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TRAFFIC MODELING OF INTERSECTIONS ON VAJNORSKÁ STREET IN BRATISLAVA

Summary. This article focuses on traffic modeling of intersections in Aimsun. The intersections studied are in Bratislava, the capital of Slovakia. Every year, the number of vehicles on roads increases and congestions are created. Individual intersections do not have unlimited capacity. Simulations help to predict possible future problems and thus the possibility to prevent them. Accordingly, at intersections on Vajnorská street, a traffic survey was carried out using video cameras. Then, simulations were carried out in Aimsun. The results are shown in the tables separately for each intersection along with the determined overall quality level of the intersection. In addition to the current situation, simulations were carried out for increased traffic by 10% and 20%, and overall quality levels were also determined. Finally, the results were evaluated and compared with each other. This article points out the importance of research into the permeability of important points of the road network: intersections. It is necessary to carry out capacity assessments when planning any construction that will affect traffic in each location.

1. INTRODUCTION

The number of vehicles on the road is increasing every year, and it is a well-known fact that the Earth is warming up and the average temperatures are rising [1]. Over the last 10 years (2009 - 2019), the number of registered vehicles in the Slovak Republic has increased by 47% [2]. On the other hand, the road network is being built more slowly and it is not possible to build new roads or widen existing ones everywhere [3]. Therefore, congestions are more frequent and traffic flow is not smooth. It has been widely recognized that about half of the traffic congestion can be attributed to non-recurrent traffic events [4 - 7]. When a traffic accident occurs on an urban road, the congestion also affects adjacent roads [8]. Intersections are important points in the road network where roads intersect or connect in a top view in such a way that they are interconnected [9]. Therefore, intersections must have sufficient permeability to allow all traffic flows to go through. Otherwise, vehicles will remain stationary at or in front of the intersection [10, 11]. When deciding on the type and shape of the intersection and the arrangement of the lanes at the intersection, the smoothness and safety of traffic must be ensured as far as possible. At present, several intersections cannot provide this, and therefore, congestions and delay times are increasing. The attractiveness of the given area has the biggest influence on the mentioned problems. In such localities, there are schools, shops and services, hospitals, etc. Also, traffic modeling is a useful method to find a solution that would improve the current situation [12, 13]. In this way, we can determine the impact of several possible solutions on traffic and compare them with each other. For each planned construction, it is necessary to determine the impact it will have on traffic in the given locality [14]. Even in these cases, traffic modeling is an important tool that can use software programs based on input data to simulate the impact of building on a particular road or intersection [15, 16]. Input data are a necessary factor for modeling [17]. This paper focuses on the modeling of 3 selected intersections in Bratislava, the capital of Slovakia. Individual simulations at intersections were performed for the current situation (the lowest and the highest traffic load) and on increasing traffic by 10% and 20%.

2. ANALYSIS OF THE TRAFFIC AT SELECTED INTERSECTIONS

Analysis and traffic modeling are performed for 3 intersections, two of which are signal-controlled and the third, which is located between them, is yield-controlled (with a give way or yield sign). All are located on Vajnorská street in the capital of the Slovak Republic, Bratislava (see Fig. 1). Vajnorská street is located on the border of the urban subdivisions Ružinov and Nové Mesto. It is one of the main transport routes in the eastern part of the city. It passes through an industrial area, which is in the northeastern part of Bratislava. A tram line passes through all solved intersections.

Fig. 1. Location of solved intersections on Vajnorská street

The first intersection is signal-controlled and marked with the letter "A" (see Fig. 1). The entrance "4", i.e., Zátišie street, serves only as an exit from the intersection because it is a one-way street (see Fig. 2).

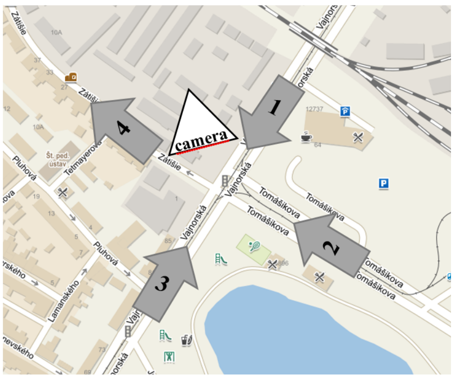

Fig. 2. Marking of the entrances and position of the camera at intersection "A" (processed by authors according to Open Street maps)

The second intersection is marked with the letter "B" and blue arrows. Arrow number 2 represents the entrance to the intersection from Istrochem firm. This intersection is yield-controlled.

