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Transport and Telecommunication Institute, Lomonosova 1, LV-1019, Riga, Latvia

MICROSIMULATION USING FOR CAPACITY ANALYSIS OF ROUNDABOUTS IN REAL CONDITIONS

Andrea Gavulová, Marek Drličiak

University of Žilina, Faculty of Civil Engineering, Department of Highway Engineering
Univerzitná 8251/1, SK-010 26 Žilina, Slovak Republic
Ph.:+421-41-513 9512. E-mail: andrea.gavulova@fstav.uniza.sk, marek.drliciak@fstav.uniza.sk

Two technical regulations for capacity estimation of roundabouts are valid in the Slovak Republic at the present time. Each of these regulations is based on a different theory of capacity estimation which affects the outcome of the capacity of roundabouts and their evaluation. The capacity of various roundabouts was estimated according to both methods in the previous analysis made at our department [3] and in some cases different results of the evaluation were achieved. The question is: which one of the mentioned theories better reflects a real capacity of the roundabout? For this reason some of the existing roundabouts in the town Žilina were selected and they were evaluated according to both methods and a micro simulation using PTV Vissim software. The geometrical parameters of roundabout, real driving behaviour (speed, proportions, acceleration, etc.) and also pedestrian behaviour were taken into account in the microscopic models. The first assumption for capacity evaluation by a microscopic traffic model is a calibration process which is based on traffic surveys results. Thus created models allow several capacity analyses during the peak traffic loading. Then, the results of micro-simulation can be compared with the capacity evaluation according to the technical regulations. The article deals with creation and calibration of microscopic traffic models and with the mentioned comparing of results.

Keywords: capacity, roundabout, micro-simulation, model, traffic

1. Introduction

The quantity of small single-lane roundabouts constantly increases in the Slovak cities. New roundabouts are projected like new traffic solutions of intersections or the reconstruction of uncontrolled intersections. The reasons for their using are mostly enhancement of safety, reduction of traffic accidents, speed reduction before entry into a town and higher traffic capacity in comparison with uncontrolled intersections. A precise project has to include so traffic load and so important factors and parameters (e.g. the geometry of roundabout, surrounding impact). These parameters are not included in capacity evaluation process according to the Slovak Technical Regulations.

Nowadays two Technical Regulations for capacity estimation of roundabouts are valid in the Slovak Republic ([1] and [2]). Each of these regulations is based on different theory of capacity estimation which affects the outcome of the capacity of roundabouts and their evaluation. Several capacity analysis of roundabouts according to the both methods of capacity evaluation has been made at author's' workplace. Different results of the evaluation were achieved [3]. To analyse differences of methodologies were selected small single-lane roundabouts in Žilina. One of the conditions for selection was standard geometry which is mostly used in the Slovak Republic. The selected roundabouts were evaluated according to the technical regulations and also using the micro-simulation in PTV VISSIM software. The entire evaluating process using micro-simulation provides a high-quality calibration model based on real values of traffic surveys. These real values in our case were determined according to detailed analysis of 16 hours video recording of the traffic process and real crossing of the roundabouts.

In the article some results of traffic survey on selected roundabouts in Žilina and their capacity evaluations according to the two Technical Regulations are presented. In addition, modelling and calibration process of the traffic flow on these roundabouts in certain conditions and capacity evaluations using results of simulation are described. Finally the results are compared with each other.

2. Traffic Survey on Roundabouts in Žilina

The single-lane roundabouts capacity was analysed for the three selected network nodes (R1, R2 and R3) in Žilina town. The first roundabout was selected for long queues on its entries. The traffic load was not the main reason of traffic problems. The roundabout is situated only 250 m from traffic-light controlled intersection and only 50 m from a bus stop.

The high value of traffic load was the main reason for selection of two roundabouts (R2 and R3). The long queues are often event on the entries of mentioned roundabouts during the peak hour. Both of roundabouts connect the large shopping centres situated near the town centre. The distance between roundabouts is only 190 m (Figure 3) and the main and the most loaded direction on the booth roundabouts is from residential quarter to town centre.

