Grzegorz SIERPIŃSKI
Silesian University of Technology, Faculty of Transport, Department of Traffic Engineering
Krasińskiego St. 8, 40-019 Katowice, Poland
**Corresponding author*. E-mail: grzegorz.sierpinski@polsl.pl

VARIANCE OF SERVICE TIMES RESEARCH ON SIGNALIZED INTERSECTIONS

Summary. Variance of service times is the measure of dispersion in the process of vehicles service. The article includes results of observation and measurements on several signalized intersections in Katowice. Measurements permitted to estimate variance of service times. Results of simulation research was presented too.

BADANIA WARIANCJI CZASÓW OBSŁUGI NA SKRZYŻOWANIACH Z SYGNALIZACJĄ ŚWIETLNĄ

Streszczenie. Wariancja czasów obsługi stanowi miarę rozproszenia w procesie obsługi pojazdów. W artykule przedstawiono wyniki badań ruchu na skrzyżowaniach z sygnalizacją świetlną w Katowicach. Badania pozwoliły określić wariancję czasów obsługi. Zaprezentowano także wyniki badań symulacyjnych.

1. INTRODUCTION

The service of vehicles on signalized intersections is a very complex mechanism. Usually there are many simplifications in traffic models. Many researchers take into consideration only intensity of arrival and service. Estimation of the variance of service times allows to reflect the real traffic processes well. It is possible to estimate dispersion in the process of vehicle service on signalized intersections by taking into consideration variance of service time.

The service of vehicles on intersection was defined as vehicle transition from crossing a stop line to leaving the intersection. Start of service was defined as crossing the stop line (when the vehicle was entering the intersection). The end of the service is the moment when the vehicle will have crossed the intersection; which means that the service time comprises also the time equivalent to the vehicle length. Location of the end of service depends on the intersection's construction. All stages of vehicle transition – from entering to leaving the intersection was presented in table 1.

The article includes results of observation and measurements on several signalized intersections in Katowice. Additional simulation research which allowed to get the relationship between variance of service time and traffic intensity was also described.

Table 1

Possible stages of vehicle transition on signalized intersection
in relationship with traffic directions

Left turn	Straight direction	Right turn	
• entering on intersection; • waiting for acceptable gap in general flow (if it exists); • waiting for possibility of transition through pedestrian crossing; • leaving intersection (end of service)	• entering on intersection; • leaving intersection (end of service)	• entering on intersection; • waiting for possibility of transition through pedestrian crossing; • leaving intersection (end of service)	in case of „conditional drive signal” existing („green arrow”): • waiting for possibility of transition through pedestrian crossing; • waiting for acceptable gap in general flow (if it exists); • entering on intersection; • leaving intersection (end of service)

2. TRAFFIC MEASUREMENTS AND SIMULATION RESEARCH

Measurements on actual intersections are the basic source of data if there is a necessity of verifying traffic models. Results of observations help to create compatibility between reality and theoretical model.

There were two methods of survey applied to get these results. Measurements at actual fixed-time signalized intersections in Katowice were the first method and a video camera was used to record all stages of vehicle transition – from entering to leaving the intersection. List of intersections was presented in table 2.

Each lane was analyzed separately. Traffic flow was measured for various traffic directions, traffic volume and various constructions of intersections. Traffic was observed for “straight” and “left turn” directions. “Right turn” direction was skipped by reason of “conditional drive signal” [1]. Measurement, in case of left turn, was done for independent movements and in case when vehicle transition depended on different traffic flows. Measurement was also done for mixed directions on one lane – “straight” and “left turn” with collision (with pedestrians).

Simulations in VISSIM were the second method to get values of variance of service times. The computer modelling of traffic flow allows receiving results in a very short time and they reflect the real traffic processes well enough. What is more, empiric methods are time-consuming and very often impossible to apply. A simulation program allowed to put various intensity of arrivals and make measurement for various traffic conditions. Simulation was made for 7 measurement points (in total: 630 experiments). Traffic was simulated 10 times for specific intensity of arrivals in range of traffic intensity from 0,1 to 0,9 (with skip 0,1).

