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Interaction of Adjacent Smart Traffic Lights During Traffic Jams at an Intersection

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Abstract: The present paper aims to study based on the movement in the transport system of Almaty, to develop an intelligent adaptive traffic light control system. The relevance of the topic under study has been substantiated. A conceptual scheme for adaptive traffic light control and a module for calculating traffic flow parameters have been developed. This allows to monitor traffic parameters and collect statistics to further improve road safety.

Keywords: Traffic management, Automated road traffic control systems, Computer simulation of vehicle traffic, Urban road intersections, Traffic objects.

1 Introduction

The development of modern digital technologies for the exchange of information and the use of intelligent control systems in the road transport industry have led to a significant change in scientific, technological and practical approaches that organize optimal traffic in densely populated cities. The existing mathematical models of traffic management are built on a deterministic basis. In some developed countries, the idea of reverse traffic, which requires a clear use of the administrative resource of the traffic police and high discipline on the part of car drivers [1]. The previous macroscopic hydrodynamic model that manages transport flows is based on a perfect laminar theory (well-ordered) movement of vehicles. In practice, this approach works up to the first obstacle on a highly loaded highway. Accidents, repairs, flooring and communal machines, which are not predictable in time and space, create additional resistance to the traffic flow, which leads to the so-called “shock wave” of congestion. As a result, the throughput of the highway begins to drop sharply in waves and many kilometers of traffic jams are formed with complete disorganization of traffic. From the perspective of hydrodynamics, the emergence of an additional obstacle (roughness) leads to a complete disorganization of the flow. This movement is called turbulent and its behavior is often difficult to be described mathematically. It is known from hydraulics that flow in different rough pipes is calculated on a semi-empirical basis for each type of pipe. In the microscopic theory of traffic flow control, the flow equations are built on the assumption that the coordinate system is tied to a particle (car) of the flow participant [2]. This approach made it possible to obtain a number of new, more adequate mathematical models of traffic flows. However, in this theory, the probability of an abnormal operation of the car is laid down. In accordance with this, the mathematically expected throughput of the highway is calculated. In practice, the drivers, for example, in the city of Almaty are oriented by background information, geoinformation service 2GIS which in the online mode allows them in case of congestion to find the best detour. An innovative approach is being developed within the framework of the international Smart City Erasmus program, implemented by a group of teachers and researchers from a number of European and Kazakhstan universities. The main idea of the project is to create a convenient, environmentally friendly and transport-optimal smart city. An important component of this project is the reduction of the harmful environmental impact of public and individual vehicles. For private cars and taxis, within the framework of the Erasmus project, studies were carried out to collect the dynamics of geodata in the city using GPS-positioning of

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cars equipped with a device based on the Lo@RA (LongRang) microcircuit. The operating range of this GPS controller is 20 km in open areas and up to 3 km in hilly and wooded terrain.

