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THE RESEARCH OF VEHICLE ACCELERATION AT SIGNALIZED INTERSECTIONS

ABSTRACT

Vehicle acceleration is an important parameter used in planning various road elements, traffic signalization, geometric elements of an intersection, signal plans of traffic lights, etc. The knowledge of vehicle acceleration values is also necessary in using simulation softwares for more accurate analysis of the total situation at an intersection, on a road section or in a traffic network. In a lot of earlier studies, acceleration values were analysed and defined, mostly in optimal conditions for traffic functioning. However, values of almost all traffic flow parameters have been changed over time, due to changes in driving-dynamic vehicle characteristics, pneumatic tyres, material used for building road surface, etc. Besides, local environment influence and changes in drivers' behaviour also significantly affect values of this parameter. According to HCM, it is advisable to perform local research for all values of the parameters recommended within the framework of this handbook, and to adapt their values to local conditions as well. The results of measuring the values of vehicles acceleration at signalized intersections in Novi Sad, Serbia, have been shown in this paper, using the procedure based on video recording processing.

KEYWORDS

vehicle acceleration, signalized intersection, video editing

1. INTRODUCTION

In order to define the level of service of intersections, it is necessary to know some of the basic parameters of traffic flow, like flow intensity, vehicles velocity and density. Acceleration is one of the input parameters for calculating start-up lost time and cycle duration, that is, programming light signal operation. Start-up lost time, as one of important parameters,

has big impact on the initial delay time at the beginning of the green phase of signalized intersections. In this way, low acceleration can influence capacity decrease and level of service decline. Alongside these basic parameters, the level of service is also affected by individual psychological drivers' parameters, that is, their driving manner, which also includes the way of acceleration and deceleration of their vehicle at certain critical points. Knowing these parameters facilitates more precise defining and planning of different road and intersection elements.

This paper presents a method for determining acceleration value for vehicles starting from the stop line at signalized intersections. The method used in this paper is based on the application of simple, easy accessible computer software programs. The research was carried out in Novi Sad, a medium size town in Serbia. The studied traffic flow is heterogeneous, and the vehicles which appeared in the flow are typical European vehicles. Different research studies into vehicle acceleration have been carried out with a wide range of results, as shown in Chapter 2. The basic goal of this paper is to show how a simple acceleration measuring procedure could be used to collect a large sample and to quite precisely determine acceleration of vehicles at signalized intersections. Also, the goal of this paper is to propose narrow intervals for the usual acceleration values.

2. PREVIOUS RESEARCH VALUES OF ACCELERATION

Previous research studies into vehicle acceleration have been carried out in several different directions

and with different output parameters. The acceleration value represents a very important parameter which influences the delays at unsignalized intersections [10] and at signalized intersections and roundabouts as well [15]. The acceleration values have influence in determining geometric elements of intersections and the traffic regulation at these intersections [11]. Also, acceleration value could help in defining the signal plans of traffic lights [23]. The value of vehicle acceleration is also one of the basic parameters taken into consideration in creating traffic flow simulation models [8] and in designing intelligent vehicles [9].

Some values of vehicle acceleration are given in the manual AAHSTO Green Book [1] and within the framework of HCM [13] and they represent predefined values for a wide range of traffic conditions. Within the framework of HCM there are recommendations that for all default values local measurements are carried out in the field, in order to determine more precisely real values of the parameters, and in this case the value is vehicle acceleration.

The significance of the study of acceleration value in different conditions was shown in previous research studies done regarding this subject. Previously, vehicle acceleration on approaches to horizontal bends was studied by Hu, Wen and Donnell [14] and Ko, Joonho, Guensler, Randall and Hunter [16] while acceleration on approaches to intersections was the research interest of Long [17] and Wang [25]. Within the paper of Rakha [19], the values of freight vehicles acceleration at intersections were processed and the model for these was created.

