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CROSSING SPEEDS OF CARS THROUGH SIGNALIZED INTERSECTIONS

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Abstract. The article deals with the problem of traffic in three traffic-light intersections in the street network of Iasi city. Usually, the existing traffic lights do not fully take into account the size, structure and parameters of the queue of vehicles waiting at intersections; which in turn affects the traffic capacity of the intersection. In the study, we used a representative set of measurements taken at the three intersections to interpret the variation in the crossing speeds of the traffic light intersection space by the vehicle columns using the linear regression method. We studied several categories of vehicles queuing before the stop line at the intersection. We made a statistical analysis of the time taken to cross three intersections by vehicles in different starting positions. The main results of the research showed estimates in good agreement with observational data as well as a significant reduction in vehicle speed (to 58%) when there are different categories of vehicles queuing at the intersection. This study can be used in the urban traffic diagnosis method, being part of a traffic study together with urban traffic forecasting and therapy.

Keywords: *conflict points, direction, distance, queue, traffic, vehicle.*

Rezumat. Articolul tratează problema traficului în trei intersecții semaforizate din rețeaua de străzi din Iași. Semaforizările existente nu iau în considerare pe deplin dimensiunea, structura și parametrii cozii de vehicule care așteaptă la intersecții; care afectează la rândul său capacitatea de circulație a intersecției. În studiu, s-a folosit un corp reprezentativ de măsurători efectuate în cele trei intersecții pentru a interpreta variația vitezelor de traversare a spațiului intersecțiilor semaforizate de către coloanele de vehicule utilizându-se metoda regresiei liniare. S-a studiat mai multe categorii de vehicule care stau la coadă înaintea liniei de oprire la intersecție. S-a făcut o analiza statistică a timpului necesar traversării unei intersecții de către vehiculele aflate în diferite poziții inițiale. Principalele rezultate ale cercetării au arătat estimări în bună concordanță cu datele rezultate din observații precum și o reducere semnificativă a vitezei vehiculului (la 58%) în cazul în care sunt diverse categorii de vehicule care stau la coadă la intersecție.

Cuvinte cheie: *puncte de conflict, direcție, distanță, coloană, trafic, vehicul.*

1. Introduction

At street intersections, some components of the traffic process influence the functioning of intersections. The management of the traffic flow on the intersection surface, as well as its functioning, depends directly on the space available in the intersection, the existing public transport and the cargo shipment.

Public transport and cargo vehicles are defined by large dimensions, poor maneuverability, slow starting and limited speeds, these vehicles place additional demands on the elements of an intersection, introducing heavy traffic conditions, which must be considered both in the calculation of traffic lights at intersections and in their design and road layout measures and provisions.

In an intersection that can provide sufficient space, management of traffic flows, the dimensioning of traffic storage lanes, the crossing is optimized, and conflict points can be eliminated or their impact on flows reduced.

In an intersection that lacks space (especially when it has built-up frontages), it is not possible to achieve a correct management of traffic flow, certain spaces are given up or others are reduced in size, resulting in difficult traffic processes, with reduced speed and flow of traffic and even increasing the possibility of conflict between vehicles or even traffic accidents [1].

But vehicle delays include many parameters such as signal timing, number of phases, vehicle advances, saturation flow, queuing, etc. [2].

It was also observed that the length of the queue depended on its composition and the associated stop time [3].

The traffic flow through signalized intersections is influenced by a series of factors, among which deserve mention: the time distribution of the traffic, the movement law of the vehicle queues waiting to enter/ cross the intersection, the features of the signal regime, the crossing speed through the intersection [4].

Since other traffic characteristics trough intersections have earlier been studied, an analysis of the variation of the crossing speeds is done in this paper taking into account several parameters as: the vehicle type, its position in the queue, the distance to be passed, the movement direction (through/ left turning) of the cars entering the intersection [5].

2. Measurements of the Crossing Speeds

2.1. Confidence Level

In order to ensure an acceptable level of confidence to the results of measurements [4], the average crossing speeds at a couple of intersections were determined on large amounts of observed vehicles, and taking care to encounter various situations able to reveal the influence of the parameters mentioned in the Introduction.