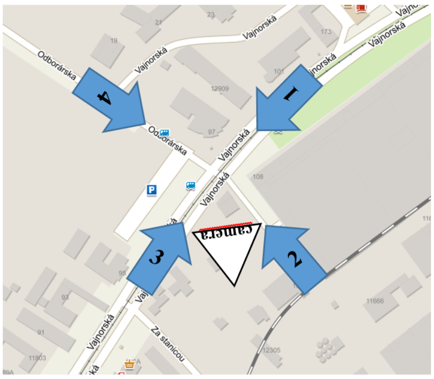

Fig. 3. Marking of the entrances and position of the camera at intersection "B" (processed by authors according to Open Street maps)

The third intersection is signal-controlled. In Fig. 1, it is marked with the letter "C". The entrances to the intersection are marked with red arrows with the numerical designation. See Fig. 4.

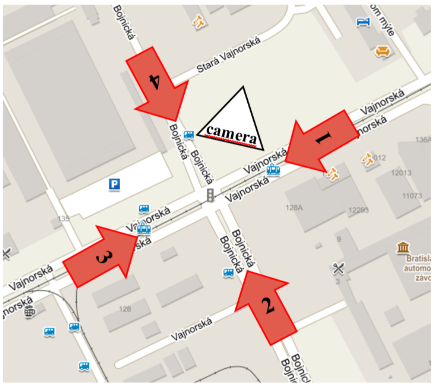

Fig. 4. Marking of the entrances and position of the camera at intersection "C" (processed by authors according to Open Street maps)

We conducted intersection turning movement surveys at the mentioned intersections, which we evaluated. It is a special type of traffic survey in which the direction of vehicles in a small area is determined. It is used to detect the movement of vehicles through the intersection and thus to determine the flow rate of individual traffic flows. The types of vehicles and the travel direction are recorded in 15-minute intervals.

The traffic survey was carried out on Tuesday (25.06.2019) at all three intersections using video cameras (6 am to 6 pm). During the traffic survey, congestions occurred mainly at intersection "A" toward the city center.

3. TRAFFIC MODELING IN AIMSUN

This chapter describes the current traffic load of selected intersections. Traffic loads are presented in the tables. For each intersection, there are tables and results for the current state with the highest traffic load (HT) and the lowest traffic load (LT). In our research, we found an increase in traffic of 10% and 20%. It was increased only for the highest traffic load of the current situation (peak hour), not for the lowest traffic load. In that area, where the individual intersections (A, B, and C) are located, it is considered that the traffic flow will increase by up to 20% by 2040. In addition, we performed simulations with a 10% increase in traffic flow to observe how these intersections would be affected before the 20% increase in traffic. The increase in traffic flow in this area is expected to be caused mainly by the planned construction. The quality level for signal-controlled intersections is determined based on the mean waiting time values according to the following table.

Table 1
Limit values of the waiting time for determining the quality level of a signal-controlled intersection

QSV	Mean waiting time (s)
A	≤ 20
B	≤ 35
C	≤ 50
D	≤ 70
E	≤ 100
F	> 100

The quality level for uncontrolled intersections (including yield-controlled and stop-controlled intersections) is determined based on the limit values of the mean waiting time according to the following graph.

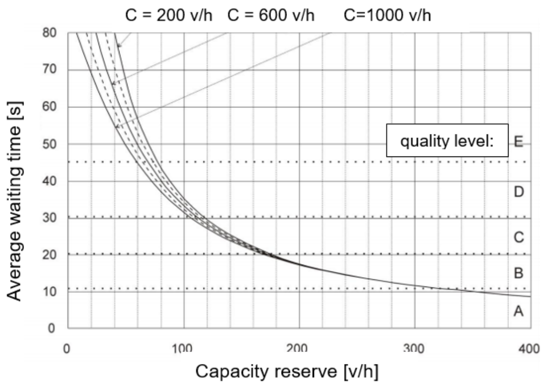

Fig. 5. Graph for determining the quality level - an uncontrolled intersection

3.1. Simulation of intersection "A" and its results

The peak hour (the highest traffic load – HT) at this intersection was from 15:30 to 16:30. The load of the intersection during peak hour is shown in table 2. A total of 3324 vehicles entered the intersection during peak hour.