The traffic surveys on the roundabouts were realized by indirect method. A traffic flow was digitally recorded and rewrite into the sheets. The length of vehicle queue was noted at the second roundabout R2 like a special parameter. The Figure 1 shows the traffic load of roundabouts R2 and R3 in the time. Traffic load histograms present equable state (2500 pcu/hour) during the approximately 11 hours. Both roundabouts have not real reserve in capacity considering construction-geometrical parameters. That means that increasing in traffic volumes will be the reason of another traffic problem. By the lack of capacity the long queue are created daily (600 – 1000 m). Figure 2 shows the traffic load and movement on roundabouts R2 and R3 during the peak hour. The straight directions are the most loaded.

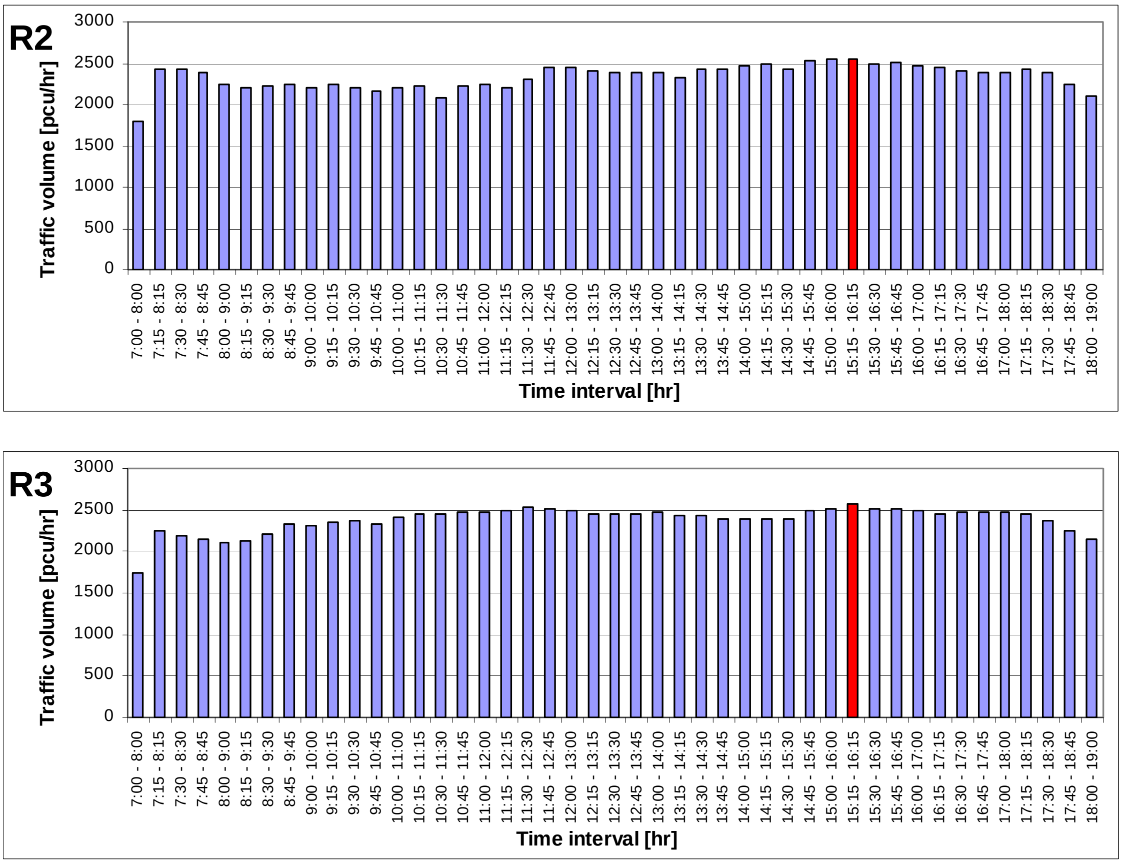


Figure 1. Traffic load histograms on roundabouts R2 (3 entrances) and R 3 (4 entrances)

