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Development of coordinated control of traffic flows at the highway section with using simulation modeling

Abstract:

As the title implies the article describes using simulation modeling of traffic flows by example on the highway section – Moskovsky Avenue in Kharkiv.

The main goal of the research is the introduction of simulation modeling methods for calculating the parameters of traffic light cycles and determination the parameters to assess the quality of traffic light regulation, in case of the control of traffic flows on the highway.

The use of modern approaches of simulation modeling allowed to obtain the estimation characteristics of the quality of traffic flow control in change the parameters of traffic signal, also the parameters of traffic flows in a virtual environment, for the successful implementation of the proposed measures. The developed model with the help of the Road Traffic Library, software “Any Logic”, allowed to reduce the optimal values of traffic light control cycles at intersections of the considered section of the highway. As an estimate criterion, was proposed to use the average time spent vehicles in the network. The research results can be applied by experts in the field of Traffic Management and transport planning in solving the problems of definition the optimal traffic light phases for the implementation of coordinated control on the highway streets.

It is proposed to use simulation models that allow to become a good tool for making decisions in the field of traffic management on a highway by finding the optimal values of traffic light control cycles and its components, taking into account changes in the intensity and speed of traffic flow.

Keywords:

traffic flows, traffic light, phase, traffic light cycle

1. Introduction

This article covers basic aspects of traffic signal coordination. Signal coordination is done when they are closely space to enable vehicle in one predominant direction to get continuous green.

The difference between the two green initiation times is referred to as the signal offset, or simply as the offset. In general, the offset is defined as the difference between green initiation times, measured in terms of the downstream green initiation relative to the upstream green initiation [1, 2].

This will reduce the delay and travel time in one direction and increases throughput. The design principles of signal coordination will be presented in this article.

Signal coordination techniques for increasing the efficiency of traffic management systems in urban road networks are widely studied, have the disadvantage of high computational complexity due to large-scale road networks and numerous time-varying parameters. One way to solve this problem is to use imitation modeling.

2. Literature review

Many of the studies are dedicated to the optimization traffic control and imitation modeling. Having analyzed the existing literature sources, it was possible to identify the main directions of the study of Signal coordination methods have been widely investigated to improve the performance of traffic control system in urban road. In the study [3] was a method to optimize and coordinate the traffic signal in urban road networks is developed, decomposing the network into several arterial roads and scattered intersections. As a result, an area coordination problem has been solved by coordinating several principal arterial roads and isolated intersections. Effectiveness of the proposed method are validated by simulations on VISSIM.

In the paper [4], the performance of the optimal signal timing plans developed by TRANSYT-7F and Synchro is compared using the microsimulation software PARAMICS. Comparison of the optimized plans is done on the basis of queue length and average delay from the simulated results of PARAMICS. Was optimized plan by TRANSYT-7F gave better results than the plan by Synchro in terms of queue length and average delay. Also in the study [5], introduced a method for area-wide traffic signal timing optimization under user equilibrium traffic with help a simulation control protocol embedded in PARAMICS. The results showed that mobility improvements are achieved after applying the proposed model along with the genetic algorithm for area-wide signal timing optimization, assessed by extended capacity ratio, and reductions in through and turning movement delays, as well as average and variance of travel time for unit distance of travel.

In study [6], presented the traffic control system controlled through a PLC, which takes the signals from different sensors on roads, which ensures the coordination of four intersections, setting a path that respects coordination type green light.

In this paper [7], author suggests the elimination pairing system – a new method for designing traffic signal timing at oversaturated intersections – is expressed. An object function with vehicle delay and stop-start numbers has been generated. Results were compared with Webster and Transyt 14 signal timing software. Webster gave exaggerated results, Transyt 14 and Elimination Pairing Systems provided better results. The result of this study, the system could be used for optimizing the traffic signal timings.

In paper [8], developed is model concurrently determine the arterial decomposition strategy and optimize the resulting signal progression plan within each subgroup. With an integrated control objective function, the proposed model minimized the required number of subgroups while satisfying the operational need. Also, the proposed model is formulated with a mixed-integer-linear- programming technique that can guarantee a global optimal solution. Using the example of 15 intersections, the effectiveness of the proposed model was obtained.

