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MODELING OF REGULATION OF THE TRANSPORT FLOW AT THE ENTRANCE ON THE BRIDGE IN THE ANY LOGIC ENVIRONMENT

Об'єктом дослідження даної роботи є транспортний потік та його параметри у критичному, з точки зору транспортної завантаженості, районі міста, а саме на в'їзді до мосту, що з'єднує правий та лівий береги річки Дніпро (м. Дніпро, Україна). Проблемою, що виникає при формуванні транспортних потоків до мосту, є виникнення заторів у зв'язку із фізичним обмеженням пропускної спроможності мосту. Особливість транспортної розв'язки біля мосту полягає у тому, що розширити проїжджу частину для збільшення пропускної спроможності неможливо без капітальної перебудови. Крім того навколишня інфраструктура підтримує інтенсивний пішохідний потік, який вклинюється у транспортний потік у довільних місцях, що призводить до зламу структури потоку чи його зупинки. Також є декілька додаткових чинників, що ускладнюють структуру потоку та затримують його. Рішенням, що може поліпшити ситуацію з найменшими витратами, є введення автоматичного регулювання транспортних та пішохідних потоків у критичних місцях.

Для визначення пунктів регулювання та режимів їх роботи було проведено аналіз транспортного середовища у районі в'їзду на міст із застосуванням польових досліджень. Проведено моделювання транспортних потоків з використанням програмного комплексу та обрано режими роботи світлофора.

Отримано статистичні данні щодо транспортних потоків вздовж прилеглих вулиць та схематизовано рух транспорту. Визначено місце розташування світлофору та часові інтервали його роботи, які дозволяють мінімізувати затори на прилеглих вулицях та збільшити швидкість проїзду.

Особливістю проведеного дослідження стало використання для моделювання потужного пакету AnyLogic, який містить спеціалізований модуль для роботи з транспортними потоками. Саме його застосування дозволило створити модель руху та провести серію експериментів, за результатами якої отримано часові інтервали регулювання.

Ключові слова: *автоматичне регулювання транспортних потоків, оптимізація транспортної системи міста, моделювання із застосуванням пакету AnyLogic.*

1. Introduction

The current state of the infrastructure of old cities is primarily characterized by road congestion. Due to the impossibility of restructuring, the problem of traffic jams and the speed of traffic flows can be partially solved with the help of the implementation of traffic management systems.

In the context of the strategic value of some objects such as bridges, it is very important to have predictable and stable throughput for the traffic flow. But the peculiarities of building up or relief on one of the coasts, which are connected by a bridge, lead to the problem of a narrow throat. For example, in the old city of Prague (Czech Republic) had to build a tunnel, because the bridge rested on a hill, a similar problem at the old bridge across the Oka River in Nizhny Novgorod (Russia), the bridge in Zaporizhzhia (Ukraine) goes to a difficult traffic intersection that has developed historically.

For the city of Dnipro (Ukraine), the bridges connecting the right and left banks of the Dnipro River are also of particular importance. A special place in the transport system occupies the Amur Bridge, originates in one of the oldest areas. But the transport hub, located on the right bank of the river, contributes to traffic congestion on the bridge, in addition, there are additional factors associated with the reconstruction of the neighboring bridge.

A problem arising in the formation of traffic flows to the bridge is the occurrence of congestion that occurs due to the physical limitation of the carrying capacity of the bridge. The peculiarity of the road junction near the bridge is that it is impossible to expand the roadway to increase traffic capacity. So the solution that can improve the situation is the introduction of automatic regulation of traffic flows.

So, it is relevant to study the structure and volume of transport flows, the definition of critical points at which regulation and the establishment of regulatory regimes can be carried out.

2. The object of research and its technological audit

The object of research is the traffic flow and its parameters in a critical, in terms of traffic congestion, area of the city of Dnipro (Ukraine), namely at the entrance to the bridge that connects the right and left banks of the Dnipro.

The overpass to the bridge originates at the intersection of Dmytro Yavornitsky Avenue (formerly K. Marx Avenue) and Pasteur Street in the city. Dnipro and ends with a stop at the Amur Bridge. Starting from D. Yavornitsky Avenue Pasteur Street has 3 lanes for road transport in one direction and 1 way each in the forward and reverse directions for the movement of trams. On this street there are many food and industrial stores that are in demand among the population. People come here not only by public, but also by personal transport. Therefore, cars are parked in the extreme right lane, which is used by drivers for parking, therefore, for the simulation, let's take into account only traffic in two lanes. On the way there is a warning sign 1.5.2, which indicates a narrowing of the road on the right side, as well as a prohibition sign 3.29, which limits the speed to 40 km/h.

