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traffic-capacity assessment; Webster; technical regulations; Aimsun; OmniTrans

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SIGNAL CONTROLLED JUNCTIONS CALCULATIONS IN TRAFFIC-CAPACITY ASSESSMENT - AIMSUN, OMNITRANS, WEBSTER AND TP 10/2010 RESULTS COMPARISON

Summary. Every increase in traffic volume on road network in towns can lead to overcrowding of road network. This results in undesirable external costs such as traffic congestions, which cause high loses in time during transportation, increased fuel consumption and thus higher production of greenhouse gases and noise. This all ultimately reduces the attractiveness of the area. The increase of traffic volume and therefrom derived traffic problems are needed to be solved during traffic-capacity assessment of every larger investment. The software can help to assess increased traffic in solved area and thus help authorities to make a right decision during approving of the investment plan. This article is focused on comparison of two software – Aimsun and OmniTrans, and calculations according to Webster and technical regulations for assessing junction capacity in the Slovak Republic. The packages outputs are also compared to the measured data at the assessed junction in this article. The analysis showed that outputs of various tools differ, generally all packages showed higher delays compared to measured data at the main road and lower delays compared to measured data at the side roads.

CALCUL DE LA CAPACITÉ DES CARREFOURS À FEUX AU COUR DE L'ÉVALUATION DES CAPACITÉS DE TRAFIC - LA COMPARAISON DES RÉSULTATS DE AIMSUN, OMNITRANS, WEBSTER ET TP 10/2010

Résumé. Chaque augmentation du volume de trafic sur le réseau routier dans les villes peut conduire à la surcharge du réseau routier. Il en résulte des coûts externes indésirables tels que des embouteillages, qui provoquent de grands retards pendant le transport, augmentation de la consommation de carburant et donc la production plus élevée de l'effet de serre et du bruit. Finalement, cela réduit l'attractivité de la région. Cette augmentation du volume de trafic et des problèmes de circulation en dérivés devraient être résolues par l'évaluation des capacités de trafic des impacts de chaque investissement plus important. En faisant cette évaluation, il est possible d'utiliser des logiciels qui aident à évaluer des effets de l'augmentation du trafic dans la zone observée et donc ils aident les autorités compétentes à prendre les bonnes décisions. Cet article se concentre sur la comparaison des deux logiciels – Aimsun et Omnitrans, et la comparaison des calculs selon Webster et selon des règlements techniques pour l'évaluation des capacités de communications terrestres de la République slovaque. Les sorties des instruments individuels sont en outre comparées avec les données mesurées sur le carrefour observé. L'analyse a montré que les sorties des différents instruments diffèrent, sur la route principale, le retards mesurés sont supérieurs aux sorties des instruments individuels, tandis que sur la route secondaire, des retards mesurés sont inférieurs à ceux des sorties de ces instruments.

1. INTRODUCTION

Every increase in traffic volume of road network in towns can lead to overcrowding of road network. This results in undesirable external costs such as traffic congestions, which cause high loses in time during transportation, increased fuel consumption and thus higher production of greenhouse gases and noise. This all ultimately reduces the attractiveness of the area. The increase of traffic volume and therefrom derived traffic problems are needed to be solved during traffic-capacity assessment of every larger investment. Good traffic situation is important for both sides –for the town and its inhabitants and for the developers. In order to achieve sustainability of traffic situation all greater investment projects of developers have to come under traffic-capacity assessment, which is standard part of the preparatory or project documentation at present. [1, 2] But methods relating to traffic-capacity assessment used in approval process of investment plans may be processed non-uniformly, they may be in different range of processing and may reflect a subjective approach of their processors. Therefore there is effort of the competent authorities to establish a uniform methodology for assessing the project documentation [3]. Bratislava gave to create the methodology with uniform traffic engineering methods [4] in order to avoid differences in approaches to the traffic-capacity assessments of great investment projects in its territory. Similar methodology is also applied in Prešov. This methodology was based on the methodology of Bratislava, but it was modified in order to suit the conditions of the town Prešov [5]. There is interesting part in these methodologies, which tells that traffic-capacity calculation may be supplemented or even replaced by the virtual simulation of the assumed traffic on the communication network of solved area or affected junctions. But how much the simulation outputs correspond (are comparable) to the outputs of analytical methods?

