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PRIORITY TRANSFER MANAGEMENT ALGORITHM, BASED ON INTERACTION OF THE PUBLIC TRANSPORT DISPATCH SYSTEMS INFORMATION AND TRAFFIC LIGHTS CONTROL

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The article is dedicated to the multi agent approach for urban public transport dispatch system to organize priority transfer management, based on interaction with traffic lights control system. The article deals with the issue of urban passenger transport priority transfer of signalized intersections. Priority transfer management algorithm developed by the authors based on interaction of traffic lights control and public transport dispatch systems. The authors considered the role of agents in interaction process of traffic lights control and public transport dispatch systems for implementation of the buses priority passage. Criterion for decision making taking into account savings and loses of time of all participants of traffic at the intersection. The results of simulation modelling of priority public transport passage a signalized intersection are presented

Keywords: urban passenger transport, signalized intersections, priority transfer management algorithm, transport dispatch system, passenger vehicle, GPSS

1. Introduction

Urban public transport affects the welfare of society and the life and production activities of millions of people. It has direct relevance to people's livelihoods and the development of the social economy. Moreover, public transport plays an important role in solving the main problems of motorization - number of accidents and environment pollution reduction (Bogumil and Efimenko, 2013; Vlasov *et al*., 2014).

Solving problems of motorization one can achieve if significant part of citizen during rush hours would transfer from passenger cars to public transport vehicles. This requires ensure more comfort and security for public transport. Then, very important to ensure regularity of service and competitive travel time if compare public transport vehicles and passenger cars (Bogumil and Efimenko, 2013; Gal-Tzur *et al*., 2011).

It is difficult to achieve these goals without special measures, because different types of public transport (buses, trams, route taxis) use the same road network as passengers cars, and they face tight traffic and the same problems of congestion (Gal-Tzur *et al*., 2011; Wahlstedt, 2011).

According to many experts, priority passage of signalized intersection is one of the most important function of the traffic light control system to improve regularity and to reduce travel time of public transport (Wahlstedt, 2011). Foreign countries pay great attention to the organization of public transport priority in major cities in order to reduce travel time for vehicles of public transport (buses, trams, etc.). One of the important directions in the development of priority transfer management algorithms is taking into account the regularity of bus traffic. The idea is to allow buses schedules compliance (Wahlstedt, 2011; Kammoun *et al*., 2014; Bhouri *et al*., 2016).

Based on conducted analysis, two algorithms were developed:

1) The priority transfer management algorithm on granting priority for public transport on a signalized intersection;

2) The algorithm of information interaction of traffic lights control system and public transport dispatch system during provision of priority to public transport on a signalized intersection.

In this paper we suggest the method of organization of the priority for public transport vehicles, taking into account the dynamics of traffic flow in all directions of movement through the intersection and the actual load of passenger vehicles passing the intersection. Actual information about load of public transport vehicles is formed by onboard passengers counting system and transferred online for the automated dispatching system of public transport. Also, the dynamics of passenger cars flows formed by detectors of transport installed at the intersection. This information transferred online for the automated dispatching system of public transport.

Section 2 represents the approach for organization of the public transport priority at signalized intersection, based on information interaction of traffic management systems and automated dispatching system for urban public transport. The main feature discussed is to give or not to give the right for priority to each passenger vehicle, according to rules writing down in this section. Therefore, we evaluate the multiply crossing of signalized intersections along the public transport route with the priority organization as regulating mechanism of public transport scheduled planned movement. This approach takes into account the number of factors, the influence of which is discussed. The formal criterion is given, based on time losses of all the road users at the intersection. In is formulated as the rule of harmonization of road users' interests.

In section 3 criterion for decision making was presented. The formal criterion is given, based on time losses of all the road users at the intersection.

In section 4 a priority decision-making algorithm based on multi agent approach was described and the algorithm represents functions and interaction of four agents. Two of them implemented by traffic lights control system, others - by public transport dispatch system.

In sections 5 details of the multi agent method for interaction algorithm implementation, roles and function of each agent were described. Finally, hierarchy of the agents in the control process architecture is given.

