ANALYSIS OF ROUNDABOUT CAPACITIES IN THE CITY OF ZAGREB

Nikola Šubić B. Eng.,
Hrvatska osiguravajuća d.d.,
Ivana Lucića 2a, 10000 Zagreb, Croatia
nikola.subic@hok-osiguranje.hr,

Hrvoje Pilko B. Eng.
University of Zagreb
Faculty of Transport and Traffic Sciences
Vukelićeva 4, 10000 Zagreb, Croatia
hrvoje.pilko@fpz.hr

Marko Matulin B. Eng.,
University of Zagreb
Faculty of Transport and Traffic Sciences
Vukelićeva 4, 10000 Zagreb, Croatia
marko.matulin@fpz.hr

ABSTRACT

In the recent twenty years the roundabouts have become the most frequent form of intersections on the roads of European countries. In practice there are many methods for the calculation of the roundabout capacities, and all are specific and implemented for various types of roundabouts. Capacity calculations require high-quality field measurements and the collection of necessary data. The paper presents the latest scientific methods to calculate roundabout capacities – method of linear regression and method according to Ning Wu. They have been used to analyze the capacity and efficiency indicators according to real measurements at fifteen roundabouts located in the urban and suburban parts of the City of Zagreb. The research results should be used, among other things, for the selection method that would be used in the calculation of the roundabout capacities in Croatia.

KEYWORDS: roundabout, capacity, capacity calculation methods, average delay method, vehicle queuing length

1 INTRODUCTION

The issues that accompany the introduction of roundabouts in the Republic of Croatia represent a certain "re-run" from other countries. Generally speaking, there is certain distrust, in experience and lack of the basic guidelines for designing, as well as of norms and rules for the users. However, the increasing implementation of roundabouts has resulted also in insufficient research regarding their safety and capacity. In order to model the capacities of roundabouts numerous models from different countries have been developed and the very selection of the model requires good field measurements with the collection of necessary data.

The paper presents several basic models with comparisons and analysis of their implementation for the actual data collected by measurements. The measurable data have been collected at fifteen roundabouts with single-lane entry/exit and circular lane in the city of Zagreb. The analysis of the traffic flows at roundabouts means assessment of capacities and adaptability of the observed solution to the needs of various types of traffic and different users, as well as of the function itself in the traffic network of the city. The indicators that can be measured and considered in the qualitative assessment of the intersection are: capacity reserve, degree of saturation, time losses and length of vehicle queues at the entry into the intersection.

2 METHODS OF LINEAR REGRESSION AND UNIVERSAL METHOD ACCORDING TO NING WU

2.1 Method of liner regression

In the mid 1990s in Germany many recordings were carried out at roundabouts, mainly at roundabouts with single lanes (1/1). Beier and Mutschler found in 1995 that the capacities exceed somewhat the capacity values obtained in 1993. This increase was also observed at the roundabouts with two lanes each (2/2). The measuring data at roundabouts were measured by video cameras, and were analysed by the method of empirical regression [5].

$$q_{u,\max} = A - B \cdot q_k \tag{1}$$

where:

$q_{u,max}$ - roundabout entry capacity,
q_k - traffic intensity on circular roadway,
A, B - regression coefficients [5, 9].

The analysis of the newly measured data using linear regression has yielded values for A and B that have optimally adapted to the actual measured data (Table 1 and Figure 1). These data have been verified by the simulation method, and it was found that the regression analysis, apart from having data dispersion in case of 1-minute interval, can reliably assess the capacity even in intervals that exceed one hour [5, 9].

Table 1: Parameters A and B for linear regression [5, 9]

Number of entry lanes	Number of lanes in the roundabout	A	B
1	1	1218	0.74
2	2-3	1250	0.53
2	2	1380	0.50
2	3	1409	0.42

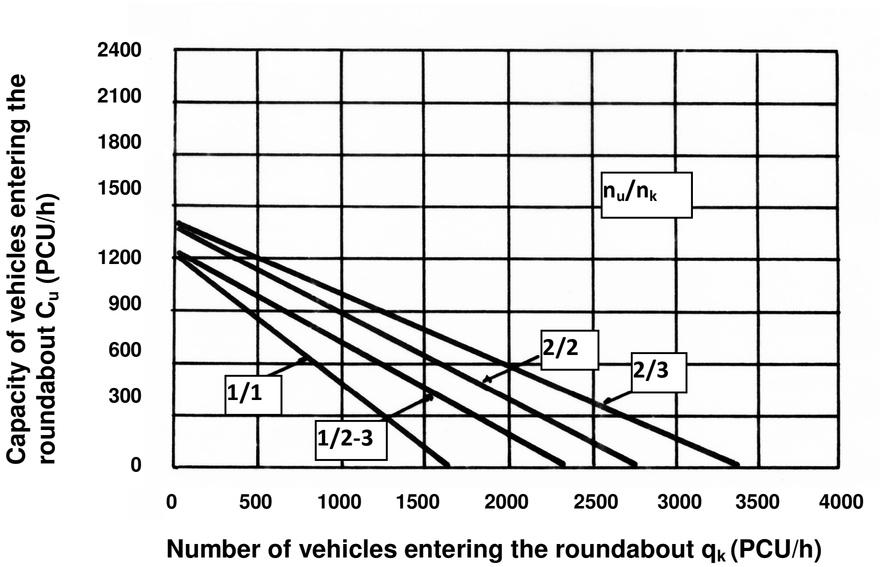


Figure 1: Lines of linear regression [5, 9]