Intersections: the measurements were performed at: I – intersection Primaverii Bvd Whit T. Vladimirescu (Figure 1), II – Intersection Independentei Bvd. With V. Alecsandri Street (Figure 2), III – Intersection at "Cotnari" (Socola Bvd. With Primaverii Bvd.) (Figure 3) [6].

2.2. Conditions for Performing the Measurements

a) Measurements were performed during periods of most intensive traffic (peak hours of traffic flow).

b) The weather, visibility roadway conditions were normal.

c) The longitudinal roadway declivities were negligible.

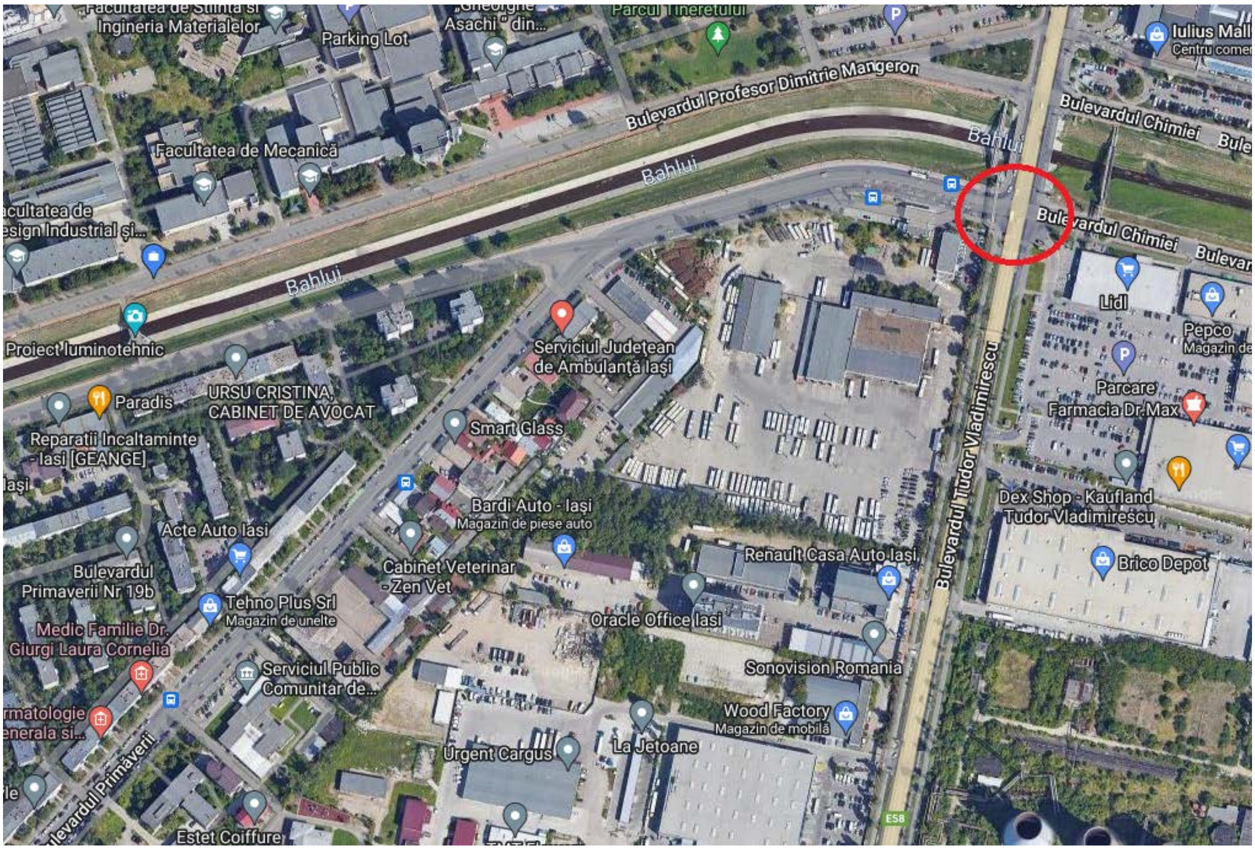

Figure 1. I – Intersection Primaverii Bvd Whit T. Vladimirescu.