This paper [9], proposes a multi-objective optimization algorithm for traffic signal control. Maximum of throughput and average queue ratio minimum achieved in the simulation environment VISSIM are selected as the objective function. The results showed good efficiency in traffic management at supersaturated intersections

One way to solve this problem is to use imitation modeling.

For the implementation of research in the field of traffic road and pedestrian flows, at the present stage, a number of software products, namely PTV Vision, AnyLogic, Vensim, Aimsum, and others are used. In Ukraine, the most common products are PTV Vision and AnyLogic. [10],

In order to improve coordinated signal timing in the short term, this study developed an approach to the implementation of coordinated management using the Any Logic program, because in the student version, the transport network size is unlimited and the simulation time is one hour, unlike the PTV software product PTV Vision. There the network is 1 km long and the simulation time is 10 minutes.

3. Research

The object of the study is the section of the main street of the urban significance of regulated traffic - Moskovsky Avenue in the city of Kharkiv. Object map is presented in Fig.1. To introduce a coordinated control will be considered:

1. Moskovsky Ave. - Chervonshchilna naberezhna,
2. Moskovsky Ave - Heroyiv Nebesnoyi Sotni Square (one-sided - 2 lanes),
3. Moskovsky Ave - Feyyerbakha Square (one-sided - 2 lanes),
4. Moskovsky Ave - Street. B. Khmelnitsky.

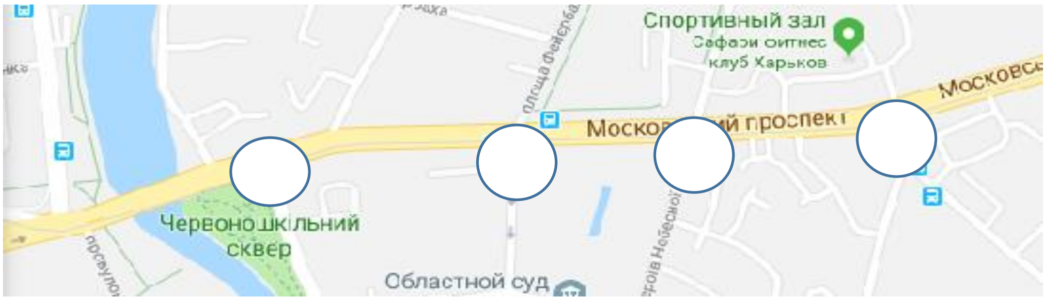


Figure 1. Fragment of the object of study

The duration of the existing control cycles at the crossroads being investigated is different. From the four intersections of the object of the study, traffic light control is at the intersections Moskovsky Avenue - Square Heroyiv Nebesnoyi Sotni ($T_c = 56$ sec), Moskovsky Avenue - Feyyerbakha Square ($T_c = 56$ sec), Moskovsky Avenue - Street. B. Khmelnitsky ($T_c = 54$ sec).

At all intersections, traffic flow and pedestrian traffic intensities were studied. At all intersections, at this moment, traffic control is organized in two phases:

1 phases - the traffic flow is organized by highway;

2 phases - the traffic flow is organized by secondary road.

The calculation of the parameters of traffic-light control at the studied intersections was carried out according to Webster's method, described in [11] and summarized in table 1.

Table 1 - Parameters of traffic-light control with coordinated control

Intersection	Calculated value					Corrected value				
	Phase 1		Phase 2		T_c	Phase 1		Phase 2		T_c
	t_{oi}	t_{ni}	t_{oi}	t_{ni}		t_{oi}	t_{ni}	t_{oi}	t_{ni}	
1	33	5	17	7	64	45	5	23	7	80
2	40	6	24	5	75	44	6	25	5	80
3	33	5	20	5	64	44	5	26	5	80
4	50	5	14	7	80	50	5	18	7	80

According to research, the speed of traffic is 30 km/h. Based on the adjusted values of cycles and main cycles at all intersections, a graph of coordinated control on the highway was built (Fig. 2).The width of the tape time is 24 seconds.