Figure1 shows that in the area of weaker flow of vehicles in the roundabout, the entry capacity to the roundabout obtained by older formulas was smaller. The most probable reason for this are the better designed elements of roundabout construction and changed motorists' attitudes at roundabouts, the so-called familiarization factor (motorists get used to various new types of roundabouts). However, it should be emphasised that the increase of capacities is minimal. The line of linear regression represents a simple method to calculate roundabout capacities, exclusively of those roundabouts that have been designed with a single lane each (1/1). For those roundabouts that have more than one lane, e.g. (n_u/n_k) = (1/2), (1/3), (2/2) and (2/3), the capacity curves have concave shapes. This means that the line of linear regression can be applied only at roundabouts where (n_u/n_k) = (1/1). The study of roundabouts with several lanes has shown that the possible intensity of vehicles inflow is systematically above the results obtained by equation $q_{u,\max} = A - B \cdot q_k$. This effect cannot be described by linear regression line. In order to solve this problem, in 1997 Ning Wu developed a universal formula using the fundamentals of the queuing theory [5, 8, 9].

2.2 Method according to Ning Wu

In 1997 Ning Wu developed a universal formula for which it is characteristic that it takes into consideration the number of lanes at the entry and in the roundabout. The curve obtained by the formula developed by Wu describes the roundabout capacity better than the exponential functions that had been used by Brilon and Stuwe. This curve has the advantage that in its closed theoretical concept based on the queuing theory, it describes the conditions at the roundabout that can in fact be considered as a series serving channel [5, 8].

$$q_{u,\max} = \left[1 - \frac{\tau \cdot q_k}{n_n}\right]^{n_k} \cdot \frac{n_u}{t_{sl.}} \cdot \exp\left[-q_k \cdot (t_0 - \tau)\right] \qquad (2)$$

where:

$q_{u,max}$ - roundabout entry capacity,
q_k - intensity of vehicles in circular lane,
n_u - number of entry lanes,
n_k - number of lanes in the roundabout;

$$t_0 = t_g - \frac{t_{sl.}}{2} \quad (3)$$

t_g - critical time gap in the vehicle stream,
$t_{sl.}$ - time gap between vehicles in the stream,
τ - minimal time gap between vehicles in the roundabout [5, 8].

The value of parameters that appear in the universal equation such as t_q ,t_{sl} and τ can be taken over from the single-lane intersections. For the calculation Wu has taken that: t_g = 4.12 s; t_{sl} = 2.88 s and τ = 2.10. With these initial values, the minimal time gap between vehicles in the roundabout was determined $\tau = 2.10^9$ which corresponds to the real conditions of vehicle flow in a roundabout. In order to see better the differences of the results of the equation set by Ning Wu and the equation of linear regression the standard deviations have been calculated (Table 2).

Table 2: Evaluating the values of individual equations [6]

Number of lanes	Standard deviation	Standard deviation	Number of measurements n
approach/circle	Linear regression (PCU/h)	Ning Wu (PCU/h)	
1/1	175	178	1504
1/2	203	179	636
1/3	185	136	243
2/2	352	382	4576
2/3	371	279	637

It may be seen from Table 2 that at single-lane intersections (1/1) the equations do not show differences. In case of those intersections which have fewer entry lanes than there are lanes in the circular flow, Wu's equation exhibits better results. Interesting is the case of two-lane roundabouts n_u/n_k = (2/2) where the linear regression equation shows a substantially better result. If the starting point is that the standard deviation is the assessment for equation validity then the linear regression equation for intersections (2/2) has priority over Wu's equation. The reason could be because the measured data contain time gaps of even up to 5s [9]. For roundabouts (1/2), (1/3) and (2/3) Wu's equation yields better results. Figure 2 shows the results obtained by the linear regression equation and with new Wu's equation [5, 8].

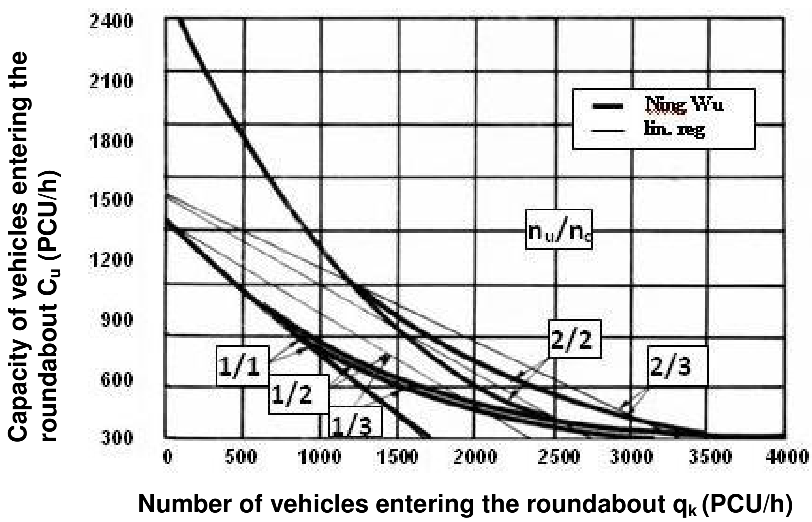


Figure 2: Comparing the curves according to Wu's equation and linear regression equation [5, 8]