2. Main features of organization of the public transport priority

Main features of organization of the public transport priority based on information interaction of traffic management systems and automated dispatching system for urban public transport. The analysis shows that the combination of features of the two systems helps to achieve a synergistic effect, which is minimization the deviation of public transport vehicles movement from the schedule during the trip. In turn, this leads to the minimization of losses by passengers at stops time (Bogumil *et al.*, 2013; Vlasov *et al.*, 2014; Wahlstedt, 2011). American scientists use special term: “Eco-Traffic Signal Priority”, which means “Gives signal priority to transit vehicles approaching a signalized intersection, considering the vehicle's location, speed, type, schedule, and number of passengers - to produce the fewest emissions at signalized intersections” (Runhuaa *et al.*, 2013). Therefore, factors under consideration for the advanced method set out above for the organization of the priority, shown in Figure 1.

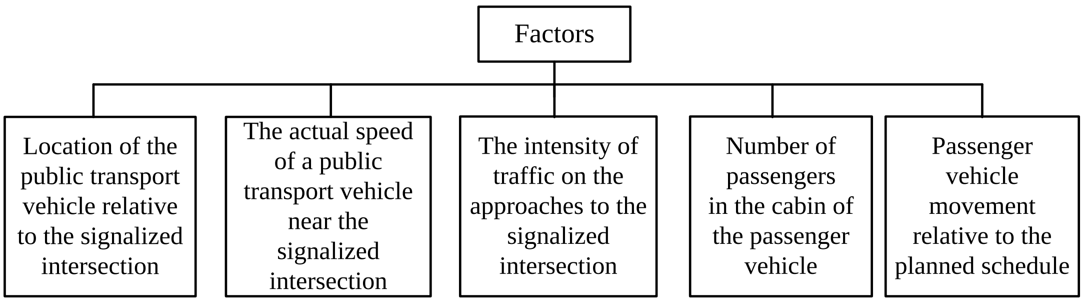

Figure 1. Factors under consideration for the advanced method of the priority organization for public transport

The synergistic effect, mentioned above, can be achieved in accordance with the following rules:

1) The signalling control system will not give the priority for passenger vehicles, if the estimated time of deviation from the schedule will be by the absolute value not more than one minute.

2) The signalling control system must give priority to public transport vehicle, if vehicle is behind schedule by more than one minute. In this case, the control system must provide the greatest possible reduction of the delay, subject to the restrictions of movement control, or reduce the deviation of the schedule to zero.

3) The control system must not give priority to public transport vehicle, if vehicle is ahead schedule in any case.

Information interaction of traffic lights control system and public transport dispatch system should be based on the following provisions:

1. All passenger vehicles need to operate under the control of the automated dispatching system. To do this, they must be equipped with navigation and communication onboard equipment.

2. During the movement near the signalized intersection, the location and speed of the public transport vehicle should be determined in real time every second and transmitted in real time for the dispatch system.

3. Information about the movement of passenger vehicles with respect to the schedule should be formed and transmitted in real time.

4. Number of passengers in the cabin of the passenger vehicle should be determined via on-board units and detectors and be transmitted after each bus stop for the dispatch system.

5. The intensity of traffic flow on the approaches to the signalized intersection must be determined using traffic detectors.

3. Criterion for decision making

Let us describe formally the components of this criterion.

To calculate the planned passengers waiting time in the *j*-th trip at the all bus stops of the route, we introduce the notation:

X_{ij} - the planned time of the vehicle stopping at *i*-th bus stop in the *j*-th trip on the route under consideration.

$X_{i(j-1)}$ - the planned time of the vehicle stopping at *i*-th bus stop in the (*j*-1)-th trip on the route under consideration.

