

# Application of Visualization Tools for Optimization Problems of the Transport Model

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## **Abstract**

The article discusses the combination of problems of transport system simulation and the visualization of the results of the optimization experiment. Simulation is widely used in logistics and supply chains, healthcare, transport, warehouse and transportation management, finance, business processes, service systems, railways, strategic planning and management. The paper discusses the solution to the optimisation problem for management of the intersection of roads of the megalopolis transport network taking advantage of one of the AnyLogic simulation tools. The AnyLogic development environment uses an object-oriented approach that helps in the organization and presentation of complex systems. Built-in animation tools make it easy to visualize the simulation model, as well as interpretation of the behavior of complex systems. The manuscript describes the visualization of the construction of an intersection and solving the problem of calculating the optimal duration of traffic light phases using an optimization experiment.

**Keywords:** Experiment visualization, simulation modeling, transport, transport system, simulation tool, intersection, road, traffic light, optimal duration, optimization experiment.

## **1. Introduction**

Currently, digital modeling of the studied objects is an integral part of the research. Here modeling is a method of studying objects of cognition with the help of their mathematical description, a way of constructing and studying real-world phenomena and concentrated objects based on mathematical formulas. It can be attributed to one of the general scientific methods of cognition, along with observation, measurement, experiment and comparison.

Simulation is often a convenient solution to practical problems [1-6]. The construction of various models is used in situations where experiments with real systems are impossible or unreasonable, for example, due to the duration of the experiment in full time or high cost [1-7].

The process consists in the development and execution on a computer of a software system that reflects the structure and functioning of the simulated object or phenomenon in time [6-9].

The computer simulation of a system is usually understood as the reproduction and study of another object, similar to the original, in a form convenient for research, and the transfer of the obtained information to the object being modeled.

There are several well-established simulation approaches: system dynamics method; discrete-event method; agent-based modeling method.

The method of system dynamics targets creation of accurate computer models of complex systems in order to design a more effective organization and policy of relationships with this system [10].

System-dynamic models are used in long-term, strategic models and take a high level of abstraction. People, products, events and other discrete elements are represented in the models of system dynamics not as individual elements, but as a system as a whole.

If individual elements of the model are important, then an agent-based or discrete-event modeling is used for full or partial processing of the model.

The discrete-event method (process-oriented) allows abstracting from the continuous nature of phenomena and considering only some "important moments" ("events") in the life of the simulated system. The approach to the construction of simulation models, which suggests approximating real processes with such events, is called "discrete-event" modeling.

In this method, the functioning of the system is represented as a chronological sequence of events. The event occurs at a certain point in time and marks a change in the state of the system. Using this method, queuing systems can be investigated [10].

The agent modeling method explores the behavior of decentralized agents and how such behavior determines the behavior of the entire system as a whole. Unlike system dynamics, the analyst determines the behavior of agents at the individual level, and global behavior arises as a result of the activity of many agents (bottom-up modeling). The agent model is a series of interacting active objects that reflect objects and relationships in the real world, simplify the understanding and management of complex social and business processes.

The highway network (road network) is a complex, large-scale system that is designed to ensure year-round safe traffic [11]. The road network is the basis for the functioning of the economy and society through the movement of people, goods and services. Today we can say about the existing imbalance between the demand in the transport industry and the supply in it. Traffic flows in large cities reach their limits, and the capacity of roads decreases [12, 13].

The task of effective traffic management is becoming more actual every year. The constant growth in the number of cars and the volume of traffic requires the improvement of methods and algorithms for traffic control. Such improvement becomes possible due to the ubiquity of global navigation and positioning systems [14].

The efficiency of the transport system is influenced by external and internal factors. External factors include the growing level of motorization of the population and the development of transport networks. Let's list the internal factors: optimization of urban transport routes; optimization of traffic flows on urban roads; improvement of interaction between vehicles and pedestrians [15]. The interaction of cars and pedestrians is controlled by pedestrian crossings and traffic lights on the roads.

The visual analysis deals with development of a visualization pipeline that allows you to present the data in a visual form [16].

Our paper is devoted to the problem of optimizing intersection management based on changing the phases of traffic lights. Quantitative and calculated indicators are usually used to assess the effectiveness of solving the task. In our case, such indicators as the number of transport units in different directions, the number of pedestrians, average speed of traffic, the mode of operation of traffic lights are suitable [13].

Visualization helps to visually evaluate such indicators and can save you from the procedure of additional calculations.