Table 2
Traffic load of intersection "A" – HT

From/to	1	2	3	4	Total
1	*	385	845	56	**1286**
2	324	*	229	41	**594**
3	1009	435	*	0	**1444**
4	0	0	0	*	**0**

In table 3, the values of the lowest traffic flow during a day for individual directions are presented. A total of 2115 vehicles entered this intersection from 6:00 to 7:00 am.

A total of 40 simulations were created in Aimsun for all 3 mentioned states. Then, an average was subsequently calculated from these. The simulation outputs are presented in the following tables and graphs.

Table 3

Traffic load of intersection "A" – LT

From/to	**1**	**2**	**3**	**4**	**Total**
1	*	256	849	48	**1153**
2	131	*	161	40	**332**
3	507	123	*	0	**630**
4	0	0	0	*	**0**

Fig. 6. Simulation display at intersection "A" in Aimsun [processed by authors]

- *Current state*

The resulting value of the waiting time is given per 1 km, for example, for 100 m of road, vehicles would wait for approximately 18.5 s – HT (or 12 s – LT), which would correspond to quality level A at this intersection.

Table 4

Results from the simulation for the current state – LT and HT

	average value - HT	**average value - LT**	**unit**
waiting time	184,52	119,94	s/km
density	20,94	15,85	veh/km
flow rate	3245,85	2083,28	veh/h
speed	19,38	20,11	km/h

The overall quality level of the intersection is determined by the worst quality level at the entrance to the intersection. The worst quality level at the entrance to the intersection was C. Therefore, the overall quality level is C. The number of vehicles per 1 km is 21 (15,9 veh/km – LT). The flow rate is 3246 vehicles per hour (2084 veh/h – LT), and the average speed is 19,38 km/h (20,11 km/h – LT).

- *ncreased traffic load by 10%*

A total of 3656 vehicles entered the intersection. The resulting value of the waiting time is given per 1 km. For example, for 100 m of road, vehicles would wait for approximately 23,1 s, which would correspond to quality level B. The worst quality level at the entrance to the intersection was D. Thus, the overall quality level is D. The number of vehicles per 1 km is 27. The flow rate is 3405 veh/h, and the average speed is 16,65 km/h.

Table 5
Increased traffic load of intersection “A” by 10%

From/to	1	2	3	4	Total
1	*	424	930	62	**1415**
2	356	*	252	41	**653**
3	1110	479	*	0	**1588**
4	0	0	0	*	**0**

Table 6
Results from the simulation for the state with increased traffic load by 10 %

	average value	unit
waiting time	231,15	s/km
density	26,15	veh/km
flow rate	3404,5	veh/h
speed	16,65	km/h

- *Increased traffic load by 20%*

A total of 3989 vehicles entered the intersection. The resulting value of the waiting time per 100 m is approximately 26,8 s, which corresponds to quality level B. The worst quality level at the entrance to the intersection was D. The overall quality level is D. The number of vehicles per 1 km is 13. The flow rate at the intersection is 3477 veh/h, and the average speed is 14,93 km/h.

Table 7
Increased traffic load of intersection “A” by 20%

From/to	1	2	3	4	Total
1	*	462	1014	67	**1543**
2	389	*	275	49	**713**
3	1211	522	*	0	**1733**
4	0	0	0	*	**0**

3.2. Simulation of intersection "B" and its results

The peak hour was from 15:00 to 16:00. The load of the intersection during peak hour is shown in table 8. A total of 3180 vehicles entered during this hour. A total of 40 simulations were created for all 3 mentioned states. Then, an average was subsequently calculated from these. The simulation outputs are presented in the following tables and graphs.

Table 8
Results from the simulation for the state with increased traffic load by 20 %

	average value	unit
waiting time	267,94	s/km
density	12,81	veh/km
flow rate	3476,2	veh/h
speed	14,93	km/h

In Table 10, t the values of the lowest traffic flow during a day for individual directions are presented - 1353 vehicles (6:00 – 7:00 am).