ρ_i - the average planned intensity of the passengers approach for the *i*-th bus stop point of the route under consideration for *j*-th trip. Then the total scheduled passenger waiting time of the vehicle in the *j*-th trip at all bus stops (T_j^p) is found from the relation:

$$T_j^p = \sum_i \rho_i \int_{X_{i(j-1)}}^{X_{ij}} (X_{ij}) dt = \frac{1}{2} \sum_i \rho_i (X_{ij} - X_{i(j-1)})^2 . \quad (1)$$

If the planned interval is the same for all stopping points and equal to *T*, then we get*:*

$$T_j^p = \frac{1}{2} \sum_i \rho_i (X_{ij} - X_{i(j-1)})^2 = \frac{1}{2} \sum_i \rho_i T^2 . \quad (2)$$

If the next bus moves with the same interval and intensity of passengers flow not changed, then the passengers waiting time for all the bus stops would be the same: $T_{j+1}^p = \frac{1}{2} \sum_i \rho_i T^2$. Therefore, for *j*-th and (*j*+1) trips planned passengers' waiting time is:

$$T_j^p + T_{j+1}^p = \frac{1}{2} \sum_i \rho_i T^2 + \frac{1}{2} \sum_i \rho_i T^2 = \sum_i \rho_i T^2 . \quad (3)$$

Let the bus of the *j*-th trip moves to the intersection behind the schedule and the lag equal to Δt seconds. So, the interval for *j*-th trip will be ($T+\Delta t$). If the bus of (*j*+1)-th trip moves according to schedule its interval will be ($T-\Delta t$). In this case passengers' waiting time will be:

$$\frac{1}{2} \sum_i \rho_i [(T + \Delta t)^2 + (T - \Delta t)^2] = \sum_i \rho_i T^2 + \Delta t^2 \sum_i \rho_i . \quad (4)$$

We can see, that irregularity will increase passengers' waiting time by $\Delta t^2 \sum_i \rho_i$.

In accordance with the rules, described in section 2, the bus of *j*-th trip will get the priority to pass the intersection, and the bus of (*j*+1)-th trip will not. If the bus of the *j*-th trip passing the signalizing intersection with priority, reduction of the backlog after the intersection will be Δt_1 seconds and new backlog value will be (Δt - Δt_1).

Total passengers waiting time at the bus stops after the intersection will decrease and effect reaches the value Δt_2:

$$\Delta t_2 = \Delta t^2 \sum_i \rho_i - (\Delta t - \Delta t_1)^2 \sum_i \rho_i = (2\Delta t \Delta t_1 - \Delta t_1^2) \sum_i \rho_i \, , \quad (5)$$

were i=1,2,…,m numbers of bus stops after the intersection.

Let, according to the on-board counting equipment, number of passengers in the cabin of bus during j-th trip in this moment equal to P_j passengers. Then value of time saved for passengers in the cabin due to priority will be equal to $P_j \Delta t_1$.

Let consider the time saving for passengers of private cars in the associated directions of traffic flow due to priority.

Let: Δt_k is increasing of the green time at the k-th associated direction, k =1, 2,..., n – the associated directions of traffic flow, passing a signalized intersection due to provision of priority for public transport vehicle; Q_k is the intensity of the traffic flow on the k-th associated direction (vehicles/second) measured using detectors on the approaches to the intersection; p_k is the average number of passengers in one private car of the k-th direction. Then the total time saving for passengers of private cars on related directions while providing priority to the public transport vehicle, in average, could be estimated as $\sum_k Q_k p_k \Delta t_\kappa$.

Consider the time loss for passengers of private cars in the competing directions of traffic flow. Let for the competing directions: Q_I - the intensity of traffic flow on the i-th competing direction (vehicles/second) measured by detectors located at the approaches to the intersection; p_l – The average number of passengers in one private car of the I-th direction; Δt_l - the red light time added in the i-th competing direction i =1, 2,..., m - the competing directions of traffic flow. Then the total time loss for passengers of competing directions in the provision of priority on average could be estimated by the value $\sum_l Q_l p_l \Delta t_l$, equal to the sum of the average number of passengers on competing destinations multiplied on the average lost time per passenger.

Based on formal descriptions of these values of savings and losses of time of the transport process participants at the signalized intersection, the proposed criterion will have the following form:

$$P_j \Delta t_1 + (2\Delta t \Delta t_1 - \Delta t_1^2) \sum_i \rho_i + \sum_k Q_k p_k \Delta t_k > \sum_l Q_l p_l \Delta t_l \, . \quad (6)$$

The left and right parts of inequality (6) represent total time savings and losses according to the participants of transport processes at the signalizing intersection in the case of priority provision to public transport vehicle. The implementation of this approach based on combining the capabilities of an automated navigation dispatch system of public transport and modern automated control systems of traffic lights. The other conditions:

- public transport vehicles shall be equipped with instrumental units for counting the number of entering and exiting passengers
- signalized intersections in addition to a traffic lights controller should include transport detectors to estimate the intensity of transport flow on the road sections near the intersection.