We formulate criteria for the effectiveness of such tools by comparing them to existing approaches [17-20]. Firstly, visualization tools allow choosing the optimal mode of operation of traffic lights without statistical processing of graphs that represent the cars and pedestrians dynamics. Secondly, compared to mathematical programming methods the based on simulation visual analysis allows solving the problem of optimizing traffic control at an intersection without strict formal restrictions and allows optimization by several indicators (parameters). Finally, by applying the visualization of the traffic model at the intersection, the analyst can quickly and visually assess the ability of the intersection to skip the maximum flows of cars and pedestrians, as well as the spatial efficiency of the intersection.

In addition, visualization is very important for a clear and understandable display of the dynamics of changes in the parameters of the model or system over time. Usually, simple

two-dimensional visual images are used in this case: graphs, charts, histograms. But we are faced with the task of multi-criteria optimization of a multicomponent transport model in dynamics, and then visual interpretation of the results obtained. Our experiments can lead to a significant increase in the amount of data on the management of the intersection, complicating their structure. As a result, it may turn out that the sources of information will become complex in structure. Therefore, the tasks of optimizing the transport model require new tools that allow combining visualization and analysis of multidimensional, multicomponent and structurally complex data on the situation and events at the intersection. The AnyLogic development environment provides such tools. AnyLogic visualization tools can be used in various fields where it is necessary to visualize the dynamics of multidimensional data for traffic control at an intersection [5, 21, 22].

The visual analysis based on the simulation helps a person to make an optimization decision on the management of the intersection without additional calculations and statistical data processing.

The object of optimization of the transport network of a megalopolis can be an intersection or a network of intersections [2, 23-25].

This paper sets the task of modeling the load on the intersection of four roads. Each of the roads contains several lanes (rows), cars move in both directions. Traffic lights ensure the passage of cars on both roads, including left and right turns of cars, as well as pedestrians crossing these roads. Each phase of the traffic light lasts a certain number of seconds.

The simulation is used to study the nature of congestion that occurs at the intersection of highways and their resolution, depending on the density of traffic flows and modes of operation of traffic lights. Cars should appear at the ends of each of the roads randomly, drive along them at the speed set when they appear, slowing down and stopping, if necessary, at the intersection, and disappearing after driving the entire road at its opposite end.

The purpose of the simulation is to study various modes of operation of traffic lights and search for their optimal operation mode. The results of such modeling are important, since unsuccessful management leads to an undesirable effect of traffic jams on the road, when the flow of traffic entering the intersection cannot overcome it.

## **2. An approach to data visualization in transport model optimization problems**

To achieve this goal, the authors propose to use simulation and visualization tools for modelling the movement of objects of the AnyLogic development environment [1, 2], which provides a multi-agent modeling approach.

Using the tools of the AnyLogic software system to solve the problem of optimizing intersection management, visual images of the intersection, roads, pedestrians, cars, traffic lights were created, properties and parameters of roads, movement of cars and pedestrians on roads, switching phases of traffic lights were configured. The tools of the AnyLogic development environment provided visualization of the logic of the intersection model in the road network, the process of traffic, rules and restrictions for traffic participants, actions when changing the phases of traffic lights.

We believe that the simulation tools of the AnyLogic development environment allow us to offer a new visual approach to solving the problems of multi-criteria optimization of the transport model based on visualization of the results of traffic control experiments with many participants.

In the tasks of optimizing the management of the intersection of the transport system, it is important to consider the different actions of all participants, especially when changing the phases of traffic lights, which is very difficult to perform when using methods of mathematical programming [17, 19, 20] and statistical data processing [26, 27]. And visualization with the help of the AnyLogic software system provides the decision-maker with various actions and operations on objects of the certain transport network. At the same time,

the person will see a clear picture that changes depending on his actions and operations with roads, cars, pedestrians, traffic lights. In addition, AnyLogic tools provide additional information by visually presenting two-dimensional graphs for various traffic characteristics such as the number of cars on the roads, the number of stops per car, the average speed of car traffic, and so on.

With the help of AnyLogic visualization tools, the optimization results can be presented in a form that ensures the effectiveness of the tasks of management of the intersection of roads of the megalopolis transport network. This form is commonly called data visualization [28]. This form allows researchers to distill large data sets into visual graphics and thus provide an understanding of the complex relationships within the data. Visualization tools, in contrast to the usual graphical interface, provide: brevity (the ability to simultaneously display a large number of different types of data); relativity and proximity (the ability to show clusters in the query results, the relative sizes of groups, the similarity and difference of groups, drop-down values). The main purpose of visualization is to simplify and speed up the perception of information. The chosen format should contribute to this, not hinder it.

AnyLogic tools allow performing visual data analysis in the tasks of optimizing the transport model of the intersection. Visual data analysis helps a person to interact directly with the results of the study, to create conclusions based on a descriptive representation of the data, to understand their essence [29].