This road is the main one, as indicated by the corresponding priority sign. Following further along the street we get to the Staromostova Square (Fig. 1).

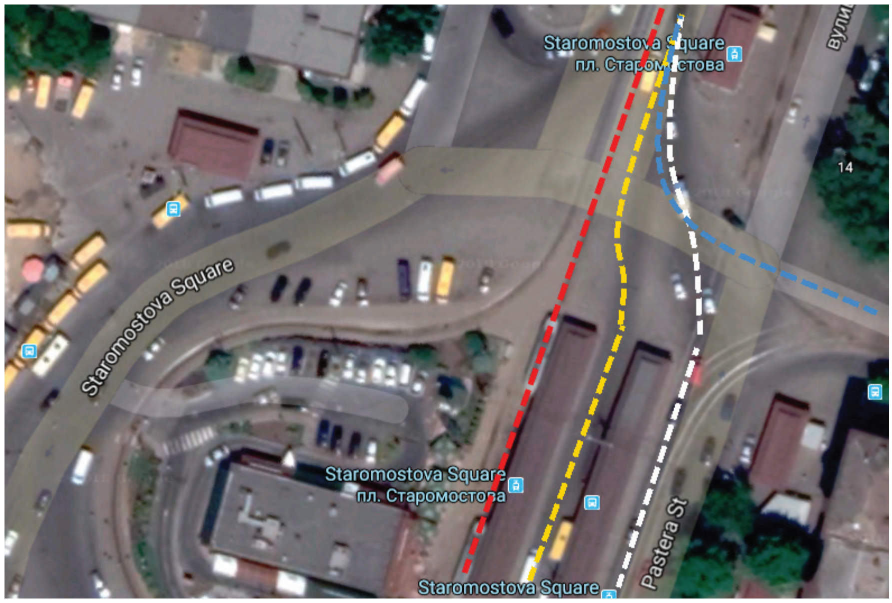

Fig. 2. The trajectory of the entrance to the bridge: the red dotted line is the tram, the yellow one is the arrival of the urban and suburban transport, the white one is the arrival from the Pasteur str., blue – from the Vokzalna Street (Dnipro, Ukraine)

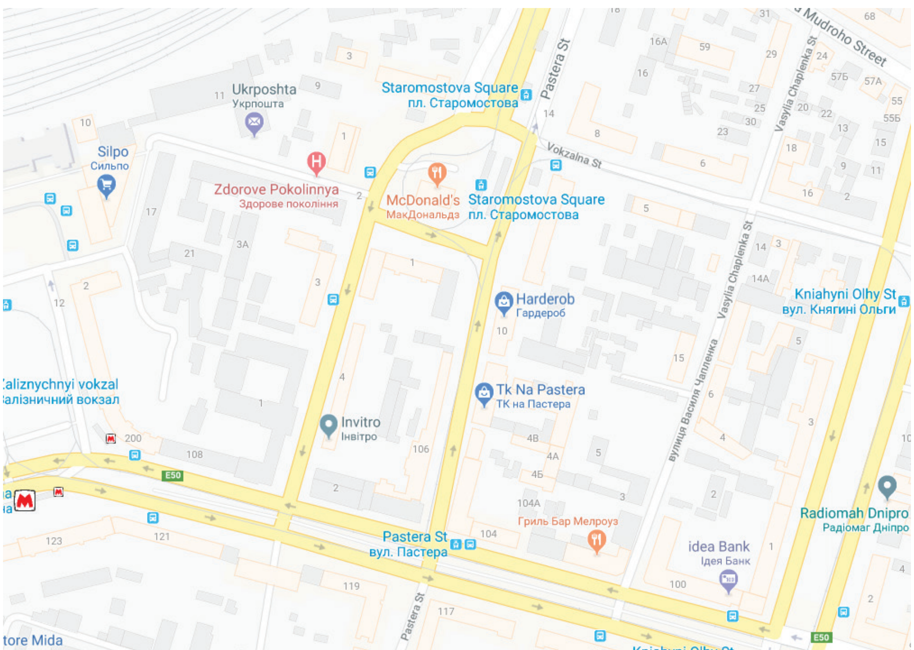

Fig. 1. Staromostova Square (Dnipro, Ukraine)

In the vicinity of this square is the McDonalds building, as well as stops for suburban and urban road transport and trams.