In the following part of the paper there are compared results of traffic-capacity calculation by the analytical method – calculation according to TP 10/2010 and Webster and simulation methods – simulation in Aimsun and in OmniTrans. The outputs are also compared to the measured data at the assessed junction. This comparison is based on delay time comparison; delay is the most common measure of operational quality, and delay can be obtained as an output of all abovementioned method.

2. DELAY TIME ACCORDING TO ASSESSED METHODS

The overall delay is the most common delay in evaluation of traffic signal control systems or signal design. The Webster or HCM delay calculation methods are preferred by traffic engineers for many years. Although the methods have considered similar parameters in determination of vehicle delays, the results obtained are not comparable to each other. One of the disadvantages of these methods is that they do not represent delay for over-saturation case. This situation is due to the ill-defined parameters in the problem; following headway, driver behaviour, arrival type, age, education, weather condition etc. are some of these parameters. Measuring of these parameters is very difficult and many studies have been carried out to fit the best model for vehicle delays [6, 7]. On the other side, some studies showed that micro-simulation presents reasonable representation of actual traffic conditions when flow volumes are high. In the light of favourable research findings, it is concluded that Aimsun is a viable tool for the evaluation and capacity analysis of a signalised intersection [8].

Delay at the signal controlled junction consists of various forms of delay (Fig. 1), which are defined as follows [9]:

- Stopped time delay;
- Approach delay;
- Travel time delay;

- Time-in-queue delay;
- Control delay;

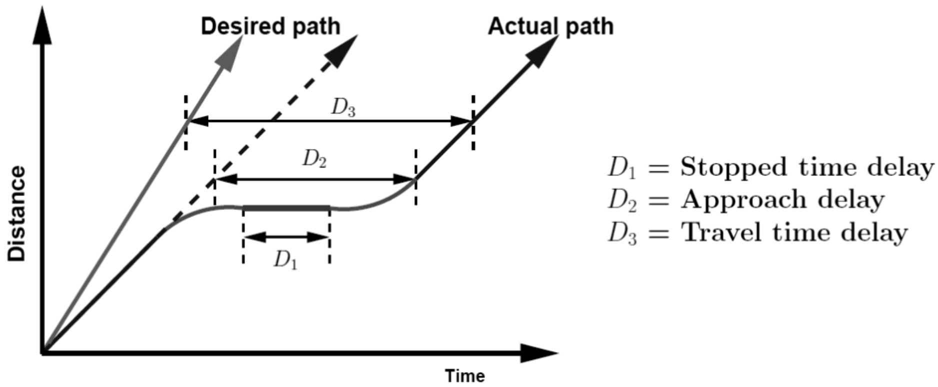

Fig. 1. Ilustration of delay measures [9]
Fig. 1. Schéma du principe de la mesure de la durée de retard

These delay measures can be quite different, depending on conditions at the signalized intersection. Fig 1 shows the differences among stopped time, approach and travel time delay for single vehicle traversing a signalized intersection. The desired path of the vehicle is shown, as well as the actual progress of the vehicle, which includes a stop at a red signal. The desired path is the path when vehicles travel with their preferred speed and the actual path is the path accounting for decreased speed, stops and acceleration and deceleration [9].

2.1. Webster delay equation

The delay calculation for the Webster method is expressed as equation 1 [10]:

$$d = \frac{c*(1-\lambda)^2}{2*(1-\lambda*x)} + \frac{x^2}{2*q*(1-x)} - 0.65*(\frac{c}{q^2})^{\frac{1}{3}} * x^{(2+5*\lambda)} \tag{1}$$

where: d = average delay per vehicle on the particular lane group of the intersection, sec/veh; c = cycle length, sec; q = flow, vehicles/sec; λ = proportion of the effective green with respect to cycle length (i.e. g/c and g is effective green, sec); and x = the degree of saturation. This is the ratio of the actual flow to the maximum flow which can be passed through the intersection from this lane group, and is given by x = g/λs, where s is the saturation flow in vehicles per second.