Compared to the approaches of data mining [29] and statistical data processing [26, 27], visual analysis is intuitive and does not require complex mathematical or statistical algorithms for processing experimental results. Therefore, the use of visualization can give a better result than statistical and automatic methods of data analysis [29].

The AnyLogic development environment consists of many libraries for process modeling [1, 2]. In particular, it is possible to simulate road traffic [2, 23, 24, 30]. The traffic library is used to solve our optimization problem.

## **2.1. Visualization of traffic at intersections using the AnyLogic development environment**

The following blocks were used for visualization: Car Source – creating cars; Car Move To –controlling the movement of cars; Car Dispose – removing cars from the model; Traffic Light – traffic light model; Road Network Descriptor –managing all vehicles located in the same road network; Ped Source – creating pedestrians; Ped Go To – mandatory transition pedestrians to a given place in the simulated space; Ped Sink – removal of pedestrians entering the object from the simulated environment; Ped Area Descriptor – description of the area that defines the rules and/or sets limits on the speed of walkers.

The proposed model consists of three components: 1) spatial representation of the intersection; 2) traffic light signal control system; 3) behavior of car drivers. Multi-agent modeling technology is used to build the model.

The default model has one agent type, Main, and a Simulation experiment. Agents are the main building blocks of the AnyLogic model. The Main agent serves as the place where the logic of the model is set: the road network is located here and the traffic is set on the process diagram. You can add a satellite image of the road to the model (Fig. 1). AnyLogic allows you to build roads and other objects (Fig. 2). In the properties panel (Fig. 3), you can configure the road parameters: the number of lanes, width and color of the dividing strip.

The process of transport movement is set using diagrams from blocks. Each block specifies a specific operation that will be performed on cars passing through the diagram.

The process diagram in AnyLogic is created by adding library objects from the palette to the graphical diagram, connecting their ports and changing the values of block properties in accordance with the requirements of the model (Fig. 4).

The properties of the car generation unit are shown in Fig. 5.

For the model to work correctly, you need to create its 3D animation. By default, cars are displayed as rectangles. You can set a different shape for cars. To do this, the "Car type" is dragged into the graphic editor. In the dialog box that opens, the "car" type is selected. Next, the Main diagram highlights the Car Source block in the graphical editor; the "Car" section in the Properties panel is opened and Car is selected from the "New Car" drop-down list.

Restrictions have been added to the scheme so that pedestrians do not move randomly on the road. It is possible to conduct experiments on traffic regulation. A snapshot of the animation is shown in Fig. 6. Traffic lights control traffic on all roads.