Arrival at the Amur Bridge takes place both by tram and cars. On the Amur Bridge there is one lane for each type of transport indicated above. Check-in takes place both from Pasteur Street and from Vokzalna Street (Fig. 2).

One of the most problematic places is the confluence of four flows at the entrance to the bridge. Moreover, the flows are filled with electric and route transport. Also, the bridge is allowed to move trucks with a semi-trailer. In addition, there are differences in the heights of the roadway at the point of confluence, which leads to a decrease in speed.

3. The aim and objectives of research

To achieve this aim it is necessary to perform the following tasks:

1. To conduct field studies of traffic flows affecting traffic on a bridge and collect statistical data.
2. To build a model of traffic flows in the AnyLogic environment.
3. To make an optimization of the model according to the criterion of minimizing the length of the jams.

4. Research of existing solutions of the problem

The work is a continuation of research on the optimization of the city's transport system.

In a previous paper [1], estimates of the quality of routes were described as part of the city's transport system. The global task is set as the construction of a decision-making system at the level of urban transport management. On the other hand, field studies are carried out in order to fill the data with an intelligent traffic management system.

Similar studies are performed for other large cities [2]. In the context of the performed work, an interesting study is presented in [3] in connection with the use of the AnyLogic tool.

The main purpose of the work was conducting simulation using the AnyLogic package, as an alternative to the implementation of formal approaches based on mathematical models [4, 5]. Inspection and evaluation of formal methods and algorithms that are currently applicable are given in [6, 7].

Simulation models in the case of traffic flows and control systems allow to obtain the necessary parameters in conditions as close as possible to the real ones. And most importantly do not require the translation of results from the mathematical language to the language of the subject area. A review of modern simulation systems is in [8], a more focused review in [9].

With the release of AnyLogic, GPSS World, ExtendSim, and Arena packages to the market, it is possible not only to carry out simulation modeling, but also to do it in an environment that best matches the system being modeled [10, 11].

5. Methods of research

Table 1 presents data on the schedule of traffic, moves the Amur bridge. As it is possible to see, the interval of movement of most of them is on average 10 minutes.

Thanks to the «Congestion in Dnipro» section, it is possible to view online traffic congestion online. Information is provided from the Google Maps Jam service. This service is very popular among drivers of the Dnieper due to current information. The level of road congestion that is displayed on the map in different colors (green — no traffic jams, yellow — almost freely, red — heavy traffic, dark red — traffic jams) helps in a few seconds to assess the situation on the roads.

Table 1

Public transport timetable

The schedule of traffic through the Amur Bridge			
No.	Transport	Route number	Interval, min
1	Trolleybus	3	2–14
		15	58–95
		20	2–14
2	Tram	6	5–10
		9	5–10
3	Shuttle buses	4	6–15
		27	10–30
		36	5–20
		31	4–15
		41	8–20
		59	20–30
		70	7–20
		82	60
		83	60
		99	2–10
		106	2–10
		149	2–11
		153	15–25
		158	4–15
4	Suburban buses	212	140–208
		230	105–210
		231	60–120
		232	115–180
		240	20–30

5.1. Movement on the Amur, Kaidak and South Bridge. According to the results of calculations, from 7:00 to 9:30 on all three bridges there are some of the busiest periods. The number of cars is growing from 7:20 to 7:40, especially noticeable on the Kaidak Bridge. The second peak comes from 8:00 to 9:00. At this time, the load on all three bridges increases: in Kaidak, the number of cars can reach 70 units, on the Amur – more than 40, in the South also – from 30 to 50 cars (Fig. 3).

In the morning, in the direction from the right to the left bank, the Amur Bridge remains the busiest. Movement on it is activated after 7:30 and reaches an average of 30 cars. After 8:40 the Kaidak Bridge becomes the busiest – the number of cars reaches 35 (Fig. 4).

In the evening, traffic on the bridges is also loaded. In the direction from the right to the left bank, the number of cars begins to grow. From 17:00 to 17:30 Amur Bridge remains the busiest – more than 45 cars. After 17:30 more intensive traffic is fixed on the Kaidak Bridge. Up to 18:30 here passes up to 50 cars in one direction. However, it should be borne in mind that Kaidak Bridge has a greater bandwidth than Amur (Fig. 5).

From the left to the right bank, the traffic in the evening is also quite loaded. Amur Bridge is a leader by the number of cars. Up to 17:30 traffic intensity increases to 50 cars (Fig. 6).