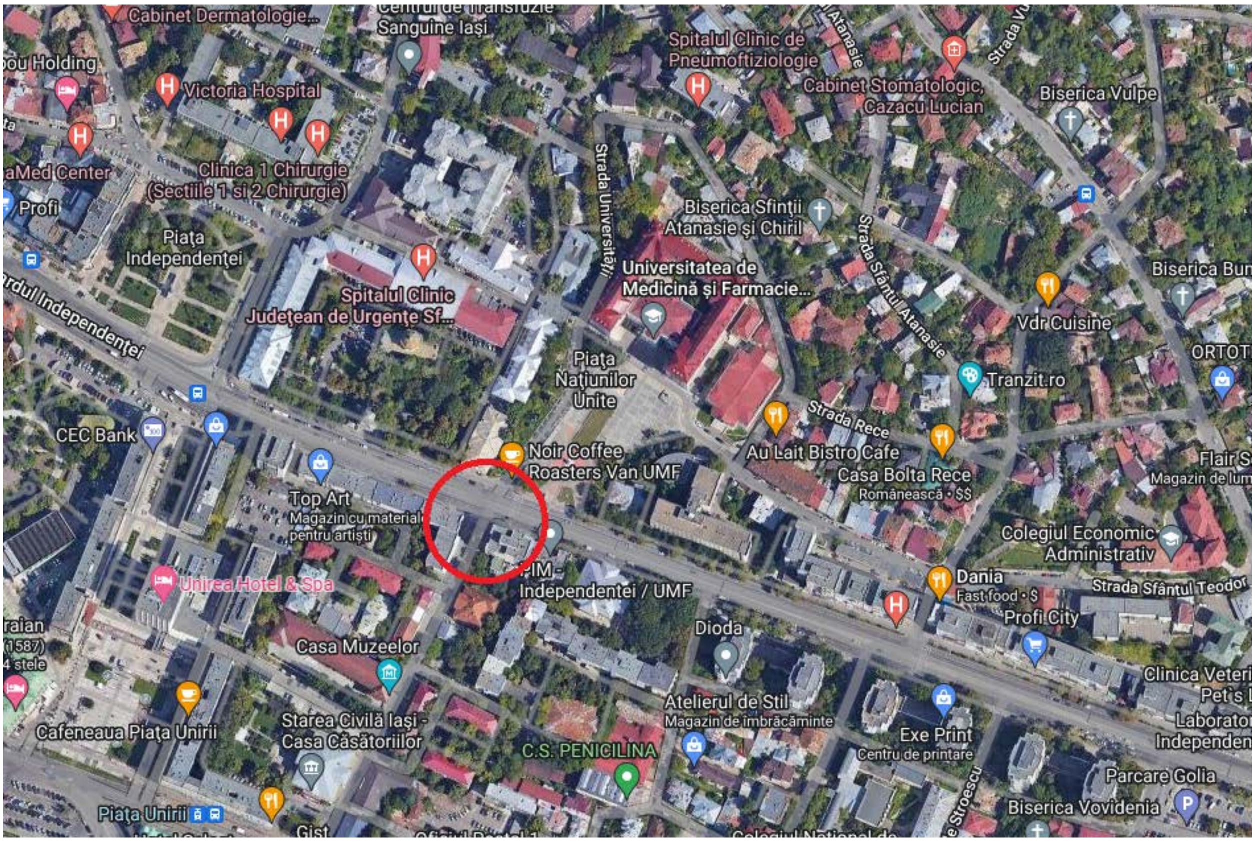

Figure 2. II – Intersection Independentei Bvd. With V. Alecsandri Street.