2 Brief review of the literature

The development of modern digital technologies, information exchange and the use of intelligent control systems in the road transport industry has led to a significant change in scientific, technological and practical approaches that organize optimal traffic in densely populated cities. Highways of large multi-million cities represent a high-tech engineering and communication infrastructure. The main and decisive purpose of urban roads is reliable, safe, environmentally friendly and optimal movement of vehicles from point A to point B [3]. The most complex processes occur at motorway intersections. A radical way to increase the capacity of intersecting roads is the construction of multi-level bridge interchanges. The high cost of these structures leads to the need to install hardware motion control transportation such as traffic lights [4]. Traffic lights, due to the changing time phases of the control signals, make it possible to automatically streamline the maneuvering of vehicles on intersecting road sections. Determination of the scientifically substantiated duration of the phases of the traffic light, for example the green permitting signal, is a complex scientific and technical problem. Research into increasing the capacity of highways was carried out at the dawn of mass motorization in the early twentieth century. In the writings of Mayborod A.E. were generalized and substantiated the prospects for ensuring traffic safety and optimization of road transport, the influence of traffic lights and other technical controls were studied in the works of G.I.Klinkovstein, Han Xu [5,6,7,8,9,10]. Mathematical models of traffic control have been summarized by the Russian scientist Gasnikov A.V. The process of transport model has strongly influenced Patriksson M. They proposed macroscopic model of traffic flows in the different versions and modifications (for example, for a single-band vehicular traffic) [11,12]. These deterministic models were built on the assumption of the absence of traffic jams and complex intersections of highways. In the initial and boundary conditions of the Cauchy differential equations, it was difficult to consider the uneven distribution of traffic flows over daily time cycles. In a modern interpretation, these approaches are highlighted in the works of Popkov Yu.S. [13]. We note the importance of the development of microscopic models for calculating the distribution of vehicles along the length of the highway. Cluster, gas-kinetic models were built considering the uneven distribution of vehicles along the length of the highway, not only in time but also the type of vehicles (trucks, buses, cars). Such calculations are carried out in the complicated gas-kinetic model of Parevi-Fontana [14]. Special attention of transport scientists is paid to modeling and calculations of the impact of vehicles with internal combustion engines on the environment. To predict the distribution fields of air pollution levels in cities with complex environmental conditions, such as the city of Almaty, Gaussian models which use special initial conditions for calculating mobile sources of pollution are proposed. The air quality is considered in the calculations using the traffic flow model in the road canyon [15]. The main drawback in the construction of deterministic mathematical models for the distribution of traffic flows in urban infrastructure is the attempt to find self-similar solutions. Stochastic models also do not practically give valuable results. In this case, the role of traffic lights, the main automatic traffic controller, increases. A smart traffic light with a set of sensors and artificial intelligence can read the number of the car, identify the driver and assess the environmental parameters of the car and the probability of the car driving safely on highways. Such endless possibilities are opened by modern digital technologies in vehicles. The development of digital technologies in road transport and the general traffic is the most important problem of modern Kazakhstan. The existing mathematical models of traffic management are built on a deterministic basis, in which differential equations empirically contain contradictory initial and boundary conditions associated with determining the type of traffic and the capacity of the transport artery for the maximum load. This leads to insufficient traffic capacity in the “rush hours” of one of the traffic lanes, with significant underloading of oncoming traffic lanes [16,17]. Collecting data on the geolocation of certain groups of vehicles in server equipment will allow finding hidden patterns in the dynamics of traffic flows at certain intervals. The use of artificial intelligence, machine learning (ML) and big data (Big Data) is an important, poorly explored area of modern research in the field of traffic management. The creation of new mobile neurophysical traffic light controllers as a collective adaptive IoT device is also a new emerging promising area of application of information technologies in the practice of the general traffic [18,19]. System analysis using simulation and simulation modeling in AnyLogic, VMware Workstation Pro, TIA Portal V13, Logo ! Soft Comfort has shown that the dynamic change in the time phases of the operation of traffic light objects, as collective intelligent IoT devices, allows to change and actively manage the dynamics of traffic flows on the most loaded sections of highways. Local application of simulation in an environment AnyLogic allows for landscape binding highways to the expected stream of cars on the main highway at the entrance/exit in densely populated cities. The disadvantage of this system is the complexity of its integration into the automated control system of road traffic. In development environments VMware Workstation Pro, TIA Portal V 13, Logo ! Soft Comfort has developments in the creation of adaptive self-adjusting digital traffic light controllers based on Siemens microcontrollers in a network design . In the technical literature and practice, there are few examples of creating traffic light controllers as IoT devices. In domestic science and practice, these works are in their infancy. The creation of collective intelligent traffic light controllers integrated with Scada by the ACS RT using advanced simulation of processes in the AnyLogic environment will be a new direction in the digitalization of the country's road traffic. The synthesis of two methods of traffic modeling creates conditions for the fruitful modernization of existing analog control systems for ACS RT. The phased introduction of smart traffic lights as an IoT device will make it possible to design and implement a modern intelligent computer network of smart traffic light objects that will be able to monitor the traffic situation in dynamics and allow the dispatchers to make optimal decisions from the central traffic control panel of the metropolis.