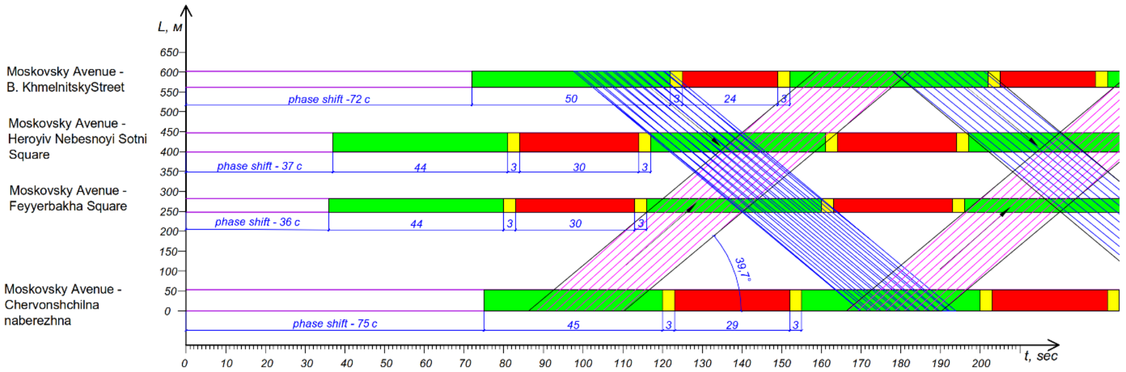


Figure 2. The time space diagram between intersections traffic flow

With the help of the graph, phase shifts were identified: 1 intersections - 75 s, 2 intersections - 36 s, 3 intersections - 37 s and 4 intersections - 72 s.

Using the method outlined in [12, 13], delays at intersections are calculated, the results are presented in the table 2 and 3.

Table 2 - Delays at intersections

Intersection	Isolated control				Coordinated control	
	The average delay of one car at the intersection,sec	The delay time per hour at the intersection, car/hour	The time spent per hour on the stretch, car/hour	The total time spent per hour at an intersection, car/hour	Average delay at the intersection in the direction of coordination,sec	Total annual time delays per hour at the intersection in the direction of coordination, car/hour
1	2	3	4	5	6	7
№1	11,612	11,56	6,139	17,699	28,64	8,76
№2	9,54	11,45	4,987	16,437	5,92	2,45
№3	10,24	13,45	6,157	19,607	5,619	2,92
№4	9,51	11,11	5,45	16,56	25,24	10,62
Total time costs on the highway	40,902	47,57	22,733	70,303	65,419	24,75
The result of the introduction of coordinated control, Decrease of time expenditures by -						22,82
Decrease of time expenditures in percentages by -						67,53%

Table 3 - Expenses of time of vehicles when traveling through all intersections

Intersection	Total time expenditures per hour of vehicles	
	Before the introduction of coordinated control	After the introduction of coordinated control
1	17,699	14,899
2	16,437	7,437
3	19,607	9,077
4	16,56	16,07
Total	70,303	47,483

4. Imitation model building

To approbate the proposed measures for the introduction of coordinated control on the investigated area, the use of simulation modeling is proposed.

The criterion of effectiveness in simulation using the Anylogis software product is the average duration of finding a single car on the network.

The construction of the simulation model will be carried out in several stages. The algorithm are presented in Fig. 3

