TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 18
Number 2
June 2024

DOI: 10.12716/1001.18.02.08

Analysis of the Capacity of Intersections with Fixed-time Signalling Depending on the Duration of the Green Phase for Pedestrians

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ABSTRACT: The article aims to analyze the capacity conditions of intersections with constant-time traffic lights using a road transport micro-modeling tool. The article uses actual data on intersections and then a model was made in the PTV Vissim program of the existing state and the changed state about the duration of the green time for pedestrians shortened to the minimum resulting from Polish regulations, the relationship between the length of the pedestrian path and the speed of pedestrian movement, but not less than 8 seconds. The results were tested at different intersections depending on the number of entrances as well as different stages of traffic lights.

1 INTRODUCTION

Due to the increasing number of cars in urban areas, cities must adapt their infrastructure to ensure safety as well as an acceptable level of capacity. Throughput is an important factor in the main communication routes with the highest traffic, especially during rush hours. Different countries have different rules for traffic lights at intersections in cities [1]–[5]. For this purpose, the most common solution is the use of traffic lights due to their wide implementation possibilities. Signaling organizes traffic by using separate traffic phases where specific signal groups, by the rules, may or may not receive a green light for a traffic maneuver [6]–[8]. As well as traffic lights connected to intersections in a sequence where the distance between them is no longer than 1000 m [9] allows you to coordinate the continuity of the journey in the designated direction [10]. Another advantage is the safety of pedestrians, who, thanks to the appropriate signal phase, can cross the road without collision. In this case, we distinguish phases for pedestrians where the green signal always appears regardless of whether the pedestrian is present at the intersection or not - constant-time signaling or adaptive signaling that will adjust the necessity of the pedestrian phase from direct notification of such a need to the controller. This controller can obtain information, for example, from a special button that the pedestrian is forced to press to cross or using automatic detection of pedestrians using various types of radars and sensors. Depending on the length of the road to overcome, pedestrians must be given the appropriate number of seconds of green light so that the route is safe. For example, in Poland, there are rules where the pedestrian speed is set at 1.4 m/s [11]. If the pedestrian had to cross only two traffic lanes with a total width of 7 m, the pedestrian would need 5 seconds to cross, however, in the example of Polish regulations, this time cannot be shorter than 8 seconds. The eight seconds are divided into two different beeps, four seconds of a solid green beep and 4 seconds of a flashing beep to indicate that the beep is ending. If, in justified cases, pedestrians at a given intersection move slower due to e.g. dysfunction or disability, the regulations allow reducing the speed of movement to 1 m/s[11]. In this case, the time needed to cross two traffic lanes totaling 7 m will be 7 seconds. Depending on the calculation used, a pedestrian cannot get less than a certain minimum according to the law in force in each country. In the example of Poland, not less than 8 seconds if the pedestrian distance is less than or equal to 11.2 meters. However, due to the comfort of pedestrians, the time allocated for the crossing is usually longer and depends on the length of the traffic phase of vehicles that have a traffic permit at the same time. From the point of view of the pedestrian, this is a very beneficial solution because the time to cross is much longer and the pedestrian does not have to appear at the crossing in the first second of the green light to have a safe crossing. However, from the point of view of capacity, especially right and left turns at inlets parallel to the crossing, the shortest possible time for pedestrians may affect the capacity of the entire intersection, obtaining better results. In this article, on the example of different geometry of real intersections with the real traffic of vehicles, the existing state was compared where the length of the green light for pedestrians was consistent with real constant-time programs and the changed state where the length of the green light for pedestrians was directly dependent on the length of the road that the pedestrian must cover on the crosswalk pedestrians. All calculations and assumptions are by the Polish law in force on April 15, 2003 regarding the design of constant-time traffic light programs [12].

2 MICROMODELING IN PTV VISSIM TOOL

The analysis was developed using the transport micro modeling program PTV VISSIM [8], [13]–[16]. To reproduce the state of the existing model as accurately as possible, real data from two intersections in the city of Gdynia were imported from [8]. Data on traffic intensity and duration of individual signals in the signaling program come from the TRISTAR intelligent traffic control system in Gdynia. The model was made using five main steps. The first step is to collect input data for the model, such as traffic volume, vehicle type structure, or the percentage of turning vehicles. Step 2 is mapping the road network, adding a generic vehicle structure, and adding traffic light programs. Step 3 is directly related to the mapping of the network because the following elements have been added to the drawn network: adding traffic lights, determining the right of way in disputed situations, implementing pedestrian traffic generators, defining vehicle routes and vehicle generators, and adding vehicles and public transport routes. Step 4 is model calibration with validation, the GEH method was used here. The last step 5 is to measure parameters such as travel times, queue lengths, or assessments of entire intersections. The scheme of creating the model is shown in Figure No. 1.