The output results were presented through the model of vehicle acceleration [3, 4] or through the values measured directly in the field [21, 18, 5]. For the development of certain models for the assessment of maximum acceleration values microsimulations were used [20]. In the mentioned paper, maximum values for passenger cars were modelled.

According to HCM recommendations, values of vehicle accelerations at intersections are within the interval from $1-4.3\text{m/s}^2$ [13]. Previous research studies done into this subject defined real values of acceleration for vehicles starting from the stop-line or having a constant velocity. In the paper written by Ahn [2], the influence of vehicle velocity value and acceleration on fuel consumption and harmful gases emission was processed. Acceleration values determined in this research are from 0 to 3.5m/s^2 , depending on the initial vehicle velocity. The mentioned values represent normal vehicle acceleration. Values of extreme vehicle acceleration were studied by Hegeduš, Ilić, and Šala [12]. They analysed the maximum vehicle acceleration while reaching the speed of 100km/h , starting from the state of rest. Results of previous research studies carried out in Serbia, at signalized and unsignalized

intersections, are presented in two papers published at local assemblies [6] and [7].

3. RESEARCH METHOD

Altogether 10 intersections in Novi Sad, Serbia, were chosen for the research, and at the time of measuring the acceleration values they were all signalized intersections. The intersections were chosen in different town zones with the aim of achieving the most possible heterogeneity of samples. All the values shown in this paper were measured in two independent research cases, in 2006 and in 2009.

The research method applied in this paper is based on using computer software programs for the purpose of more accurate and simpler data collecting. The studied traffic flow at signalized intersections was recorded by means of a digital camera, and with subsequent processing and analysis of video recordings, acceleration values for each individual vehicle, at starting from stop lines, were determined. Similar method of video analysing for a different purpose was also used by Maini, Pawan and Khan in their paper [18]. The traffic flows at the chosen intersections were recorded from the nearby buildings, and the angle of recording was especially considered for reducing the perspective influence, that is, for better view of the intersections. To reduce the moving of camera during the recording, it was fixed to an immovable object or set on a support. All intersections were recorded in the period of the noon and afternoon peak hour in conditions of dry road surface.

The obtained recording in the duration of half an hour to an hour was adjusted for reproduction on a computer. A simple video player was used for video recording processing, then the frames were copied from the player into the background of CAD software, for assessing accurate positions of referential points for the measurement needs. The accurate dimensions of the intersection and other elements like horizontal

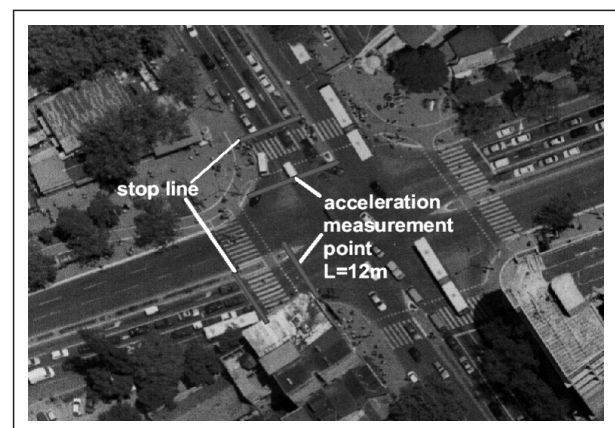


Figure 1 - Defining measure lines in a photograph of an intersection

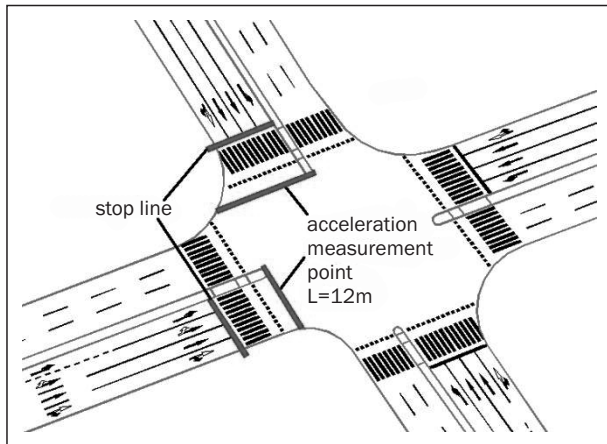


Figure 2 - Defining measure lines in an intersection drawing

signalization, dividing islands and others were taken from ortho-photographs and precise project drawings of intersections.

