COMPARISON OF TRAFFIC FLOW CHARACTERISTICS OF SIGNAL CONTROLLED INTERSECTION AND TURBO ROUNDABOUT

ALICA KALAŠOVÁ[1], SIMONA SKŘIVÁNEK KUBÍKOVÁ[2], KRISTIÁN ČULÍK[3], JÁN PALÚCH[4]

Abstract

In the Slovak republic, there is an increase of building roundabouts in both urban and non-build-up areas. The construction of roundabouts in urban areas brings mainly calming of traffic intensity. A roundabout in non-build-up areas could be built only within certain conditions. In this paper, we have been studying a small roundabout location and its traffic characteristics in the city of Hlohovec. In some cases, a small roundabout could be very good solution for exceeded traffic flow capacity of signal controlled intersections as well as for intersections with a high number of traffic incidents. But in our case, a small roundabout is not suitable for such intensity of vehicles as we measured in transport survey. So we focused on other possibilities how to improve this current situation. We have decided to make a proposal of signal controlled intersection as well as a turbo roundabout and compare the results of traffic characteristics of each proposal. We have made several simulations of each variant of traffic situation, using transport-planning software Aimsun, and calculate average values of all recorded traffic characteristics. As inputs, we have used intensities and other basic data obtained from transport survey. Using simulations outputs of transport planning software, we have been able to compare a current state with signal controlled intersection and turbo roundabout. Traffic characteristics of turbo roundabout show significant improvements compare to signal controlled intersection, f.e. in delay time (more than 68%), travel time (more than 22%), number of stops (more than 73%). Turbo roundabout seems to be the best solution for traffic organising at this chosen intersection in the city of Hlohovec, regarding travel time, delays, number of stops and safety at all.

Keywords: traffic flow; turbo roundabout; signal controlled intersection; simulation

[1] University of Žilina, Faculty of operation and economics of transport and communications, Univerzitná 1, 010 26 Žilina, Slovakia, e-mail: alica.kalasova@fpedas.uniza.sk

[2] University of Žilina, Faculty of operation and economics of transport and communications, Univerzitná 1, 010 26 Žilina, Slovakia, e-mail: simona.kubikova@fpedas.uniza.sk

[3] University of Žilina, Faculty of operation and economics of transport and communications, Univerzitná 1, 010 26 Žilina, Slovakia, e-mail: kristian.culik@fpedas.uniza.sk

[4] University of Žilina, Faculty of operation and economics of transport and communications, Univerzitná 1, 010 26 Žilina, Slovakia, e-mail: jan.paluch@fpedas.uniza.sk

1. Introduction

The city of Hlohovec representatives have asked our university to make a transport survey on the selected small roundabout because of rising intensities and related congestions. Residents of the city complained on traffic situation – long time in congestions, overloaded adjacent roads, often delays of public transport. This type of intersection should not be situated on I. class roads and roads with high intensity because of small capacity and permeability of small roundabout. So our department accepted the requirement of the city and tried to solve this situation and make some proposals how to improve the current traffic situation and make residents lives simpler [12]. The first step was to carried out a transport survey at the selected roundabout and obtained intensities of traffic flow during twelve hours. We have made the survey from 6 a.m. to 6 p.m. and recorded all modes of transport (individual vehicles, trucks, freight vehicles, buses, motorcycles and bikes). These data are the base for next step, creating microscopic simulations in Aimsun.

The chosen junction is four-armed small roundabout. It is situated between cities of Leopoldov and Hlohovec. The road of II. class crosses the Priemyselná street at roundabout. The entrances number 3 and 4 have a connection lane on a through lane at roundabout exit. At the entrance number 2, there is a pedestrian crossing. Between entrances 3 – 4 and 4 – 1, there are branches of roundabout. There are also several interest points in the immediate vicinity of the chosen roundabout. You can see the layout of roundabout in the Figure 1.

The entrance number 1 consists of road II/513, where a high intensity of traffic occurs because this communication represents an important transit route from/to Leopoldov, Trnava, Sereď and connection to D1 highway.

The entrance number 2 exits in city district Šulekovo. In this part of the city Hlohovec there are several manufacture companies such as Faurecia Interior Systems, Peter Wetter Slovakia, Coavis Slovakia, Plastic Omnium as well as municipal collection yard.

The entrance number 3 represents an exit from Hlohovec in one way and in opposite direction you can get Hlohovec city through the bridge over the river Váh. Behind the bridge, there is another roundabout, which allows you to change your route direction to Piešťany along the road II/507 or use connection on road II/514 to Topoľčany.

Using the entrance number 4 you can get to hypermarket Tesco and shopping centre called Váh, which is visited by many inhabitants of the nearby towns and villages, whether for shopping or work duties.