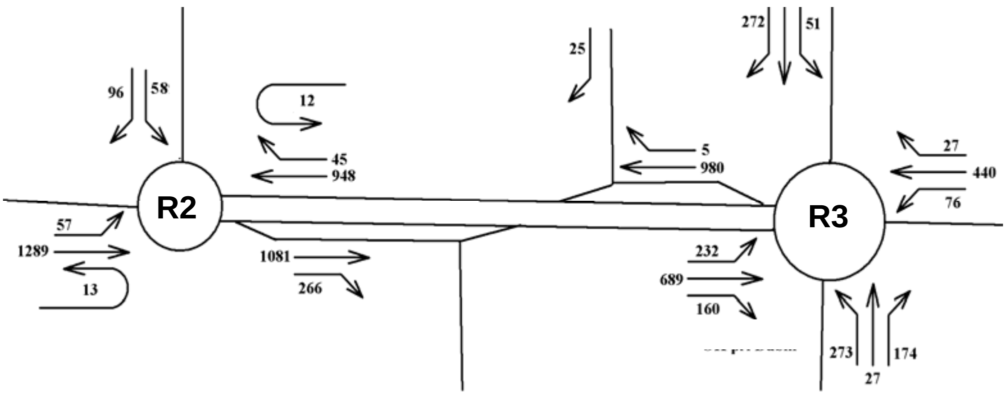


Figure 2. Traffic load and movement on roundabouts R2 and R3 during peak hour

3. Capacity Evaluation of Small Roundabouts According to Regulations

The capacity of small roundabouts is calculated like a system of uncontrolled intersections with one-way operation (direction). Calculation process generally uses two different principles: Empirical relations and Time Gap theory. Two mentioned theories are included in the two Slovak Technical Regulations for capacity evaluation of roundabout entrances:

- **The Technical Regulation TP 04/2004** [1] – issued from the Swiss empirical method of capacity calculation according to BOVY (1991). The method is based on experimental measuring (traffic volumes counting) in time when the roundabouts is overloaded (the capacity is spent).

- **The Technical Regulation TP 10/2010** [2] – issued from method according to WU (1997) which is based on theory of waiting time gaps. The entrance capacity is depended on values of critical time gap, consecutive time gap and on theoretical dividing of time gap in the traffic flow. This method is included in German guideline HBS (2001).

3.1. Capacity calculation according to TP 04/2004

The theoretical capacity of a roundabout entrance is calculated according to TP 04/2004 [1] from equation:

$$K_{\max,e,i} = 1500 - \frac{8}{9} \cdot \left(\beta \cdot M_o + \alpha \cdot M_a\right) \tag{1}$$

where

$K_{max,e,i}$ – maximal capacity of entrance [pcu/hour],

M_o – traffic volume on the circle between an evaluated entrance and an exit [pcu/hour],

M_a – traffic volume on an exit lane [pcu/hour],

α – coefficient expressing the effect of distance “b” between the entrance collision point and exit collision point of evaluated entrance,

β – coefficient of traffic volume influence on circle for various number of circle lanes.

The main disadvantage of this method is using the coefficients taken from abroad experimental measuring. The values of these coefficients (α and β) have not been validated for Slovak conditions. This method of capacity calculation does not consider roundabout geometry parameters (inscribed circle diameter, entrance radius, exit radius, lane width, etc.), either speed or roundabout pass time.

3.2. Capacity calculation according to TP 10/2010

The theoretical capacity of a roundabout entrance is calculated according to TP 10/2010 [2] like maximal number of entering vehicles which use acceptable time gap. The basic capacity of an entrance is calculated from equation:

$$K_{zi} = 3600 \cdot \left(1 - \frac{t_{\min} \cdot M_{okr}}{n_k \cdot 3600}\right)^{n_k} \cdot \frac{n_z}{t_f} \cdot e^{-\frac{M_{okr}}{3600}\left(t_g - \frac{t_f}{2} - t_{\min}\right)} \tag{2}$$

where

K_{zi} – basic capacity of entrance [pcu/hour],

M_{okr} – traffic volume on the circle [pcu/hour],

n_k – number of circle lanes [-],

n_z – number of entrance lanes [-],

t_g – critical time gap (considering 4,1) [s],

t_f – consecutive time gap (considering 2,9) [s],

t_{min} – minimal time gap between two vehicles on circle lane (considering 2,1) [s].

The disadvantage of described method is using the not calibrated time gaps for Slovak traffic conditions. The values were taken from German guideline HBS. The time gap values have not been defined for different pass speed. This method of capacity calculation also does not consider roundabout geometry parameters (except the number of lanes).