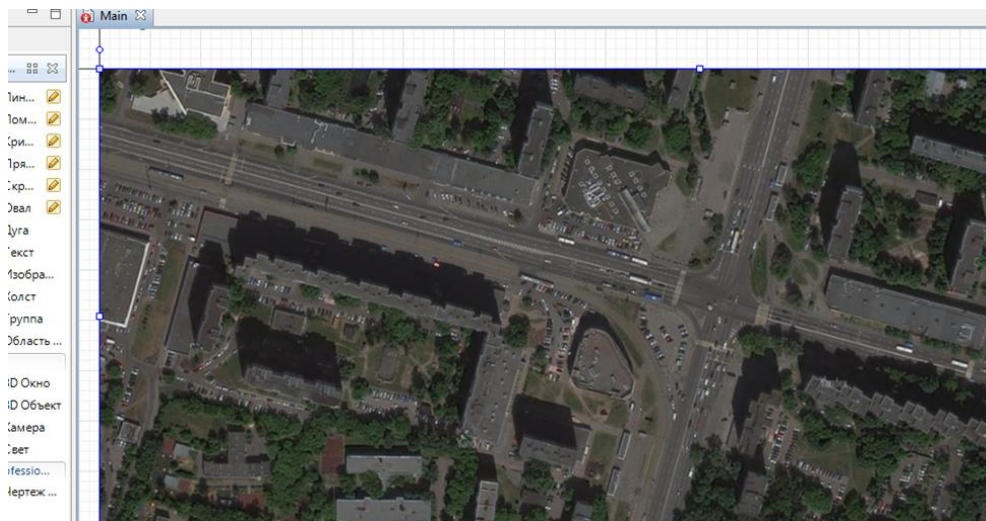


Fig. 1. Image in Main

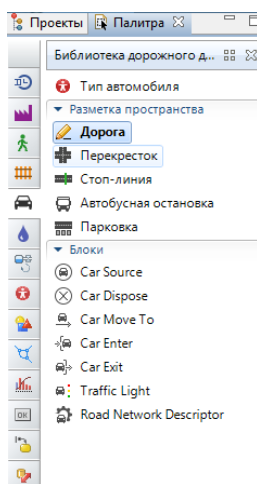


Fig. 2. Available objects

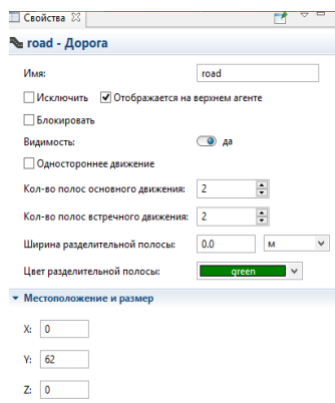


Fig. 3. Road properties

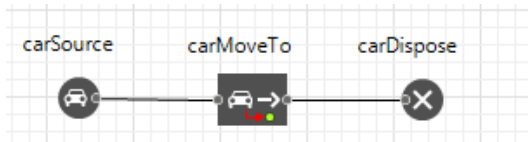


Fig. 4. Blocks for the diagram

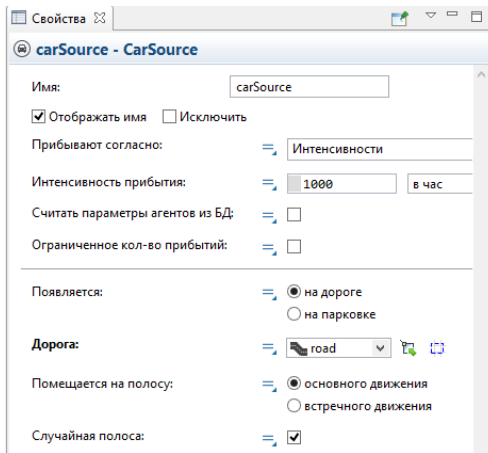


Fig. 5. Properties of the Car Source block



Fig. 6. Animation

## 2.2. Experimental results

### 2.2.1 Results of the first experiment

Four traffic lights control only the movement of pedestrians (pedestrians move in five directions). The results of the AnyLogic software system for the first experiment are shown in Fig. 7-13.

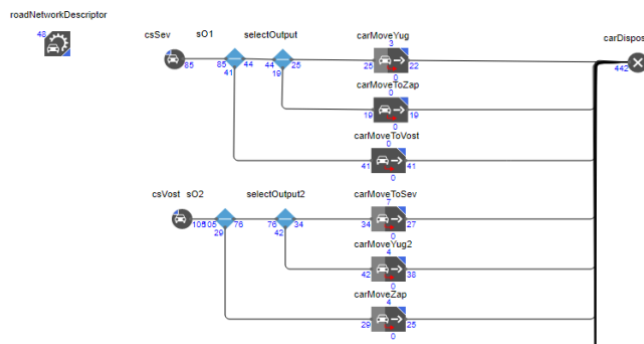


Fig. 7. Data on the movement of cars in the first experiment for the first and second traffic lights

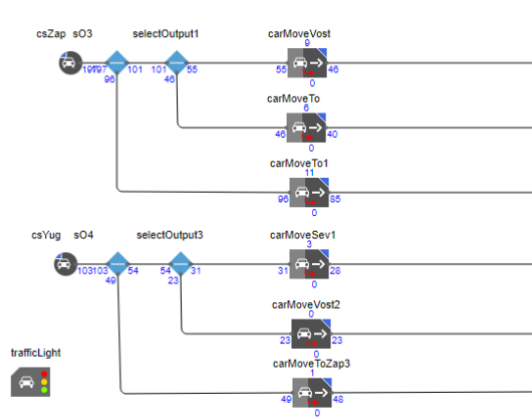


Fig. 8. Data on the movement of cars in the first experiment for the third and fourth traffic lights