[1] According to the Decree of Minister and Transport, in case of specific technical conditions of road signs and signals, and traffic safety devices, and conditions of their position on the road [6] “conditional drive signal” is allowed to be used only until 31.12.2008. Roads Administrators asked to explain this notation in August 2006. The Ministry of Transport answered that this Decree will be changed in the year 2007. The official opinion was: “Ministry of Transport informs that in the present state of law, impediments for using signaling device S-2 on streets (in current project) do not exist.” Therefore if the notation about “conditional drive signal” will be in revision of this Decree, it will be necessary to measure traffic also in this case.

Table 2

List of places of traffic measurement

<table>
<tr><th>Intersection</th><th>Symbol intersection /inlet (or direction)</th><th>Direction on lane</th><th>Lane location</th><th>Additional information</th></tr>
<tr><td>Graniczna – Krasińskiego</td><td>1.1</td><td>mixed (straight direction / left turn)</td><td>ul. Graniczna (from al. Górnośląska)</td><td>left turn – collision with pedestrians</td></tr>
<tr><td rowspan="4">Korfantego – Misjonarzy Oblatów – Katowicka</td><td>2.1</td><td>left turn</td><td>al. Korfantego (from Siemianowice Śl.)</td><td>independent movement</td></tr>
<tr><td>2.2</td><td>straight direction</td><td>al. Korfantego (from Siemianowice Śl.)</td><td></td></tr>
<tr><td>2.3</td><td>left turn</td><td>al. Korfantego (from centre of Katowice)</td><td>independent movement</td></tr>
<tr><td>2.4</td><td>straight direction</td><td>al. Korfantego (from centre of Katowice)</td><td></td></tr>
<tr><td rowspan="2">Mikołowska – Poniatowskiego – Strzelecka</td><td>3.1</td><td>left turn</td><td>ul. Mikołowska (from centre of Katowice)</td><td>collision with general flow</td></tr>
<tr><td>3.2</td><td>straight direction</td><td>ul. Mikołowska (from centre of Katowice)</td><td></td></tr>
</table>

Service times $t_{\mu\, i}$ was estimated by noticing the moments when vehicles entered the intersection $t_{start\, i}$ (start of service) and the moments when the service was finished $t_{end\, i}$. In addition moments when vehicles arrived $t_{entry\, i}$ were also noticed (fig. 1).

The average of service times was counted from the equation (1).

$$\overline{t_{\mu}} = \frac{1}{n} \cdot \sum_{i=1}^{n} t_{\mu\, i} \quad [s]; \tag{1}$$

where: $t_{\mu\, i}$ – service time of i-th vehicle [s]; n – number of observations [-].

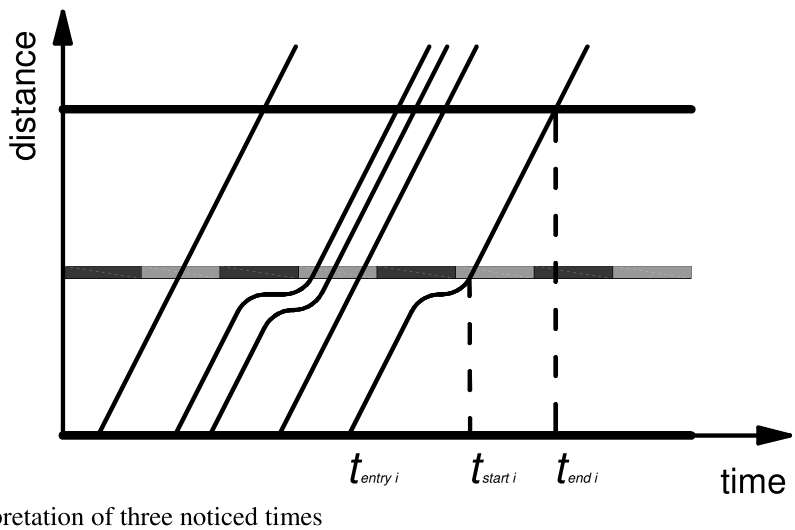

Fig. 1. Graphic interpretation of three noticed times
Rys. 1. Ilustracja trzech rejestrowanych wielkości

The variance of service times was estimated from equation (2).

$$\sigma_{\mu}^{2} = \frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(t_{\mu i} - \overline{t_{\mu}} \right)^{2} \quad [s^2]; \tag{2}$$

where: $t_{\mu i}$ – service time of i-th vehicle [s]; $\overline{t_{\mu}}$ – average of service time [s]; n – number of observations [-].