Fig. 1. The chosen roundabout with marked entrances

2. Transport survey on the chosen small roundabout

We carried out the transport survey at the chosen roundabout on Wednesday 13th of September 2019 and it took 12 hours. We began in early morning hour from 6 a.m. to 6 p.m. Weather was shiny but at the end of the survey was getting cloudier and windy. Recorded vehicles were divided according type into following categories

- OA – individual automobile
- NA – freight vehicle
- TNA – truck
- M – motorcycle
- C – bike [1].

During the transport survey, a peak quarter-hour was recorded from 7:30 a.m. to 7:45 a.m. of intensity of 588 vehicles which is 647.5 of passenger car units. A peak hour was recorded from 6:45 a.m. to 7:45 a.m. of intensity of 2084 vehicles, which is 2304 of passenger car units [25].

Fig. 2. Camera recording traffic movements over the roundabout

We recorded traffic intensity and vehicle categories using camera located at the entrance number 3 (see Figure 2). The camera was located in 25 m distance from outside circle of the small roundabout. It was situated on the street light pole in height of 5 m above the ground level. The camera was constantly connected to a power source that kept it running throughout the whole period of the survey. The camera has also protective cover, which protects camera lens against direct sunlight as well as bed weather conditions. The following Table 1 represents a matrix of traffic routing on the roundabout during the peak hour [1, 2].

Tab. 1. Matrix of traffic routing

O/D Matrix	1	2	3	4	Sum
1	-	59	658	25	742
2	20	-	144	8	172
3	992	133	-	1	1 126
4	19	6	19	-	44
Sum	1 031	198	821	34	2 084

The most loaded entrance during a peak hour is the entrance number 3 with intensity of 1126 vehicles. The least loaded entry was the entry number 4 with intensity of 44 vehicles. The total intensity of traffic during 12 hours' transport survey was 19717 vehicles which represents 22457.5 passenger car units. Road traffic flow composition can be seen in the following Figure 3 [4].
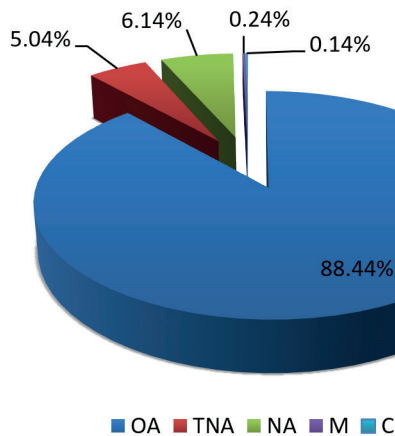
Fig. 3. Road traffic flow composition during the peak hour

3. Creating and simulating of transport environment in transport planning software

We have used the Aimsun software to make a simulation of the chosen roundabout. Road network was created based on the suitable map base in an appropriate scale. For every simulated traffic situation, we have made twenty-five simulations and made an average of recorded characteristics. The car-following model has been implemented takes into account the additional constraints on the breaking capabilities of the vehicles. The implementation tries also to capture the empirical evidence that driver behaviour depends also on local circumstances. This is done by means of model parameters whose values, calculated at each simulation step, depend on the current circumstances and conditions at each part of the road network [2]. Every simulation took two hours. The intensity during simulation was set on double value of a peak hour. We wanted to ensure the least distortion of results due to incoming transport on the road network [4]. Aimsun microscopic simulator has taken advantages of the state-of-the-art in the development of object-oriented simulators. The traffic model is suitable to be implemented also on other roundabout. There is a need to make some modifications of course to calibrate model on different situation. But in general the model could be used [2].

In order to set up the model correctly, we have made capacitive calculation of a small roundabout and set the required speeds by reality. The simulation assumes that the traffic demand is defined in terms of Origin-Destination matrices (see Table 1). The main input to traffic simulation model is a time dependent origin-destination matrix, each of whose ODi entries represents the number of trips between the corresponding Origin-destination pair for the selected time period i [2, 16].

In the following Figure 4, you can see the recorded simulation of a current traffic state during the morning traffic peak [2, 11]. As you can see on the mentioned Figure 4, congestions have occurred during simulations, mainly in direction from the cities Hlohovec and Leopoldov. The road makes a connection to highway D1. Congestions have occurred during workdays' mornings as well as evenings.
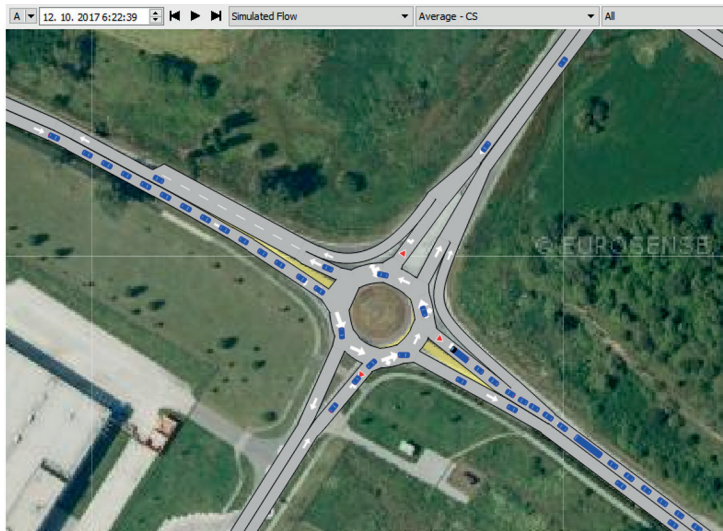

