis

4.1. Single-Lane Traffic Circles

To predict the capacity of single-lane traffic circles, ln(R+1) term in equation (5) is taken as a depended variable and the method of regression analysis is applied between ln(R+1) and Q_c. The results of different observation sites are given in Table 2 disclosing that term 't' in equation (4) varies between '3.60 sec' (3600/1000) and '3.27 sec' (3600/1100).

Table 2. Results of regression analysis for single-lane traffic circle

Observation Area	Regression equation coefficients		R^2
	A	*B*	
Bostanlı 1	–0.0165	0.0010	0.999
Bostanlı 2	–0.0149	0.0011	0.995
Soğukkuyu	–0.0198	0.0011	0.999
Egean Univ.	–0.0248	0.0010	0.999
Gündoğdu 1	–0.0339	0.0011	0.996
Gündoğdu 2	–0.0146	0.0010	0.999
Sanayi	–0.0571	0.0011	0.993

Fig. 2 shows the results of regression analysis that includes all data. The figure clarifies that value 't' can be accepted as '3.6 sec (3600/1000)'. The capacity of single-lane traffic circles can be found using the equation given below:

$$Q_{ecap} = \frac{Q_c}{(e^{Q_c/1000} - 1)}. \quad (16)$$

For further investigation, regression analysis has been performed showing the relation between Q_{ecap} and Q_c (Fig. 3). Fig. 3 indicates the results of the carried out regression analysis. The conducted studies have shown that an exponential model gives better results than linear models (Tanyel *et al.* 2006). The predicted capacity values obtained from equation (16) are also plotted on the Figure which also presents that equation (16) gives acceptable results of moderate circulating flows but under estimates for low major flow conditions. On the other hand, the regression analysis model reveals a better representation of the observed data.

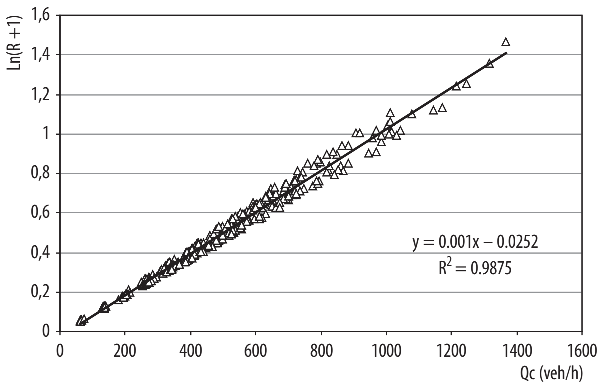

Fig. 2. Results of the regression analysis of all data on the single-lane traffic circle

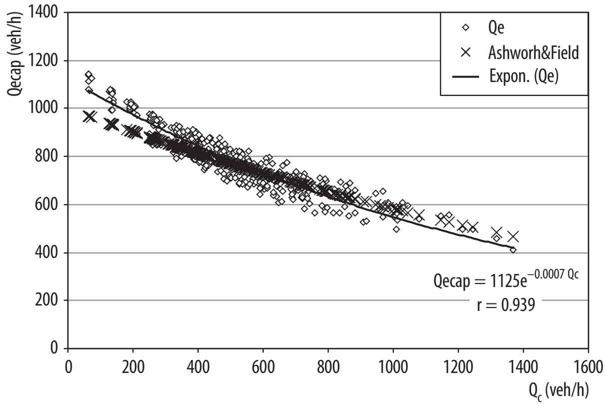

Fig. 3. Results of regression analysis and comparison of Ashworth & Field method

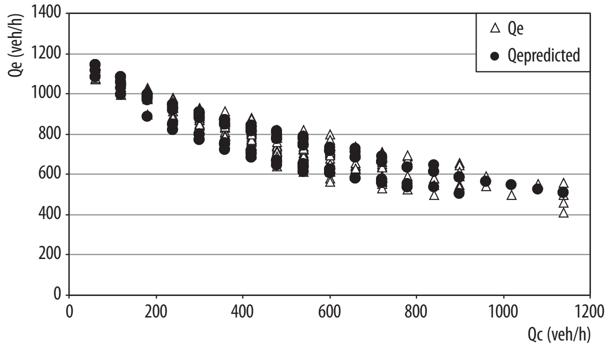

Fig. 4. The plot of the observed and predicted capacity values of the critical gap acceptance method

Fig. 4 discloses the results of the critical gap acceptance method plotted against the observed data values. The figure clearly indicates that the critical gap acceptance method represents the actual capacity values better than Ashworth and Field (1973) method and the regression analysis model.