3. DISCUSSION ABOUT RESULTS

The comparison of values of average service times and variance of service times for all measurement points was presented in table 3. Considerably longer average service time was observed for left turn with collision (with general flow) – point 3.1. The reason for higher variance of service time on point 3.2 is periodical disturbance on this intersection. Empirical distributions were received by single observation process for specific measurement points, therefore the received results only have a general character.

Measurements on actual intersections not allow for a wide analysis of the relationship between variance of service time and other factors. Simulations allow to research the relationship between variance of service time and traffic intensity in all measurement points (table 4). Graphic interpretation of relationship $\sigma_{\mu}^{2}(\rho)$ was presented on figures (fig. 2 – 8).

The analysis of results indicated that:

- in case of independent movements – variance of service time is below 0,5; variance of service time decreases when degree of saturation increases (except – measurement point 2.1 – increase of variance for degree of saturation equals 0,2);
- in case of collision with pedestrians point 1.1 any relationship between variance and traffic intensity was not observed;
- the highest value of variance was noticed for left turn with collision (point 3.1), in this case the value of variance of service times quickly increases with the growing of degree of saturation (increase over 140% in observed range).

Table 3

The comparison of values of average service times and variance of service times for all measurement points

Symbol intersection /inlet (or direction)	Number of observed vehicles [P]	Average of service time [s]	Variance of service time [s^2]
1.1	432	5,066	2,749
2.1	324	8,949	1,696
2.2	495	6,554	1,957
2.3	260	11,058	3,781
2.4	308	7,612	2,961
3.1	109	36,628	601,313
3.2	526	6,926	12,551

Table 4

The comparison of values of variance of service from simulation program VISSIM for various traffic intensity ρ [-]

Symbol intersection /inlet (or direction)	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
1.1	5,676	5,374	6,248	6,987	7,059	6,256	5,885	6,282	5,248
2.1	0,373	0,461	0,304	0,306	0,280	0,290	0,262	0,246	0,231
2.2	0,421	0,323	0,300	0,279	0,259	0,249	0,239	0,232	0,197
2.3	0,352	0,324	0,299	0,284	0,273	0,260	0,257	0,244	0,234
2.4	0,493	0,418	0,367	0,337	0,299	0,276	0,287	0,260	0,229
3.1	497,527	506,206	672,426	815,265	915,614	929,083	978,911	1137,919	1213,553
3.2	0,269	0,227	0,186	0,180	0,165	0,150	0,145	0,125	0,121

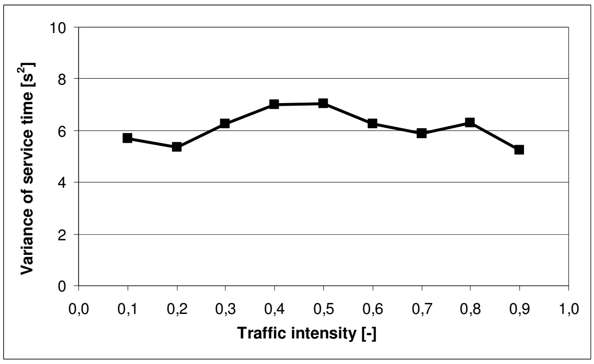

Fig. 2. Relationship between variance of service times – results from simulations (point 1.1)
Rys. 2. Zależność wariancji obsługi od intensywności ruchu na podstawie symulacji (punkt 1.1)