Figure 2 shows that the universal formula matches well the line of linear regression for single-lane intersections (1/1). In intersections with several traffic lanes the universal formula obviously shows better results. It should be emphasised here that the observed capacity of roundabouts is the value which can be maximally accepted (served) by one entry during one hour. Such values can be expected in the construction of new roundabouts which means that they may be the basic data in planning. Care should be taken that in case of greater capacities also longer vehicle queues have to be taken into account. Therefore, for practical capacity 100 PCU/h have to be subtracted from the obtained values [5, 8].

2.3 Average time delay

Average time of delay is a standard parameter which is used to measure the efficiency of round and classical intersections. The average time of delay is the necessary time the driver spends waiting for a proper moment of merging into the roundabout traffic flow, without endangering themselves and other traffic participants. The formula that shows the delay is [6]:

$$d = \frac{3600}{c_{m,x}} + 900T \cdot \left[\frac{q_u}{c_{m,x}} - 1 + \sqrt{\left(\frac{q_u}{c_{m,x}} - 1 \right)^2 + \frac{\left(\frac{3600}{c_{m,x}} \right) \cdot \left(\frac{q_u}{c_{m,x}} \right)}{450T}} \right] \tag{4}$$

where:

d - average time of delay (s/PCU),

q_u - number of vehicles entering the roundabout (PCU/h),

$c_{m,x}$ - approach capacity (PCU/h),
T - analyzed period of time (for the whole hour T = 1, for 15 minutes T = 0.25) [6].

Average time of delay grows exponentially with the increase in the entry capacity into the circular lane. Small changes in the capacity have large influence on the huge vehicle entry delays. Special attention should be paid to the capacity of vehicles entering the circular lane and that the degree of saturation does not exceed 1.0 since otherwise the average time of delay grows exponentially regarding larger delays [6].

Table 3: Level of service of roundabouts according to average delay control [6]

Level of service for roundabouts	Average control of delay (s/veh.)
A	0 – 10
B	> 10 – 15
C	> 15 – 25
D	> 25 – 35
E	> 35 – 50
F	> 50

2.4 Length of vehicle queuing

The length of vehicle queuing represents an essential parameter in roundabout design. It is defined as the length of queues of vehicles waiting to enter the circular lane. In designing the roundabouts it should be taken into consideration that in 95% of cases the length of vehicle queues in front of the entry into the circular traffic flow is not exceeded. The formula for 95% queuing is [6]:

$$Q95 = 900T \cdot \left[\frac{q_u}{c_{m,x}} - 1 + \sqrt{\left(1 - \frac{q_u}{c_{m,x}}\right)^2 + \frac{\left(\frac{3600}{c_{m,x}}\right) \cdot \left(\frac{q_u}{c_{m,x}}\right)}{150T}} \right] \cdot \left(\frac{c_{m,x}}{3600}\right) \tag{5}$$

Q_{95} - 95% vehicle queuing (PCU),
q_u - number of vehicles entering the circular lane (PCU/h),
$c_{m,x}$ - approach capacity (PCU/h),
T - analyzed period of time (for the whole hour T = 1, for 15 minutes T = 0.25) [6].

Since the level of usage should not exceed 1.0, during intersection design the valid length of vehicle queuing should be taken (Figure 3).

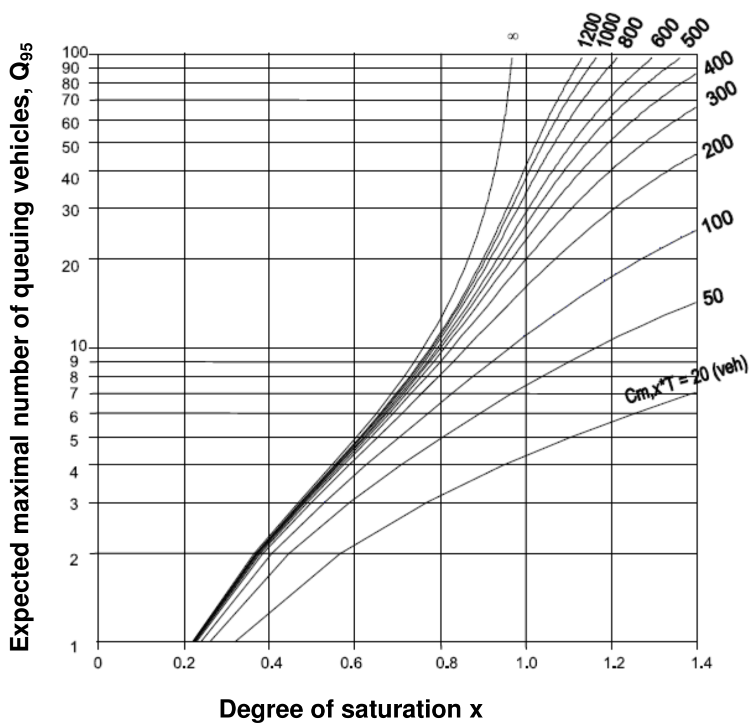


Figure 3: Dependence of degree of saturation and vehicle queuing [6]