Fig. 4. Simulation of a current state of a small roundabout

As the capacity calculation of the small roundabout according to TP 102 showed the exceeding of the capacity at the entrances to the roundabout, we created a design of the signal controlled intersection and its subsequent capacity calculation. The signal-controlled intersection can be added with public transport preference, which can reduce travel time to bus stops [8, 13, 23]. We have made calculation of suitable signal plan for signal controlled intersection according [23]. The signal plan calculation includes set up of passage times, length of traffic lights cycle and length of green light signals. We have made these calculation according [23], using equations as follows:

a. Passage time calculation – it is a time between the end of one signal phase and the beginning of incoming phase (1).

$$t_z = t_{Ue} + t_r - t_e \qquad (1)$$

t_z – passage time, s

t_{Ue} – time of passage during the „yellow light", s

t_r – passage time of leaving vehicle from one stop line to other stop line, s

t_e – passage time of entering vehicle from one stop line to other stop line, s.

b. Departures of vehicles and capacity – a number of vehicles which can leave within green light (2).

$$n = \frac{t_f + t_{Ue}}{t_b} \tag{2}$$

n – number of vehicles which can leave intersection within green light signal, veh

t_f – green light signal, s

t_{Ue} – time of passage during the „yellow light", s

t_b – the mean „shortest" distance between two follow up vehicles, s.

c. Saturated intensity – based on the value of tb the saturated intensity qs could be determined. It is a value of theoretical number of vehicles that are able to pass the intersection within an hour of green light signal (3).

$$q_s = \frac{3600}{t_b} \tag{3}$$

q_s – saturated intensity, veh/h

t_b – the mean „shortest" distance between two follow up vehicles, s.

d. Green light signals – the length of green light signal of every phase of traffic light cycle (4a, 4b).

$$t_F = n * \frac{3600}{q_s} \tag{4a}$$

t_F – green light signal, s

n – number of vehicles which can leave intersection within green light signal, veh

q_s – saturated intensity, veh/h.

This equation (4a) is a simplified version which does not take into account different traffic conditions for each driving lane and phase of cycle. More specific and useful is to calculate green light for each phase according (4b).

$$T_{F,i} = \frac{\frac{q_{massg,i}}{q_{s,i}}}{\sum_{i=1}^{p} \frac{q_{massg,i}}{q_{s,i}}} * (t_U - T_z) \tag{4b}$$

$T_{F,i}$ – green light signal for each phase, s

t_U – length of traffic lights cycle, s

T_z – total passage time, s

p – number of phases

$q_{mass,i}$ – decisive intensity of driving lane for certain phase i, veh/h

q_s – saturated intensity for certain phase i, veh/h.

e. Traffic lights cycle – the length of cycle is affected by various traffic, organizational and construction conditions (intersection in urban or non – urban area). In practise, the cycle length of 60 s to 90 s is proposed.

$$t_U = \frac{1.5*T_z+5}{1-\sum_{i=1}^{p}(q_{massg,i}/q_{si})} \qquad (5)$$

where $T_z = \sum_{i=1}^{p} t_{zi}$ (6)

t_U – length of traffic lights cycle, s

T_z – total passage time, s

p – number of phase

$q_{mass,i}$ – decisive intensity of driving lane for certain phase i, veh/h

q_s – saturated intensity for certain phase i, veh/h

$t_{z,i}$ – decisive passage time for certain phase i, s.

In accordance of mentioned calculations (1), (2), (3), (4a, 4b), (5) and (6) we were able to create signal plan with three phases, see Figure 5.
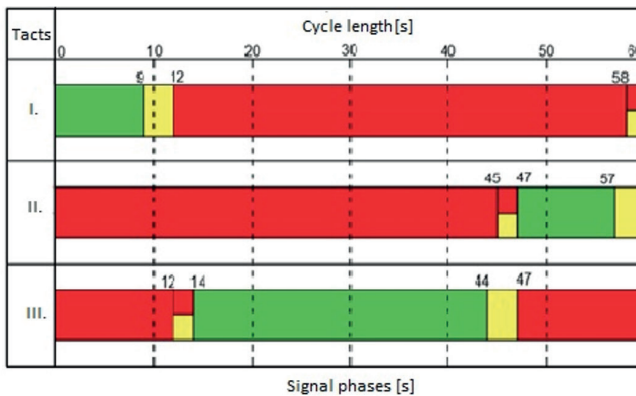