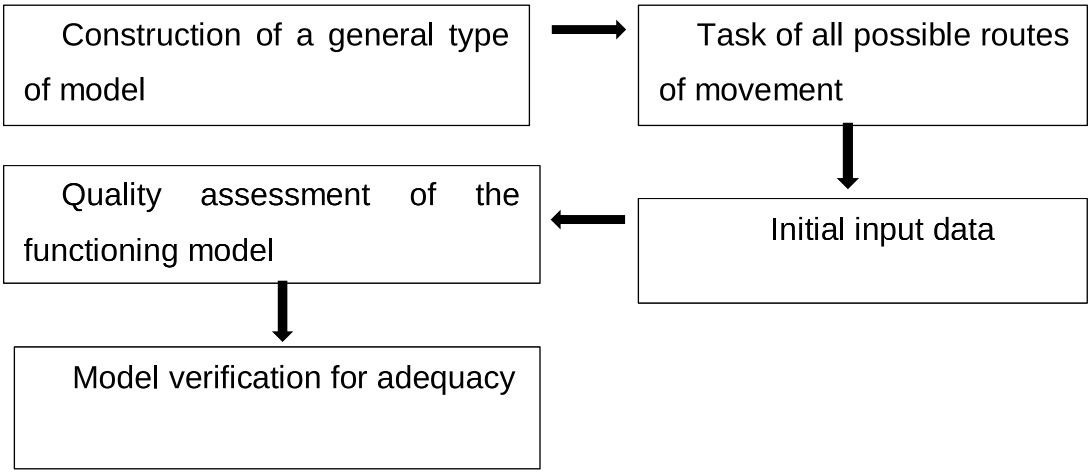


Figure 3 - Algorithm for constructing an imitation model

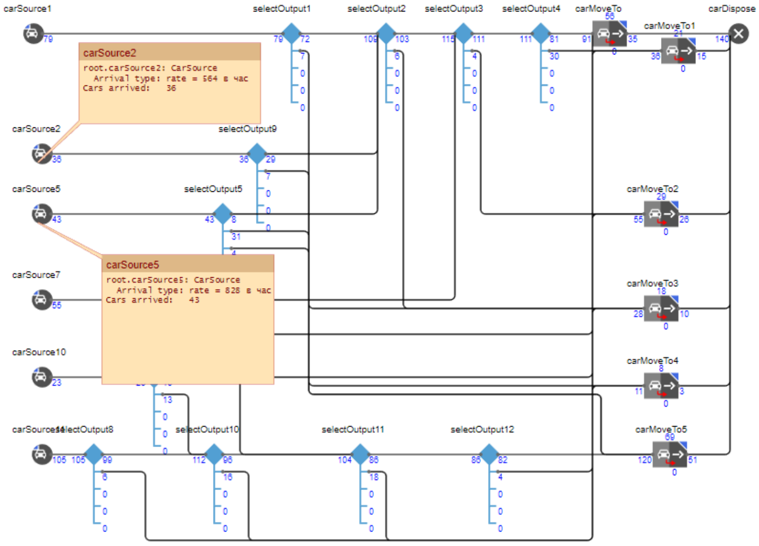
Stage 1 - construction of a general type of model: satellite imagery loading and zooming, road mapping, task directions (Fig.4).

```
trafficLight2
Количество фаз:                 4
Индекс текущей фазы (0..3):     3
  Длительность, секунды:        44
  Оставшееся время, секунды:    15.788
```

```
trafficLight3
Количество фаз:                 5
Индекс текущей фазы (0..4):     4
  Длительность, секунды:        44
  Оставшееся время, секунды:    17.788
```

Figure 4. General type of model

Stage 2 - the introduction of all possible routes: block diagram of the model is shown in (Fig.5).



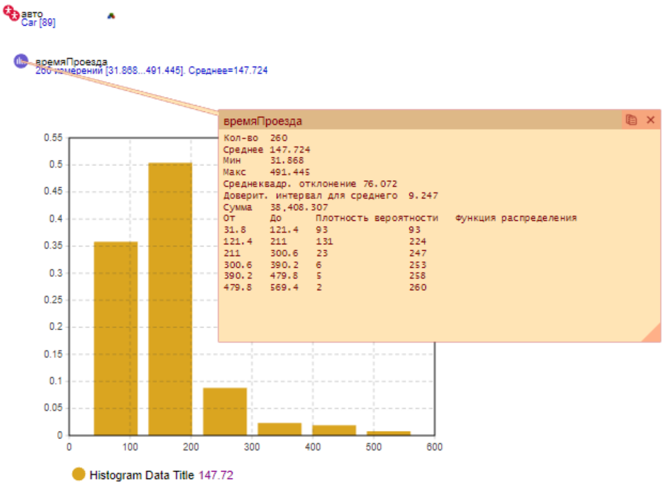
```
carSource2
root.carSource2: CarSource
  Arrival type: rate = 564 в час
Cars arrived:   36
```

```
carSource5
root.carSource5: CarSource
  Arrival type: rate = 828 в час
Cars arrived:   43
```

Figure 5. Block diagram of the simulation model

Stage 3 - Introduction of source data into model blocks based on collected and processed survey forms.