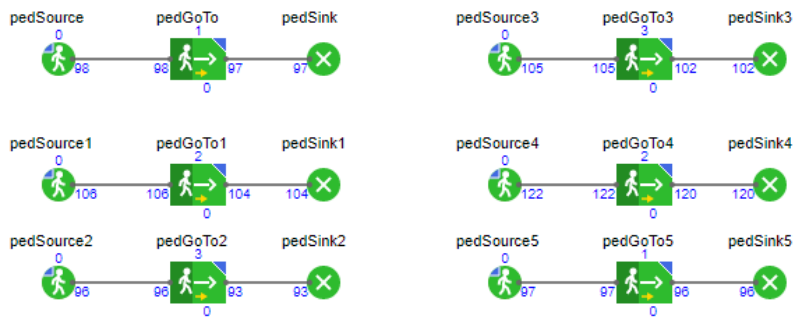


Fig. 9. Pedestrian traffic data in the first experiment

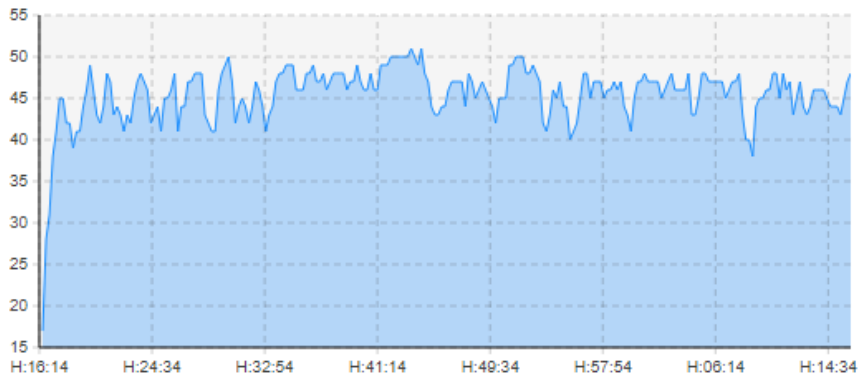


Fig. 10. The number of machines in the system of the first experiment

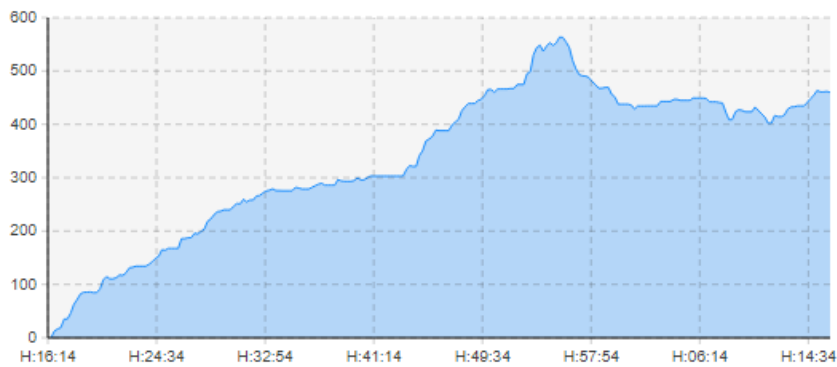


Fig. 11. Average time in the system of the first experiment, seconds



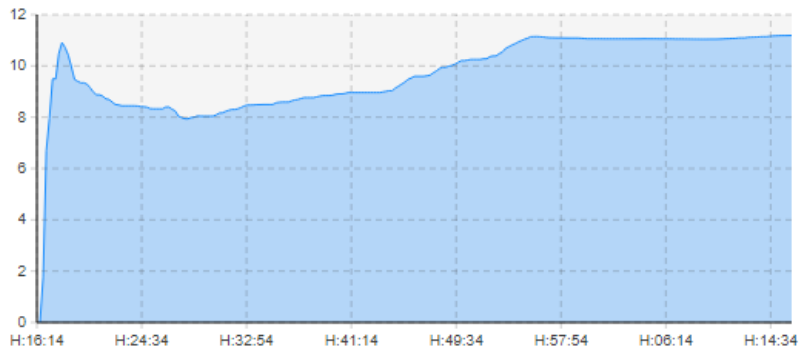


Fig. 12. Number of stops per car in the first experiment

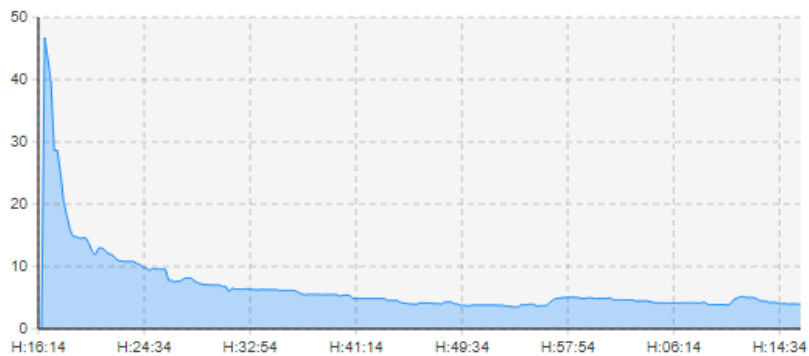


Fig. 13. Average speed in the first experiment, km/h

### 2.2.2 Results of the second experiment

Four traffic lights control traffic on all roads. A snapshot of the phases for one traffic light is shown in Fig. 14. The results of the AnyLogic system for the second experiment are presented in Fig. 15-19.