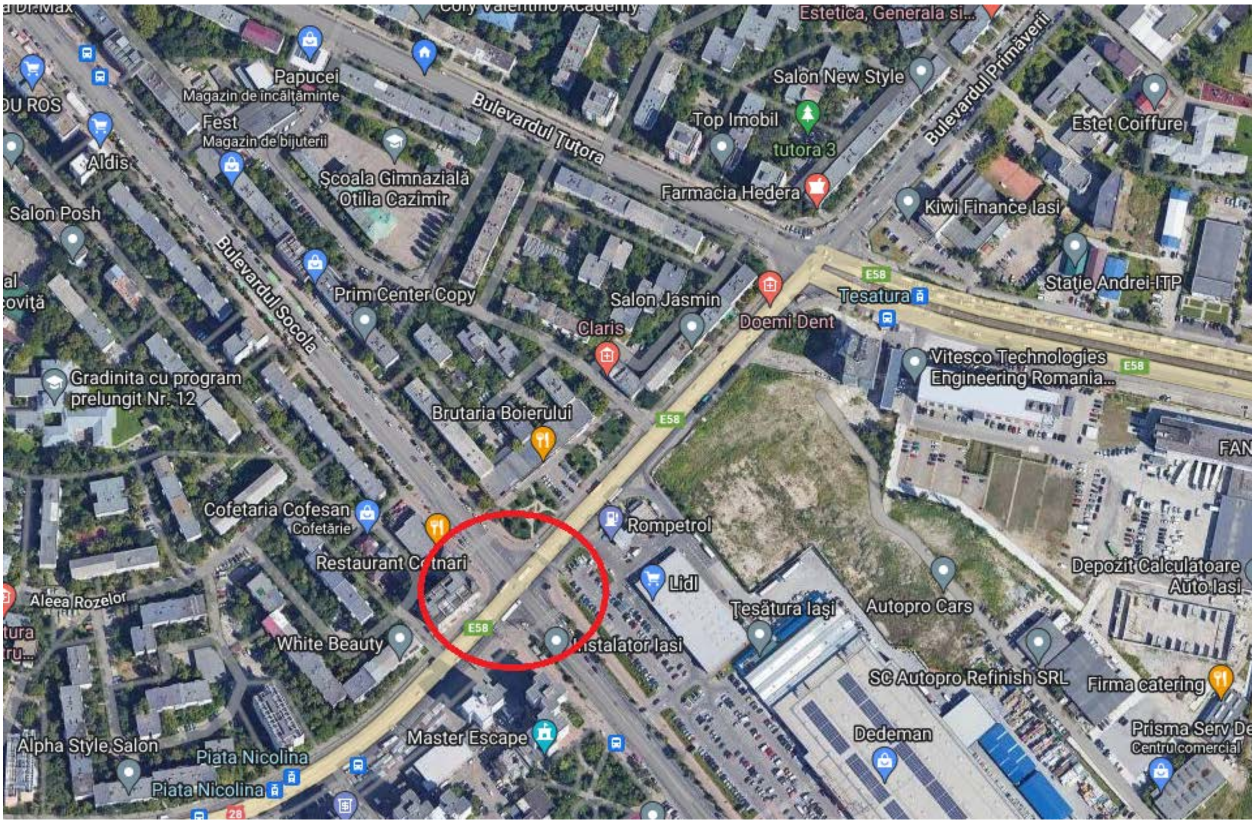

Figure 3. III – Intersection at "Cotnari" (Socola Bvd. With Primaverii Bvd.).

d) The intersections selected for measurements were quite different as regards the traffic features.

e) The crossing speeds were measured from the starting moment of the queue having waited behind the STOP line by the signal.

The average crossing speeds over the distance D (Figure 4) were calculated by use of the Eq. (1) [7-16]:

$$v = \mathrm{D}/\Delta t \tag{1}$$

Where the distances to be crossed were measured in meters and the crossing times (in seconds) were measured by direct observation of the crossing process, using a chronometer. More exactly, $\Delta t = t_2 - t$, where t_1 is the starting moment, while t_2 is the moment at which the vehicle has covered the distance D, (Figure 4) [7-16].