Stage 4 - the quality of the model is evaluated using a histogram (Fig.6).



```
времяПроезда
Кол-во  260
Среднее 147.724
Мин     31.868
Макс    491.445
Среднеквадр. отклонение 76.072
Доверит. интервал для среднего  9.247
Сумма   38,408.307
От      До      Плотность вероятности   Функция распределения
31.8    121.4   93                93
121.4   211     131               224
211     300.6   23                247
300.6   390.2   6                 253
390.2   479.8   5                 258
479.8   569.4   2                 260
```

Figure 6. Histogram of finding a car in the network

5 Stage - assessment of the adequacy of models.

In simulation modeling, the estimation of the adequacy of the model is performed by comparing the output data and the results of the program. In this case, the verification of the model is carried out by comparing the length of the queue in (Fig.7) and during the simulation experiment in the Anylogis software product (Fig.8).

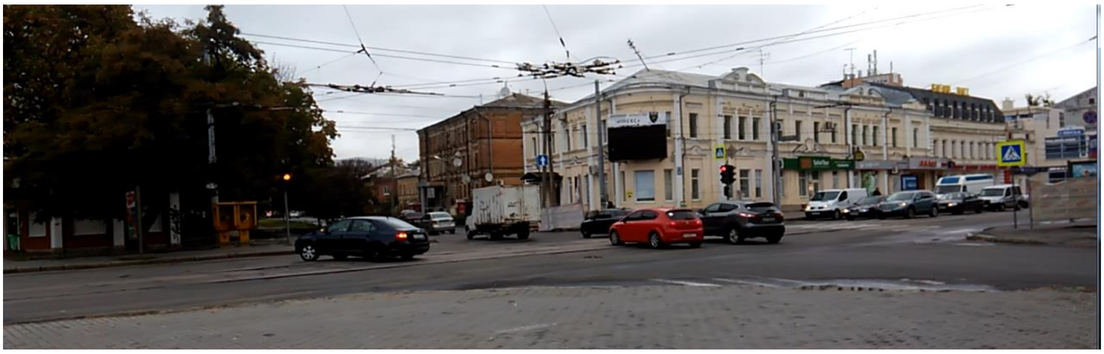


Figure 7. Length of the queue at the intersection
Moskovsky Avenue -Heroyiv Nebesnoyi Sotni Square

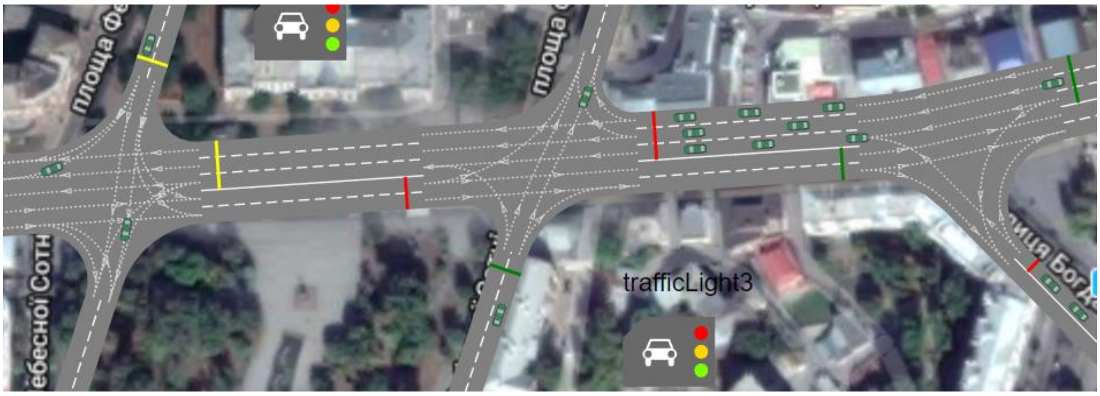


Figure 8. Length of the queue at the intersection
Moscow Avenue -Heroyiv Nebesnoyi Sotni Square in the Anylogis software product

Changing the intensity of the network and the speed of movement also changes the criterion of the efficiency of the transport system.