Fig. 5. The signal plan of a signal controlled junction

Figure 5 represents the signal plan of three phases' intersection control. The cycle length is sixty seconds (5). Based on the capacitive calculations we found out that the longest green light phase is included in the third tact, which is thirty seconds of green light. This tact was calculated for the road which connects cities Hlohovec and Leopoldov. The road was set up as a main road regarding a high intensity of traffic [4, 25]. The first tact has a length of nine seconds. Within this tact, it is possible to turn right, turn left or go straight forward through the intersection from entrance number 2 to 4 and vice versa. The second phase includes movements at entrances number 1 and 3. There are only left turns possible from the main road (4a, 4b). Figure 6 shows vehicles' movements through the intersection in 2D and 3D views [12, 14, 17].

Fig. 6. Simulation of a signal controlled junction

The area of the intersection where directions are crossing each other and collision points occur is marked with yellow. This setting is called „yellow box" in the software. Using yellow box, vehicles do not stop at the intersection when congestion occurs but in front of traffic lights equipment. The intersection remains passable even if congestions occur at any of entrances [9, 17, 25].

Another proposal is turbo roundabout. In terms of the Slovak technical regulations no. 102, this type of roundabout is defined as a special roundabout with two or more spirally arranged lanes on the roundabout traffic strip which together with physical separation of lanes, do not allow to crossing vehicles on that strip. Recommended turbo roundabout diameter is from 45 m to 65 m and the capacity of that type of roundabout is in range of 25 000 to 40 000 vehicles per a day according to technical regulations no. 102 [23].

In terms of recommendations of the Slovak technical regulations, we approached to make a proposal of a turbo roundabout using Aimsun software. An outline diameter of turbo roundabout we designed on 50 m with variable number of lanes on the circuit. Two lanes are situated on the road II/513, where the highest traffic intensity is recorded. A lane's wide on the circuit is 4.75 m. In the following Figure 7, there is 2D and 3D view of turbo roundabout simulation [4, 5].
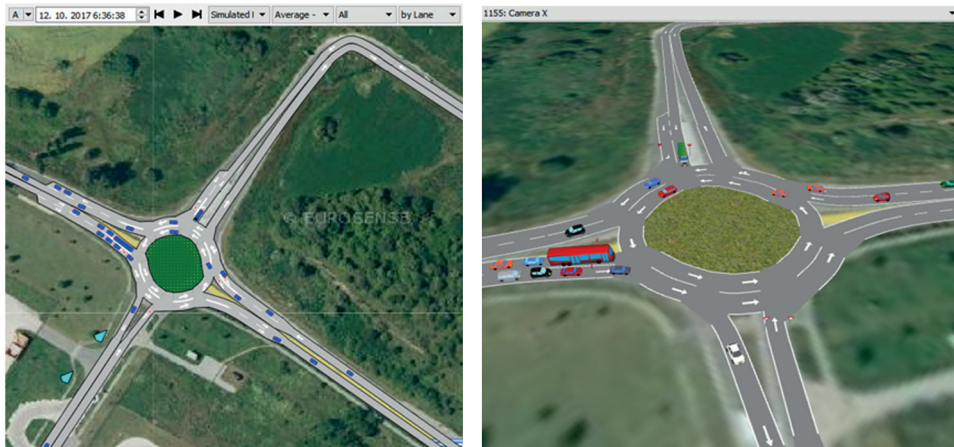
Fig. 7. Simulation of the turbo roundabout (2D and 3D)

3.1 Microsimulations' outputs

We were interested in comparison of signal-controlled intersection with turbo roundabout. We also include a current state into mentioned comparison of traffic characteristics of each proposal. Outputs of simulations are shown in following figures and tables. We used following abbreviations

- CS – current state
- LTJ – signal controlled intersection
- TR – turbo roundabout.

Important traffic characteristics, which were watched during microsimulations, are as follows: delay time, stop time, travel time, speed, flow, density and number of stops. These characteristics we assume as very important so we have recorded them in intervals of ten minutes.