2.2. TP 10/2010 delay equation

Technical regulations TP 10/2010 sets the rules for roads´ capacity calculation in the Slovak Republic. They are based on HCM 2000 [11] and HBS 2001 [12]. According to TP 10/2010 it is possible to verify, if the signal controlled junction has the capacity to manage expected traffic flow during peak hour and the traffic flow quality. The waiting time calculation for this method is expressed as equation 2 [13]:

$$w = \frac{t_U*(1-f)^2}{2*(1-q/q_s)} + \frac{3600*N_{GE}}{f*q_s} \tag{2}$$

where: w = average waiting time, sec; t_U = cycle length, sec; f = proportion of green; f = t_F/t_U [-], where t_F is green time, sec; q = traffic flow at the traffic lane, veh/hour; q_S = saturation flow for the traffic lane, veh/hour; and N_{GE} = average vehicle queue at the end of green;

2.3. Aimsun

Aimsun - is an integrated transport modelling software, developed and marketed by TSS - Transport Simulation Systems, Spain. Aimsun software is used by government agencies, municipalities, universities and consultants worldwide for traffic engineering, traffic simulation, transportation planning and emergency evacuation studies. It is used to improve road infrastructure, reduce emissions, cut congestion and design urban environments for vehicles and pedestrians. It is macroscopic, mesoscopic and microscopic simulation tool. Simulation in Aimsun provides various outputs, which are divided into groups: network statistics, section and turn statistics, subpath statistics, O/D matrix statistics and public transport statistics. For each groups are generated statistics as mean flow, density, mean speed, harmonic mean speed, travel time, delay time, stop time, number of stops, total travel, total travel time, fuel consumed, pollution emitted; the differences among groups are in the inputs into calculation and in the units, into the which the output are calculated [14, 16].

In our case, delay time was obtained as the output of microsimulation in Aimsun, where subpaths statistics were recorded. Every subpath was created from the entrance section, turning, and exit section at the junction according to traffic flow as can be seen at Fig. 3. As the exit sections from the junction are not connected to any other section in our model (see Fig. 2), delay times at these sections are very close to zero (about 0.5 sec) and therefore we can ignore them and consider so created subpath delay time as the junction delay time. Delay time in Aimsun for subpaths is defined as follows: average delay time per vehicle for all vehicles that have traversed the subpath. This is the difference between the expected travel time (time it would take to traverse the subpath under ideal conditions) and the experienced travel time [14].

2.4. OmniTrans

OmniTrans – was developed by the Dutch company Goudappel Coffeng and firs time introduced in 1998. It is macroscopic simulation tool for transport modelling and planning. It is used for traffic problem modelling in small towns, cities and even in national level. It is multimodal analytic tool that can simulate transport modes such as cars, trucks, buses, trains, cyclists and pedestrians [15, 17].

The calculation of the average delay in OmniTrans uses three parameters for calculation, these are load, capacity and green-time. The calculation of the delay for a signalized junction can be found in the signalized class and is the following [19]:

$$D = \min(d_1 + d_2 + d_3, d_{\max}) \tag{3}$$

where: D = average delay; d_1 = uniform delay; d_2 = incremental delay; d_3 = geometric delay;

So the average control delay is the sum of the separate delays with a maximum of d_{max}. The different d_i are all calculated in their own way, they are all calculated per lane, and they are described in Technical note - Junction Modelling in OmniTrans [18].

The model in OmniTrans for our comparison (Fig. 2) was created with the use of traffic load data (see Fig. 3), junction´s geometry and traffic condition data. For the delay calculation in OmniTrans the junction modelling within a static assignment was used.