We change the speed of the traffic flow from 20 to 40 km / h and the intensity from 3877 to 6249 car / hour, we determine the efficiency criterion (average time of occurrence of vehicles on the network) for each of the pairs of values of the input parameters. The results are presented in table 3.1, Fig.9 - 12.

Table 4 – Time in the network when changing transport parameters

N, car/hour	*V*, km/hour				
	20	25	30	35	40
3877	188,66	156,501	100,699	133,413	121,145
4546	208,972	156,501	144,434	132,414	125,698
5113	195,303	170,032	141,969	130,275	175,599
5678	207,015	162,626	147,724	149,074	136,494
6249	185,702	190,071	164,112	144,657	157,528

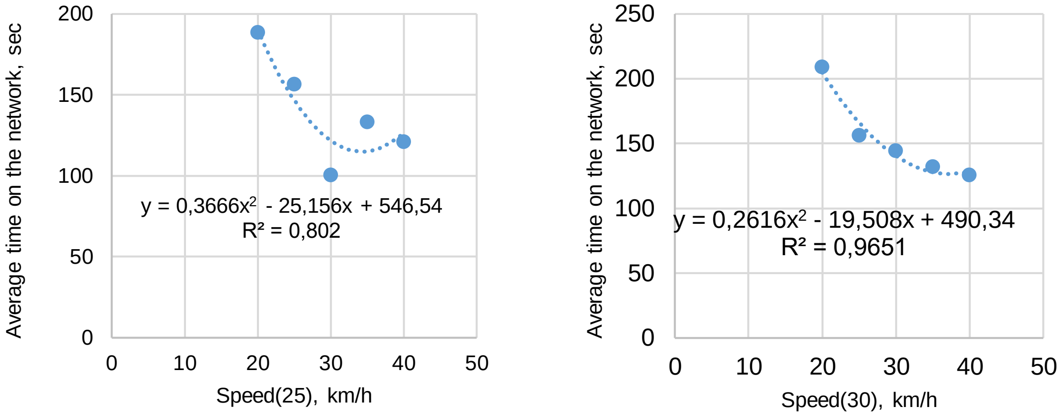


Figure 9. The dependence of the average time in the network from the speeds of 25 and 30 km/h

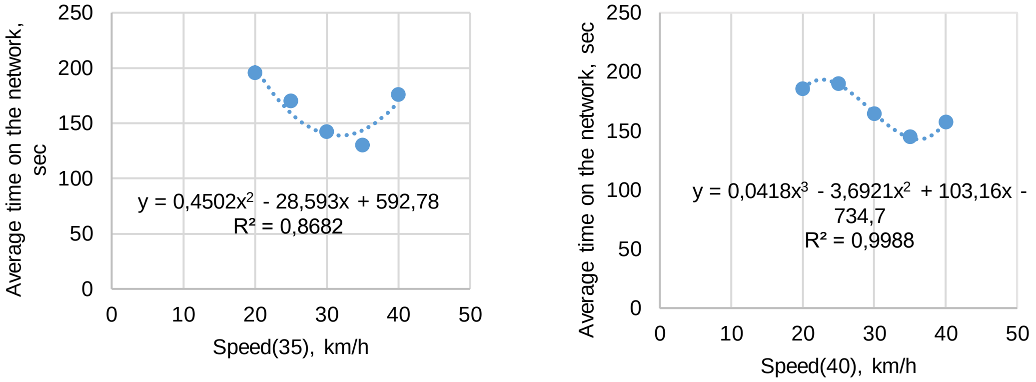


Figure 10. The dependence of the average time in the network from the speeds of 35 and 40 km/h