Фазы:

Длительности, сек:	40	40	40	40	30	3
Стоп-линии:						
stopLine	Green	Red	Red	Red	Red	Yellow
stopLine1	Red	Green	Red	Red	Red	Yellow
stopLine2	Red	Red	Green	Red	Red	Yellow
stopLine3	Red	Red	Red	Green	Red	Yellow

Действия

При смене фазы: `pedAreaDescriptor.setOpen(currentPhaseIndex == 4);`

Fig. 14. Traffic light phases





Fig. 15. Snapshot of the model's operation

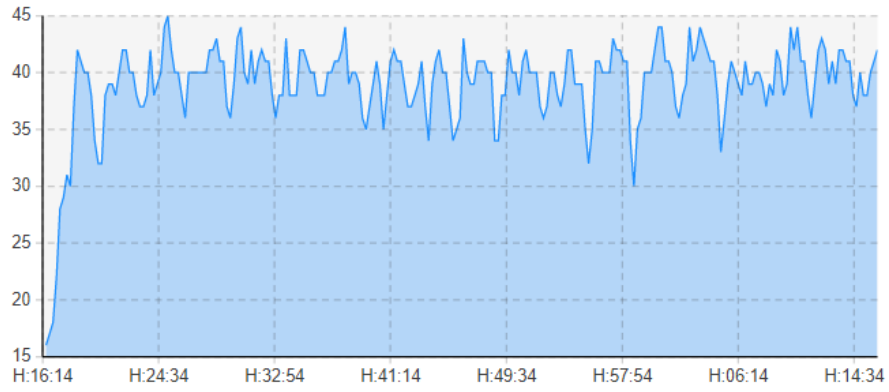


Fig. 16. The number of machines in the system of the second experiment



Fig. 17. Average time in the system of the second experiment, seconds

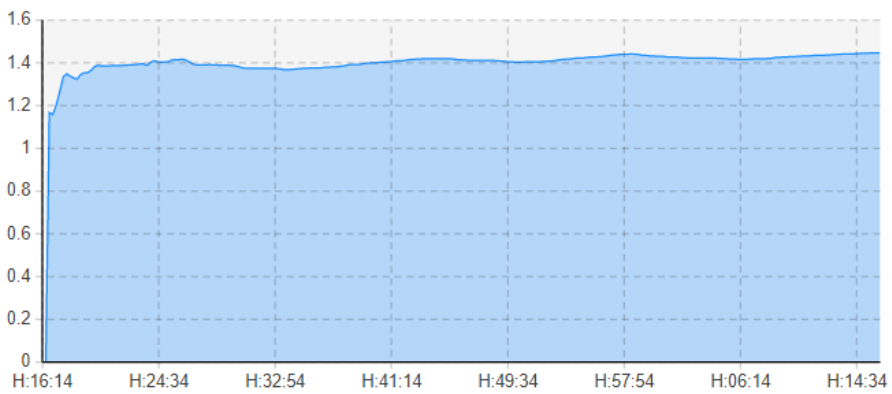


Fig. 18. Number of stops per car in the second experiment



Fig. 19. Average speed in the second experiment, km/h

From the graphs (Fig. 16-19) it can be seen that the average time in the system of the second experiment decreased compared to the first experiment, the number of stops per car also decreased, the average speed increased.

### 2.2.3 Results of the optimization experiment

It is possible to create an optimization experiment in the AnyLogic software system (Fig. 20). The initial data for optimization is shown in Fig. 21. Four parameters have been created: parameter  $p_1$  allows movement on the western road, parameter  $p_2$  – on the northern, parameter  $p_3$  – on the eastern, parameter  $p_4$  – on the southern. These parameters will vary in the range from 5 to 90 during the experiment.

The optimization results are shown in Fig. 22. It follows from the results of the experiment that the best values for the parameters are:  $p_1=65$ ,  $p_2=35$ ,  $p_3=50$ ,  $p_4=20$ . Traffic data is displayed in the form of graphs, which are shown in Fig. 23-26.