Graphical running of each traffic characteristic regarding time can be seen in Figures 8, 9 and 10. On the left, there is a current state; on the right, there is a proposal of signal controlled intersection and under these two graphs is turbo roundabout characteristics output.
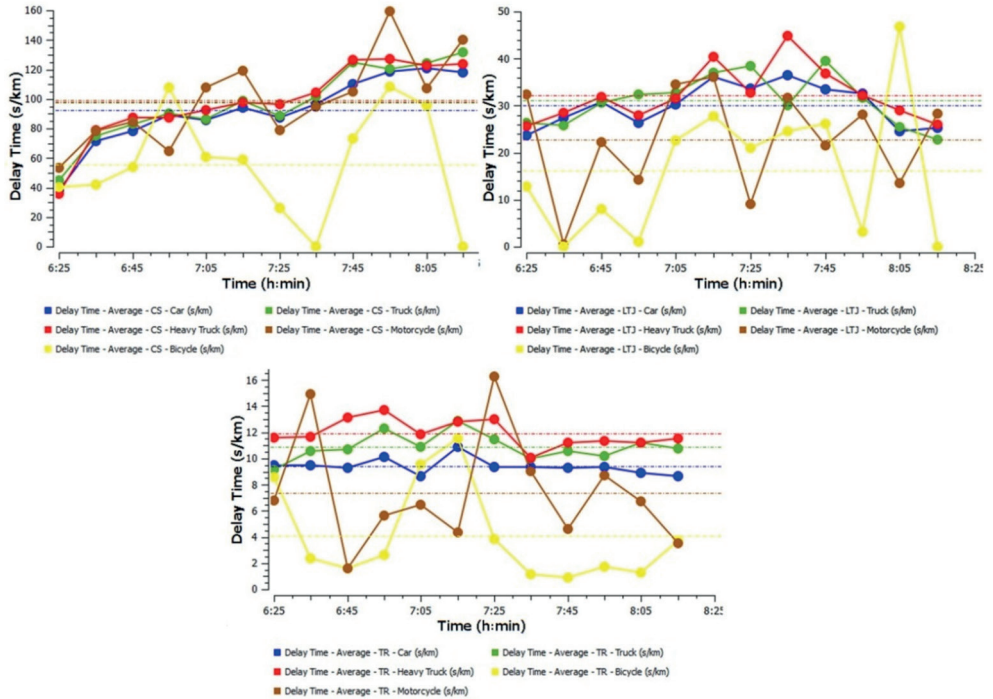
Fig. 8 Simulation running of delay time

In the Figure 8, there is a simulation running of delay times. Every mode of transport is marked with different colour. Dotted lines, which are leading horizontally through the graph, represent an average value of each characteristic during the simulation.

The simulation running of number of stops is recorded in range of (0-0.9) of stops per a vehicle and per a kilometre (see Figure 9). Even these small changes (acceleration and deceleration of vehicles) affect permeability and traffic flow [25].
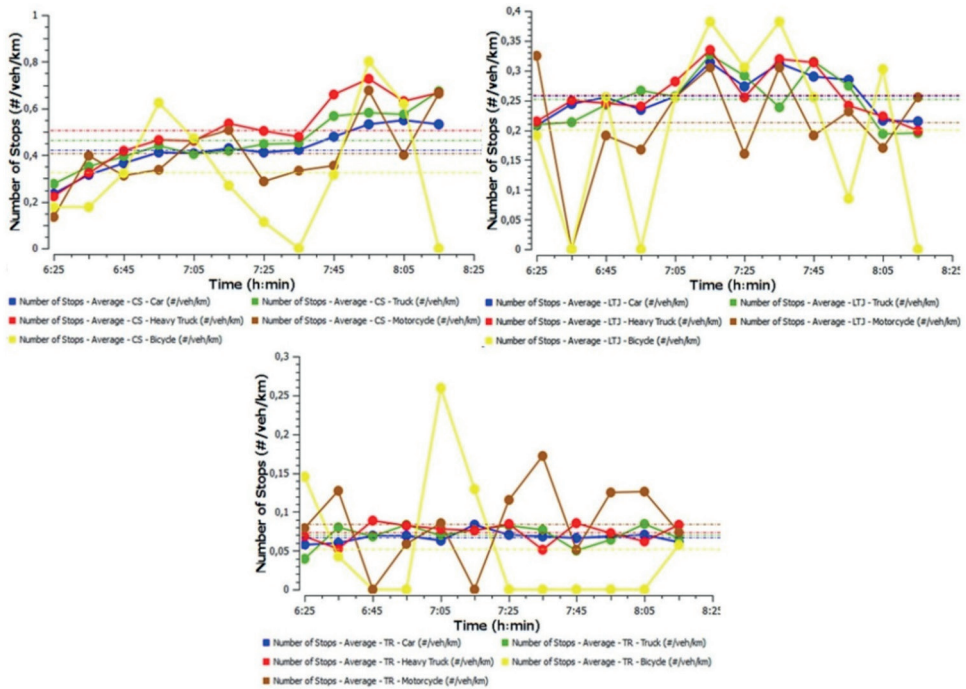
Fig. 9 Simulation running of number of stops