3 Research methods

The modern software and hardware allows to develop and use imitation and simulation methods for modeling road traffic features in the AnyLogic PLE and Arduino IDE programming environment. The designed prototypes of IoT devices and traffic lights with adaptively changing time cyclograms of turning green light on/off to increase the highway throughput depending on the traffic load of the route allow the use of system analysis methods for probabilistic assessment of the adequacy of simulation models to real road traffic processes. Methods of computer technologies allow the creation of networked stationary and mobile digital traffic light objects capable of identifying the traffic situation, calculating the number and speed of traffic flow and transmitting actual data to the adjacent traffic light via computer networks. The method of controlling a digital smart traffic light that has an Internet connection with the server is adaptive with feedback and with a time adjustable compensator. The technique of replacing industrial IoT devices and traffic lights with small-sized prototypes is an important direction of computer modeling, which allows creating and testing a small-sized traffic light model in laboratory conditions. Note that traffic light models are created on the basis of certified industrial microcontrollers of the AVR, ESP 32, LOGO ! 230 RCE and S 7-1200 from Siemens. All of the above microcontrollers are licensed and comply with the certification methods of the metrological services of the Republic of Kazakhstan. Inductance sensors and timers have been verified with the standards and will make it possible to identify a mobile vehicle with an accuracy of 99.98 percent within a radius of 2-3 meters. Software products are represented by licensed versions of Arduino PDE, LOGO! Soft Comfort v 8,TIA Portal v13, VMware Workstation Pro. The calculated data obtained using the listed software and hardware adequately reflects the parameters of the traffic lights controlled by them and reliably transmit the digitized data over Ethernet networks. Correspondence between the operating modes of real traffic lights and calculations based on simulation models is confirmed by experiments, certificates and acts of implementation. The most important method of improving the existing traffic light technology is its modernization. The method of improving the RC-2 road controller does not have great electrical complexity. Figure 26 shows the internal layout of the RC-2 road controller and the external view of the reprogrammable logic controller (RLC) Siemens LOGO! 230RCE. Note that the size of the RC-2, and the length to

Figure 1: Layout of RC-2 and general view of PLC LOGO ! 230 RCE.

DIN - rails allow without significant design changes to fix the rail to the RLC LOGO ! 230 RCE. In fact, an additional relay with the function of reprogramming and data exchange via Ethernet networks will be installed in the RCK-2 frame. An important functionality of new equipment is constantly expanding library of applications and the availability of simulation in the software LOGO ! Soft Comfort. The use of this method makes it possible to improve the traffic light in the IoT device without significant changes in the wiring diagrams.

4 Increase of the congestions

Due to the rapid economic growth of the city of Almaty, the level of motorization has increased by almost 10 percent. In addition, the territory of the city has been increased. Accordingly, issues such as traffic jam hours, a decrease in the average speed on the main and secondary streets, the presence of various points in the city and environmental problems arise. The figure shows a forecast map for the possible load of the main lines during draft. The red color represents the road network that will be traffic congestion. Yellow means city traffic is slower. Green signifies free movement.

Figure 2: Traffic jams are expected to grow by 2023.

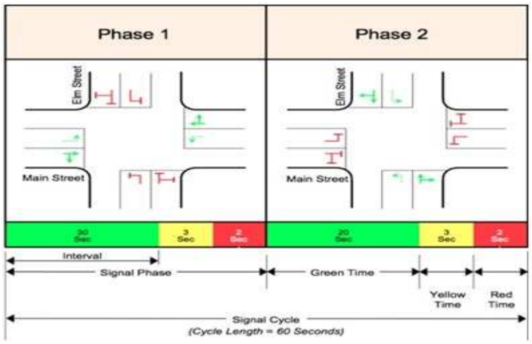

Figure 3: The scheme of the crossroad intersection and the basic concepts of the operation of a traffic light object.

5 Traffic light as a finite automaton for traffic flows control

Traffic light regulation is carried out by state machines. Its the algorithms gradually began to become more complicated by expanding the basic functionality of the traffic light with a number of additional options. For example, flashing green light is more informational than regulatory one. Additional digital displays with a reverse report also increase the information content of traffic lights. Additional displays handle weather conditions and road works. Thus, as technology develops, traffic lights become not just an electronic regulator, but an adaptive "smart" traffic light. To understand the principles of operation of a modern traffic light, we give an example of a crossroad channel for the distribution of two flows of particles (cars) with four regulators (traffic lights) operating in two phases. The first phase allows the particles of the first stream to move straight, right and left; the second phase also allows the particles to move straight, right and left. This is an algorithm for the model of a classic European cross-road intersection. In a number of states and cities of the United States, as well as with manual regulation in the city of Almaty, Nur-Sultan, inscriptions and precedents of turning to the right at a red light began to appear. Additional sections at traffic lights and traffic conditions dictate reforms in the rules of the road, which requires a change in the design of the traffic light itself. Figure 1 shows a diagram of the operation of traffic lights at a crossroad intersection, the basic concepts of the cycle, phase and interval of traffic light operation. The most important parameters of traffic light objects in collective work is the ability, by increasing and decreasing the duration of the green light phase between traffic lights, with the goal of creating a difference in time between turning on the green light at the first traffic light and the second traffic light. Figure 2 shows that a group of cars can cover the path from the first traffic light to the second when the green light is constantly on. Such a scheme for switching on traffic lights is called a "green wave". For example, in the city of Almaty on a number of streets one can get into this "wave" at a speed of about 50 km/h. As one can see, the task of creating, calculating and