4. Priority transfer management algorithm

Priority decision-making algorithm takes into account traffic conditions at the intersection and the actual loading of passenger vehicle entering the intersection, according to criterion (6). So initial parameters are:

- the intensity of traffic flow on the competing directions (vehicles/second) measured by detectors located at the approaches to the intersection;
- the average number of passengers in one private car of the each direction;

- the red light time added in the each competing direction;
- actual load of public transport vehicles according to the onboard equipment for passengers counting;
- the average planned intensity of the passengers approach for the each bus stop point of the route under consideration.

The algorithm of decision-making on granting priority when one public transport vehicle approaches to the intersection will be as follows:

1. Start.

2. Getting information about the appearance of public transport vehicles near the zone of influence of a signalized intersection and its direction of motion.

3. Getting information about the scheduled movement of the passenger vehicle (according to the schedule, ahead the schedule, behind the schedule).

4. The passenger vehicle goes according to the schedule?

If "Yes", then go to 10.

5. The movement of passenger vehicles is ahead of schedule?

If "Yes", then go to 10.

6. Movement of passenger transport is behind the schedule.

7. Obtain information about the actual load of passenger's vehicles according to the onboard equipment for passengers counting.

8. Verify the fulfilment of the criterion (6) of providing priority of passage.

9. Is the criterion (2) fulfilled? If "Yes", go to algorithm of traffic lights regulation in the provision of priority to public transport at the crossroads.

10. The end.

5. Using multi agent method for interaction algorithm implementation

The algorithm of information interaction of public transport dispatch system and traffic lights control system intended for the harmonization of all information processes in the system, the implementation of priority movement through intersections on routes for passenger vehicles.

The algorithm complexity depends on a large number of processes. Moreover, those processes occur simultaneously.

It is natural to consider the decomposition processes of information exchange associated with the task of providing priority on the separate signalized intersections. When information processes are associated with the signalized intersections, they become mutually independent, because in the sense of solving the priority tasks, these processes are local.

In accordance with the definition done in (Bhouri *et al*., 2012; Tlig and Bhouri, 2011; Kammoun *et al*., 2014): multi-agent system (MAS) is a system formed by multiple interacting intelligent agents, which are implemented using hardware and software of the control system. In multi-agent systems can appear self-organization and complex behaviours even if the behaviour strategy of each agent is rather simple. In a multi-agent system, the agents have several important characteristics:

1. Autonomy: agents are at least partially independent
2. Limited information: None of the agents has any idea about the whole system, or the system is too complex, to the knowledge of it had practical application for the agent.
3. Decentralization: there are no agents that control the entire system.

We use the results of computer modelling of priority passage of public transport vehicles based on technology of multi-agent systems (Tlig *et al*., 2011), to understand how this technology can be adapted to a real satellite navigation public transport dispatch system for interacting with the traffic lights control system in the organization of priority passage for passenger vehicles through signalized intersections. For this purpose it is necessary to use four types of agents.

The roles of agents in automated navigation dispatching system are shown in Table 1.

Table 1. The role of agents in interaction process of traffic lights control and public transport dispatch systems