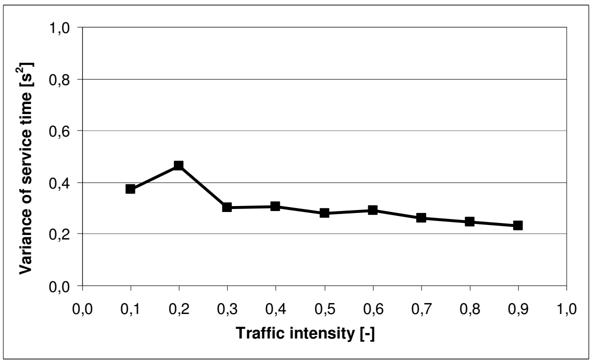

Fig. 3. Relationship between variance of service times – results from simulations (point 2.1)
Rys. 3. Zależność wariancji obsługi od intensywności ruchu na podstawie symulacji (punkt 2.1)

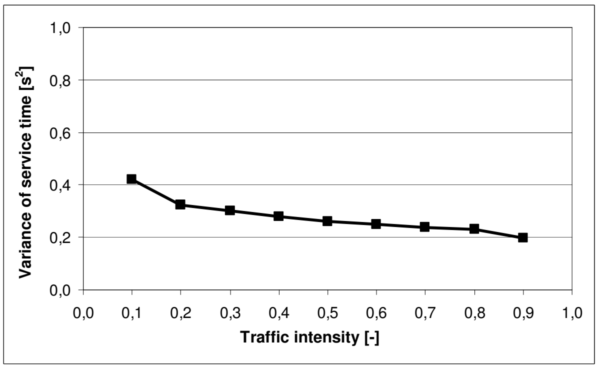

Fig. 4. Relationship between variance of service times – results from simulations (point 2.2)
Rys. 4. Zależność wariancji obsługi od intensywności ruchu na podstawie symulacji (punkt 2.2)

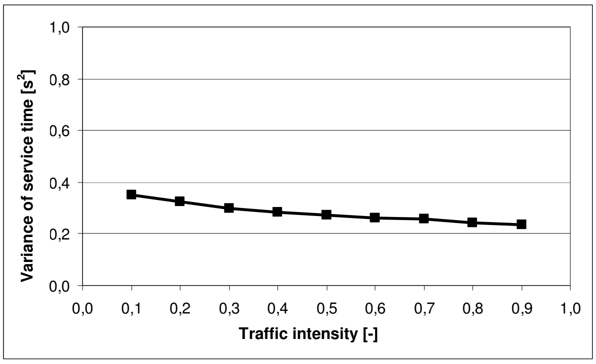

Fig. 5. Relationship between variance of service times – results from simulations (point 2.3)
Rys. 5. Zależność wariancji obsługi od intensywności ruchu na podstawie symulacji (punkt 2.3)

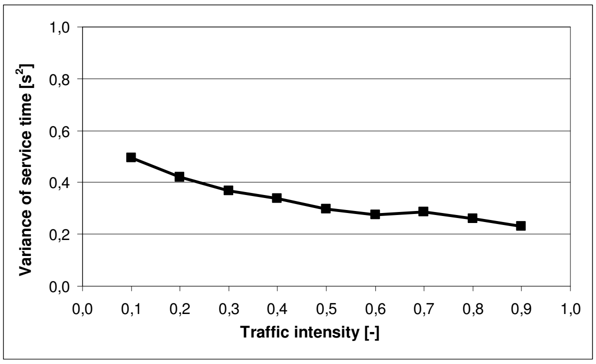

Fig. 6. Relationship between variance of service times – results from simulations (point 2.4)
Rys. 6. Zależność wariancji obsługi od intensywności ruchu na podstawie symulacji (punkt 2.4)

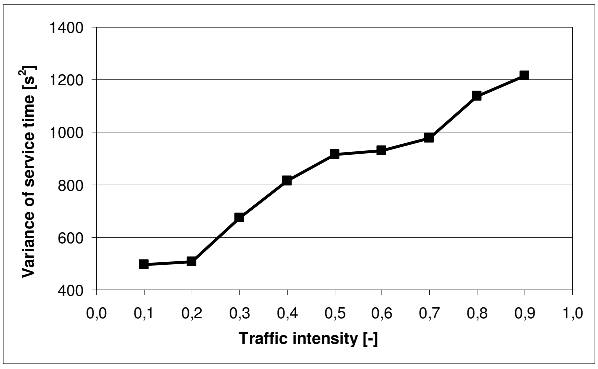

Fig. 7. Relationship between variance of service times – results from simulations (point 3.1)
Rys. 7. Zależność wariancji obsługi od intensywności ruchu na podstawie symulacji (punkt 3.1)