To compare the performance of models, linear regression analysis is performed between the observed and predicted capacity volumes. The received results are shown in Table 3 indicating that the gap acceptance model gives better results than the others. Regression analysis gives the second best result.

Table 3. Comparison of capacity models and observed data

Capacity analysis model	Regression equation coefficients		*r*
	A	*B*	
Gap Acceptance	–26.01	1.01	0.977
Regression Analysis	125.53	0.85	0.945
Ashworth & Field	264.45	0.64	0.939

4.2. Multi-Lane Traffic Circles

Although its applicability for single-lane traffic circles is discussed in the previous section, Ashwort and Filed (1973) have suggested their model for traffic circles having two entry lanes. According to the procedure, if ln(2R+1) is taken as a dependent variable and regression lines are fitted to the observed data for each of the weaving section, the following results in Table 4 are obtained.

Table 4. Results of the regression analysis of multi-lane traffic circles

Observation area	Regression equation coefficients		r
	A	B	
Alsancak Gar	–0.0504	0.0010	0.939
Cumhuriyet	–0.0146	0.0009	0.938
Montrö	0.0259	0.0010	0.839
Lozan	0.0156	0.0014	0.959

The table demonstrates that except for Lozan Intersection, 't' parameter can be accepted as 3.6 sec (3600/1000). However, observations at Lozan Intersection give the highest correlation factor. For a more generalized approach, regression analysis was performed on all collected data on multi-lane traffic circles (Fig. 5). The results have revealed that 't' can also be assumed as 3.6 sec for multi-lane traffic circles. Thus, the capacity of the multi-lane traffic circle approach having two entry lanes can be calculated using the following equation:

$$Q_{ecap} = \frac{2Q_c}{(e^{Q_c/1000} - 1)}. \quad (17)$$

As for single-lane traffic circles, regression analysis is performed for multi-lane intersections (Fig. 6). As can be seen from the Figure, both linear and exponential relations are investigated between Q_{ecap} and Q_c. The worked out equations are as follows:

$$Q_{ecap} = 2107e^{-0.806Q_c},\ r = 0.815; \quad (18)$$

$$Q_{ecap} = 2537e^{-0.0007Q_c},\ r = 0.776. \quad (19)$$

The linear model gives a slightly higher coefficient of correlation.

Another step is to apply the gap acceptance model described in the previous sections of the study. This is performed under two assumptions:

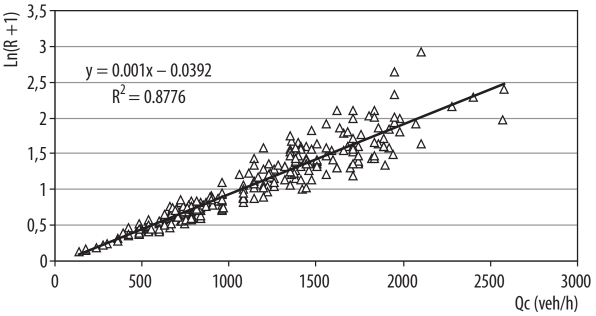

Fig. 5. Results of the regression analysis of all data on the multi-lane traffic circle

1. No gap forcing or priority sharing exist.
2. Gap forcing or priority sharing conditions are valid.

The capacities of traffic circles are calculated using equation 11 for the first assumption. When the predicted values are compared with the observed capacities using linear regression, the following result is obtained:

$$Q_{epredicted} = 0.780Q_{eobserved} + 169.38, \quad (20)$$

where: $Q_{epredicted}$ and $Q_{eobserved}$ are the predicted and observed capacity values respectively. In equation A, the coefficient should be close to '1' and interception should be close to zero, however, intercept is found to be rather high. A better solution can be obtained by investigating the applicability of the second assumption.