Table 9

Traffic load of intersection "B" - HT

From/to	1	2	3	4	Total
1	43	3	958	282	**1286**
2	23	*	6	0	**29**
3	1077	16	1	394	**1488**
4	0	0	377	*	**377**

Table 10

Traffic load of intersection "B" - LT

From/to	1	2	3	4	Total
1	10	1	584	62	**657**
2	6	*	0	2	**8**
3	381	6	0	127	**514**
4	0	0	174	*	**174**

Fig. 7. Simulation display at intersection "A" in Aimsun [processed by authors]

- *Current state*

The resulting value of the waiting time per 100 m is approximately 7,1 s (4,4 s – LT), which would correspond to quality level A. The worst quality level at the entrance to the intersection was C. Therefore, the overall quality level is C. The number of vehicles per 1 km is 3 (1,5 veh/km – LT). The flow rate is 3115 veh/h (1387 veh/h – LT), and the average speed is 39,53 km/h (40,94 km/h – LT).

Table 11

Results from the simulation for the current state

	average value - HT	average value – LT	unit
waiting time	70,90	44,18	s/km
density	2,60	1,45	veh/km
flow rate	3114,70	1386,83	veh/h
speed	39,53	40,94	km/h

- *Increased traffic load by 10%*

A total of 3499 vehicles entered the intersection. The resulting value of the waiting time per 100 m is 10,9 s, which corresponds to quality level B. The worst quality level at the entrance to the intersection was D. The overall quality level is D. The number of vehicles per 1 km is 4. The flow rate is 3386 veh/h, and the average speed is 37,95 km/h.

Table 12

Increased traffic load of intersection “B” by 10%

From/to	1	2	3	4	Total
1	47	3	1054	310	**1415**
2	25	*	7	0	**32**
3	1185	18	1	433	**1637**
4	0	0	415	*	**415**

Table 13

Results from the simulation for the state with increased traffic load by 10 %

	average value	unit
waiting time	109,27	s/km
density	3,63	veh/km
flow rate	3385,15	veh/h
speed	37,95	km/h

- *Increased traffic load by 20%*

A total of 3816 vehicles entered the intersection. The resulting value of the waiting time per 100 m is approximately 14,8 s, which corresponds to quality level B. The worst quality level at the entrance to the intersection was E. The overall quality level is E. The number of vehicles per 1 km is 5. The flow rate is 3614 veh/h, and the average speed is 36,66 km/h.

Table 14

Increased traffic load of intersection „B“ by 20%

From/to	1	2	3	4	Total
1	52	4	1150	282	**1543**
2	28	*	7	0	**35**
3	1292	19	1	473	**1786**
4	0	0	452	*	**452**

Table 15

Results from the simulation for the state with increased traffic load by 20 %

	average value	unit
waiting time	148,47	s/km
density	4,73	veh/km
flow rate	3613,8	veh/h
speed	36,66	km/h

3.3. Simulation of intersection "C" and its results

The peak hour was from 15:15 to 16:15. The traffic load of the intersection during peak hour is shown in table 14. A total of 3174 vehicles entered during this hour. In table 17, the values of the lowest traffic flow during a day for individual directions are presented. A total of 1666 vehicles entered this intersection from 6:00 to 7:00 am.

Table 16

Traffic load of intersection "C" - HT

From/to	1	2	3	4	Total
1	*	58	482	69	**609**
2	88	*	161	320	**569**
3	766	133	*	279	**1178**
4	65	319	343	*	**727**

Table 17

Traffic load of intersection "C" - LT

From/to	1	2	3	4	Total
1	*	14	635	40	**689**
2	42	*	57	223	**322**
3	145	47	*	187	**379**
4	26	103	147	*	**276**

Fig. 8. Simulation display at intersection "C" in Aimsun [processed by authors]

- *Current state*

The resulting value of the waiting time per 100 m is approximately 6,5 s (3,3 s – LT), which would correspond to quality level A. The worst quality level at the entrance to the intersection was B. Thus, the overall quality level is B. The number of vehicles per 1 km is 10 (5 veh/km – LT). The flow rate is 3143 veh/h (1698 veh/h – LT), and the average speed is 33,56 km/h (35,97 km/h – LT).