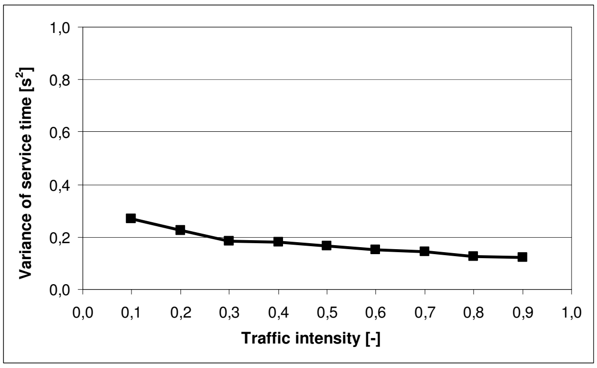

Fig. 8. Relationship between variance of service times – results from simulations (point 3.2)
Rys. 8. Zależność wariancji obsługi od intensywności ruchu na podstawie symulacji (punkt 3.2)

4. CONCLUSIONS

The analysis of results of traffic measurements and simulation research shows that in case of independent movements – variance of service times decreases when degree of saturation increases, but in case, when vehicle transition depends on different traffic flows (in case of left turn with collision), value of variance of service times quickly increases with the growing of the degree of saturation.

The variance of service times on signalized intersections needs more measurements. Getting formula to estimate variance of service times (for specific parameters of intersections) is a destination of future observations. It will help to apply this variance as coefficient in existing traffic models.

Literature

1. Allsop R. E.: *Delay at a fixed time traffic signal – I: Theoretical analysis.* Transportation Science, 6, 3, 260-285, London, 1972.
2. Datka S., Suchorzewski W., Tracz M.: *Inżynieria ruchu.* WKiŁ, Warszawa, 1999.
3. Gartner N., Messer C. J., Rathi A. K.: *Traffic Flow Theory A State-of-the-Art Raport.* Transportation Research Board, Washington, 2001. Revised version of Special Report: Traffic Flow Theory, Washington, 1975.

4. Hutchinson T. P.: *Delay at a fixed time traffic signal – II: Numerical comparisons of some theoretical expressions.* Transportation Science, 6, 3, 286-305, London, 1972.
5. Luttinen R. T., Nevala R.: *Capacity and level of service of Finnish signalized intersections.* Finnish Road Administration. Finnra, Reports 25/2002.
6. *Rozporządzenie Ministra Infrastruktury z dnia 3 lipca 2003 r. w sprawie szczegółowych warunków technicznych dla znaków i sygnałów drogowych oraz urządzeń bezpieczeństwa ruchu drogowego i warunków ich umieszczania na drogach.* DzU nr 220 z dnia 23 grudnia 2003 r., poz. 2181.
7. Sierpiński G.: *Obsługa pojazdów na skrzyżowaniach z sygnalizacją świetlną.* Zeszyty Naukowe Politechniki Śląskiej, s. Transport, z. 56, Gliwice 2004, s. 347-352.
8. Sierpiński G.: *Opóźnienie „kolizyjne" na skrzyżowaniach z sygnalizacją świetlną – pojazdy skręcające w lewo.* Zeszyty Naukowe Politechniki Śląskiej, s. Transport, z. 57, Gliwice 2005, s. 365-370.
9. Sierpiński G.: *Użycie modelu kolejkowego M/G/1 do budowy modelu strat czasu pojazdów na skrzyżowaniu z sygnalizacją świetlną.* Problemy transportu, Półrocznik nr 1 (1), Wydawnictwo Politechniki Śląskiej, Gliwice 2006, s. 253-257.
10. Sierpiński G.: *Zmienność czasów obsługi na skrzyżowaniach z sygnalizacją świetlną.* Zeszyty Naukowe Politechniki Śląskiej, s. Transport, z. 63, Gliwice 2006, s. 209-213.

Received 15.11.2006; accepted in revised form 05.06.2007