After defining all the necessary measures, all measure lines used afterwards for determining the vehicle acceleration values were measured and defined.

The photograph with defined measuring points, that is, lines, was copied into the video editing soft-



Figure 3 - Static lines in the video represent measuring points for acceleration

ware, where the defined static lines represent the predicted positions for acceleration measuring.

Setting static lines in the photographic recording has double significance. Apart from the fact that it is possible at every moment to determine with precision vehicle crossing the line, it is also possible to move the line to another preferable position in case when the observed vehicle does not start from the stop line. In this way the possibility of making a mistake is eliminated because the accurate value of distance was always used in the calculation for acceleration measuring. Accelerations at intersections were measured from two distances in relation to the start line, the closer one - up to 20 metres, and the farther one, 40-50 metres, in order to determine the change of acceleration depending on the distance from the start line.

After defining the measuring lines and distances, time measuring was carried out and it referred to the time vehicles needed for reaching certain measuring points after start-up. Time measuring was done by means of software for video editing, where the time on the recording is shown with the accuracy of 0.01s. The accuracy of measuring is given through errors of the software used; therefore, apart from the stated possible error in time measuring, the possible error during length measuring is about 0.2m.

The acceleration value and possible error was calculated by the formula used for acceleration calculation, where time and distance dominate:

$$a = 2 \cdot S/t^2$$

where:

- a - acceleration of vehicle,
- S - distance during acceleration,
- t - time during acceleration;

so that acceleration possible error is $\Delta a = 0.03m/s^2$

And the obtained values were calculated in tables.

Every measured acceleration which was considered to be extreme was discounted from further analysis. Extreme values were processed in the paper [12], where it was stated that the average acceleration value for sport cars does not exceed $5.6m/s^2$, at acceleration of 0-100km/h. Considering the fact that this research was performed on average cars, values higher than the stated $5.5m/s^2$ were discounted from

Table 1 - The results of field measurements and acceleration calculation

Turning movement	Vehicle in the queue	Vehicle type	t(s)	S(m)	a(m/s ²)
Right		Ford	4.08	12	1.441753
Right		Toyota	3.92	12	1.561849
Right		others	4.91	12	0.995516
Through	1	Citroen	3.32	12	2.177384
Through	1	Peugeot	3.48	12	1.981768
Left	1	BMW	3.68	12	1.772212
Through	2	Zastava	4.28	12	1.310158

further analysis. Also, very low values, that is all values lower than 0.5m/s^2 were discounted from further analysis.

Values for the first and the second vehicle in the line were specially analysed. In this analysis it was determined that in a formed line, the acceleration of the third, the fourth and the following vehicles has a negligibly low value, lower than 0.5m/s^2 ; therefore, they were discounted from the research. Another analysis was carried out, acceleration according to the type of manoeuvre the vehicle performed, that is, whether after crossing the stop line the vehicle moves straight, to the left or to the right.

After having sorted the data, these were statistically processed. The results of the total data processing are presented in this paper.

4. VALIDATION OF THE METHOD

Measuring of the values of some traffic flow parameters processing video recording has been used since the first half of the 20th century. Systems based on video recording processing have been developed lately. They measure with precision almost all traffic flow parameters on certain parts of the street network. However, these systems are complex and they are not always available for they are only developed on the parts of the street network where flow demands are high. The proposed traffic flow measuring procedure is based on the processing of video recordings of real traffic flows recorded by a recording camera. The video recording is processed by means of easily available software programs with satisfactory accuracy of the measured values of the traffic flow parameters.