3.3. Capacity evaluation

The evaluation of quality of traffic flow movement on roundabouts is essentially identical in the TP 04/2004 and TP 10/2010 (TP – Technical Regulation). The average waiting time at an entrance of roundabout cannot be greater than the value of average standard waiting time. This average waiting time appreciates the level of service (LOS). The LOS is expressed by six degrees of quality of traffic flow (Table 1). The degree F means that the entrance has not free capacity; and the saturation is higher than 1,0. The average waiting time at entrance of roundabout depends on calculated reserve of capacity. The reserve of capacity presents the difference between calculated capacity and real traffic volume on entrance. The real traffic volume and the entrance capacity are very important for capacity evaluation of roundabouts.

The values of average scale of reserve of capacity are shown in Table 1 including the average waiting time. The values correspond to the degrees of LOS (the data are assigned from graphical dependence in the Technical Regulation).

The previous analysis [3] proved that the theoretical performance of roundabout (i.e. capacity evaluation process) is depended on chosen Technical Regulation. Therefore our capacity evaluation analysis was completed with results from micro-simulations.

Table 1. Average waiting time for individual LOS

Level of service (LOS)	**A**	**B**	**C**	**D**	**E**	**F**
Average waiting time t_c [s]	≤ 10,0	≤ 20,0	≤ 30,0	≤ 45,0	> 45,0	- - - [1)]
Average scale of capacity reserve [pcu/hr]	≥ 330	170 - 329	115 - 169	70 - 114	50 - 69	< 50
[1)] LOS "F" – the degree of saturation is greater than 1,0						

4. Capacity Evaluation of Roundabouts Using Micro-Simulation

Micro-simulation in software PTV Vissim was used for capacity estimation of roundabouts at the Department of Highway Engineering, Faculty of Civil Engineering. The software PTV Vissim is a part of software for transportation planning and traffic engineering named PTV Vision. The PTV Vissim is a microscopic, flexible tool for traffic simulations which consider human traffic behaviour. It is useful for traffic modelling, visual approach of traffic flow behaviour on the traffic network and intersections. The microscopic model considers the roundabout geometry parameters, real driving behaviour (speed, acceleration, etc.) and also pedestrian behaviour. The output data from a model could be used for traffic analysis and evaluation of the suitability of proposed solutions. The average and maximal values of waiting time, the average and maximal length of queue of vehicles are the most used output data from a microscopic model of roundabouts. These average values are calculated from 60 seconds intervals. The results are presented as time function of queue of vehicles or as waiting time. The final outputs resulting from Technical Regulations evaluation represent only average hourly values.

Outputs of micro-simulation reflect not only the specific roundabout geometry, but also other influencing factors (e.g. bus stop, other intersections and turns situated near by evaluated roundabout). These may reduce capacity value of roundabouts. This fact is a main advantage of micro-simulation.

4.1. The modelling of traffic flows on roundabouts and calibration of the model

The three selected roundabouts (R1, R2 and R3) were modelled in the PTV Vissim. The Figure 3 shows roundabouts R2 and R3. Our models of roundabouts were created on exact background files (.dwg) considering all geometric parameters. These models consist of links, connectors, routes, etc. Pedestrian crossing, another turns, bus stops, etc. situated near by roundabouts were also defined in models. Traffic volume, routing of vehicles and traffic composition was determined from the traffic survey and defined in the model for each entrance and direction. The example of traffic rout setting is shown in the Figure 3.

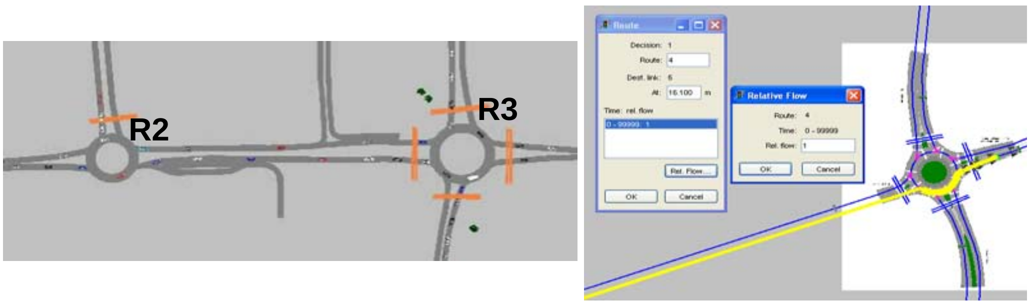


Figure 3. Modelled roundabouts R2 a R3 (left) and set-up of routes in Vissim (right)