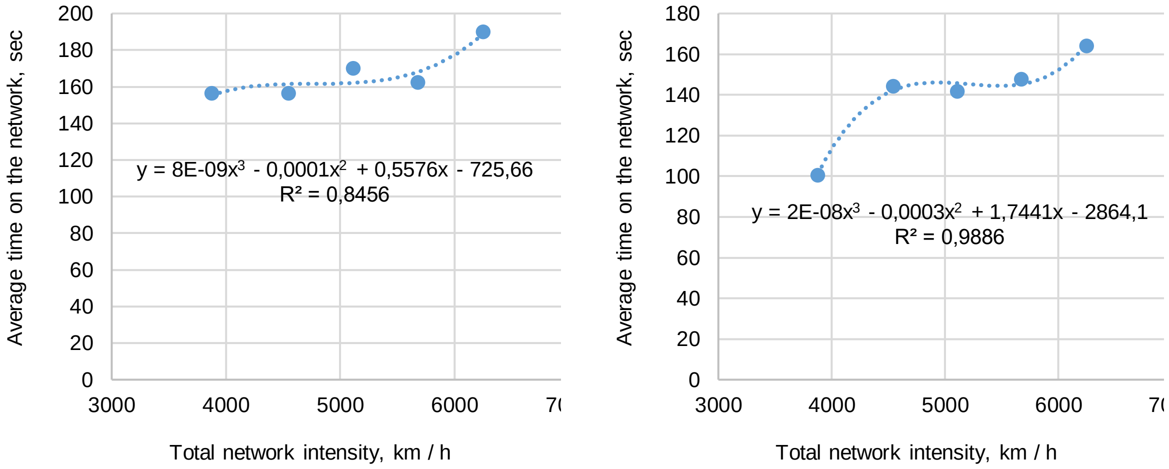


Figure 11. The dependence of the average time in the network on intensity at a speeds of 25 and 30 km/h

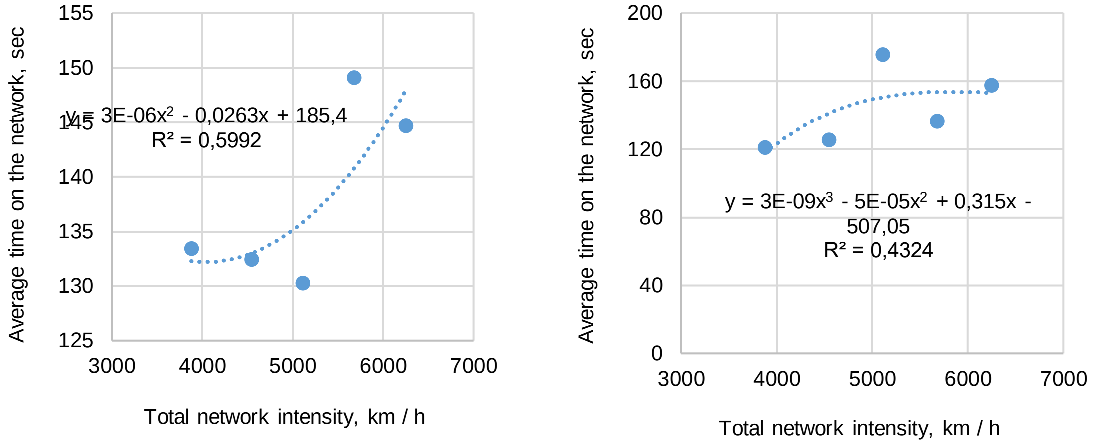


Figure 12. The dependence of the average time in the network on intensity at a speeds of 35 and 40 km/h

5. Development a regression model

Since the intensity of the traffic flow affects the speed of the traffic flow and, accordingly, the average time that vehicles stay on the network, we will study the parameters using the STATGRAPHICS software using the Multiple Regression tool.

We develop the dependence of the average time of finding vehicles on the network from:

- traffic speed, km/h;
- traffic intensity, car/h.

The result is presented in the table 5-7.