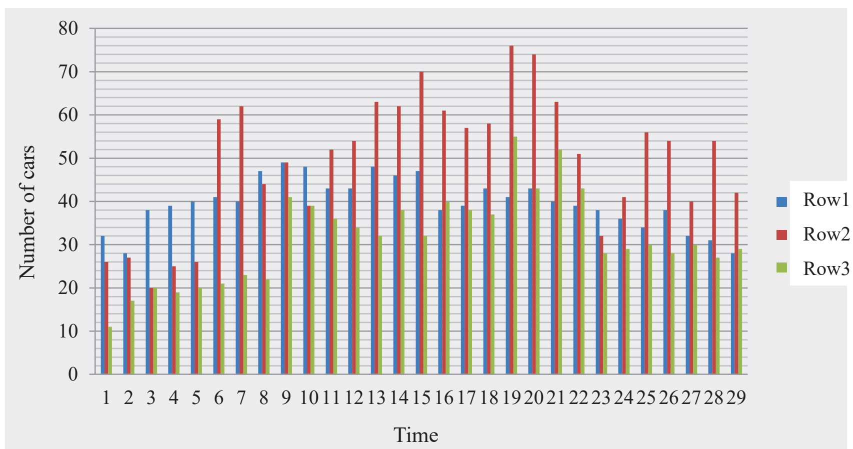

Fig. 3. Intensity of flow in units of morning time from left to right bank along three bridges, measured with an interval of 10 minutes. Starting from 7:00 10 minutes: Row 1 – Kaidak Bridge, Row 2 – Amur Bridge, Row 3 – South Bridge

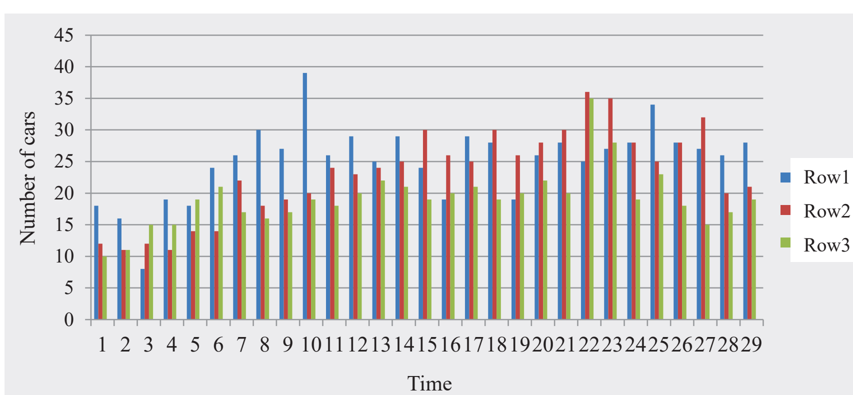

Fig. 4. The flow intensity in units of morning hours from the right to the left bank along three bridges, measured at intervals of 10 minutes. Starting from 7:00 10 minutes: Row 1 – Kaidak Bridge, Row 2 – Amur Bridge, Row 3 – South Bridge

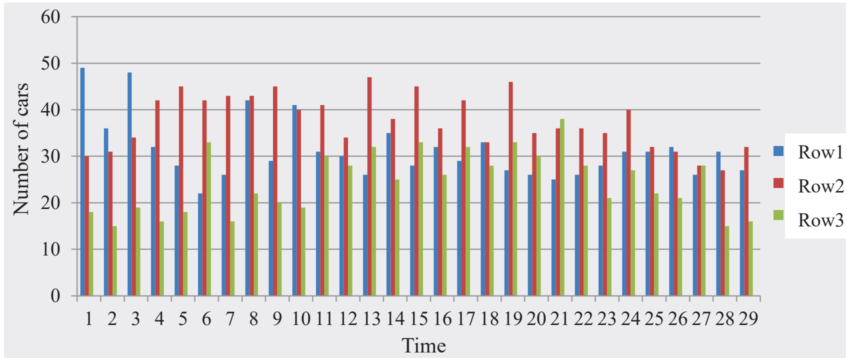

Fig. 5. The intensity of the flow in units in the evening from the left to the right bank along three bridges, measured at intervals of 10 minutes. Starting from 17:00: Row 1 – Kaidak Bridge, Row 2 – Amur Bridge, Row 3 – South Bridge