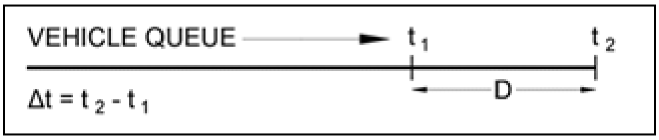

Figure 4. Time interval and distance to be covered for crossing an intersection.

3. Results and Discussion

The present study focuses on *determining the variation of crossing speeds of traffic-light intersections by columns of vehicles* through manually collected data using the linear regression method for three signalized intersections under heterogeneous traffic conditions in the city of Iasi.

Note that crossing speeds are a function of some specific elements such as:

- Intersection crossing direction (forward, left turn) and crossing distance (intersection I forward - 36 m, left turn - 28 m; intersection II forward - 67 m, left turn - 24 m; intersection III forward - 47 m). The greater the distance, the more the column of vehicles can exceed the starting speed stage and enter a normal speed development mode. The speeds developed by vehicles crossing the intersection in the forward direction are higher than the speeds of vehicles in a column turning left, for example.
- Vehicle type (PC - passenger cars, MWV - mid-weight vehicles, B - buses, B3 - 3-axle buses, T - trucks, SV - special vehicles). Lighter and faster vehicles can develop higher crossing speeds than heavier vehicles.

The average values of the crossing speeds determined for the intersections under observation (in this study), also depending on some above mentioned features, are presented in Table 1 and their variation for the through and left turn directions are illustrated in diagrams of Figures 5 and 6.

The shapes of the variation curves of the mean crossing speeds as depending on the vehicle positions in the queue (Figures 5 and 6) clearly suggest that most of them are piecewise almost linear, therefore they may be piecewise approximated by segments of straight lines that together form open polygonal lines. In order to obtain better approximations, the x-axis was divided into several intervals, but these partitions differ from one intersection to another and they also depend on the vehicle type and on moving direction. Thus, the mean crossing speed y depends on the vehicle position in the queue x (which is a positive integer variable) via a linear equation of the form Eq. (2):

$$y = \mathrm{a}_{ij} * x + b_{ijk}, \tag{2}$$

where is related to the intersection and movement direction, j corresponds to the vehicle category (PC – passenger cars, MWV – mid-weight vehicles, B – buses, B3 – 3-axle buses, T – trucks, SV – special (very heavy) vehicles); finally, k corresponds to the current interval in one of the above mentioned partitions (each of them associated to a subscript pair (i, j). The coefficients a_{ijk} and b_{ijk} were estimated based on the statistical data presented in (Table 1), using the method of linear regression.

Table 1

Mean Intersection Crossing Speeds, [m/s]

Inter-section	Direction	Distance	Vehicle type	Vehicle position in the queue								
				1	2	3	4	5	6	7	8	9
I	through	D = 36 m	PC	5.71	6.20	6.50	6.75	7.07	7.52	7.83	8.26	8.72
			MWV	5.45	5.72	5.97	6.23	6.51	6.65	6.92	-	-
			B	4.58	4.79	4.97	5.14	5.35	5.52	-	-	-
			B_3	4.33	4.56	4.72	4.91	5.11	5.26	-	-	-
	left	D = 28 m	PC	5.49	5.79	6.02	6.36	6.75	7.20	7.55	8.00	-
			MWV	5.15	5.38	5.52	5.77	6.00	6.22	-	-	-
			B	4.54	4.91	5.15	5.31	5.40	5.53	-	-	-
			B_3	4.01	4.19	4.42	4.62	4.80	-	-	-	-
			SV	3.78	3.92	4.03	4.16	4.27	4.38	-	-	-
II	through	D = 67 m	PC	7.12	7.40	7.70	7.98	8.27	8.54	8.76	8.93	9.07
			MWV	7.05	7.21	7.40	7.64	7.86	8.09	8.29	-	-
			B	5.58	5.83	6.09	6.43	6.69	-	-	-	-
			B_3	5.45	5.76	5.91	6.09	6.26	-	-	-	-