Table 5 - Characteristics of the model

Parameter	dimensionality	Borders	Coefficient	Standard Error of Est	T-Statistic	
					calculated	calculated
Traffic speed	*V,* km/h	20-40	- 2,7371	0,5105	-5,36076	2,02
Traffic intensity	*N,* car./h	3877-6249	0,0109446	0,0043	2,52061	2,02

Table 6– Confidence intervals coefficients of the linear model

Parameter	lower limit	Upper limit
Traffic speed	-3,79598	-1,67822
Traffic intensity	0,00193975	0,0199495

Table 7– Results of statistical estimation of the model

Parameter	Volue
F-Ratio	17,55
R-squared	61,4652
Mean absolute error	12,2289

We get the following equation:

$$T = 183,441 + 0,0109446N - 2,7371V \, . \qquad (1)$$

Let us construct a graph of the obtained equation for the dependence of the average time that vehicles are in the network from the intensity and speed, Fig.13. Calculations of the equation for plotting are presented in table 8.

Table 8 – Results of calculations of the equation

N, car/h	*V*, km/h				
	20	25	30	35	40
3900	171,4	157,7	144	130,3	116,6
4500	177,9	164,3	150,6	136,9	123,2
5100	184,5	170,8	157,1	143,5	129,8
5700	191,1	177,4	163,7	150	136,3
6300	197,6	184	170,3	156,6	142,9

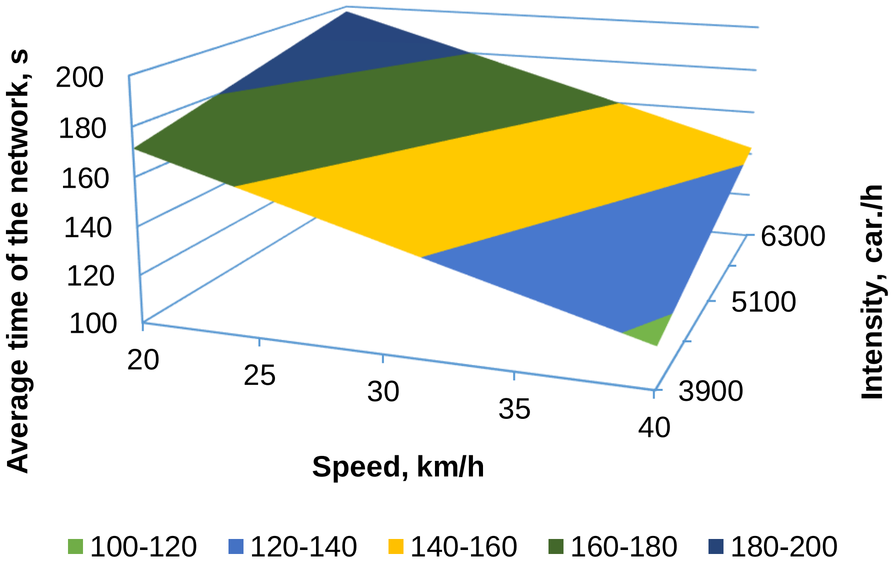


Figure 13. Dependence of average time of finding vehicles on the network from intensity and speed

6. Conclusion

Analysis of research papers on the main coordinated control of traffic flow on the network found that one of the tools for making decisions is the use of simulation models.

As an example, an object consisting of four intersections on the site of the Moscow Avenue that is located in Kharkiv was considered. The characteristics of the introduction of coordinated control are determined.

The simulation model of the section of the highway in the AnyLogic software product is constructed and verified.

The simulation was carried out with a change in the speed of the traffic flow from 20 to 40 km / h and intensity from 3800 to 6300 car / h, and the efficiency criterion is defined - the average time of vehicle arrival in the network.

On the basis of modeling data, a regressive model of the dependence of the average time of finding a vehicle in a network on the speed and traffic flow intensity was developed.

It is advisable to use the developed model for determining the average time spent by a vehicle in the network on the speed and intensity of traffic flow, as an assessment of the proposed measures for the coordinated control, which consists of four intersections and the total intensity at the entered in the intersection from 3900 to 6300 car/h.

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