Figure 10 represents stop times running. Values of stop time for motorcycles and bicycles sometimes reach more than 100 seconds per kilometre [12, 23].
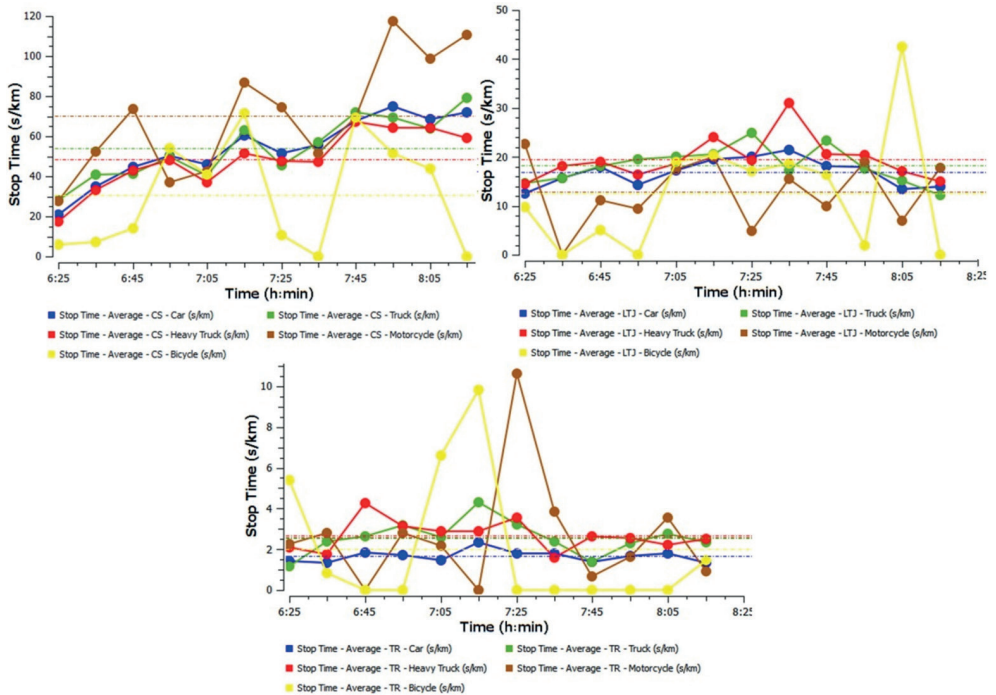
Fig. 10 Simulation running of stop time

We have made averaged values of all chosen traffic characteristics recorded within simulations. The outputs are shown in Table 2. You can see big differences between values of current state, signal controlled intersection as well as turbo roundabout.

Tab. 2. Recorded traffic characteristics

Parameters	CS	LTJ	TR	Units
Delay Time	93.77	30.30	9.62	s/km
Density	23.30	12.70	10.29	veh/km
Flow	1997.70	2284.70	2289.00	veh/h
Number of Stops	0.43	0.26	0.07	#/veh/km
Speed	23.85	44.36	53.40	km/h
Stop Time	54.13	17.13	1.78	s/km
Travel Time	169.86	88.49	68.42	s/km

As you can see, a current state of traffic situation at a small roundabout is worse compare to both new variants. We took a closer look at signal controlled intersection and turbo

roundabout. In following Table 3, there are outputs of simulations of these two variants and their comparison with percentage differences.

Tab. 3. Comparison of proposed variants of roundabout

Parameters	LTJ	TR	Units	Percentage gap	Increase/decrease
Delay Time	30.30	9.62	s/km	68.25%	decrease
Density	12.70	10.29	veh/km	18.98%	decrease
Flow	2284.70	2289.00	veh/h	0.19%	Increase
Number of Stops	0.26	0.07	#/veh/km	73.08%	decrease
Speed	44.36	53.40	km/h	20.38%	Increase
Stop Time	17.13	1.78	s/km	89.61%	decrease
Travel Time	88.49	68.42	s/km	22.68%	decrease

In terms of traffic characteristics, we noticed a decrease of values in 5 cases and in 2 cases was noticed an increase of values of traffic flow intensity and speed. It is possible to assume savings in the form of fuel consumption and lower emissions due to increasing traffic flow permeability and lower travel time. In our case, we were recording emissions of CO_2, NO_x, PM, and VOC (Table 4) [10, 13, 18].

Emissions could decrease also due to a new trend of hybrid vehicles. A number of hybrid vehicles registered in the Slovak republic is still rising. Hybrids are very popular and Slovak parliament provides cash contribution to people who have bought this type of vehicle. This contribution is quite big motivation for people to buy hybrid vehicle, which after all, has a positive effect on environment, especially in urban areas where congestions often occur [3, 19, 20].

Tab. 4. Comparison of emissions

Parameters	CS	LTJ	TR	Units
IEM Emission - CO_2	1 188 201	1 073 549	1 061 274	g
IEM Emission - NO_x	3 903.1	3 426.47	3 362.4	g
IEM Emission - PM	262.24	191.23	197.94	g
IEM Emission - VOC	2 15.1	1265.8	1 03.2	g
IEM Emission - CO_2 - Interurban - All	313 437.4	284 254.6	295 293.5	g/km
IEM Emission - NO_x - Interurban - All	1 029.61	907.26	935.57	g/km
IEM Emission - PM - Interurban - All	69.18	50.64	55.07	g/km
IEM Emission - VOC - Interurban - All	568.5	335.16	288.04	g/km

In Table 4, you can see an overview of each recorded emissions during simulations. Values of emissions are shown in grams and in grams per kilometre according to Konečný and Petro (2017) [10]. Red colour marks the highest achieved value of emissions and the green one highlights the lowest value of emissions. We compared only signal controlled intersection and turbo roundabout. With lower emissions, we noticed also lower total fuel consumption on the chosen road network [10, 21, 25].