3. COMPARISON PROCEDURE

In order to compare calculation outputs and simulation outputs there were carried out delay measurements, calculations, and simulations at signal controlled junction in the town of Žilina, where traffic load data were available - junction I/64 Rajecká cesta – Dlhá (see Fig. 3). This junction is signal controlled from 4th November 2013. Reasons for building traffic lights at this junction were safety and mainly problematic turnings from side roads (E2 and E4) to the main road (E1 – E3) at the time of traffic peak. As can be seen in the Fig. 3 there are separate lanes for the traffic flows turning left (1, 4, 7, 10). Traffic flow 2 (straight flow) has the common lane with the traffic flow 3 (flow turning right), the common lane for the movements also have traffic flows 8+9 and 11+12. The cycle length is equal 100 sec, green times are 56 sec for the leg 1, 13 sec for the leg 2, 69 sec for the leg 3, and 11 sec for the leg 4.

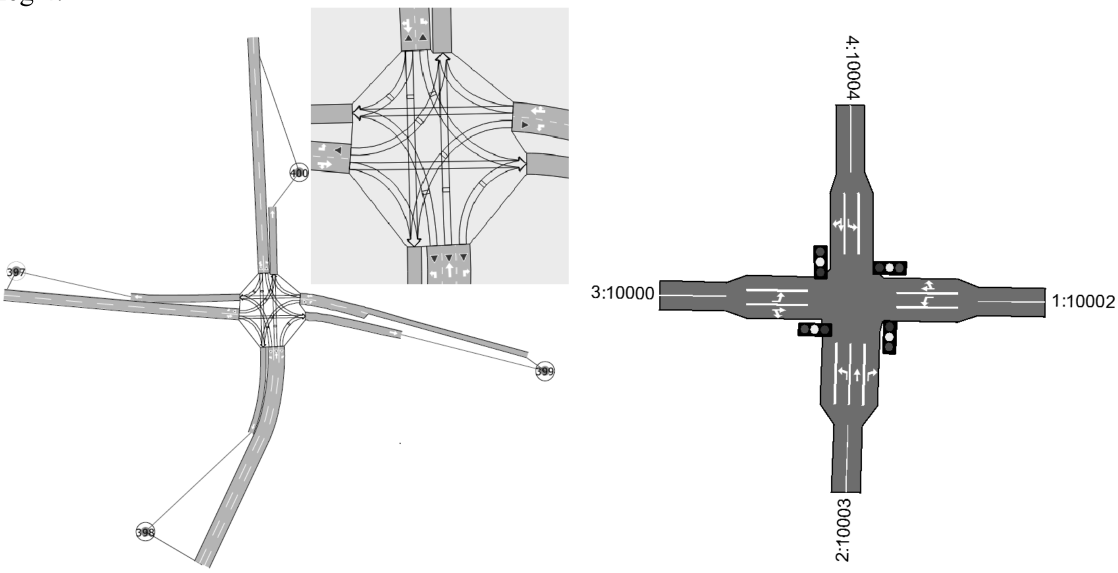

Fig. 2. Junction model in Aimsun (on left), junction model in OmniTrans (on right)
Fig. 2. Modèle de carrefour dans Aimsune (à gauche), modèle de carrefour dans Omnitrans (à droite)

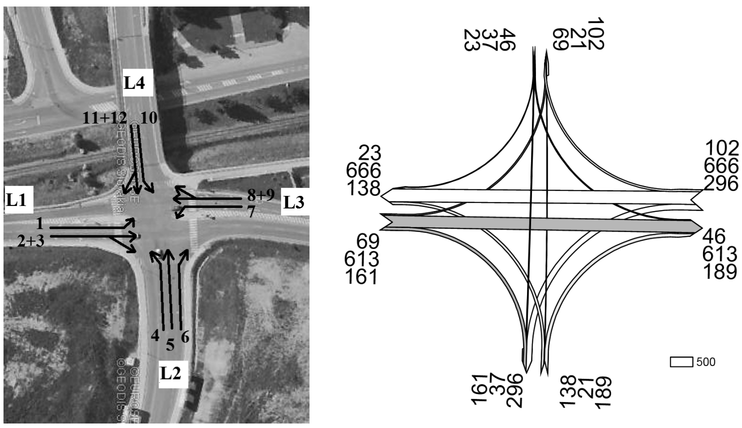

Fig. 3. Junction legs (L1-4) and traffic flows labelling according to TP 10/2010 rules (on left), traffic state during traffic peak (on right)
Fig. 3. Les branches de carrefour (L1-L4) et l'étiquetage des flux de trafic selon TP 10/2010 (à gauche), la congestion des routes aux heures de pointe (à droite)