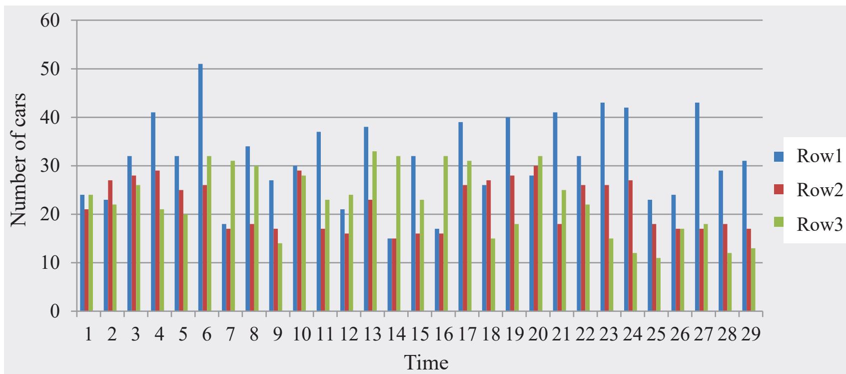

Fig. 6. The intensity of the flow in units in the evening from the right to the left bank along three bridges, measured at intervals of 10 minutes. Starting from 17:00: Row 1 – Kaidak Bridge, Row 2 – Amur Bridge, Row 3 –South Bridge

5.2. Movement on the Amur Bridge. In the morning the traffic on the Amur Bridge is sufficiently loaded. The peak of the intensity of movement falls on the period from 7:30 to 8:00. Currently, the number of cars in the direction to the right bank reaches 75 and more. From 8:00 to 9:30 the average number of cars remains at the level of 65–70. At the same time, traffic on the left bank is much less intensive. From 7:00 to 9:30 the number of cars remains at the level of 20–25 cars (Fig. 7).

Amur Bridge remains the busiest in the evening. On the right bank, on average, 75 cars are moving. The intensity of movement is variable. 50 cars are moving to the left bank (Fig. 8).

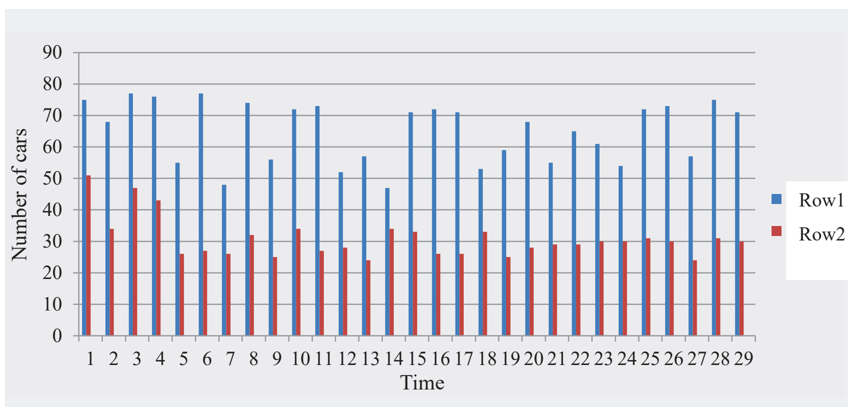

Fig. 8. The intensity of the flow in units in evening time on the Amur Bridge, measured at intervals of 10 minutes. Starting from 17:00: Row 1 – from right to left bank, row 2 – from left to right bank

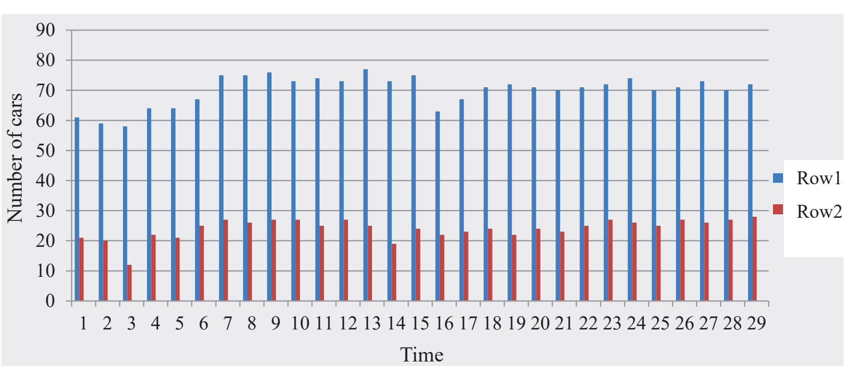

Fig. 7. The intensity of the flow in units in morning time on the Amur Bridge, measured at intervals of 10 minutes. Starting from 7:00: Row 1 – from right to left bank, row 2 – from left to right bank

So, from the obtained statistics, it can be seen that the Amur Bridge is an overload during peak hours, which increase in proportion to the length of traffic jams. On the other hand, it is difficult to enter the bridge from the right bank and it needs to be modernized.