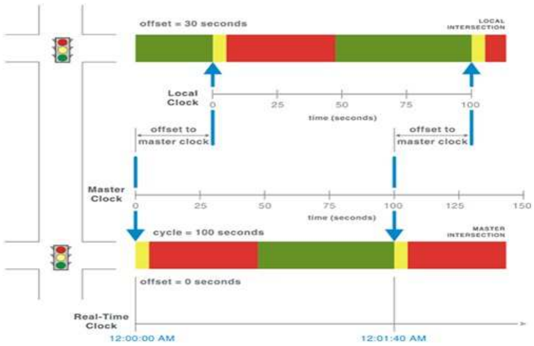

Figure 4: Scheme of collective interaction of two traffic lights and the procedure for calculating the average speed of a group of cars crossing both intersections in the "green wave" mode.

configuring a set of traffic lights operating in the "green wave" mode is difficult and requires a semi-empirical approach. Realities show that it is often impossible for a driver to dynamically tune into the "green wave" while driving on city highways due to a sharp increase/deceleration of the speed of movement, if the phase displacement is a constant value. Currently, in the cities of Almaty and Nur-Sultan , the same technology is used during rush hours with manual regulation of traffic flows on the main highways of these cities by special communication with traffic police, with one difference that the duty traffic controller stands at the crossroads day and night in any weather. Note that in developed foreign countries, a manual regulation system is introduced only in emergency situations. From a technological point of view, this practice of the metropolitan traffic police must be considered flawed.

6 Multistage imitation Anylogic modeling

With the help of simulation modeling we visualize our work. AnyLogic is the only tool that has all the ways and means to do simulation and computation. 3D animation allows the user to explain the result in simple language. In addition, models can be exported as Java applications with a separate full functionality. It can view and run AnyLogic application on any platform without user installation. It is a cutting edge multidimensional modeling technology program with special flexibility features. It also can be used to make optimal decisions in all business cycles, i.e. in all industries: supply chain from logistics to production and market analysis. One tool of the program allows one to save time and money for organizations of various business problems, link models of different sections, improve the exchange of knowledge between departments. Thus, this transport hub was not chosen by chance, but from the principle of an important intersection of traffic flows in the geographical and business center of the city. At the same time, it should be noted that 10-point traffic jams are rarely created on this section of city highways. This intersection is full of traffic light objects. All of them work with additional sections to organize turns to the left from Abai Avenue to Baitursynov Street when moving from west to east and from Abai Avenue to Baitursynov Street to the left when moving from east to west. It is important to note that left turns from Baitursynov Street are prohibited. It is important to have simulation prototypes of traffic light objects of a traffic light microcontroller, which will be considered in the AnyLogic PLE environment. The main functionality of such a traffic light is simulation of the cycles and phases of changing control signals and their interfacing with the traffic on the control object. The simplest traffic light, as mentioned above, has three light round windows, which, according to the traffic light algorithm, light up red, yellow and green. It should be noted that precedents began to appear in Kazakhstan practice, when the inscription “Allowed to turn right at a red light” was put at the intersection. Hence, it follows that red light is not always a traffic-inhibiting light. Green light is a light allowing movement, green light blinking refers to an information message about the imminent turning off of the yellow light and cannot be interpreted as a prohibiting light. When switching from “red” to “yellow”, the yellow light is strictly regulated as a light prohibiting movement and is of an informational nature about the imminent inclusion of the green permitting light. The transition of permissive green light to “yellow” is also not unambiguously interpreted in the practice of the traffic police. If the car at that moment turned out to be at an intersection (behind the traffic light line), then the driver has the right to continue his maneuver with the aim of clearing the intersection. In the simulation model, these nuances of real traffic are not incorporated into the algorithms of the application. Traffic light model construction can be conventionally divided into two sections: agent-based and presentation parts. It is known that making a left turn using the penetration method is a difficult and very dangerous maneuver, which often leads to accident situations. Figure 5 shows a diagram of this maneuver. As one can see, the green car needs to accurately calculate the moment in time that it is safe to enter the gap between the red and white cars. On Abai Avenue, large gaps between cars occur very rarely, since this highway during working hours is one of the busiest highways in the city of Almaty. In addition, the complexity of this maneuver at the intersection of Abai Avenue and Baitursynov Street is associated with multi-lane oncoming traffic, so traffic lights with additional sections for the left turn were installed. It should be noted that the retrofitting of the additional section of the analogue traffic light controller requires significant financial investments, which are not enough in the city of Almaty. An additional section of the traffic light allows to close the traffic in the oncoming lane for 15-20 seconds, which allows buses, trolleybuses and cars to make a safe left turn. As mentioned above, a state machine in the form of a standard traffic light is designed in the AnyLogic PLE environment in the form of a cyclic agent structure that controls the state of four variables of a logical type using time transitions configured for traffic light cycles. To expand the functionality of a standard traffic light, select a graphical image of the state and make changes to the items “Action on entry” and “Action on