In order to achieve accurate results, calibration of the microscopic models was carried out. The Vissim program tool actually contains a number of simulation parameters that can affect the simulation results (network, vehicle and driver characteristics). The calibration process was focused mainly on the parameters, defined in the Vissim in the so-called Priority Rules. In the parameters themselves the rules of driving, the minimum critical gap time (drivers' reaction time) and the minimum headway are determined. The Vissim determines priority to a certain participant according to the set Priority Rules. Depending on the situation at the conflict area, an individual decides either to continue with their route or to wait for more suitable traffic conditions. At the marked spot, they must always examine both pre-determined conditions (minimum headway and the minimum gap time), before continuing with their route. More conflict markers (green) can appertain to one stop line (red). The Figure 4 shows settings of Priority Rules function in Vissim.

Mentioned parameters of Priority Rules defined in Vissim were set for all entrances independently. That means independently for passenger cars and for heavy vehicles. The calibration of the model was based on analysis of average values from 12-hour video record of traffic. The example of the described parameters for the roundabout R1 is presented in the Table 2. The pedestrian crossings were also included in the Priority Rules definitions.

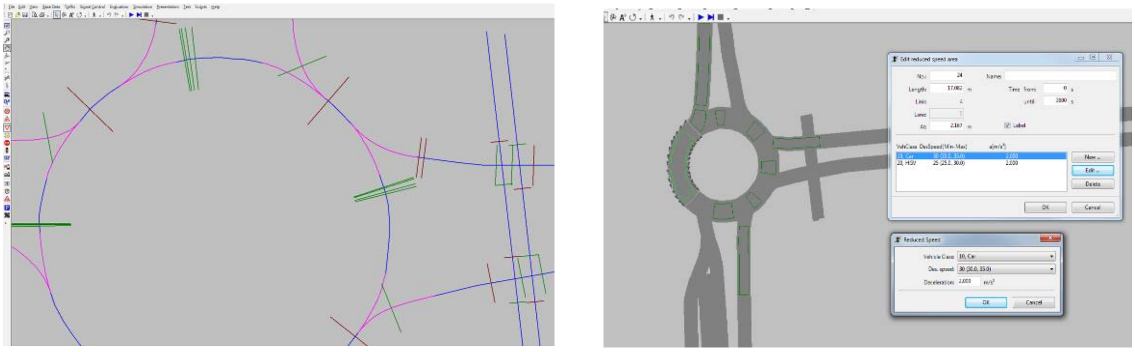


Figure 4. Priority rules (left), reduced speed areas (right) in Vissim

Next step in the calibration process of the models was setting the real speed of all defined kinds of vehicles. The speed was monitored at the entrance, exit and on the roundabout circle lane. The radius of an entrance and exit lanes of roundabouts affects speed reduction. The higher values of radius due to more fast-pass through a roundabout and positive modify capacity of roundabout. The widths of lane of the roundabout R1 are visible in the Table 2. The passing speed on small roundabout is relative low (the diameter of centre island is about 7-10 m). The speed of passenger cars was reduced from 50 km/hr to 30 km/hr, speed of heavy vehicles from 40 km/hr to 25 km/hr in the R1 and from 40 km/hr to 20 km/hr in the R2 and the R3, respectively. Described changes are showed on the Figure 4. The speed was adjusted not only by detailed analysis of the video recording but also on the basis of multiple real pass of passenger car through the roundabout.