4. Conclusion

Obviously, building small roundabouts outside the urban areas is complicated and difficult. Traffic intensity can be different in few years and a roundabout will not be able to fill its primary function. Better traffic flow permeability and thus less traffic congestion can be achieved even at higher traffic intensity by changing the traffic organization from a small roundabout to a signal controlled intersection or turbo roundabout. In our case, the best solution for current state of traffic situation on the small roundabout is to change the organization of traffic on turbo roundabout. It is possible to conclude, based on the simulation outputs, that traffic is smoother in case of turbo roundabout. Talking about stop times, the savings are approximately 68% simulating with the same traffic intensity. We were able to improve also other traffic characteristics, increasing speed (more than 20%), decreasing stop times (more than 89%) and travel times (more than 22%). Even the impact on environment is much more lesser using turbo roundabout compare to small roundabout. We recorded lower quantity of all parameters of emissions producing. It could be caused by lower number of stops, lower travel times as well as better permeability of traffic flow.

Finally, let us introduce some good examples of turbo roundabout implementations: In the Czech Republic, the first turbo – roundabout was realized an intersection of streets Kamenice – Netroufalky in Brno. It is concerned as type "egg". Its largest diameter is 52 m. In the terms of traffic safety of motor vehicles, there is one of the most important safety criterion and it is the number of conflict points. Conflict points are dividing to the crossing, merging and diverging. Their number in turbo – roundabouts depends on its type. The reduction of conflict points is, according to arrangement of turbo – roundabout, between (38-66)%, what is still significant safety benefit [22]. It is necessary to submit that this turbo – roundabouts serve to the road traffic without any significant problems according to [22].

Another good example is the turbo - roundabout in the city of Sosnowiec in Poland. According Before reconstruction, the main road in the city was characterised by unfavourable road and traffic conditions, insufficient capacity level and low level of road traffic safety, which was visible in the queues of vehicles waiting for the possibility of inclusion to the traffic. After rebuilding the analysed road and designing turbo roundabout, the congestion of traffic flow significantly decreased. Moreover, the traffic and road conditions and the level of traffic safety were considerably improved [15].

Fortuijn (2009) found out that turbo roundabouts provide higher capacity than two-lane conventional roundabouts, due to both raised lane dividers and spiral markings, which in turn result in better use of the inner lanes of the turbo roundabout [6, 7].

In Slovenia, where the capacity of the conventional small two-lane roundabouts was a concern, Tollazzi et al. (2011) indicated that the Slovenian experience with turbo roundabout is very satisfying and successful. The turbo design can handle daily traffic ranging from 38 000 to 42 000 vehicles per a day with no bottlenecks nor gridlocks [6, 24].

Regarding simulations' outputs as well as mentioned good examples worldwide, we can say that for the selected small roundabout in the city of Hlohovec would be better to

change its organisation on turbo roundabout. It would be better solution for current traffic situation including shorter travel time, better permeability as well as lower number of possible collision points at the turbo roundabout.

5. Acknowledgement

6. Nomenclature

2D   Two – Dimensional

3D   Three – Dimensional

C   Bicycle

CO_2 Carbon Dioxide

CS   Current State

LTJ   Signal Controlled Intersection

M   Motorcycle

NA   Freight vehicle

NO_x Oxides of Nitrogen

O/D   Origin/Destination

OA   Individual Automobile

PM   Particulate Matter

TNA   Truck

TP   Technical Regulations

TR   Turbo Roundabout

VOC   Volatile Organic Compound

7. References

[1] Aboud G.M., Abdulwahab A.M., Banyhussan Q.S., Zubaidi H.A.: A Case Study on Roundabout under Congestion: Proposal to Improve Current Traffic Operation. Civil engineering journal-Tehran. 2019, 5, 2029–2040, DOI: 10.28991/cej-2019-03091391.

[2] Barcelo J., Codina E., Casas J., Ferrer J., Garcia D.: Microscopic traffic simulation: A tool for the design, analysis and evaluation of inteligent transport systems. Journal of Intelligent and Robotic Systems. 2005, 41(2-3), 173–203, DOI: 10.1007/s10846-005-3808-2.

[3] Barta D., Mruzek M.: Factors influencing the hybrid drive of urban public transport buses. Management Systems in Production Engineering. 2015, 20, 213–218, DOI: 10.12914/MSPE-04-04-2015.