ContinuationTable 1

	left	D = 24 m	PC	5.02	5.26	5.57	5.70	5.91	6.22	6.54	6.87	7.10
			MWV	4.63	4.93	5.04	5.14	5.23	5.41	5.54	-	-
			B	4.24	4.53	4.77	4.90	5.00	-	-	-	-
			B_3	3.44	3.77	4.05	4.19	4.35	-	-	-	-
III	through	D = 47 m	T	5.26	5.42	5.54	5.66	5.80	5.93	6.06	6.14	-
			SV	3.78	3.92	4.03	4.16	4.27	4.38	-	-	-

The maximum deviations from the estimated values, for each line corresponding to a triple (i, j, k) of subscripts, are listed in the last two columns of (Table 2 and Table 3), while the middle column contains the linear equation of the line segment assigned to each of these triples. These deviations (given in percent, above and under the estimated value, respectively) enable us to remark that the approximation of variation curves of the crossing rates (speeds) with the vehicle position in the queue (and with the other three features) is very accurate: the largest deviation found was equal to 1.6%.

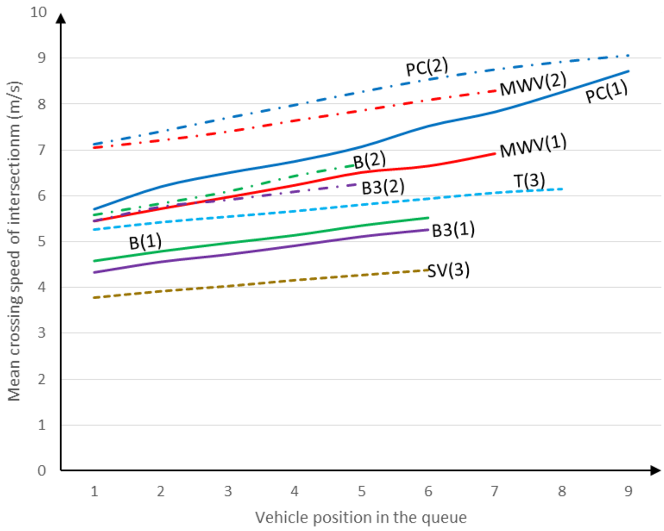

Figure 5. Mean crossing speeds vs. vehicle position in the queue, for through movement and five vehicle types.

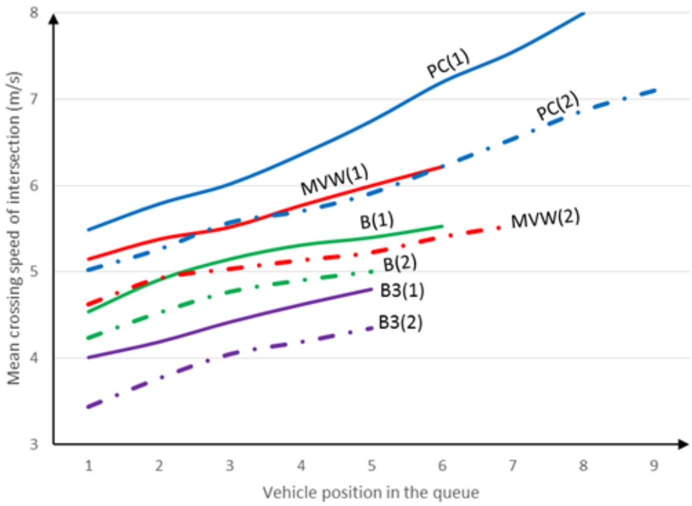

Figure 6. Mean crossing speeds vs. vehicle position in the queue, for LEFT TYRBS movement and four vehicle types.