The examination procedure was as follows:

1. Delay time measurements at the junction;
2. Delay time calculation according to Webster [10];
3. Delay time calculation according to TP 10/2010 [13];
4. Creation of the transport model and simulation in Aimsun [14];
5. Creation of the transport model and simulation in OmniTrans [15];
6. The calculations and simulations were executed for the same signal control and the traffic flows:
    a. according to traffic surveys uniformly reduced by 20% (-20%);
    b. according to traffic surveys uniformly reduced by 10% (-10%);

c. according to traffic surveys (basic state - BS);
d. according to traffic surveys uniformly increased by 10% (+10%);
e. according to traffic surveys uniformly increased by 20% (+20%);

7. Outputs comparison.

4. RESULTS

According to outputs (see Fig. 4 and Fig. 5), there are more significant differences between average delay times of vehicles entering the junction from main road (Fig. 4), where delay times are lower (around 10 sec), and vehicles entering from side roads (Fig. 5), where delay times are around 40 sec and higher. This may be caused mainly by different green, which is much higher for the main road in comparison to side roads (56 sec and 69 sec in comparison to 13 sec and 11 sec). This can be also seen when looking at measured data, although the differences at the measured data are not as great as at calculated or simulated data.

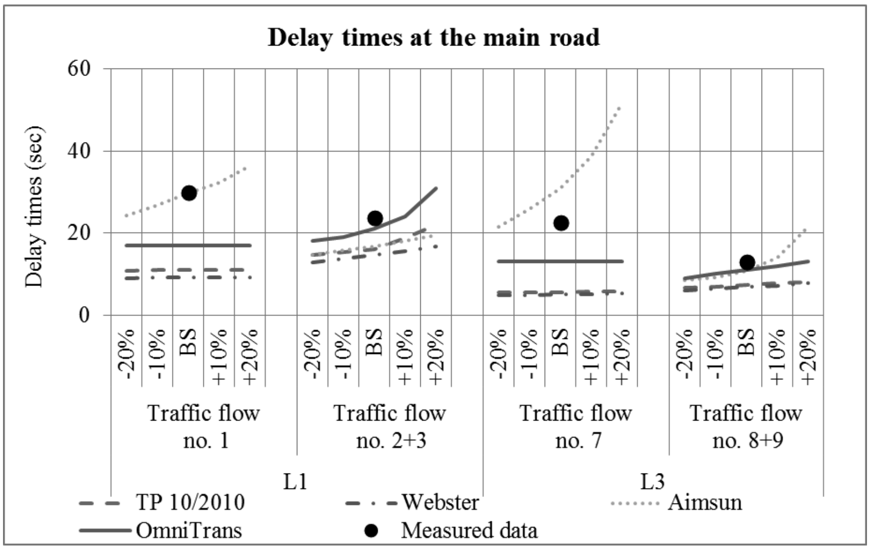

Fig. 4. Delay times of particular traffic flows at the main road
Fig. 4. La durée de retard des flux de trafic individuel sur la route principale