To determine the accuracy of this procedure, a measurement of traffic flow parameters has been carried out in 22 test rides of vehicles at a test site, without interference of other vehicles. Onboard test vehicle there were GPS devices – PBOX Performance Sport, as well as the accelerometer Vericom VC3000,

and simultaneously the recordings were made by a recording camera. The measurement was carried out in Novi Sad, on 21st September 2012 in the period from 11:00a.m. to 12:00a.m.

After the test rides, the data from both measuring devices were downloaded, and the video recordings were processed in the way described in Section 3. All data were analyzed and shown in *Table 2*.

Comparing the values in *Table 2*, it can be seen that the results of acceleration measurements on both measuring devices (PBOX i VERICOM) are very similar, with the mean deviation of about 0.06m/s^2 . On the other hand, comparing the values obtained by video editing in relation to either of the measuring devices, a certain deviation can be noticed, with the mean error not exceeding the value of 0.1m/s^2 .

Taking into consideration the determined results deviation obtained in video editing processing, in relation to the measuring results on other measuring devices, it can be concluded that the proposed procedure is reliable enough for measuring the traffic flow parameters.

The proposed procedure has the advantage in relation to classic procedures of acceleration measurements, taking into account that the behaviour of a driver is real in the traffic flow. The acceleration value achieved by the vehicles depends exclusively on the traffic conditions at a certain intersection. Besides, for the procedure simplicity, the sample size is practically indefinite. Considering the simplicity and availability of video editing technology as a method for measuring traffic flow parameters, video editing processing can be recommended for measuring parameters in a real traffic flow, without the risk of change in the drivers' behaviour.

5. RESULTS

For the needs of acceleration measurement in the street network of Novi Sad, two completely indepen-



Figure 4 - Test instruments and test rides

Table 2 - Comparative review of results obtained in test rides

Test No.	PBOX			VERICOM			VIDEO EDITING		
	time (s)	distance (m)	accel. (m/s ²)	time (s)	distance (m)	accel. (m/s ²)	time (s)	distance (m)	accel. (m/s ²)
1	4.26	20.03	2.21	4.3	19.967	2.16	4.26	20	2.20
2	3.54	19.99	3.19	3.6	20.651	3.19	3.50	20	3.27
3	3.31	20.07	3.66	3.3	20.184	3.71	3.33	20	3.61
4	5.81	19.99	1.18	5.9	21.082	1.21	5.67	20	1.24
5	3.49	20.03	3.29	3.5	20.418	3.33	3.50	20	3.27
6	3.82	20.00	2.74	3.8	20.367	2.82	3.73	20	2.88
7	4.59	20.06	1.90	4.7	20.341	1.84	4.53	20	1.95
8	3.41	19.99	3.44	3.5	20.685	3.38	3.50	20	3.27
9	3.46	19.99	3.34	3.4	19.594	3.39	3.40	20	3.46
10	3.20	20.03	3.91	3.1	20.521	4.27	3.10	20	4.16
11	4.99	20.01	1.61	5.0	19.872	1.59	5.00	20	1.60
12	3.30	20.02	3.68	3.3	20.121	3.7	3.27	20	3.74
13	3.33	19.98	3.60	3.3	19.762	3.63	3.30	20	3.67
14	4.08	20.01	2.40	4.1	20.663	2.46	4.00	20	2.50
15	3.56	20.00	3.16	3.6	20.369	3.14	3.67	20	2.97
16	3.51	20.02	3.25	3.5	19.993	3.26	3.47	20	3.32
17	4.47	19.99	2.00	4.6	19.911	1.88	4.80	20	1.74
18	4.44	20.04	2.03	4.5	20.227	2.00	4.37	20	2.09
19	3.61	20.06	3.08	3.6	19.812	3.06	3.56	20	3.16
20	3.50	20.03	3.27	3.5	19.943	3.26	3.53	20	3.21
21	3.22	20.01	3.86	3.3	21.206	3.89	3.16	20	4.01
22	3.37	20.03	3.53	3.3	19.910	3.66	3.37	20	3.52

dent measurements were carried out, first in 2006, and the other in 2009.