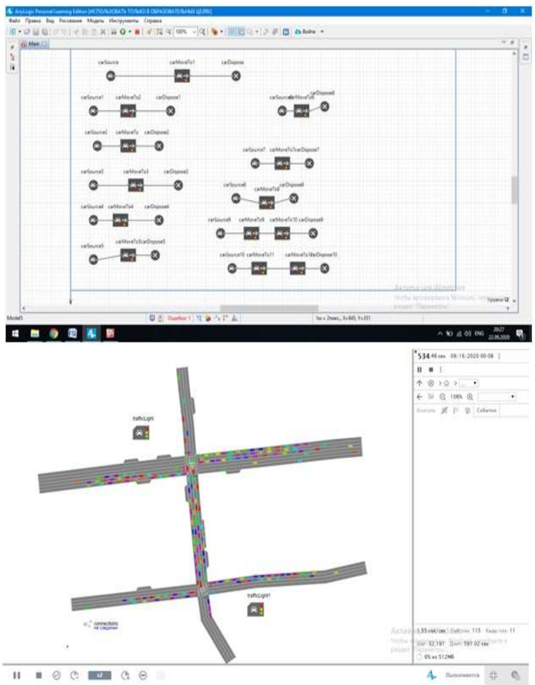

Figure 5: Logics of the model created on the basis AnyLogic.

Figure 6: Splash screen of the initial loading of the project and the main menu in the AnyLogic PLE environment.

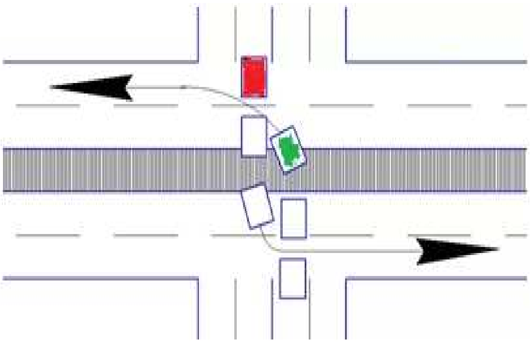

Figure 7: Diagram of a left turn at an intersection using the penetration method.

exit" as shown in Figure 6. To make a presentation with animation on a graphic screen, you need to perform a number of operations. In the palette, select the Presentation item, then select the oval as a graphic image of the traffic light and set the dynamic mode as shown in Figure 9. After completing all technological operations to set up the simulation system, a dynamic picture of changing traffic light control modes will appear on the graphic screen (see Figure 10)

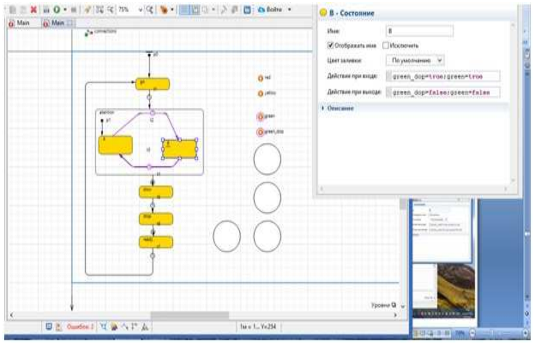

Figure 8: Screenshot of the screen with the code of the traffic light control program with additional section.

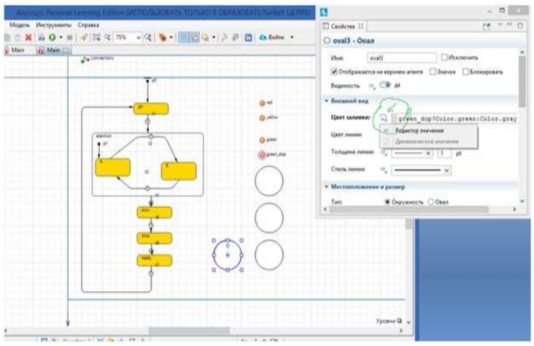

Figure 9: Setting the dynamic mode of presentation animation in the AnyLogic PLE environment.