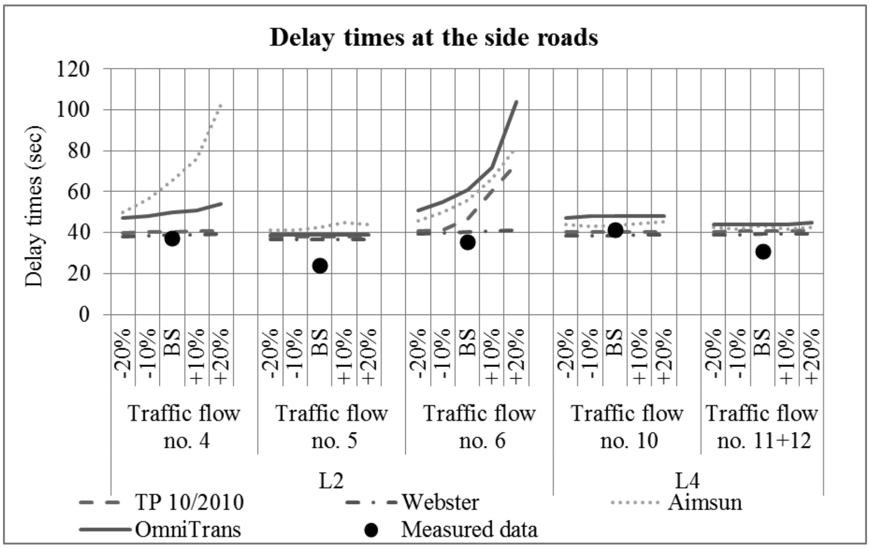

Fig. 5. Delay times of particular traffic flows at the side roads
Fig. 5. La durée de retard des flux de trafic individuel sur la route secondaire

4.1. Measured data

The delay time measurements at the junction were carried out with the help of the PolCam PC2006 system [19]. During the time of the traffic peak (see Fig. 3) vehicle fitted with this PolCam system traversed this junction for the 48 times, while the position, travel distances, travel times, and other data were recorded. Then there were calculated desired travel times (travel times without delays) as the travel times of the vehicle which approaches to the junction with the speed equal to maximal allowed speed (speed limit) and traversed the junction with the speed suitable for the movement it does.

The travel times obtained from the measurement were compared to the calculated desired travel times and thus the delay time for each traffic flow was calculated as the difference between measured time and calculated (desired) time (see Fig. 1).

Tab. 1 shows delay time which was calculated from the data measured at the junction with the help of PolCam PC2006 system. There is also information about percentage proportion of junction crossings when the measuring vehicle had to stop at the junction because of red signal, and the last column shows average place in the row of stopped vehicles in the case the measuring vehicle had to stop.

Table 1

Measured delay time at the junction

Junction´s leg	Traffic flow	Delay time	Proportion of number of stops on number of junction crossing	Average place in a row
		sec	%	#
L1	1	29.8	0.25	1
	2+3	23.75	0.5	9
L3	7	22.6	0.75	6
	8+9	12.95	0.5	3
L2	4	37.4	0.75	4
	5	23.9	0.75	1
	6	35.5	0.75	2
L4	10	41.3	1	3
	11+12	30.75	0.75	2

As it can be seen in this table (Tab.1), lower delay times are achieved at the main road, mainly at the junction´s leg L3, and higher delay times are achieved at the side roads. These differences can be assigned to the different green length. The highest delay times are achieved at the junction´s leg L4 (traffic flow no. 10), where green phase lasts only 11 sec. Measuring vehicle had to stop each time when it wanted to cross junction at these directions.

4.2. Webster

Delay time calculation according to Webster (equation 1) give us the lowest delay time values. Also there are not significant changes in delay time in the case that traffic load decreases/increases by 20% in any traffic flow. Even traffic flows turning left have not increased delay times values.

According to this calculation it would be possible to declare that there are nearly no problems at this junction. The cars can traverse this junction with the acceptable delay also in the case that traffic load during traffic peak will increase by 20%.

4.3. TP 10/2010

Calculation according to technical regulations TP 10/2010 give us delay time values very similar to Webster´s outputs. The total average difference (see Tab. 2) is only about 10%. And also slight decrease/increase in delay time can be seen when traffic load changes and this decrease/increase is very similar to Webster´s outputs. The only significant increase compared to Webster can be seen in the delay times of the traffic flow no. 6. (see Fig. 5)

According to this calculation it would be possible to point out potential problems at the junction leg L2, where right turning of the traffic flow no. 6 is expected to be problematic. Other traffic flows are expected to have no problems even when the traffic flow increase by 20%.