3 ANALYSIS OF ROUNDABOUT CAPACITIES IN THE CITY OF ZAGREB

The analysis and assessment of capacities was carried out at fifteen roundabouts in central and peripheral part of the City of Zagreb. The key role in their selection was their physical location in the traffic network of the city of Zagreb, and the design elements (figure 4), especially the number of lanes at approaches and in the circular roadway. The intersections have been divided into three groups according to the size of the external diameter: Mini RKT ($Dv \leq 26$ m), Mini roundabouts in the function of small roundabouts and Small RKT ($22 \text{ m} \leq Dv \leq 35$ m), and the breakdown and the design elements are presented in Table 4.

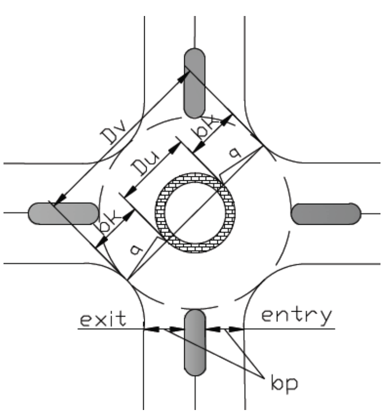


Figure 4: Design elements of roundabout

Table 4: Design parameters of selected roundabouts [1]

Red. br.	Oznaka	Naziv raskrižja	Kružni kolnik				Privozi			Napomena
			Dv (m)	Du (m)	bk (m)	q (±%)	n (-)	bp (m)	uvoz/ izvoz(m)	n-tračnost (k/p)
	a) m -	Mini RKT (Dv ≤ 26 m)								
01.	RKTm	Sv.Duh-Kunišćak	20	6	7	-1,5	3	7,1	3,5/3,6	1
02.	RKTm	Bukovčev trg	20	8	6	-2	4	6,25	3,0/3,25	1
03.	RKTm	Ljudevita Posavskog-Zavrtnica A	19	6	6,5	-	3	7	3,5/3,5	1/1 (2x RKT)
04.	RKTm	Ljudevita Posavskog-Zavrtnica B	19	6	6,5	-	3	7	3,5/3,5	1/1 (2x RKT)
	(m) M -	Mini raskrižja u funkciji malih								
05.	RKT(m) M	Petretićev trg	22,2	5,7	8,5	-1,5	3	8,5	4,5/4,0	1
06.	RKT(m) M	Bundek-S.R.Njemačke	26	10	5,5	-1,5	3	7,25	4,0/3,25	1
07.	RKT(m) M	Šestinski vijenac-Pantovčak	25	9	8	-4	3	9	4,5/4,5	1
08.	RKT(m) M	Vinogradska-Podolje	10	4	3	-	4	7	3,5/3,5	1
	b) M -	Mala RKT (22m ≤ Dv ≤ 35 m)								
09.	RKTM	Petrova-Jordanovac	25	12	6,5	-1,5	4	8	3,5/4,5	1
10.	RKTM	Lavoslava Ružičke-Ivana Lucića	32	21	5,5	-1,5	3	8	4,0/4,0	1
11.	RKTM	Petrova-Bukovačka	30	10	7,5	-2	4	7	3,0/4,0	1
12.	RKTM	Bukovačka-Barutanski j.	30	15	6	-3	3	7,5	3,5/4,0	1
13.	RKTM	Voćarska-Bijenička	22	13	4,5	-3	4	8	4,0/4,0	1
14.	RKTM	Miroševečka-Sunekova	24	7	5	-1,5	4	7	3,5/3,5	1
15.	RKTM	Radnička cesta-Petruševec	40	28	6	-0,5	4	6,5	3,0/3,5	1

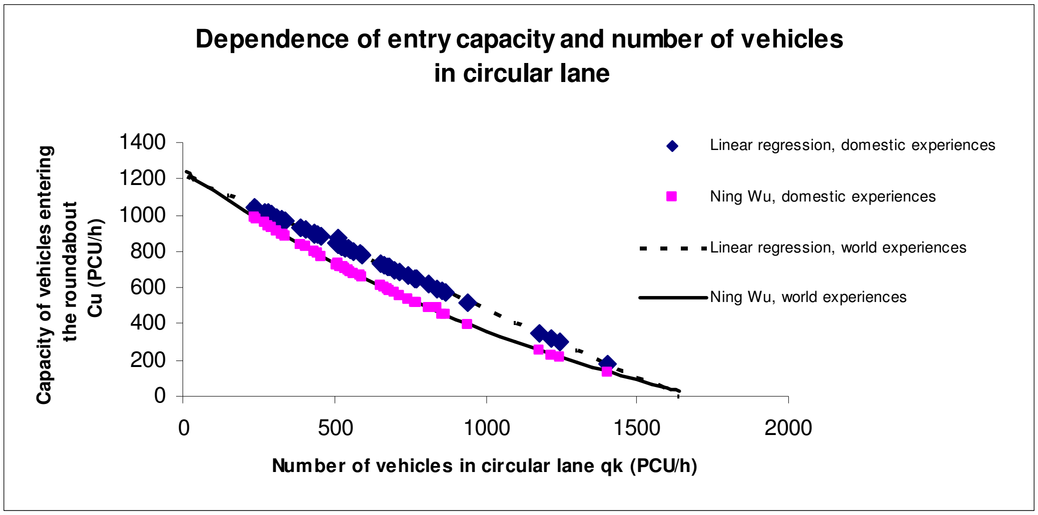
Data from Table 4 are essential for the calculation of roundabout capacities using the linear methods since the linear method uses geometrical elements of the circular lane, approach and number of lanes at the entry into the circular lane. The methods of calculating roundabout capacities according to Ning Wu is based on the number of entry lanes into the roundabout and in the circular lane. Table 5 shows all the traffic parameters with calculated capacity, calculated according to the mentioned methods.