7 Traffic model to motion control

It is required to develop a finite state machine that simulates the operation of a traffic light that controls the movement of vehicles. To build a state machine, you need to create an AnyLogic statechart using the tools of the "Statechart" palette.

To make the name of the transition displayed on the diagram, you need to set its "Display name" property to the active state. One can achieve the desired position of the transition name on the diagram after selecting the transition line with the mouse as well as grabbing the transition name and dragging it to the desired position. Here is the link damping coefficient. Explore how the link performance is affected by changes in parameters such as gain, time constant and damping factor as they change in the ranges: Take the following initial values:Set

8 Results and Discussion

Consider as the sample-standard to simulate modeling of the transport hub in the city of Almaty at the crossroads

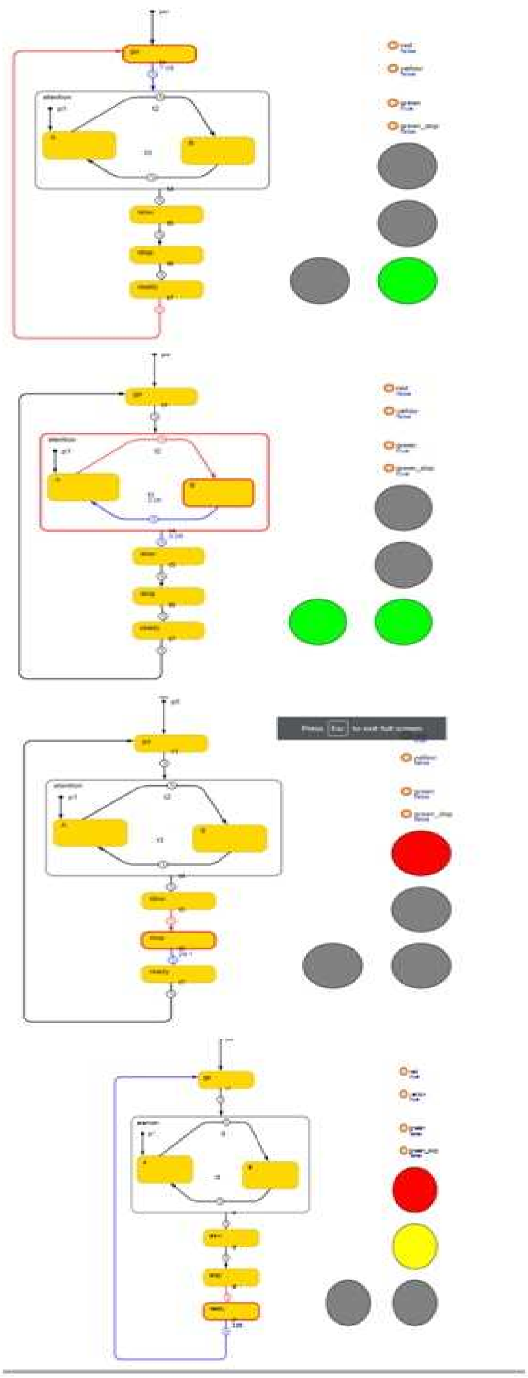

Figure 10: Phase changes of traffic lights with an additional section for turning left.

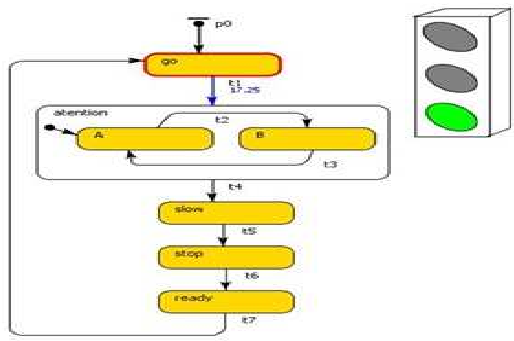

Figure 11: View of a working traffic light control model.

Table 1:

N	Name	Input action	Output action
1	the Go	green = true	green = false
2	Atention		
3	A		
4	B	green = true	green = false
5	Slow	yellow = true	yellow = false
6	Stop	red = true	red = false
7	Ready	red = true	red = false
		yellow = true	yellow = false

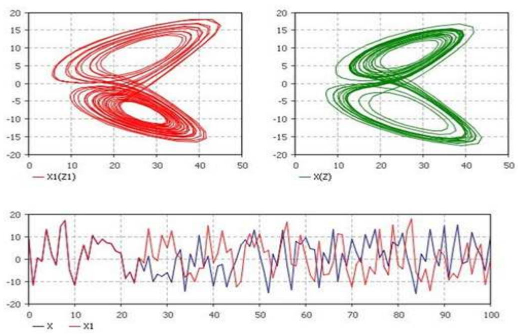

Figure 12: Model process graphs.