4.4. Aimsun

Compared to Webster and to TP 10/2010 the simulation in Aimsun can show us significant difference in delay times at particular traffic flows. The differences are visible mainly at the left turning traffic flows 1, 7, and 4, but not at the left turning no. 10 (see Fig 4 and Fig. 5). For instance, the traffic flow no. 7 has according to Aimsun the delay time nearly 6 times higher than according to Webster calculations (see Tab.2). At the same time, increased delay time is shown at the traffic flow no. 6, which was also problematic according to TP 10/2010. Simulation outputs for other traffic flows are similar to the outputs of other methods.

According to Aimsun it would be possible to point out problematic left turnings of abovementioned traffic flows (1, 7, 4) and problematic right turning no. 6.

4.5. OmniTrans

Simulation in OmniTrans shows slightly higher delay times for nearly all traffic flows in comparison to other methods, but looking at the Fig. 4 and Fig. 5 the only problematic traffic flow seems to be traffic flow no. 6, where increase in delay time is significant when traffic load is increased. Increased delay times can be also seen at other traffic flows (2+3, and 4), but this increase is not very significant.

Table 2

% differences between each examined method

Junction´s leg	Traffic flow	Measured data				TP			Webster		Aimsun
		TP	Webs.	Aims.	OmniT.	Webs.	Aims.	OmniT.	Aims.	OmniT.	OmniT.
		%	%	%	%	%	%	%	%	%	%
L1	1	63.4	69.5	0.3	43	16.7	173.9	56	228.9	87.2	41.9
	2+3	32.2	38.5	29.5	11.6	14.4	4.6	29.4	15.2	52.3	32.1
L3	7	75.2	77.9	37.2	42.5	10.7	498.2	132.3	569.5	160.2	57.7
	8+9	43.6	47.5	16.6	15.1	6.9	71.3	49.7	83.4	60.7	14.5
L2	4	8	3.7	74.6	33.7	4	73.3	23.8	80.5	29	25
	5	59.8	52.7	77.4	63.2	4.5	11.7	2.1	16.9	6.8	8.5
	6	32.1	13.5	57.7	71.8	19.5	14.8	29.8	48.5	69.7	13.2
L4	10	2.2	6.5	5.6	16.2	4.3	9	18.4	13.9	23.7	8.6
	11+12	32.7	27.5	41.8	43.1	3.9	4	8.4	8.2	12.7	4.2
Average		38.8	37.5	37.9	37.8	9.4	95.7	38.88	118.3	55.8	22.9

Tab. 2 shows % differences between each examined method. It is possible to see in the table that calculations according to both methods are more similar to each other (average difference is 9.4%) than calculations and simulation outputs (average difference is greater than 38%). Higher similarity can be seen also in comparison two software products, where average difference is 22.9 %.

But here it is necessary to mention, that all calculations and simulations were carried out for the traffic peak, which was even increased by 20%. Looking at the Fig. 4 and Fig. 5 it is possible to see higher similarity of the delay times when traffic flow is not so high. According to these facts it is possible to assume, that the differences in delay time begin to show, when the traffic flows achieve values close to the junction or the lane capacity.

Also at the Tab. 2 can be seen, that outputs of analytical calculation are closer to the measured data at the side road, where the traffic flow is not so high, but there are greater differences at the main road, where the traffic flow is higher. On the other side, simulation outputs are closer to the measured data at the main road and there are greater differences in outputs at the side roads.

5. CONCLUSION

Creation and adoption of the methodology for traffic-capacity assessment of investments plans within the conditions of the Slovak towns has clearly positive impact on the uniformity of the method for assessment of the projects. According to experiences of the Slovak capital city Bratislava the simulation software product could be very effective tool for traffic-capacity assessment of these projects. With exceptional features such as clarity, versatility, ability to implement into calculation influence of the surroundings, they have an advantage over conventional calculations according to TP10/2010. Although simulation and analytical calculation were carried out for the same junctions and for the same traffic volumes the outputs of particular tools differed from each other and they also differed from the measured data. There were significant differences in outputs at some traffic flows. One of the recommendations is that towns (which will create such methodology for traffic-capacity assessment) should put their attention on setting rules for approval/modification/rejection of the investment plan.

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