Table 5: Capacity and presentation of other traffic indicators of the selected roundabouts

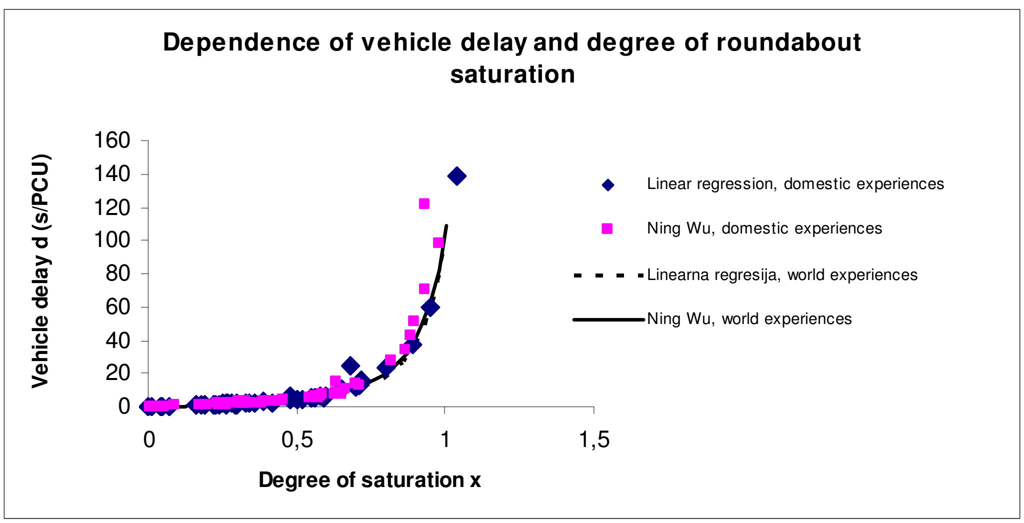
	METHODS			LINEAR REGRESSION				NING WU			
Roundabout name	Number of vehicles in rounda.			Capacity	Level of usage	Time and number of waiting vehicles		Capacity	Level of usage	Time and number of waiting vehicles	
	At entry	At exit	Circular flow								
	qu (PCU/h)	qi (PCU/h)	qk (PCU/h)	C (PCU/h)	*100 (%)	d (s/PCU)	Q95%(PCU)	C (PCU/h)	*100 (%)	d (s/PCU)	Q95%(PCU)
Sveti Duh - Kunišćak											
Approach 1	418	410	527	828	0,5	4,43	3,02	712	0,59	7,16	4,14
Approach 2	216	306	535	822	0,26	1,56	1,06	705	0,31	2,26	1,31
Approach 3	427	345	445	889	0,48	3,74	2,74	785	0,54	5,46	3,5
Bukovčev trg (Mašićeva)											
Approach 1	480	274	386	932	0,52	4,1	3,14	839	0,57	5,72	3,92
Approach 2	434	472	592	780	0,56	5,77	3,68	656	0,66	10,61	5,58
Approach 3	224	264	554	808	0,28	1,71	1,14	689	0,33	2,52	1,43
Approach 4	3	131	514	872	0	0,014	0,01	723	0,00	0,02	0,015
Ljudevita Posavskog - Tuškanova											
Approach 1	184	194	279	1012	0,18	0,79	0,66	944	0,19	0,92	0,72
Approach 2	429	242	269	1019	0,42	2,57	2,16	954	0,45	3,08	2,42
Approach 3	141	318	456	881	0,16	0,78	0,57	775	0,18	1,03	0,66
Ljudevita Posavskog - Tuškanova											
Approach 1	250	865	943	520	0,48	6,41	2,72	396	0,63	15,37	4,81
Approach 2	583	166	328	975	0,59	5,47	4,36	895	0,65	7,46	5,41
Approach 3	438	240	745	667	0,65	10,21	5,47	536	0,82	27,89	10,95
Pertetićev trg											
Approach 1	50	55	244	1037	0,04	0,17	0,15	979	0,05	0,19	0,16
Approach 2	306	208	239	1041	0,29	1,44	1,24	984	0,31	1,65	1,34
Approach 3	214	307	337	969	0,22	1,05	0,84	886	0,24	1,29	0,95
Bundek - S.R. Njemačke											
Approach 1	475	693	744	667	0,71	13,1	6,92	537	0,88	42,93	15,36
Approach 2	275	122	526	829	0,33	2,16	1,48	713	0,39	3,17	1,86
Approach 3	507	442	679	715	0,7	12,06	6,86	587	0,86	34,35	14,01
Šestinski vijenac - Pantovčak											
Approach 1	305	194	292	1002	0,3	1,57	1,3	931	0,33	1,88	1,45
Approach 2	283	171	403	920	0,3	1,74	1,32	823	0,34	2,29	1,56
Approach 3	229	452	515	837	0,27	1,62	1,12	722	0,32	2,32	1,38
Vinogradska - Podolje											
Approach 1	447	453	538	820	0,55	5,25	3,52	703	0,64	8,87	5,03
Approach 2	300	309	526	829	0,36	2,46	1,69	713	0,42	3,67	2,15
Approach 3	323	302	523	831	0,39	2,76	1,89	715	0,45	4,15	2,44
Approach 4	39	45	544	815	0,05	0,22	0,15	697	0,06	0,3	0,17
Petrova - Jordanovac											
Approach 1	467	391	590	781	0,6	6,82	4,34	659	0,71	13,04	6,81
Approach 2	139	242	666	725	0,19	1,18	0,7	597	0,23	1,83	0,9
Approach 3	384	427	563	801	0,48	4,14	2,72	681	0,56	6,81	3,78
Approach 4	190	120	520	833	0,23	1,28	0,88	718	0,26	1,81	1,075
Lavoslava Ružičke - Ivana Lucića											
Approach 1	125	495	505	844	0,5	4,32	3	731	0,58	6,81	4,05
Approach 2	12	14	435	896	0,01	0,05	0,04	794	0,02	0,06	0,04
Approach 3	498	426	433	898	0,55	4,98	3,66	796	0,63	7,51	4,85
Petrova - Bukovačka - Prilesje											
Approach 1	373	192	1219	316	1,18	392	41,86	230	1,62	1178	78,61
Approach 2	985	1141	1400	182	5,41	8141	405,14	136	7,24	11598	427,95
Approach 3	202	267	1244	297	0,68	25,04	5,69	216	0,94	121,23	14,25
Approach 4	984	944	1179	346	2,84	3373	323,56	252	3,90	5331,02	369,98
Bukovačka cesta - Barutanski jarak											
Approach 1	242	165	312	987	0,24	1,18	0,97	911	0,27	1,43	1,08
Approach 2	318	372	389	930	0,34	2,01	1,55	836	0,38	2,64	1,82
Approach 3	156	179	335	970	0,16	0,71	0,57	888	0,18	0,86	0,63
Voćarska - Bijenička											
Approach 1	478	318	840	596	0,8	23,13	10,34	488	0,98	97,88	24,39
Approach 2	171	358	768	650	0,26	1,98	1,06	519	0,33	3,42	1,46
Approach 3	436	598	813	616	0,71	13,88	6,75	486	0,90	51,12	15,96
Approach 4	427	238	651	736	0,58	6,73	4,03	609	0,70	13,61	6,56
Miroševečka cesta - Sunekova											
Approach 1	179	272	677	717	0,25	1,67	0,99	588	0,30	2,69	1,3
Approach 2	819	545	584	786	1,04	138,57	44,25	664	1,23	449,79	91
Approach 3	40	30	858	583	0,07	0,45	0,22	454	0,09	0,77	0,28
Approach 4	416	607	868	576	0,72	15,86	7,15	447	0,93	70,06	18,4
Radnička cesta - Petruševec 1.											
Approach 1	664	593	701	699	0,95	59,37	24	570	1,16	338	62,84
Approach 2	122	120	772	647	0,19	1,29	0,69	516	0,24	2,17	0,92
Approach 3	572	631	774	645	0,89	37,23	16,26	514	1,11	259,58	47,18
Approach 4	153	167	715	689	0,22	1,49	0,85	559	0,27	2,43	1,12