The first research was carried out in 2006; the acceleration for the vehicles which start from the stop line and for the vehicles which were the second in the line were analysed, using the method previously described. The primary intensity of acceleration was measured after 10-20 metres from the moment of starting the vehicle from the stop line. In order to determine if the intensity of acceleration decreases at

greater distance from the stop line, an additional measuring was carried out at the distance of 40-50 metres from the stop line. This is the reason for having two measured values in this research, at a close and at a far measuring point.

The sample of 1,210 vehicle accelerations at 6 intersections was analysed within the first research. The intersections were chosen according to their position in the street network and for this research only the signalized intersections were isolated. The position of

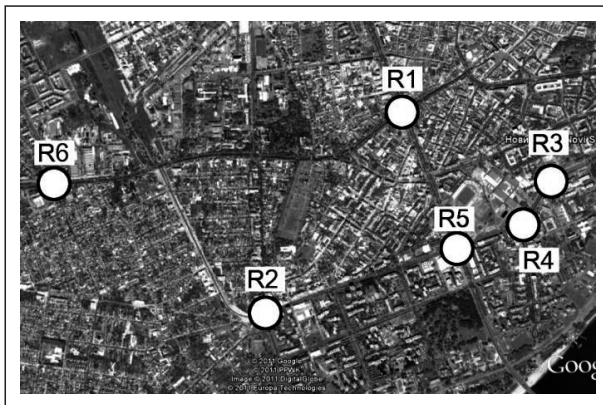


Figure 5 - Position of studied intersections in the first research in 2006

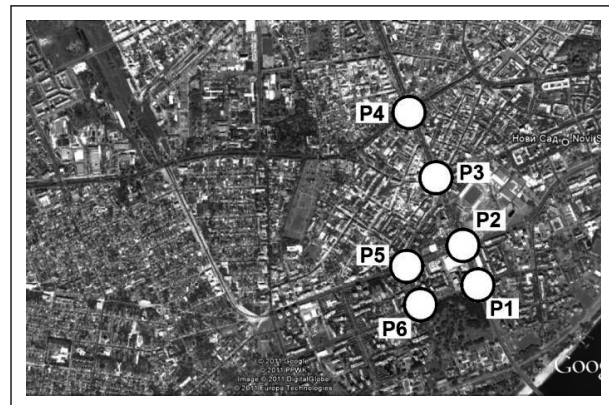


Figure 6 - Position of studied intersections in the second research in 2009

these intersections has been presented in Figure 4 and Figure 5.

Table 3 - Studied intersections

Intersection	Number of vehicles
Bulevar Oslobođenja St. - Jevrejska St. - Futoška St.(R1)	493
Cara Lazara St. - Cara Dušana St.(R2)	155
Stražilovska St. - Cara Lazara St.(R3)	28
Fruškogorska St. - Cara Lazara St.(R4)	109
Bulevar Oslobođenja St. - Cara Lazara St.(R5)	143
Futoški Put St. - Slobodana Jovanovića St.(R6)	282
Total	1,210

The second research was carried out in 2009 in order to verify the results obtained in the first research and to determine the possible changes. In the second research, 1,433 acceleration values for the vehicles unclassified according to the type were analysed at 6 intersections. In the second research one typical intersection from the first research was kept (R1 = P4), while others were taken at random.