Table 2. General and simulation parameters of roundabout R1

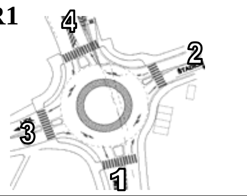
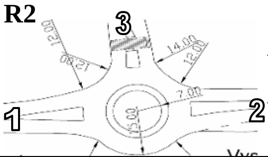
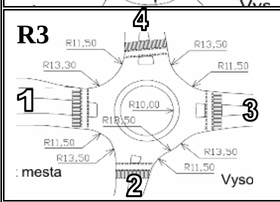
General parameters of roundabout							
Number of entrances					4		
Roundabout diameter / island radius					31 m / 10 m		
Pass speed of passenger vehicle / heavy vehicle					30 km/hr / 25 km/hr		
Entry parameters of roundabout and Priority Rules							
Entrance	**Entrance radius [m]**	**Exit radius [m]**	**Width lane [m]**	**Min. gap time [s]**		**Min. headway [m]**	
				passenger	**truck**	**passenger**	**truck**
1	12,0	14,0	3,5	3,0	3,5	3,2	4,0
2	17,0	12,0	3,0	3,0	3,8	3,2	4,2
3	12,0	13,0	3,25	3,0	4,0	3,5	4,5
4	12,0	11,5	3,5	3,4	3,6	3,2	4,3

The model was functional and real reflected the traffic flow behaviour in roundabouts after definition of all important parameters. The final results (average waiting time, average length of queue etc.) were compared with the real values. The microscopic model was iterative calibrated. The comparison the results from micro-simulation capacity analysis with results from capacity analysis according to Slovak Technical Regulations was possible after mentioned calibration process.

5. Comparison of Capacity Evaluations of Roundabout According to Technical Regulations and Micro-Simulation

The Table 3 presents the results from capacity analysis according to the both Technical Regulations. The final results are comparable in relation to LOS. The exceptions are only for entrance 2 at the R1 and the R2. The both Technical Regulations evaluated the R1 with capacity reserve, the R2 and the R3 without capacity reserve. The mentioned disagreement in evaluation can be seen for the R2, the entrance 2. LOS determined according to the TP 04/2004 is "F" and according to the TP10/2010 it is "E". The results from the TP 10/2010 approach to the real results from micro-simulation (similar state is on the roundabout R3, the entrance 2).

Table 3. Capacity evaluation of small roundabouts according to the Slovak Technical Regulations and VISSIM simulation

Scheme of roundabout	*Entrance*	*Traffic volume [pcu/hr]*	*TP 04/2004*			*TP 10/2010*			*VISSIM*	
			Capacity reserve [pcu/hr]	t_c	*LOS*	*Capacity reserve [pcu/hr]*	t_c	*LOS*	t_c	*LOS*
R1 	1	1630	297	12	**B**	263	13	**B**	14	**B**
	2		597	7	**A**	441	8	**A**	6	**A**
	3		759	5	**A**	570	6	**A**	1	**A**
	4		348	10	**A**	392	10	**A**	39	**D**
R2 	1	2518	- 341	>90	**F**	- 196	>90	**F**	>90	**F**
	2		- 232	>90	**F**	44	55	**E**	83	**E**
	3		437	10	**A**	299	11	**B**	1	**A**
R3 	1	2507	- 8	>90	**F**	- 45	>90	**F**	>90	**F**
	2		40	63	**E**	- 22	>90	**F**	>90	**F**
	3		211	18	**B**	237	15	**B**	4	**A**
	4		290	12	**B**	171	20	**B**	34	**D**

The monitored values of average waiting times, average length of queues from micro-simulation were recorded every 60 seconds on all of roundabout entrances. The data from detectors in the R1 are shown in the Figure 6 (waiting time) and Figure 7 (length of queues). The capacity evaluation of the R1 according the Slovak Technical Regulations is satisfying (LOS is "A" respectively "B"), but the LOS from micro-simulation is "D" what reflects real condition during the peak hours. The results confirmed 150 m length of queue and longest waiting time on entrance 4. This situation is caused by the near frequented bus stop. It is situated only 50 m before the entrance to the roundabout. The second impact on capacity has also the high rate of buses which is caused by the main bus lines routing to north directions (43 buses per peak hour). The next limiting factor was the adjoining intersection with low capacity. The queue from this intersection influenced the monitored roundabout R1. The capacity evaluation according to the Slovak Technical Regulations does not regard to the mentioned factors.

The similar results were calculated for the roundabout R3 where the LOS of the entrance from residential area Vlčince (the entrance 4) according to the Technical Regulations was evaluated "B" and evaluation using the micro-simulation was "D". The result of micro-simulation reflects real situation, which is caused by geometrical parameters and high volumes on pedestrian crossing.