Agent name	**Description of the agent role in the model**
Bus Agent (BA)	The BA after each bus stop sends to the Bus Route Agent the following information: - identification number of the telematics block; - The route number and direction; - Leaving time of the zone of bus stop; - Bus location (latitude, longitude); - Number of passengers in the cabin, estimated using onboard equipment
Bus Route Agent (BRA)	BRA determines if the bus stop located before a signalized intersection. If so, the BRA calculates the actual deviation from the schedule using information that BA sent and bus schedule. If the deviation is not detected (no more than±1 minute) or if the bus is ahead of schedule, the request for priority is not formed. Otherwise, the BRA: 1) Sends to the Intersection Agent (IA) request for priority and the following additional information: the identification number of bus telematics block; signalized intersection identifier; the direction of movement to the signalized intersection; bus location (latitude, longitude); number of passengers in the bus cabin. 2) Sends to the Bus Agent command to retranslate navigation data to the Intersection Agent immediately
Intersection Agent (IA)	The IA using detectors of transport at the intersection continuously counts the number of vehicles approaching the intersection from each direction in every control cycle. The IA receives from the BRA request for priority and information about the time of passing the last stop before the intersection and navigation information sent by bus telematics unit. The IA estimates the actual time bus to reach the intersection zone of influence. the IA organize priority passage for bus, requesting priority, in the following order: 1) Check the criterion (2), determining the possibility of giving priority to public transport vehicle. 2) If the condition (2) fulfills, then the IA calculates the time interval for the bus pass: Specify the start time (Tbegin) and end time (Tend). The start time shows when the bus arrives at the stop line; It includes a green time, required for the passage of all vehicles that are moving in the intersection zone of influence before the bus. The interval is calculated as follows: $T_{begin} = T_0 + L/3.6V$ $T_{end} = T_{begin} + ND + T_{evacbus}$ L = distance (meters) to “Stop” line of the intersection from the current position of the bus; N = number of vehicles before the bus in the intersection zone of influence, calculated by transport detector; V = bus velocity (km / h); D = saturation flow, T_0 = current system time; Tevacbus = time, needed to pass the intersection “Stop” line (we assume Tevacbus equal to 2 seconds).
Phases agent (PhA)	When Phases agent (PhA) receives information from Intersection Agent (IA) it begins to calculate the order and length of signalling phases to organize bus priority passage of the intersection.

6. Simulation

The purpose of the simulation is to determine the state of traffic flows at the intersection, in which the public transport priority will be effective in terms of the overall time delays of passengers. We have simulated an intersection shown in Figure 2. Movement through the intersection is carried out rectilinearly (turns are forbidden) and is regulated by traffic lights. Simulation was carried out for the case of free flow in all directions.

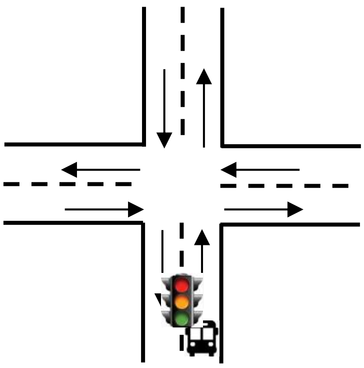

Figure 2. Topology of the considered intersection

GPSS (General Purpose Simulation System) environment was used for simulation. The initial data for modelling are presented in Table 2. The passenger cars flow from west to east and from east to west within the one experiment is considered the same and takes values from the interval from 50 to 600 veh./h. in increments of 50 veh. These values correspond to the free flow conditions (Bogumul, 2011). The situation with the passenger cars flow from south to north and from north to south is similar. The public transport approaches the intersection in the direction from south to north. As a prototype of the public transport vehicle, a LiAZ-5292 bus with a maximum capacity of 112 people is taken. Within the one experiment, the number of passengers in the public transport is modelled by a uniform distribution in the intervals indicated in the table.

Table 2. Initial data for modelling

Parameter	**Values of simulation parameters**
Flow rate from west to east and from east to west	50 veh./h., 150 veh./h., 200 veh./h., 250 veh./h., 300 veh./h., 350 veh./h., 400 veh./h., 450 veh./h., 500 veh./h., 550 veh./h. and 600 veh./h.
Flow rate from south to north and from north to south	50 veh./h., 150 veh./h., 200 veh./h., 250 veh./h., 300 veh./h., 350 veh./h., 400 veh./h., 450 veh./h., 500 veh./h., 550 veh./h. and 600 veh./h.
The frequency of generation of public transport	10 min., 5 min. and 2 min.
The number of passengers in the public transport	low congestion: from 0 to 40 people, average congestion: from 40 to 80 people, high workload: from 80 to 110 people
Average number of passengers in a passenger car	1,5 persons
The coefficient of reduction the public transport to a passenger car	3
Time of crossing by the vehicle stop line of intersection	2 s.
Time of crossing intersection by a passenger car	3 s.
The Simulation time	1 hour
The length of the traffic light cycle	80 s
The interval for changing the duration of the traffic light phases	from 15 to 65 s. in increments of 5 s.