Table 2

The Equations Modelling the Variation of the Crossing Speeds with the Vehicle Position in the Queue

Intersection, Direction	Vehicle type	Vehicle position	Linear regression equations (including a parabolic equation)	Maximum deviation [%]	
				+	-
I through	PC	1-7	y = 0.340x + 5.450	1.10	1.10
		7-12	y = 0.540x + 4.000	1.60	1.40
	MWV	1-7	y = 0.262x + 5.190	0.10	0.20
		7-12	y = 0.205x + 5.475	0.20	0.20
	B	1-6	y = 0.188x + 4.400	0.20	0.30
	B3	1-6	y = 0.188x + 4.157	0.50	0.60
II through	PC	1-5	y = 0.288x + 6.830	0.10	0.10
		5-9	y = 0.210x + 7.220	0.40	0.80
	MWV	1-3	y = 0.172x + 6.887	0.20	0.10
		3-7	y = 0.227x + 6.712	0.10	0.30
	B	1-5	y = 0.277x + 5.290	0.50	0.50
	B3	1-2	y = 0.310x + 5.140	0.00	0.00
		2-5	y = 0.167x + 5.425	0.30	0.10
III through	T	1-8	y = 0.127x + 5.146	0.40	0.40
	SV	1-6	y = 0.120x + 3.670	0.40	0.30

Table 3

The Equations Modelling the Variation of the Crossing Speeds with the Vehicle Position in the Queue

Intersection, Direction	Vehicle type	Vehicle position	Linear regression equations (including a parabolic equation)	Maximum deviation [%]	
				+	-
I left turns	PC	1-3	y = 0.255x + 5.255	0.40	0.40
		3-8	y = 0.388x + 4.856	0.80	0.50
	MWV	1-3	y = 0.180x + 4.986	0.30	0.60
		3-6	y = 0.233x + 4.827	0.10	0.20
	B	1-4	$y = -0.057x^2 + 0.540x + 4.057$	0.30	0.10
		4-6	y = 0.110x + 4.865	0.30	0.10
	B3	1-5	y = 0.198x + 3.182	0.40	0.40
II left turns	PC	1-5	y = 0.227x + 4.830	0.90	1.10
		5-9	y = 0.295x + 4.490	0.90	0.30
	MWV	1-2	y = 0.300x + 4.330	0.00	0.00
		2-5	y = 0.100x + 4.730	0.00	0.20
		5-7	y = 0.155x + 4.455	0.00	0.40
	B	1-3	y = 0.265x + 3.975	0.00	0.60
		3-5	y = 0.115x + 4.425	0.00	0.30
	B3	1-3	y = 0.305x + 3.135	0.00	0.70
		3-5	y = 0.150x + 3.600	0.20	0.00

4. Conclusions

A couple of conclusions may be drawn from the presented data and the piecewise linear estimations of the mean intersections crossing speeds as functions of the vehicle position in the queue, of the particular intersection observed, of the vehicle type and of the movement direction, using the linear regression method:

1. The crossing speed steadily grows from the first vehicle (on the first position in the queue), because of the delay due to the start from a still state, towards the most remote positions in the queue. The latest vehicles take advantage of the time needed to reach a higher speed until entering the intersection.

2. The lower is the crossing speed, the heavier is the vehicle.

3. The crossing speeds for vehicles moving through are higher than the ones for left-turning vehicles if we compare them for the same vehicle type and position in the queue. This difference is natural because of the difficulties of left turns.

4. The distance D to be covered also influences the crossing speeds, which grow with it since the vehicles can reach a higher speed due to a longer time for acceleration.

5. The composition of the waiting queue is less important for an approach street with several (two or three) lanes, but it is significant for one-lane approaches. The same holds for the percent of left-turning vehicles, which cause delays in the movement of the whole queue.

As a conclusion, it may be appreciated that the mathematical modelling of the crossing speeds through street intersections using *piecewise linear equations* obtained by *linear regression* gives (very) accurate results. Therefore, it may be useful in the analysis (diagnosis) of the urban traffic flow through signalized intersections, and it thus provides a basis for studies aiming at the improvements of traffic signal regimes.

Conflicts of Interest: The authors declare no conflict of interest.

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