[4] Čulík K., Kalašová A., Kubíková S.: Simulation as an instrument for research of driver vehicle interaction. MATEC web of conferences, LOGI 2017 18th international scientific conference. 2017, 134, 00008, DOI: 10.1051/matecconf/201713400008.

[5] Dambach T., Gottlich S., Knapp S.: Car path tracking in traffic flow networks with bounded buffers at junctions. Mathematical methods in the applied sciences. 2019, 43(6), 3331–3353, DOI: 10.1002/mma.6121.

[6] Elhassy Z., Abou-Senna H., Shaaban K., Radwan E.: The Implications of Converting a High-Volume Multilane Roundabout into a Turbo Roundabout. Journal of advanced transportation. 2020, 5472806, DOI: 10.1155/2020/5472806.

[7] Fortuijn L.: Turbo roundabouts: estimation of capacity. Transportation Research Record: Journal of the Transportation Research Board. 2009, 2130, 83–92, DOI: 10.3141/2130-11.

[8] Gnap J., Konečný V.: The Impact of a Demographic Trend on the Demand for Scheduled Bus Transport in the Slovak Republic. Communications: Scientific Letters of the University of Žilina. 2008, 10(2), 55–59.

[9] Havel K., Bálint V., Novák A.: A number of conflicts at route intersections - rectangular model. Communications: Scientific Letters of the University of Žilina. 2017, 19(2), 145–147.

[10] Konečný V., Petro F.: Calculation of emissions from transport services and their use for the internalisation of external costs in road transport. Procedia Engineering. 2017, 192, 677–682, DOI: 10.1016/j.proeng.2017.06.117.

[11] Kong X., Yang J.: A scenario-based map-matching algorithm for complex urban road network. Journal of intelligent transportation systems. 2019, 23(6), 617–631, DOI: 10.1080/15472450.2019.1586543.

[12] Korfant M., Gogola M.: Possibilities of using traffic planning software in Bratislava. Procedia Engineering. 2017, 192, 433–438, DOI: 10.1016/j.proeng.2017.06.075.

[13] Kupčuljaková J.: Possibilities of ensuring urban public transport priority. Archives of transport system telematics. 2012, 5(4), 12–16.

[14] Ližbetin J., Stopka O.: Proposal of a Roundabout Solution within a Particular Traffic Operation. Open engineering. 2016, 6(1), 441–445, DOI:10.1515/eng-2016-0066.

[15] Macioszek E., Kurek A.: A case study analysis of roundabouts entry capacity localised on one of the main road in Sosnowiec city (Poland). Scientific Journal of Silesian University of Technology. Series Transport. 2019, 105, 139–156, DOI: 10.20858/sjsutst.2019.105.12.

[16] Meszaros F., Markovits-Somogyi R., Bokor Z.: Modelling and multicriteria optimization of road traffic flows considering social and economic aspects. Logi - Scientific Journal on Transport and Logistics, 2012, 3, 70–82.

[17] Ondruš J., Paľo J.: The modelling of transportation and transport processes of the region of Žilina. Advances in transport systems telematics 2. Section V: Systems in road transport - Katowice: Silesian University of Technology, 2007, 29–37, ISBN 978-83-917156-6-6.

[18] Rievaj V., Synák F.: Does electric car produce emissions? Scientific Journal of Silesian University of technology. Series Transport. 2017, 94, 187–197, DOI: 10.20858/sjsutst.2017.94.17.

[19] Rievaj V., Vrábel J., Synák F., Bartuška L.: The Effects of Vehicle Load on Driving characteristics. Advances in Science and Technology - Research Journal. 2018, 12, 142–149, DOI: 10.12913/22998624/80896.

[20] Skrúcaný T., Harantova V., Kendra M., Barta D.: Reducing energy consumption by passenger car with using of non-electrical hybrid drive technology. Advances in Science and Technology-Research Journal. 2017, 11(1), 166–172, DOI: 10.12913/22998624/66505.

[21] Skrúcaný T., Šarkan B., Figlus T., Synák F., Vrábel J.: Measuring of noise emitted by moving vehicles. Conference on Dynamics of Civil Engineering and Transport Structures and Wind Engineering (DYN-WIND). 2017, 107, DOI: 10.1051/matecconf/201710700072.

[22] Skvain V., Petru J., Krivda V.: Turbo – roundabouts and their Basic Evaluation at Realized Constructions in Czech Republic. Procedia Engineering: Structural and Physical Aspects of Construction Engineering. 2017, 190, 283–290, DOI: 10.1016/j.proeng.2017.05.339.

[23] Technical conditions no. 102: Calculation of road communications capacity. Ministry of Transport and Construction of the Slovak Republic, 2015.

[24] Tollazzi T., Turnšek S., Renčelj M.: Slovenian experiences with turbo-roundabouts. Proceedings of the 3rd International Conference on Roundabouts. USA, 2011.

[25] TSS-Transport simulation systems: Aimsun 8 Adaptive Control Interfaces Manual, 2015.