The simulation was carried out in two stages. At the first stage, for the given traffic flow, for each value of the frequency of generation of public transport and the number of passengers in it, the optimal from the point of overall time delays of passengers duration of the traffic light phases were determined. These experiments were conducted without using the public transport priority. The purpose of this stage is to determine, on the one hand, the optimal durations of the traffic light phases, and on the other hand the "base" values of the time delays reduced to the total number of passengers.

The second stage of modelling was to determine the overall time delays of passengers using the public transport priority. For each values of the traffic flows, the values of the duration of the traffic light phases, obtained in the first stage, were used. For each value of the frequency of generation of public transport and the number of passengers in it, the value of the overall time delay reduced to the total number of passengers was determined and compared with the "base" values. In Figure 3 shows the aggregated data obtained as a result of modelling and in Figure 4 is a diagram constructed from this data.

		10 min.					2 min.			
		50-150	150-300	300-450	450-600		50-150	150-300	300-450	450-600
0-40	50-150	0,05	-0,02	0,03	0,02		0,36	0,26	0,26	0,20
	150-300	0,10	0,05	0,01	0,05	•••	0,54	0,44	0,38	0,41
	300-450	0,16	-0,05	0,05	-0,07		0,72	0,59	0,48	0,52
	450-600	0,21	0,03	-0,14	-0,31		0,91	0,65	0,64	0,61
			⋮						⋮	
80-110	50-150	0,10	0,03	0,04	0,07		1,07	0,89	0,99	0,77
	150-300	0,32	0,23	0,10	0,06		1,51	1,20	1,22	1,13
	300-450	0,69	0,33	0,17	0,09	•••	2,12	1,92	1,53	1,53
	450-600	0,84	0,50	0,26	0,25		**2,89**	**2,19**	**2,10**	**1,77**

Figure 3. Total winnings of passengers in relation to the traffic flow, the frequency of generation of public transport and the number of passengers in it