The model examined two intersections in the city of Gdynia, connected by a flyover. The model lasts two hours, of which the first half hour is for filling the network with vehicles, then one hour for measurement, and the last half hour. These intersections differ from each other in terms of both traffic volume and geometry and the number of entrances. The first intersection is a connection between the Morska Road and the Kwiatkowski flyover. It is a central island junction with four inlets and four outlets. Traffic at this intersection is a combination of urban traffic from high-density districts with traffic entering the city from the Tri-City Ring Road. The second intersection is the connection of Hutnicza Road with the Kwiatkowski Flyover. This intersection is characterized by increased traffic of heavy goods vehicles moving to and from Port facilities or private companies related to container transport. Junction 2 has only three entrances and exits. The geometry of Junction 1 is shown in Figure 2. Figure 3 shows a diagram of Junction 2.

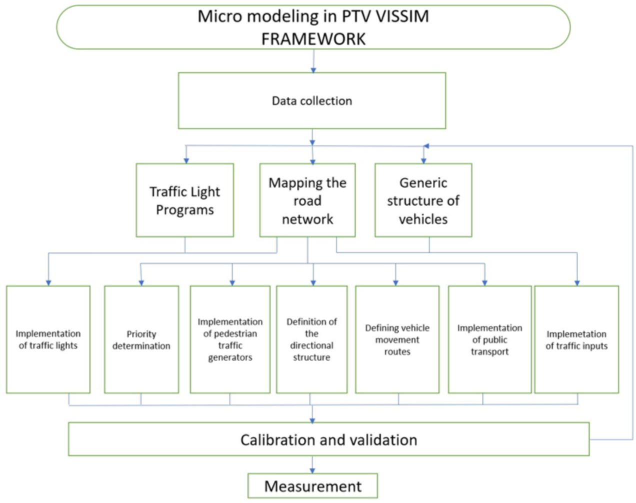

Figure 1. PTV VISSIM - Micromodel framework [8]

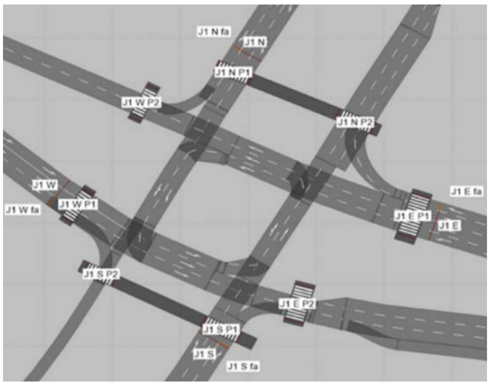

Figure 2. Junction 1 - Morska - Kwiatkowskiego

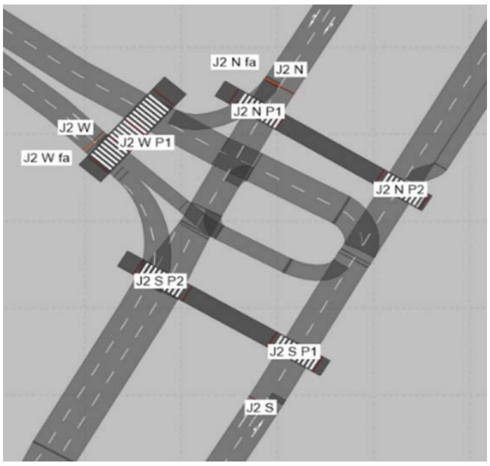

Figure 3. Junction 2 - Hutnicza-Kwiatkowskiego

2.1 *Data*

Data on traffic volume are from the vehicle counting system as part of the Intelligent Traffic Control System in Gdynia. These data distinguish the intensity also by vehicle type. Referring to Figures 2 and 3, where the entrances of two intersections have been marked, Table 1 shows the traffic volume of vehicles at the analyzed intersections along with the percentage share of traffic directions.