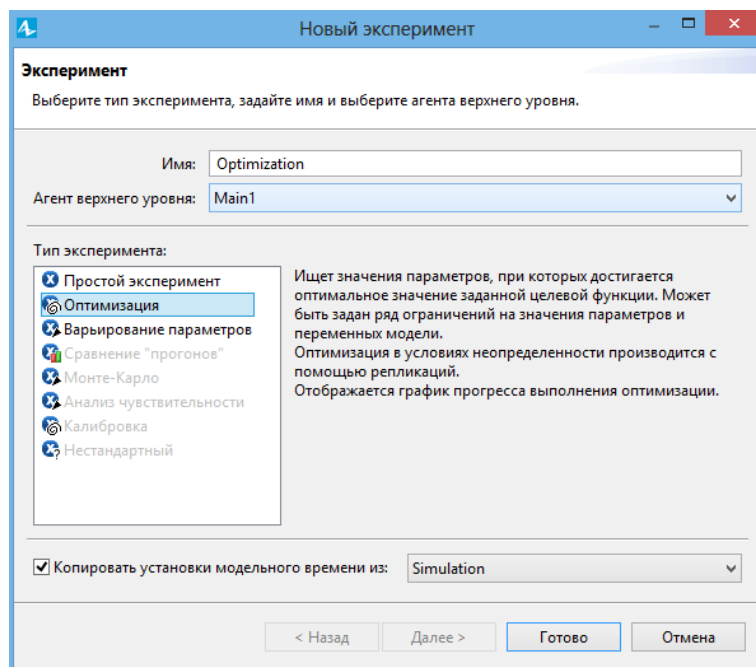


Fig. 20. Selection of an optimization experiment in the Any Logic system

**Optimization - Оптимизационный эксперимент**

Имя: Optimization  Исключить

Агент верхнего уровня: Main1

Целевая функция:  минимизировать  максимизировать

root.TimeInModel.mean()

Количество итераций: 500

Автоматическая остановка

Максимальный размер памяти: 512 M6

Создать интерфейс

**Параметры**

Параметры:

Параметр	Тип	Значение			
		Мин.	Макс.	Шаг	Начальное
p2	дискретный	5	90	5	5
p1	дискретный	5	90	5	5
p3	дискретный	5	90	5	5
p4	дискретный	5	90	5	5

Fig. 21. Input data of the optimization experiment

Car Traffic : Optimization

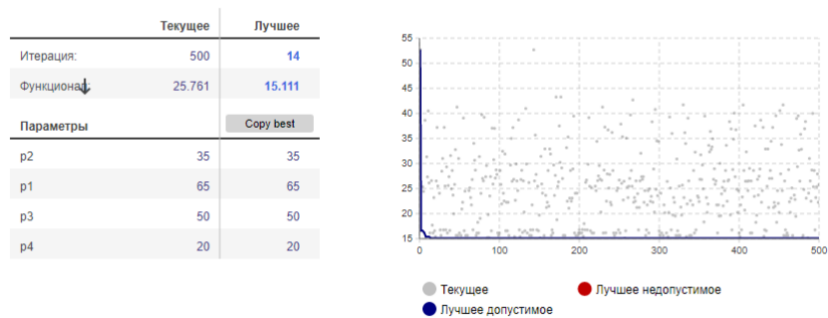


Fig. 22. Output data of the optimization experiment

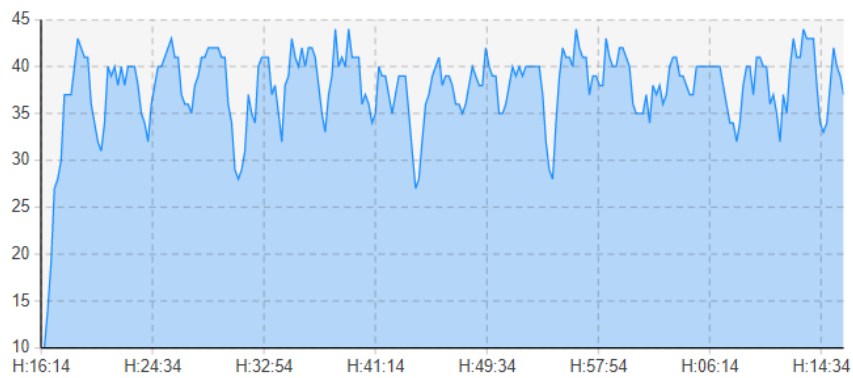


Fig. 23. The number of machines in the system of the optimization experiment



Fig. 24. Average time in the system of the optimization experiment, seconds

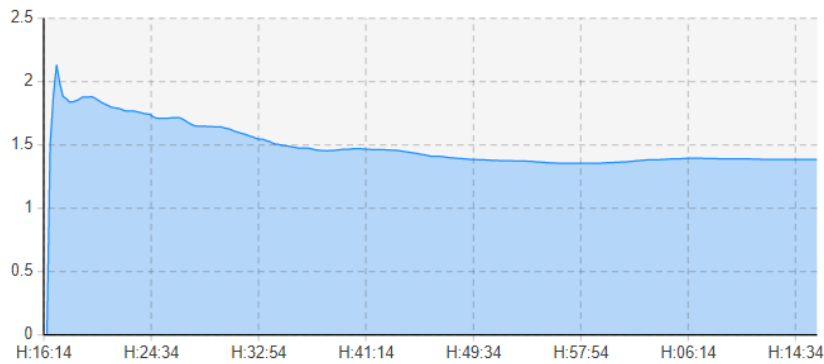


Fig. 25. Number of stops per car in the optimization experiment



Fig. 26. Average speed in the optimization experiment, km/h

### 2.3. Discussion of experiments on visualization of the optimization problem

The concept of optimization can be viewed from different angles. For construction issues, the effectiveness of optimization methods can be expressed by minimizing construction costs. In our experiments, the distribution of traffic flows can be distinguished by the set