Table 4 - Intersections where acceleration was measured in the second research

Intersection	Number of vehicles
Bulevar Oslobođenja St. - Narodnog Fronta St.(P1)	289
Bulevar Oslobođenja St. - Bulevar Cara Lazara St. (P2)	345
Bulevar Oslobođenja St. - Maksima Gorkog St. - Braće Ribnikar St. (P3)	320
Bulevar Oslobođenja St. - Jevrejska St. - Futoška St. (P4)	158
Bulevar Cara Lazara St. - Šekspirova St.(P5)	168
Narodnog Fronta St. - Šekspirova St. (P6)	153
Total	1,433

Table 5 - Average acceleration values and deviation at close measuring point

	Sample	Mean	Min	Max	Standard deviation
Close measuring point	917	1.895	0.537	4.459	0.599

Table 6 - Distribution of acceleration values by groups at close measuring point

Acceleration value (m/s ²)	Count	Cumulative count	Percent	Cumulative Percent
0.79 - 0.87	14	14	1.527	1.527
0.87 - 1.67	350	364	38.168	39.695
1.67 - 2.47	413	777	45.038	84.733
2.47 - 3.26	118	895	12.868	97.601
3.26 - 4.06	18	913	1.963	99.564
4.06 - 4.86	4	917	0.436	100.000

The obtained data were statistically processed and recommendations were given on acceleration values in the studied conditions. Results analyses are further presented. The analysis and statistical data processing have been carried out.

5.1 Data analysis - the first research

In Tables 5-8 the overview of results obtained in the first research and their statistical processing is presented. The measurement results obtained at two different measuring points showed that these results differ; therefore, they are given separately, that is, the values for the close and those for the far measuring point.

Close measuring point

Statistical data processing obtained in the first research showed that the vehicle acceleration acts in a general pattern of normal distribution as shown in Figure 6.

After previous results analysis, it can be concluded that at the close measuring point the acceleration intensity is dominant in the interval of 1-2.5 m/s², and

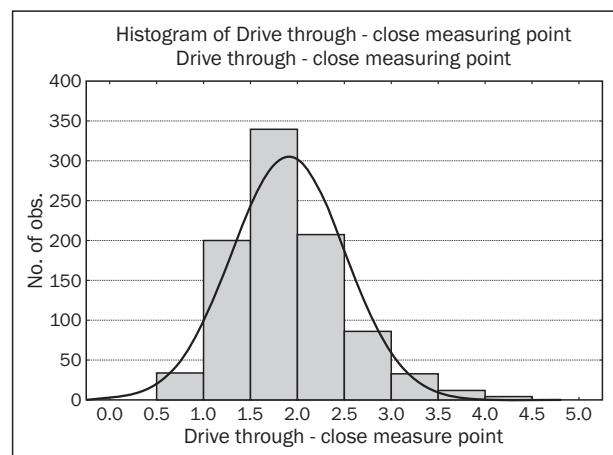


Figure 7 - Graphical representation of measurement results at close measuring point

Table 7 – Mean values of acceleration and deviation at far measuring point

	Sample	Mean	Min	Max	Standard deviation
Far measuring point	209	1.785	0.937	3.278	0.352

Table 8 – Distribution of acceleration values by groups at far measuring point

Acceleration value (m/s ²)	Count	Cumulative count	Percent	Cumulative Percent
0.70 – 1.17	3	3	1.436	1.436
1.17 – 1.64	70	73	33.493	34.929
1.64 – 2.11	99	172	47.368	82.297
2.11 – 2.58	32	204	15.311	97.608
2.58 – 3.04	4	208	1.914	99.522
3.04 – 3.51	1	209	0.478	100.000

that the dominant group with 45% of measured values is within the range of 1.67-2.47 m/s². According to Table 5 it can be seen that 95% of the measured values of acceleration are in the interval of 0.87-3.26 m/s².

Far measuring point

Measuring at far measuring point showed some different results. The mean and maximum measured values of acceleration have lower intensity, which in-

dicates that acceleration decreases with moving away from the start line. These values are expected, for it can be assumed that with moving away from the start line vehicles will accelerate with lower intensity for the very constructive characteristics, that is, because of the fact that acceleration decreases in higher transmission degrees. Similar conclusions can be found in paper [24].