3.1 Analysis and comparison of research results

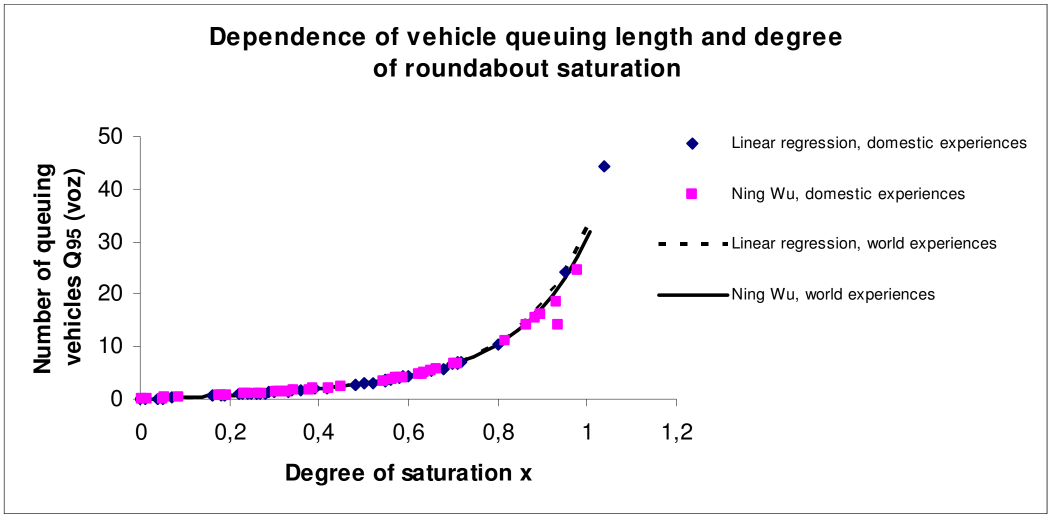
In order to make clearer comparison and presentation of results of the carried out research in the city of Zagreb with the results of previous research, using the mentioned methods, the following graphs are given:



Graph 1: Dependence of entry capacity and number of vehicles in circular lane



Graph 2: Dependence of vehicle delay and degree of roundabout saturation

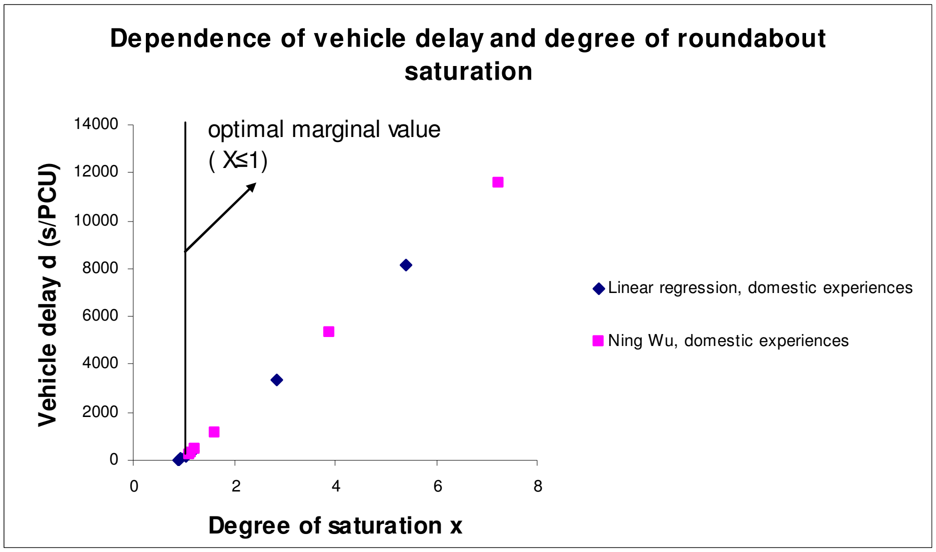


Graph 3: Dependence of vehicle queuing length and degree of roundabout saturation

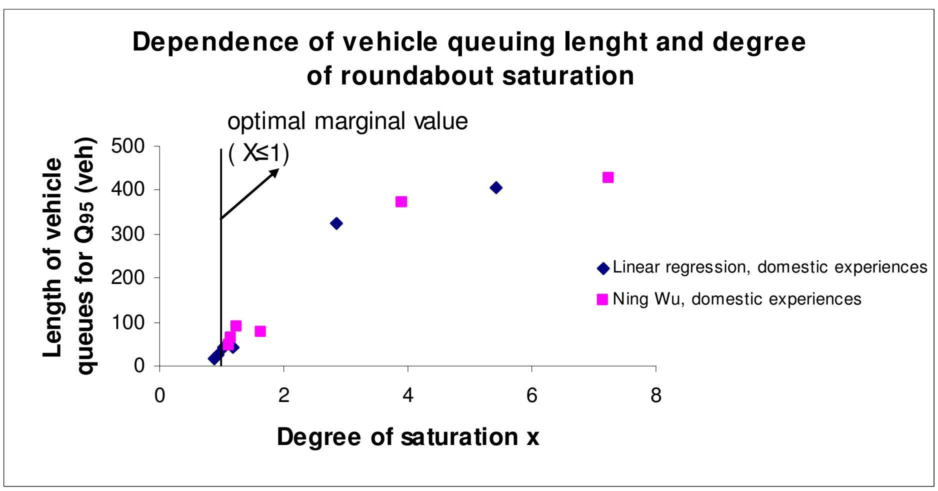
It may be concluded that the results obtained by our measurements, in relation to foreign results are within the limits of tolerances. This confirms the thesis that foreign methods can be used in Croatia for the calculation of roundabout capacities with a single lane at entry/exit and the circular lane. However, out of fifteen roundabouts only three deviate from the foreign results, i.e. they are not within the tolerance limits. The mentioned calculations for roundabouts that are not within the tolerance limits are presented in Table 6 and Graphs 4 and 5.