Dzhandosova-Gagarin, a schematic map which is taken from the application the Google the Map (Figure 13). Figure 13 shows important and frequently visited cultural, entertainment, financial and shopping centers in this area. Transport accessibility is provided by buses, trolleybuses and metros. Traffic along Abai Avenue is carried out along a six-lane highway in two directions: from east to west and from west to east, each of which has dedicated lanes for public transport. Satpayev Avenue also plays an important role in the traffic of the city's transport. It connects the city center in a west-east direction. Along this street there are banks, shopping centers, hospitals,

Figure 13: Map-scheme of the transport hub of the city of Almaty at the intersection of Satpayev Avenue with Gagarin Boulevard.

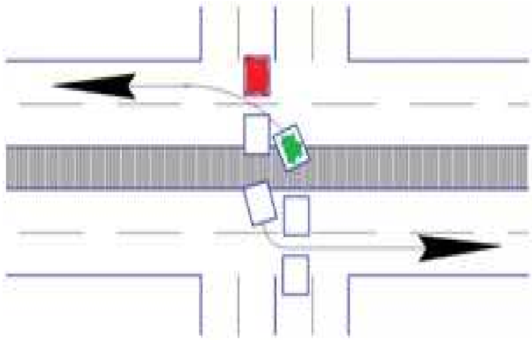

Figure 14: Diagram of the left turn at the intersection by the penetration method.

universities and colleges. Along Gagarin Boulevard one can go to the Northern Ring highway. Along Satpayev Avenue. Al-Farabi Avenue through Seifulin and Zharokov streets exists to the Eastern Ring. This intersection is full of traffic light objects. All of them work with additional sections to organize turns to the left from Satpayev Avenue to Gagarin Boulevard when moving from west to east and from Gagarin Boulevard to Satpayev Avenue to the left when driving from north to west. It is important to note that left turns from Baitursynov Street are prohibited. It is important to have simulation prototypes of traffic light objects in the AnyLogic PLE environment . The main functionality of such a traffic light is simulation of the cycles and phases of changing control signals and their interfacing with the traffic on the controlled object. The transition of permissive green light to "yellow" is also not unambiguously interpreted in the practice of the traffic police. If the car at that moment turned out to be at an intersection (behind the traffic light line), then the driver has the right to continue his maneuver with the aim of clearing the intersection. In the simulation model, these nuances of real traffic are not included in the algorithms of the application. In the additional literature and tutorials, tasks with a conventional traffic light are considered constructing finite automat of a standard traffic light in detail in the paper by R.F. Malikov [20]. However, we will give a more complex solution to this problem. It is known that making a left turn by the penetration method is a difficult and very dangerous maneuver, which often leads to emergency situations. Figure 14 shows a diagram of this maneuver [21]. An additional section of the traffic light allows to close the traffic in the oncoming lane for 15-20 seconds, which allows buses, trolleybuses and cars to make a safe left turn. As mentioned above, a state machine in the form of a standard traffic light is designed in the AnyLogic PLE environment in the form of a cyclic agent structure that controls the state of four logical variables using time transitions configured for traffic light cycles and phases.

To expand the functionality of a standard traffic light, select the graphical image of state B and make changes to the "Action upon entry" and "Action upon exit" items as shown in Figure 3. As one can see, the embedded

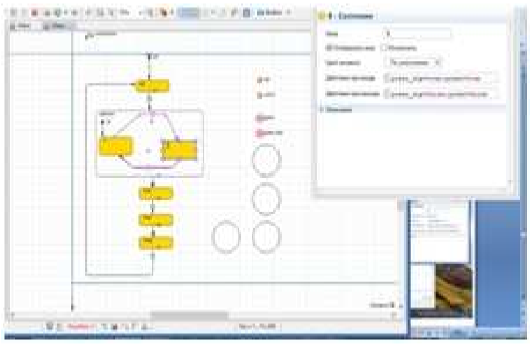

Figure 15: Screenshot of the screen with the code of the traffic light control program with an additional section.