Statistical processing shows that results obtained in measuring at far measuring point have approximately normal distribution, and that the dominant acceleration value is in a narrower interval, 1.4-2.0 m/s². The dominant group with 47% of the measured values is in the interval of 1.64-2.11 m/s². Altogether 95% of the measured values are in the interval of 1.17-2.58 m/s².

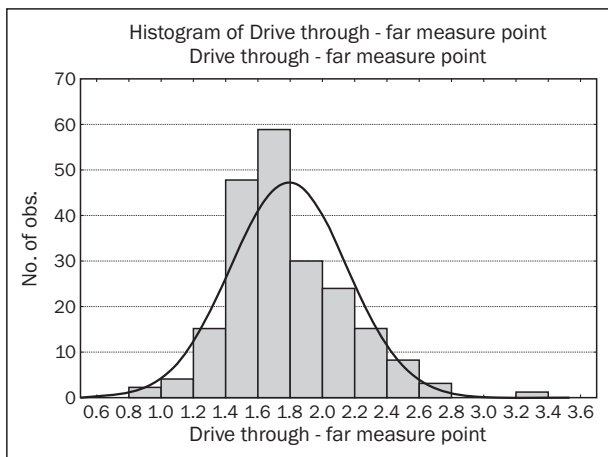


Figure 8 – Graphical representation of measurement results at far measuring point

5.2 Data analysis – the second research

The second research was carried out in 2009 and the intensity of 1,433 vehicle accelerations was determined at 6 signalized intersections. In the second research there was no vehicle classification, but the intensities were given as a total. Also, the measuring was carried out on only one measuring line, on about 15-20m, which corresponds to the close measuring position within the framework of the first research. The obtained results are presented in Tables 9 and 10.

Table 9 - Average values of acceleration and deviation in the second research

	Sample	Mean	Min	Max	Standard deviation
Far measuring point	209	1.785	0.937	3.278	0.352

Table 10 - Distribution of acceleration values by groups in the second research

Acceleration value (m/s ²)	Count	Cumulative count	Percent	Cumulative Percent
0.70 – 1.17	3	3	1.436	1.436
1.17 – 1.64	70	73	33.493	34.929
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3.04 – 3.51	1	209	0.478	100.000

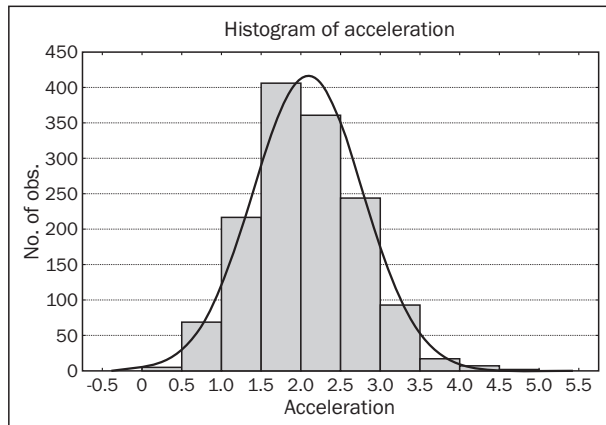


Figure 9 - Representation of the measured values of acceleration in the second research

According to the results of statistical processing, it can be seen that the value of acceleration intensity matches the approximately normal distribution, as previously determined in the first research, which is presented in Figure 8.

As it can be seen in the graph, most measured values are in the interval of 1.5 – 2.5m/s². About 49% of the measured acceleration values are in the interval of 1.61 – 2.51m/s², while over 95% of the values are in the interval of 0.71 – 3.40m/s².

6. DISCUSSION

Acceleration, as well as other parameters describing vehicle movement at intersections (velocity, gaps,...) have a significant part in the procedures for analyzing traffic conditions and in designing the systems for traffic regulation and management. Most software programs for simulating traffic flows, such as SimTraffic, VISSIM and others, have the possibility of defining the velocity, acceleration and other parameters, in order to make the simulation as close as possible to real traffic conditions. Determining the values of these parameters in real conditions is sometimes a complex procedure which demands extensive preparation and expensive equipment. The method proposed in this paper is based on the simple procedure of measuring traffic flow parameters in completely real conditions with satisfactory level of accuracy.