6. Research results

6.1. Development of a traffic flow model in a given area. Modeling takes place at the site of arrival at the Amur Bridge from Pasteur Street, Vokzalna

Street, as well as from the bus stop of the urban and suburban transport.

To build a model, find out the details of the simulation. Let's start with traffic restrictions set on the road. From January 1, 2018, the speed within the city is limited to 50 km/h. Also note that traffic on Pasteur Street is limited to 40 km/h by a road sign. On Pasteur Street there is a sign for the main road, and therefore Vokzalna Street is secondary and car drivers from Pasteur Street have an advantage in the race on the bridge. As in front of the drivers, follow the road from the suburban bus station.

After analyzing the data are given in Table 1 it is possible to say that about 20 units of public road transport are sent along different routes from the Staromostova Square, each of which has its own traffic interval. On average, with an interval of 10–15 minutes, about 14 cars are sent along different routes. So about 70 units of public transport will depart from the stop in one hour.

The traffic intensity on the streets will be taken as «rate», that is, cars are generated at a specified arrival speed (which is equivalent to an exponentially distributed arrival time with an average value = 1/speed).

Restrictions on the length of the car will take the following: for public transport and small trucks – 7–8 m, for passenger 5–6 m. The intensity of the flow of transport can be set in various ways: according to the arrival interval, the number of units for a period of time, according to the route, etc. Building a model in the Any Logic environment is as follows, shown in Fig. 9.

By launching the model and tracing the movement of traffic, one can see traffic congestions in a narrow part of the road, namely, at the narrowing of the paths before entering the bridge. Due to the modeling and clarity, the problem place of the road was determined. Due to the accumulation in that zone, it is also possible to observe a delay in the intersection of the intersection.

Table 2 presents the results of the experiment. Judging by the given conditions, 884 cars enter the bridge in 1 hour, and the intersection crosses a total of 1590 cars. At the intensity that was set, there is an accumulation of cars. The average speed at which the car crosses the intersection is 32.22 s, the minimum is 7.62 s, and the maximum is 9 min 47 s.

Table 2

The results of observations in 1 hour

Flow number	Road number			Type of car	Number of cars at the exit	Number of cars at the exit
	Appearance	Motion	Disappearance			
CarSourse	0	1.5	5	passenger car	1600/h	442
CarSourse 1	3	1.5	5	passenger car	1000/h	294
CarSourse 2	0	1.5	5	cargo	100/h	64
CarSourse 3	3	1.5	5	cargo	50/h	45
CarSourse 4	4	5	5	bus	50/h	39
CarSourse 5	0	2	2	passenger car	500/min	270
CarSourse 6	0	3	3	passenger car	500/min	268
CarSourse 7	3	2	2	passenger car	500/min	170

At the time of the greatest accumulation of cars at the intersection of the vehicle, which moves from the Vokzalna Street, spends 2 min 36 s on the ride on the bridge from the moment of departure to the intersection. Vehicle moving from the Pasteur Street spends 1 min 58 sec. Transport, which departs from the stop – 2 min 28 seconds.

6.2. Development of a traffic flow model with traffic light regulation. Let's build a model in which traffic light regulation is installed.

A traffic light will be installed at the intersection of Vokzalna and Pasteur streets. Arriving at the transport bridge from the stop will not be regulated by a traffic light.

Table 3 shows the modes of operation of the traffic light, the results are presented in the hour of observations.