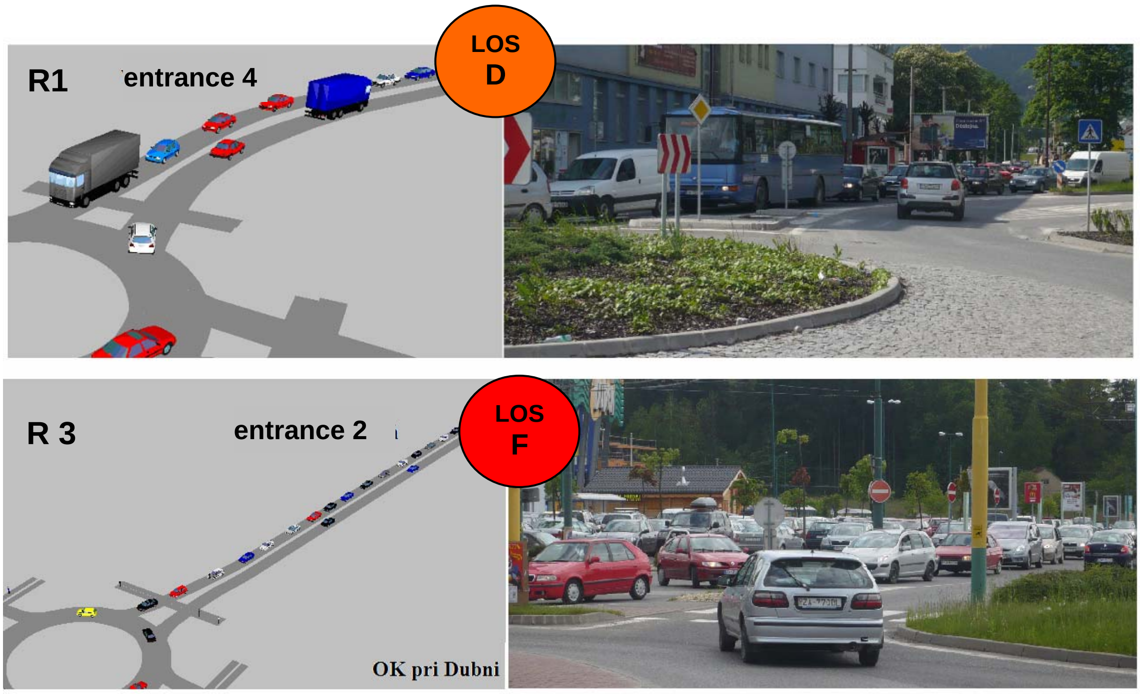


Figure 5. Traffic queues on the roundabout R1 (the entrance 4) and the roundabout R2 (the entrance 2), micro-simulation (left) and real situation (right)