The main advantage of this procedure of traffic flow parameters measuring in relation to other procedures based on video recording processing is that there is no need for special equipment and specialized software programs. Apart from acceleration measuring, this procedure can be also applied to measuring of other traffic flow parameters.

Recommendations for vehicle acceleration values at intersections are given in a wide range in the litera-

ture commonly used in engineering practice [13]. The results of previous research studies into acceleration were usually the models or acceleration values measured in the field for some specific situations, while some other study results were extreme acceleration values. The results of research studies into acceleration are in accordance with the values recommended in the reference books [13], or they are the result of previous research studies [4, 12]. However, acceleration values shown in this paper have been grouped and given in considerably narrower range in relation to most previous research studies. In data processing, all extreme values have been excluded; therefore the obtained results can be regarded as common acceleration values achieved at signalized intersections in medium sized towns. For that reason, the results of this research can be applied in cases when common traffic situations at intersections are analysed.

7. CONCLUSION

The main purpose of this research was to show the results of an experimental measuring of acceleration values at signalized intersections of street network. Besides, the aim was to present the method based on using simple and easily accessible computer software programs reliable for measuring some of the traffic flow parameters. Intersections used in the measurement are common in the street network of big towns. Acceleration values were measured in the period of peak hours, when the degree of interaction among vehicles in the traffic flow increased. The purpose of this paper was to determine the acceleration values which can be applied in traffic flow planning and regulating at signalized intersections. For that reason the extreme values were not considered. The basic conclusions reached in this research are the following:

- acceleration values at starting a vehicle at an intersection are within the interval of 1.8-2.0m/s²,
- after leaving the start line the values decrease to 1.7-1.9m/s²,
- acceleration value corresponds to normal distribution,
- in the period of the studies carried out in the interval of 3 years (2006-2009) there was no significant change in the parameter value ,
- vehicles in the line after the second vehicle reach significantly lower acceleration values.

Further research on this subject should be directed to the analysis of acceleration values at other types of signalized intersections, with specific geometry, traffic system, etc. Apart from that, for determining the influence of the town size, the research should be performed in smaller towns and in the cities.

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SAŽETAK

ISTRAŽIVANJE UBRZANJA VOZILA NA SIGNALISANIM RASKRSNICAMA

Ubrzanje vozila predstavlja jedan od osnovnih parametara koji se koriste kod projektovanja različitih putnih elemenata, saobraćajne signalizacije, geometrijskih elemenata raskrsnice, signalnih planova semafora i slično. Poznavanje vrednosti ubrzanja vozila je takođe neophodno prilikom korišćenja simulacionih softvera radi analize celokupne saobraćajne situacije na raskrsnici, deonici puta ili nekoj saobraćajnoj mreži. U mnogim ranijim istraživanjima analizirane su i definisane vrednosti ubrzanja, uglavnom u optimalnim uslovima odvijanja saobraćaja. Međutim, vrednosti gotovo svih parametara saobraćajnog toka su se tokom vremena menjali zbog promene vozno-dinamičkih karakteristika vozila, pneumatika, materijala za izradu kolovoza itd. Pored toga, uticaj lokalne sredine i promene u ponašanju vozača takođe imaju značajan uticaj na vrednosti ovog parametra. Prema HCM-u, za sve vrednosti parametara koje su preporučene poželjno je izvršiti lokalna istraživanja i prilagoditi njihove vrednosti lokalnim uslovima. U okviru rada prikazani su rezultati merenja vrednosti ubrzanja vozila na signalisanim raskrsnicama u Novom Sadu, u Srbiji, uz korišćenje jednostavne metodologije za prikupljanje podataka.

KLJUČNE REČI

ubrzanje vozila, signalisana raskrsnica, obrada video zapisa

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