Table 6: Calculated values that deviate significantly from the tolerance limits

	METHODS			LINEAR REGRESSION				NING WU			
Roundabout name	Number of vehicles in rounda.			Capacity	Level of usage	Time and number of waiting vehicles		Capacity	Level of usage	Time and number of waiting vehicles	
	At entry	At exit	Circular flow								
	qu (PCU/h)	qi (PCU/h)	qk (PCU/h)	C (PCU/h)	*100 (%)	d (s/PCU)	Q95%(PCU)	C (PCU/h)	*100 (%)	d (s/PCU)	Q95%(PCU)
Petrova - Bukovačka - Prilesje											
Approach 1	373	192	1219	316	1,18	392	41,86	230	1,62	1178	78,61
Approach 2	985	1141	1400	182	5,41	8141	405,14	136	7,24	11598	427,95
Approach 3	202	267	1244	297	0,68	25,04	5,69	216	0,94	121,23	14,25
Approach 4	984	944	1179	346	2,84	3373	323,56	252	3,90	5331,02	369,98
Miroševečka cesta - Sunekova											
Approach 1	179	272	677	717	0,25	1,67	0,99	588	0,30	2,69	1,3
Approach 2	819	545	584	786	1,04	138,57	44,25	664	1,23	449,79	91
Approach 3	40	30	858	583	0,07	0,45	0,22	454	0,09	0,77	0,28
Approach 4	416	607	868	576	0,72	15,86	7,15	447	0,93	70,06	18,4
Radnička cesta - Petruševec 1.											
Approach 1	664	593	701	699	0,95	59,37	24	570	1,16	338	62,84
Approach 2	122	120	772	647	0,19	1,29	0,69	516	0,24	2,17	0,92
Approach 3	572	631	774	645	0,89	37,23	16,26	514	1,11	259,58	47,18
Approach 4	153	167	715	689	0,22	1,49	0,85	559	0,27	2,43	1,12
Index:											
inadequate traffic indicators											
adequate traffic indicators											



Graph 4: Dependence of vehicle delay and degree of roundabout saturation



Graph 5: Dependence of vehicle queuing length and degree of roundabout saturation

The limit value is reflected in the degree of saturation $X \leq 1$, whereas all other degrees of saturation for the values $X \geq 1$ cannot support the roundabout capacity and other traffic parameters, since large waiting queues are formed as well as big time losses that are reflected in delays. Observing the mentioned three roundabouts that have degrees of saturation greater than $X \geq 1$ it can be seen that large queues are formed, from 200 to 400 vehicles, and the delay of 300 to 12.000 s/PCU which is not acceptable, of course. Obviously, the mentioned three intersections, not only differ in comparison, but neither do they satisfy the majority of the mentioned traffic indicators, thus causing reduced capacity and safety of roundabouts which at some time has to lead to the requirement of their reconstruction. The factors that influence certain deviation from marginal values are: physical location of intersections in the traffic network of the city, traffic congestion and the direction of movement of individual traffic flows through the intersection, intersection design elements, traffic flow quality and motorists' behaviour.

4 CONCLUDING CONSIDERATIONS

The carried out field recordings and results analysis, and by comparing the obtained results using two mathematical methods, it may be claimed that the capacity and traffic indicators are within the tolerance limits and the acceptable values (see Graphs 1, 2, 3). For these reasons the implementation of the latest scientific methods and experiences in domestic conditions is applicable at roundabouts of the form (1/1 – one lane at approach and in circular lane). The carried out research represents the basis for further research both for the roundabouts of the studied shape, and for other shapes (1/2, 1/3, 2/1, 2/2, etc.). However, out of the analyzed fifteen roundabouts in the city of Zagreb, the results of only three roundabouts are not within the tolerance limits. Their calculated values of capacities and traffic indicators deviate significantly from the limit values and greatly question the observed roundabouts regarding their capacity and their very safety (see Graphs 4 and 5). In the near future, the queues and delay control will be the fundamental basis for the capacity and safe traffic flows at roundabouts, both in Croatia and in the world.

REFERENCES

1. Korelacija oblikovnosti i sigurnosti u raskrižjima s kružnim tokom prometa (Correlaton of Design and Safety at Intersections with Circular Traffic Flow - study under way, 2008-2011), Faculty of Transport and Traffic Sciences, Zagreb.

2. Legac, I.: Raskrižja javnih cesta/Cestovne prometnice II (Public Road Intersections / Roads II), Faculty of Transport and Traffic Sciences, Zagreb, 2008.

3. Evidencija prometnih nezgoda na javnim cestama Hrvatske (Register of traffic accidents on public roads of Croatia). Annual of Ministry of the Interior for years 1998-2007, Department of Traffic Police, MUP Bulletins, Zagreb, 2002. (1998)

4. Smjernice za projektiranje raskrižja u naseljima sa stajališta sigurnosti prometa (Guidelines for design of intersections in populated areas from the aspect of traffic safety) (proposal). Faculty of Transport and Traffic Sciences and HC/PGZ, Zagreb, 2004.

5. Mateljak, P.: Proračun kapaciteta kružnih raskrižja (Calculation of roundabout capacities) (workbook), Ulm-Zagreb, 2003.

6. Highway Capacity Manual (HCM 2000). Spec. Rpt. 209, 4th Edition, Washington DC, 2000.

7. Merkblatt für die Anlage von kleinen Kreisverkehrsplätzen. FSV, Köln, 1998.

8. Ning W.: Eine universele Formel für Berechnung der Kapazität der Kreisverkehrsplätzen, Bochum, 1997.

9. Brillon, W., Stuwe, B., Drews, O.; Sicherheit und Leistungfähigkeit von Kreisverkehrsplätzen, Ruhr-University, Bochum, 1993.