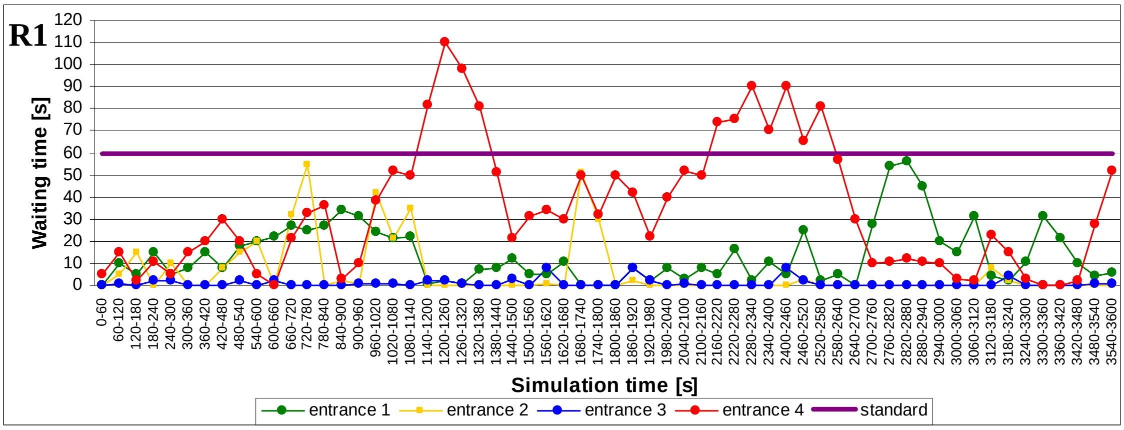


Figure 6. Average waiting time on the entrances for the roundabout R1

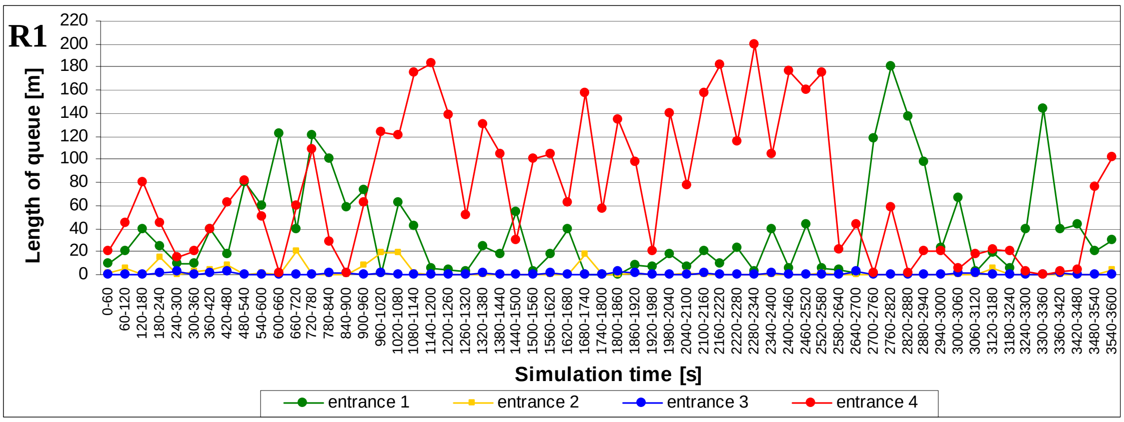


Figure 7. Average length of queue on the entrances for the roundabout R1

6. Conclusions

The detailed analysis of video records from traffic surveys allowed the set-up of input parameters in the microscopic models. The results from the models were comparable with real measured data on roundabouts. Consecutive comparison of final data with the results from evaluations according to the Slovak Technical Regulations showed differences in some cases. The mentioned differences were caused by real impact factors, which were not included in the Slovak Technical Regulations (bus stop, near intersection with low capacity, etc.) For these reasons, a microscopic model of roundabout is an accepted way for evaluation of its capacity in difficult surrounding conditions.

The time and economic demands included in creation and calibration process of models caused that the micro-simulations of intersections (in general) could not be used each time. The results from described capacity analysis of "independent" roundabouts prove using of the Slovak Technical Regulations. The evaluation process according to the Technical Regulations is very ready. Moreover the results from TP10/2010 and results from micro-simulations are similar. Described conclusions have to be verified using many of examples of traffic loads schemes. Our next steps will related to detailed analysis of other intersections with different traffic loads and different movements. The data will be also compared with data calculated according to the Technical Regulations. We will analyse the two-lane roundabouts.

The application of calibrated microscopic models is one of the ways for verification of capacity analysis of roundabouts. That means that it is possible to choose the right regulation in dependence on type of roundabout and on surrounding conditions. The new view on roundabouts capacity analysis allows to project new proposal solutions (for example for increasing of efficiency and safety on roundabouts). For instance, the microscopic model could be also used for capacity analysis of turbo-roundabouts, because evaluation process of their capacity is not included in Slovak Technical Regulations.

References

1. *Technical Regulation TP 04/2004 Design of roundabouts on the roads and urban roads*. Bratislava, Slovak Republic, 04/2004, p. 44. (In Slovak)
2. *Technical Regulation TP 10/2010 The roads capacity calculation*. Bratislava, Slovak Republic, 10/2010, p. 197. (In Slovak)
3. Gavulová, A., Jandačka, D. *The capacity evaluation of roundabouts according to Slovak Technical Regulations: Report RVT 2009*. Žilina, Slovak Republic, 02/2010, p. 43. (In Slovak)

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