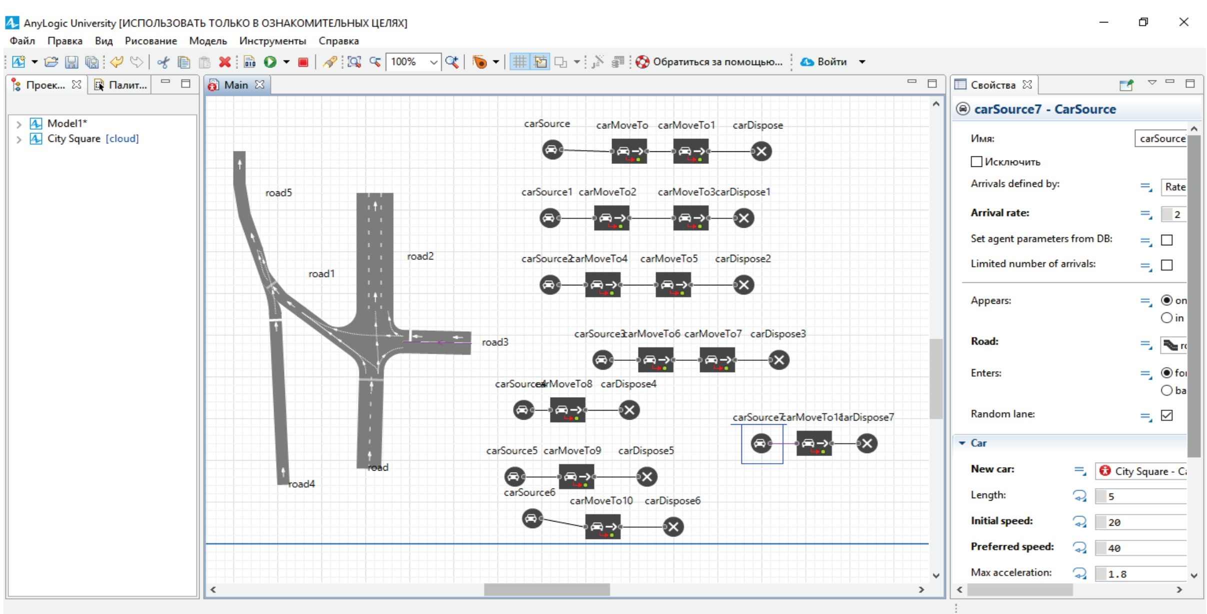

Fig. 9. Appearance of building a model

Table 3

Modes of operation of the traffic light

	Duration, s / Stop lines					Total number of cars	Number of cars on the bridge	Average speed, m/s
1	Duration, s	20	5	45	5			
	0	r	y	g	y	1134	643	32,7
	3	g	y	r	y			
2	Duration, s	20	5	60	5	0	0	0
	0	r	y	g	y	1128	617	32.4
	3	g	y	r	y			
3	Duration, s	30	5	60	5	0	0	0
	0	r	y	g	y	1135	660	32.6
	3	g	y	r	y			

Note: the letter «r» denotes the red color of the traffic light, «y» – yellow, «g» – green

At the time of the greatest accumulation of cars at the intersection of paths in the mode of operation of the traffic light number 3 vehicle, which moves from the Vokzalna Street, spends 1 min 8 s to hit the bridge from the moment of departure at the intersection, provided that the vehicle is the first at the traffic lights at the time of switching from the permissive signal to the prohibitory. Vehicle moving from the Pasteur Street spends from 40 to 50 seconds under the precondition. In order to choose the optimal mode of operation of the traffic light, it is necessary to conduct an experiment and introduce conditions and restrictions for modeling (Fig. 10).

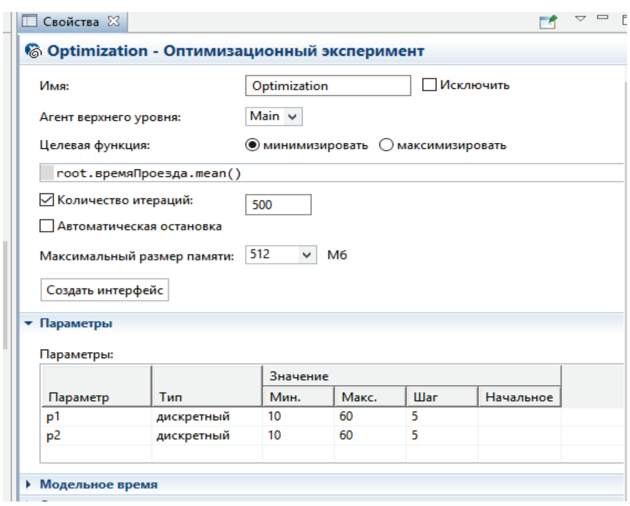

Fig. 10. Conditions for the formation of the optimization experiment

According to the results of the experiment, it is revealed that the best mode would be if the first traffic light would operate in a permit mode of 55 s, and the other – 10 s.

Having established the working conditions of the traffic light and analyzing the flow behavior, it is possible to note the following:

1. The total number of cars crossed the intersection – 1140, the number of cars that drove the bridge – 610.
2. The average time of intersection duration – 31 s, the minimum – 7.62 s, maximum – 2 min 35 s.

Having built two models of the intersection at the entrance to the Amur bridge, it is possible to see that with an arbitrarily set intensity of cars arriving at the intersection and at the actual ride to the bridge, where the road narrows to one lane, a traffic jam will occur and the traffic flow will decrease. From the first model it can be seen that when crossing the intersection and hitting the car on the bridge, it varies from 2 to 3 minutes. In addition, cars move from the Vokzalna Street should skip the flow from the Pasteur Street, thus spending more time in order to break into the general flow. According to the results of calculations carried out in the program, it turned out that about 884 drives into the bridge.