algorithm and the animation presentation program adequately reflect the features of the operation of a real traffic light object. In the next section, a simulation model will be created with animation of discrete-event traffic of cars at a number of intersections in the city of Almaty. In accordance with the technology of building simulation models of road traffic in the environment, it is necessary to use the primitives of the Road traffic library. Figure 8 reveals that with traffic intensity of up to 600 cars per hour, jamming phenomena are not observed at this intersection. Even with the traffic lights turned off, cars pass through the intersection in an organized manner. A more complex model with traffic lights and high traffic volumes requires changing the settings in building the model. Thus, first set up the lights. Technology and traffic lights setup and phase operation control signals are not of great complexity and require only intuitive knowledge

(Figure 16). Simulation experiments shown in Figure 17

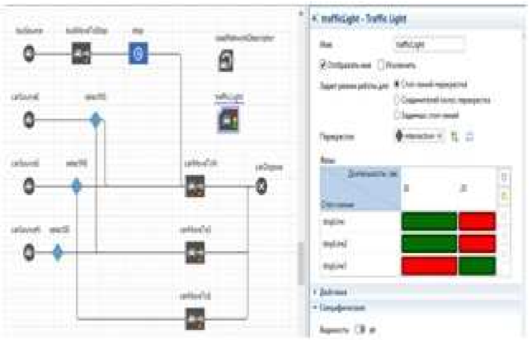

Figure 16: Discrete-event code for traffic control of traffic at the Dzhandosov-Gagarin intersection.

reflect the dependence of the appearance of congestion processes on the traffic intensity of cars on Gagarin Street. As you can see, an increase in traffic intensity on

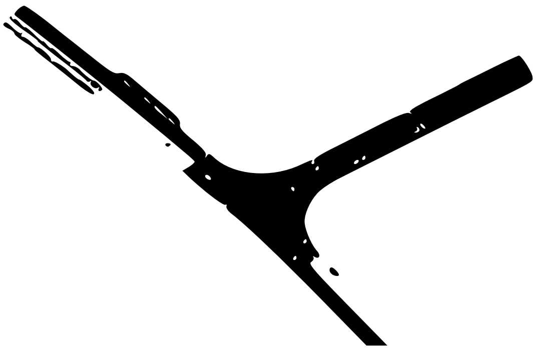

Figure 17: Dynamics of development of congestion processes at the intersection of Dzhandosov-Gagarin streets.

Gagarin Street from 1000 to 1200 cars per hour leads to the emergence of congestion processes, which develop into a congestion after 4 traffic light cycles.

9 Conclusion

Over the next three decades, 70 percent of the world's population lives in cities. This fact presupposes the creation of advanced experience in improving the management of urban resources. The fundamental basis of smart cities is the integration of information and communication platforms into various technical systems and infrastructure of the city. The Smart City (UG) concept assumes the modernization of the city's infrastructure with the latest centralized management capabilities, a new level of services and security. Transport is one of the main areas of research in the field of smart cities and the main component of the architecture of smart urban infrastructure management. New problems are emerging that need to be solved. Examples of such tasks may include: analysis and classification of infocommunication technologies used in transport systems, smart cities, analysis of the process of transition of a private city to Smart City technology, analysis and development of a transition model based on the intelligence of current transport systems, analysis and assessment of the need for smart stations, determination of their functionality within the ITS, traffic flow modeling, development and implementation of ITS software and hardware systems. The work provides for scientific tasks of creating an intelligent transport system. The research is based on smart traffic lights for the development of traffic intersections . A deep analysis of modern infocommunication technologies in the field of "Smart City" ITS was carried out and a statistical study was conducted to assess the needs and functionality of a traffic light, which is the most important component of an ITS. A model for determining the priority of traffic lights was developed, based on modeling a hardware-software complex, statistical analysis and evaluating the result. The aim of the work was to create models and methods of an intelligent transport system HC. The object of research was transport systems, infrastructure and technologies for the transition of HS. In the course of the study, the following methods were used: scientific metric analysis of literature data, statistical analysis, modeling, software modeling. As a result, an additional model of UG transition process was developed on the basis of the European Smart City model used in Kazakhstan. The developed model shows the influence of ITS and traffic light parameters on six different characteristics: environment, mobility, ecology, management/leadership, society and economy. To determine the priority areas of traffic congestion and their functionality, a statistical study was carried out, and a model for modeling traffic flows was developed. The proposed model is implemented in the form of a network of smart city terminals, on the basis of which models of software components of terminals are created and coded.

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Conflict of Interest The authors declare that they have no conflict of interest.

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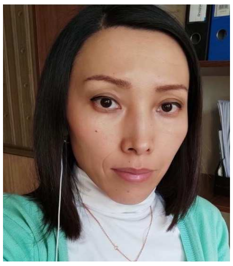

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