The theories of traditional gap acceptance have assumed that the drivers of the minor-stream accept any gap greater than the critical gap and reject any gap smaller than the critical gap (Troutbeck and Kako 1999). However, when an approach or lane of the approach is highly saturated, gap forcing or reverse priority can occur. Hagring (1998) has defined gap forcing as a situation in which a minor-stream driver forces the major stream to give way which means that the minor-stream driver uses a gap so small that the major-stream drivers have to decelerate or completely stop. Like gap forcing, different merging systems can be defined. Reverse and shared priorities are two of those. Reverse priority can be defined as the complete reversal of priorities (Hagring 1998). Shared priority is the condition where the priority of the major-stream vehicles was not necessarily absolute (Troutbeck and Kako 1999). Troutbeck (1998) suggested constant 'C' used to reflect the effect of limited priority merge conditions:

$$C = \frac{1 - e^{-\lambda T_0}}{\left[1 - e^{-\lambda(T - T_0 - \Delta)} - \lambda(T - T_0 - \Delta)e^{-\lambda(T - T_0 - \Delta)}\right]} \quad (21)$$

$$for\ T_0 + \Delta > T > \Delta.$$

For multi-lane traffic circles, equation (21) can be rewritten as:

$$C_M = \frac{1 - e^{-\Lambda T_0}}{\left[1 - e^{-\Lambda(T - T_0 - \Delta)} - \Lambda(T - T_0 - \Delta)e^{-\Lambda(T - T_0 - \Delta)}\right]}, \quad (22)$$

where: C_M is the correction constant for multi-lane traffic circles. Note that equation (22) is valid only if all circulating lanes have the same Δ value. Therefore, the capacity of the approach can be modified to:

$$q_{ecap} = C_M \Lambda \prod_i \frac{\alpha_i q_{ci}}{\lambda_i} \frac{e^{-\Lambda T}}{e^{-\Lambda\Delta}(1 - e^{-\Lambda T_0})}. \quad (23)$$

The observed and predicted capacity values found using equation (23) and are compared applying linear regression analysis (Fig. 6). It is clear that equation (23) gives acceptable results with the observed capacity values (Equation 23 is suggested for one approach lane. Capacity for each approach lane is calculated separately. Approach capacity is the total capacity of all approach lanes.).

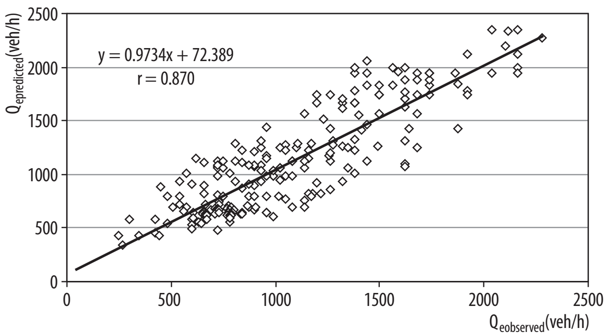

Fig. 6. Comparison of the observed and predicted values using equation (23)

For comparison, linear regression was performed between other models (Equations 17, 18 and 19) and the observed data. The results are presented in Table 5.

Table 5. Comparison of capacity models and observed data on multi-lane traffic circles

Capacity analysis model	Regression equation coefficients *A*	Regression equation coefficients *B*	*r*
Gap Acceptance	169.38	0.780	0.866
Gap Acceptance *(with limited priority merge)*	72.39	0.973	0.870
Regression Analysis *(linear function)*	362.25	0.664	0.815
Regression Analysis *(exponential function)*	337.99	0.669	0.826
Ashworth and Field	438.49	0.536	0.825

The coefficients of the variation of all models are quite close with each other. However, the gap acceptance method of a limited priority merge assumption gives the best result as its interception is the smallest and 'A' coefficient is close to '1'. Ashworth and Field (1973) model is the least valid model.

5. Conclusions and Suggestions

This study has suggested a simple capacity calculation method for single and multi lane traffic circles. For this purpose, besides traditional methods like gap acceptance and regression analysis, the applicability of the model produced by Ashworth and Field (1973) has been investigated. Consequently, the following results have been obtained:

- The method of critical gap acceptance gives more accurate results than the other models. The results of the critical gap acceptance method shows that, at multi-lane traffic circles, limited priority merge conditions should be taken in consideration in the majority of cases. This situation probably originates from the unstandardized geometric structure of intersections.
- A simple application of the regression analysis method has been applied in the article. Although they give poorer results than the method of gap acceptance, a more detailed study should be carried out to improve the validity of regression methods.
- Ashworth and Filed method gives the least accurate results of all models for both single and multi lane traffic circles. This is due to its rough structure. However, it may be used as an initial approach in order to have an idea of the performance of traffic circles but it cannot be applied for further analysis.
- Like regression analysis, the further studies of the critical gap acceptance method should be conducted.

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