$F = \{(c_1, x_1) \cup (c_2, x_2) \cup (c_3, x_3) \cup (c_4, x_4)\}$ , where  $x_1$  – the set of time-varying values of the average speed in km/h,  $x_2$  – the set of time-varying values of the number of stops per car,  $x_3$  – the set of time-varying values of the number of machines,  $x_4$  – the set of multiple values in dynamics of the average time in seconds,  $c_1, c_2, c_3, c_4$  – numerical values of weight coefficients, respectively, of the sets  $x_1, x_2, x_3, x_4$ , and denote  $F$  as an optimization criterion for four sets  $x_1, x_2, x_3, x_4$ . In special cases, you can assign the highest weight to some set. In our three experiments, the weight coefficients were assigned by values  $c_1 = c_2 = c_3 = c_4 = 1$ .

Let's discuss the three described experiments on modeling the loading of the road network. As a result of the optimization (simulation) experiment, the optimal value of the traffic light phases for the intersection was automatically found (see Fig. 22). If the traffic intensity of cars changes, the experiment can be repeated.

The article considers the problem of visualizing the solution to the problem of optimizing the transport network of a megalopolis.

The features of visualization of the simulated data are that it is necessary to look at and try all the variants of the model, and there are an infinite number of them, then choose the best option. These features impose limitations on the use of traditional statistical processing of graphs, since during statistical processing it is necessary to discard the worst and best modeling results. And among the discarded results, there may be just the most suitable one for managing a specific intersection or intersections. Therefore, it is necessary to create and use new tools for simulation modeling of transport systems, visualization and visual analysis of the results of optimizing the management of the intersection of roads of the transport network. Such tools clearly and quickly show the result of optimization, allow making

decisions about changing the control of traffic light phases sooner. At the same time, all possible solutions are analyzed, including the best and worst, as opposed to statistical processing.

Visualization allows in real time see and visually, directly, analyze the impact of such indicators on traffic at the intersection. Without visualization, it would be necessary to obtain calculated values of indicators based on statistical processing of experimental results. In the case of analytical or numerical analysis, we would have to switch to dimensionless parameters, which is quite a difficult problem. In visual analysis, the transition to a dimensionless task is not required. We believe that simulation modeling tools and visualization tools built into them are the basis for optimizing traffic control at the intersection. Visualization and visual analysis make the results of optimizing intersection management clear and visual to the decision-maker.

To test the effectiveness of the proposed approach to solving the optimization problem using AnyLogic visualization tools, a number of experiments were conducted in the author's modeling environment. The average speed, the number of stops per car, the number of cars, and the average time were used as performance indicators. As a result, our approach has shown good results, providing a higher throughput of the intersection by adjusting the phases of traffic lights (10-15% as follows from the comparison of the results of the first and third experiments).

In the presence of intersections with a large flow, traffic lights are often installed. For effective use of traffic lights, it is necessary to optimize the phases of their operation, accounting the directions of movement. To simulate the operation of traffic lights at an intersection, we use the AnyLogic simulation environment. The AnyLogic platform includes various libraries that allow you to build models and optimize their parameters. In AnyLogic, you can set certain restrictions for movement. The user-friendly interface and numerous support tools for model development in AnyLogic make not only the use, but also the creation of computer simulation models in this modeling environment accessible even for beginners. Therefore, the AnyLogic development environment can be used in the educational process to study, for example, information technologies in transport logistics.

### **3. Conclusion**

The article considered the problem of optimization of the transport network. To achieve the task, a simulation model of the transport system was built, including cars moving in different directions, and also the optimization criterion  $F$  is proposed. The paper considers the issues of visualization of the results of an optimization experiment based on the AnyLogic development environment. The optimization experiment showed that it is possible to set the optimal phases of the traffic light cycle with high accuracy and minimal time costs, which will eventually increase the intensity of traffic flows and eliminate the appearance of traffic jams on the road. The results can be used in practice, in the road sector.

This topic has already been covered in science from different angles [10-15, 23-26, 30, 31]. The novelty of our research lies in the fact that a model has been developed that allows, on the basis of visual analysis, without significant financial and time resources, to solve issues of traffic management on the ground, including optimizing traffic management at intersections.

From the comparison of the results of the first and third (optimization) experiments, it follows that after implementation in practice, the capacity of the road network can increase by 10-15% only due to the regulation of traffic light phases. In the book [2, p. 360] it is stated that "...optimization of the management of the company's transport fleet allows you to reduce costs compared to work at the level of experience and intuition by up to 25%."

The use of visualization tools and other AnyLogic tools gives certain advantages: low cost of implementation; visual predictable results; the opportunity to try all the variants of the model and choose the best one.

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