Another model involved the settlement of traffic at the intersection by establishing a traffic light. As a result, a reduction in the intersection time and the formation of a traffic jam was achieved. Since the flow from the Vokzalna Street is not so intense, then the resolving signal of the traffic light is less durable. Also, due to this, the transport of urban and suburban transport can be squeezed into the general flow with less obstacles. The duration of the crossing was reduced to 1–1.5 minutes. The maximum intersection time of the intersection was reduced from almost 10 minutes to almost 3. The best mode of operation of the traffic light was found thanks to the optimization experiment in Any Logic.

7. SWOT analysis of research results

Strengths. The task of modeling was analysis of the real situation in the selected section of the overpass and selection of the optimal method of traffic control. The task of such a simulation was caused by the repair of the New Bridge and the redirection of all personal transport vehicles to other sections of the Dnipro River, in particular, on the Amur bridge.

Having built two models for crossing the intersection of the Amur Bridge, it became clear that with an arbitrarily given intensity of cars arriving at the intersection and at the bridge itself, where the road narrows to one lane, a traffic jam occurs and the traffic speed decreases. From the first model it can be seen that when crossing the intersection and getting cars on the bridge varies from 2 to 3 minutes. In addition, cars that move from the Vokzalna Street should skip the flow from the Pasteur Street, thus spending more time in order to break into the general flow. According to the results of the calculations carried out in the program, it turned out that about 884 cars enter the bridge.

Another model involves the regulation of traffic at the intersection through the establishment of a traffic light. As a result, a reduction in the intersection time of the intersection and the organized opposition to the formation of a traffic jam were achieved. Since the flow from the Vokzalna Street is not so intense, then the resolving signal of the traffic light is less durable. Also, thanks to this, the transport stops of urban and suburban transport can be squeezed into the general stream with fewer obstacles. The duration of the crossing was reduced to 1–1.5 minutes. The maximum intersection time of the intersection has been reduced from almost 10 minutes to almost 3. The best mode of operation of the traffic light was found thanks to the optimization experiment in Any Logic.

Weaknesses. However, the simulation results have a local positive effect on the system of movement around the bridge. Some elements of the flow of transport interact with the flow from the bridge, moreover, the interaction of traffic and pedestrian traffic, which affects stochastic traffic, is very complex.

Opportunities. Hence, there are tasks to modernize the existing model, namely the inclusion in the model of flows with feedback, the inclusion of pedestrian flows for consideration and the extension of the radius of accounting for surrounding traffic flows. The gradual introduction of simulation results can improve the transport situation on the Amur Bridge at low financial costs compared with reconfiguring the route grid or rebuilding overpasses.

Threats. When introducing research results, there are two main threats. The first is the slow response of the city utilities, both to the problem as a whole and to proposals for its solution. This is due to the problems of financing, interaction and formal procedures for the design of projects. The second is the variability of the environment, namely changes in timetables for passenger transport, changes in pedestrian traffic, and rules of travel. Both threats lead to aging of the model settings.

8. Conclusions

1. Field studies of traffic flows affecting traffic on the bridge were carried out, and statistical data were collected. It is identified that:

– the intensity of the flow in the morning from the left to the right bank of the three bridges;
– the intensity of the flow in the evening from the left to the right bank along three bridges;
– the intensity of the flow in the morning from the right to the left bank along three bridges;
– the intensity of the flow in the evening from the right to the left bank along three bridges;
– intensity of flow in the morning from the right to the left bank along the Amur bridge;
– the intensity of flow in the evening from the right to the left bank along the Amur bridge.

2. A model of traffic flows in the AnyLogic environment has been built and the problematic place of the road has been identified, namely, a part of the Pasteur Street from Yavornitsky Avenue to Staromostova Square. The model is based on statistical data from field studies and is a set of active agents whose behavior is adjusted. It was proposed to introduce a traffic light regulation and a comparative computational experiment was conducted in which the functioning of the nobility system was compared without adjustment and with adjustment. It was determined that the presence of even one traffic light significantly reduces traffic congestion at the entrance to the bridge.

3. The model was optimized according to the criterion of minimizing the length of traffic jams due to the selection of traffic light operation modes. As a result, the average duration of the intersection at the entrance to the bridge was reduced to 1–1.5 minutes. The maximum intersection time has been reduced from almost 10 minutes to almost 3 minutes.

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