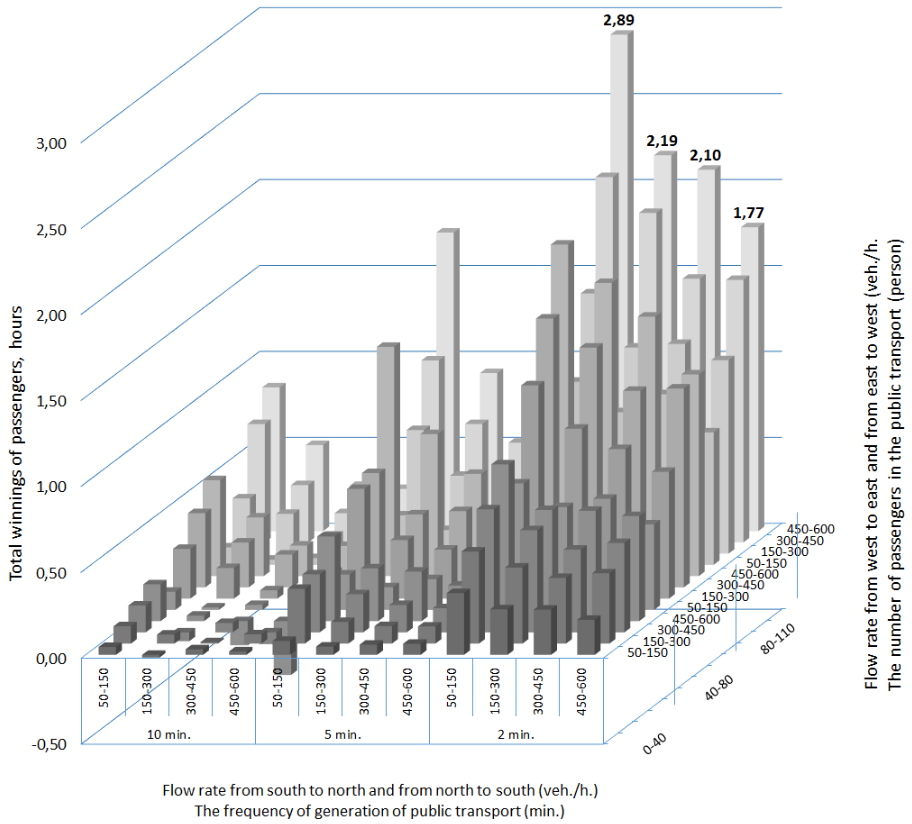

Figure 4. Total winnings of passengers depending on traffic flow through the intersection, the frequency of generation of public transport and the number of passengers in it

The diagram has two levels along the lower axes. The lower level of one of the axes represents three constant frequencies of generation of public transport: 10 min., 5 min. and 2 min. The upper level of this axis is the intervals of the simulated values of the traffic flow in the directions south-north and north-south (values in both directions are assumed to be the same). The public transport arrives to the intersection in the direction from the south to the north. On the other axis in the lower level, the number of passengers in the cabin of public transport: low load (from 0 to 40 people), average load (from 40 to 80 people) and high load (from 80 to 110 people). The upper level represents the intervals of the simulated values of the traffic flow in the directions west-east and east-west (in the same way as in competing directions, the values in both directions are assumed to be the same). The vertical axis depicts the total winnings in hours of all the passengers (both in the public transport and in passenger cars) crossing an intersection during the simulation time (1 hour).

The results of the simulation show that the maximum winnings with public transport priority is achieved under the following conditions (upper right part of the figure 4):

- The number of passengers in the public transport: high load.
- The traffic flow in the direction of west-east, east-west: from 300 to 600 veh./hour.
- The frequency of generation of public transport vehicle: 2 min.
- The traffic flow in the direction of south-north, north-south: from 50 to 600 veh./hour (whole range).

On the other hand, it should be noted that the public transport priority gives a very small time gain, and in some cases a loss under the following conditions (lower left area of the Figure 4):

- The number of passengers in the public transport: low load.
- The traffic flow in the direction of west-east, east-west: from 50 to 600 veh./hour (whole range).
- The frequency of generation of public transport: 10 min.

- The traffic flow in the direction of south-north, north-south: from 50 to 600 veh./hour (whole range).

Thus, we can formulate a decision rule for the automated intersection agent:

```
IF
    the number of passengers in the public transport > 80 people
AND
    the frequency of generation of public transport ≤ 5 min.
AND
    the traffic flow rate in the direction of the public transport
    movement is ≥ 50 veh./h. and ≤ 600 veh./h.
AND
    the traffic flow rate in a direction competing with the public
    transport movement ≥ 300 veh./h. and ≤ 600 veh./h.
THEN use the public transport priority,
ELSE use standard phases durations.
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As follows from the above rule, the key role in minimizing the total loss of time for passengers crossing the intersection has information on the number of passenger in public transport and the frequency of generation of public transport. It should also be noted that the received total winning of passengers are minimal, since the simulation of priority passage was carried out with the duration of the traffic light phases optimized at the first stage of the simulation.

7. Conclusion

This article represents optimization criteria, which deals with the number of people, crossing the signalized intersection including the passengers of public transport. This corresponds to modern trend to increase the people's mobility. We use the multi agent approach for urban public transport dispatch system to organize priority transfer management, based on interaction with traffic lights control system. Utilizing this method needs only four types of agents with strictly defined functions and information interface. Bus agent is the only type that needs a mobile implementation. This agent is the simplest due to its functions and to restriction of its hardware and software capabilities. But one should take in mind that this type of agent is the most numerous.

Results show that the public transport priority doesn't always yield a win if, as an optimization criterion "The minimization of total passenger time losses crossing the intersection" is considered. A decision rule was formulated that shows the values of the main parameters under which it is necessary to use priority travel. For our future works, we will focus on a refinement of the obtained decision rule. We are planning a comparison the results of optimization the duration of the traffic light phases using the criterion of "Maximizing number of vehicles crossing the intersection" with optimization based on the criterion "Minimization of passenger time losses".

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