Table 1. Traffic volume at the Junction 1 and Junction 2

A – Intersection; B – Inlet; C – Traffic Flow (0-3600)
D – Direction; E – Volume; F – Traffic Flow (3600-7200)
G – Direction; H – Volume

A	B	C	D	E	F	G	H
J1	N	980	R	359	868	R	387
			S	0		S	0
			L	353		L	481
			U-turn	0		U-turn	0
	E	1117	R	481	1254	R	505
			S	444		S	553
			L	169		L	170
			U-turn	22		U-turn	25
	W	1690	R	570	1525	R	529
			S	763		S	664
			L	356		L	332
			U-turn	0		U-turn	0
	S	297	R	144	298	R	151
			S	0		S	0
			L	153		L	147
			U-turn	0		U-turn	0
J2	N	312	R	236	395	R	325
			S	53		S	41
			L	0		L	0
			U-turn	0		U-turn	0
	W	420	R	210	453	R	317
			S	0		S	0
			L	210		L	136
			U-turn	0		U-turn	0
	S	782	R	0	704	R	0
			S	52		S	9
			L	730		L	695
			U-turn	0		U-turn	0

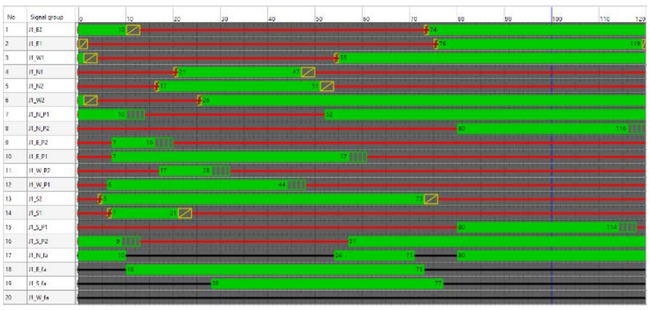

Figure 4. Signal program - Junction 1

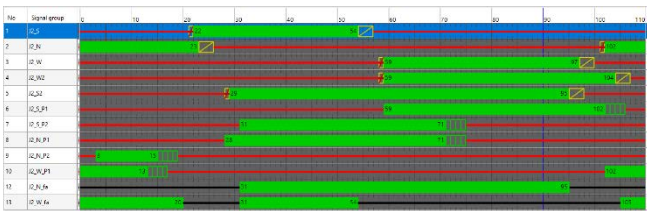

Figure 5. Signal Program - Junction 2

Traffic light programs from the Tristar Intelligent Traffic Control System have been implemented in the model. According to the schedule on the signaling controller, the model was made based on the program for the morning peak. Figure 4 below shows the signaling program for Junction 1 and Figure No. 5 shows the signaling program for Junction 2.

2.2 *Variants*

The assumption of the model was to compare two variants. Variant 1 is the existing state of intersections with real data on traffic intensity and vehicle type structure. The signaling program is also real. Variant 2, on the other hand, is a variant where the duration of the green light for pedestrians has been reduced to the minimum specified in the act on the design of constant-time traffic lights. The general rule is that the pedestrian speed is 1.4 m/s and then you can calculate the time needed for the pedestrian to cross by using the general formula $t = s/v$ [s],where: s – the road that must be walked by a pedestrian [m], v – walking speed [m/s], t – the time needed by the pedestrian to cross the street [s].

According to the rules, however, the total time cannot be shorter than 8 seconds, it is the sum of four seconds of a continuous green signal and four seconds of a flashing signal [11] informing the pedestrian about the termination of the pedestrian crossing permit. After calculations, it turns out that the limit of 8 seconds applies in the case where there are three or fewer lanes of 3.5 m wide each. In the case of four lanes, the length of the green light is already extended to 10 seconds. Table 2 presents the data of the modeled pedestrian crossings: their length (the path that the pedestrian must take), the duration of the green signal in variant 1, and the duration of the green signal in variant 2.

Table 2. Comparison of the length of the green time

	Length	Variant 1	Variant 2
J1_N_P1	10.5	82	8
J1_N_P2	10.5	40	8
J1_E_P2	7	13	8
J1_E_P1	14	54	10
J1_W_P2	10.5	15	8
J1_W_P1	10.5	42	8
J1_S_P1	10.5	38	8
J1_S_P2	7	76	8
J2_S_P1	7	47	8
J2_S_P2	10.5	44	8
J2_N_P1	10.5	47	8
J2_N_P2	7	16	8
J2_W_P1	7	25	8