Table 18

Results from the simulation for the current state

	average value – HT	average value – LT	unit
waiting time	65,32	32,66	s/km
density	9,25	4,81	veh/km
flow rate	3142,35	1697,13	veh/h
speed	33,56	35,97	km/h

- *Increased traffic load by 10%*

A total of 3392 vehicles entered the intersection. The resulting value of the waiting time per 100 m is 7,9 s, which corresponds to quality level A. The worst quality level at the entrance to the intersection was C. The overall quality level is C. The number of vehicles per 1 km is 12. The flow rate is 3429 veh/h, and the average speed is 32,02 km/h.

Table 19

Increased traffic load of intersection "C" by 10%

From/to	1	2	3	4	Total
1	*	64	530	76	**670**
2	97	*	177	352	**626**
3	843	146	*	307	**1296**
4	72	351	377	*	**800**

Table 20

Results from the simulation for the state with increased traffic load by 10 %

	average value	unit
waiting time	79,44	s/km
density	11,11	veh/km
flow rate	3428,78	veh/h
speed	32,02	km/h

- *Increased traffic load by 20%*

A total of 3700 vehicles entered the intersection. The resulting value of the waiting time per 100 m is approximately 10,1 s, which corresponds to quality level A. The worst quality level at the entrance to the intersection was C. The overall quality level is C. The number of vehicles per 1 km is 14. The flow rate is 3733 veh/h, and the average speed is 29,85 km/h.

Table 21

Increased traffic load of intersection "C" by 20%

From/to	1	2	3	4	Total
1	*	70	578	83	**731**
2	106	*	193	384	**683**
3	919	160	*	335	**1414**
4	78	383	412	*	**872**

Table 22

Increased traffic load of intersection "C" by 20%

	average value	unit
waiting time	101,26	s/km
density	13,85	veh/km
flow rate	3732,91	veh/h
speed	29,85	km/h

3.4. Comparison of the resulting waiting times and quality levels of solved intersections

The worst results were achieved at the uncontrolled intersection "B". A 20% increase in traffic can cause a waiting time of 14,8 s and an overall quality level E. The situation at intersection "A" is expected to deteriorate to quality level D when traffic increases by 20 %. At intersection "C", quality level C is expected after a 20% increase in traffic. Nevertheless, it is still quite a favorable result. Attention should be paid to intersections "A" and "B". Quality levels D and E are expected there, which is an unfavorable situation. It is necessary to propose a suitable solution to ensure smooth traffic flow, for example, through the introduction of traffic lights at intersection "B". This could have a positive effect on the traffic flow. Traffic lights would help to improve the smoothness of traffic flow at this intersection. We suggest introducing traffic lights at this intersection also due to the so-called green wave (green signal at all 3 intersections simultaneously at a certain time). In addition, we propose the introduction of actuated control at all these intersections, which would reduce the waiting time and increase the capacity of the intersections.

Table 23

Comparison of simulation results of solved intersections

	Waiting time				Quality level			
	Current state - LT	Current state - HT	10 % increase	20 % increase	Current state - LT	Current state - HT	10 % increase	20 % increase
Intersection „A“	12	18,5	23,1	26,8	B	C	D	D
Intersection „B“	4,4	7,1	10,9	14,8	B	C	D	E
Intersection „C“	3,3	6,5	7,9	10,1	A	B	C	C

4. CONCLUSION

Modeling of intersections and roads is very important to ensure smooth traffic flow. Transport in a certain area is mainly affected by the construction of buildings such as shopping centers, factories, blocks of flats, etc. These buildings attract more people, which in turn will affect traffic. It is necessary to perform simulations to determine how the traffic will change after construction. However, we must also consider the annual increase in traffic. We must react quickly to problems that arise because traffic is very dynamic. Thus, traffic modeling and simulations can help us to predict how the situation may change. In this way, we could have solutions ready in advance. In addition, large congestion can be prevented. Well-functioning transport is the basis of the economy of a well-functioning country. Representatives of the government must recognize the importance of preventing problems. They have the competencies to influence well-functioning road traffic through laws, regulations, etc. However, the opinion of experts must be considered for the management of traffic.

Our paper describes the results of simulations of 3 intersections in the capital of Slovakia. The results show that, if, in the future, traffic increases, the quality level will deteriorate and the traffic flow will become less smooth. It is important to find a solution that would help to ensure smooth traffic.

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