2.3 *Results*

In the PTV VISSIM tool, it is possible to use node evaluation; you can record data from nodes of microscopic and mesoscopic simulations in the Vissim network. Node evaluation is especially used to determine specific data from intersections without first having to define all sections manually to determine the data. One such assessment is the level of service (LOS). [8] "Level of service (transport quality): The levels of transport quality A to F for movements and edges, a density value (vehicle units/mile/lane). It is based on the result attribute vehicle delay (average). The current value range of vehicle delay depends on the level of service scheme type of the signalized or non-signalized nodes. The LOS in Vissim is comparable to the LOS defined in the American Highway Capacity Manual of 2010" [20]. To better illustrate the results, numerical values have been assigned to specific LOS determinations and thus LOS A corresponds to 1, LOS B corresponds to 2, and similarly to the other values. The results of the simulation showed that by shortening the duration of the green light for pedestrians without shortening the length of the entire phase, we will obtain improved traffic conditions at intersections for vehicles. The number of pedestrians was assumed to be constant in both variants and amounts to 1,000 pedestrians per hour for each pedestrian crossing. In both variants, pedestrians could only cross during the green light. It should also be noted that the traffic volume at the inlets increased because more vehicles could arrive at the intersection than in the case of variant 1. Despite the increased traffic volume, the LOS parameter did not deteriorate anywhere. The only case on the South inlet of Junction 1 was where both traffic volume and LOS did not change. In the remaining cases, the changes were positive, and the obtained results significantly improved the road traffic conditions, e.g., at Junction 2 from level 6 (i.e. F - the worst) there was an improvement to level 2 (i.e. B). In Figure 6 these changes are presented in a graph.

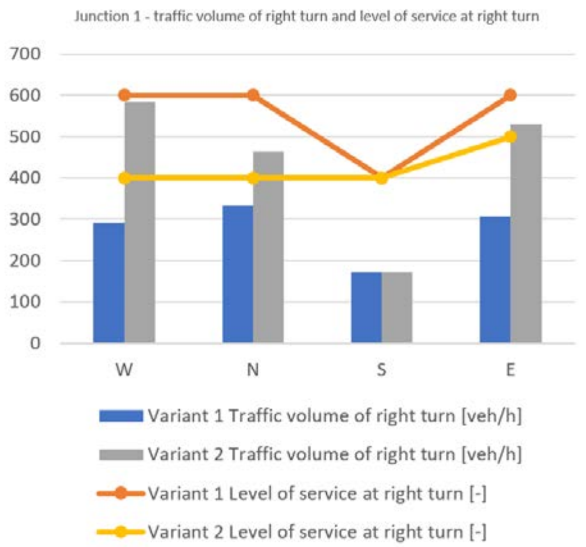

Figure 6. Junction 1 LOS comparison

Table 3. Level of service comparison on Junction 1 and Junction 2

Inlet	Traffic volume of right turn [veh/h]	Level of service at right turn [-]	Inlet	Traffic volume of right turn [veh/h]	Level of service at right turn [-]
J1 Variant 1			J1 Variant 2		
W	291	6	W	583	4
N	333	6	N	463	4
S	172	4	S	172	4
E	306	6	E	531	5
J2 Variant 1			J2 Variant 2		
N	146	6	W	338	2
W	258	5	N	266	2

Table 3 presents the detailed results of the improvement of traffic conditions at the analyzed intersections and shows changes in the traffic intensity at the entrances. The improvement of traffic conditions on right-turning roads has the greatest impact on the analyzed intersections due to the immediate vicinity of pedestrian crossings with simultaneously allowed traffic. It is these places that are critical when, despite the green light, drivers are unable to leave the intersection due to pedestrian traffic.

3 CONCLUSIONS

Although significantly better traffic results have been obtained by reducing the duration of the green light for pedestrians in fixed-time schemes, the changes will not necessarily be readily implemented by local road authorities. Due to the Smart Cities trend, or restoring cities to people, shortening the pedestrian crossing time would not be politically welcome. However, the results obtained in this article show that this solution brings significant improvements in traffic conditions. Therefore, they should be used in special situations where the traffic volume is so high that even a short program change could be beneficial. It should also be remembered that not everywhere such changes can be introduced, in the case of places with a high volume of traffic of people with limited mobility, shortening the duration of the green light for pedestrians is even discouraged due to the slower speed of pedestrians. Currently, cities equipped with intelligent traffic control systems can implement the presented solution after additionally adding an appropriate algorithm that calculates the forecast profits in improving traffic conditions to the deterioration of pedestrian comfort, which shortens the crossing time.

ACKNOWLEDGEMENTS

This research was funded by Gdynia Maritime University—WN/2023/PZ/10 and WN/2023/PZ/06 projects.

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