

**CREATION OF A SIMULATION MODEL OF BUS TRAFFIC
IN URBAN ROUTES**

The expediency of developing simulation models for studying the operation of buses on city bus routes has been substantiated. The main advantages of using simulation models are shown. An agent-based simulation is most suitable for building a bus route model. The paper shows the main disadvantages of the developed simulation models on the early versions of the Anylogic program. A methodology has been developed for constructing a simulation model for the operation of a bus route using the Anylogic 8.5.2 software tools, which takes into account the movement of buses on the general traffic flow. This can help bus schedule designers to take into account traffic density. The sequence of using the program tools for entering data on passenger traffic and bus operation along the route is given. The proposed methodology makes it possible to monitor the movement of buses, both existing routes and projected ones. In the work, the developed logical schemes for constructing a simulation model of bus routes with coincident stops, as well as bus routes with the same initial stops. To improve the quality of passenger service, it is proposed to take into account the regularity of the arrival of passengers at the bus stop points. The logic diagram shows tools and program codes for entering and changing passenger arrival parameters.

Keywords: bus route, route network, model, simulation, agent.

Дашдаміров Ф.С. Створення симуляційної моделі руху автобусів на міських маршрутах. Обґрунтовано доцільність розробки імітаційних моделей для дослідження роботи автобусів на міських автобусних маршрутах. Показані основні переваги застосування імітаційних моделей. Для побудови моделі автобусного маршруту найбільш підходить симуляція, що заснована на агентному моделюванні. У роботі показані основні недоліки розроблених імітаційних моделей на ранніх версіях програми Anylogic. Розроблено методіку побудови моделі симуляції роботи автобусного маршруту за допомогою інструментів програмного забезпечення Anylogic 8.5.2, яка враховує рух автобусів у загальному транспортному потоці. Це може допомогти розробникам розкладів руху автобусів враховувати транспортну цільність. Дана послідовність використання інструментів програми для введення даних пасажиропотоку і роботи автобусів за маршрутом. Для введення параметрів руху запропоновано використання бібліотеки Road, а для введення параметрів руху пасажирів – бібліотеки Pedestrian. З метою спостереження руху автобусів в загальному транспортному потоці введення параметрів транспортного потоку також передбачається з використанням бібліотеки Road. Запропонована методіка дає можливість стежити за рухом автобусів як існуючих маршрутів, так і тих, що проектується. Для автобусних маршрутів з співпадаючими зупинками прийнято доцільним облік пропускнує спроможності кожної зупинки. При великій кількості маршрутів, які використовували однакову зупинку, можна розподілити зупинки відомим методом, на який є посилання у статті. У роботі розроблені логічні схеми для побудованої симуляційної моделі автобусних маршрутів з співпадаючими зупинками, а також автобусних маршрутів з однаковими початковими зупинками. Для підвищення якості обслуговування пасажирів запропоновано облік закономірностей прибуття пасажирів у пункти зупинки автобусного маршруту. У логічній схемі показані інструменти та програмні коди для введення параметрів прибуття пасажирів і їх зміни.

Ключові слова: автобусний маршрут, маршрутна мережа, модель, симуляція, агент.

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Description of the problem. In large cities the public transport network is constantly changing as urban infrastructure changes. Therefore there is a need to revise the work of the route network more often. Changing route lines, using new modes of transport and creating passenger exchange points requires the creation of effective models that quickly reflect changes in the public transport system.

The development of the urban public transport system largely depends on the correct application of a systematic approach to this system. In modern conditions, the quality of passenger service determines the competitiveness of each transport company that offers the appropriate services. When organizing the work of city bus routes, the correct accounting of the flow of passengers is of great importance in terms of saving the resource of vehicles and in terms of reducing the loss of time of passengers. To achieve the goal, one should use the capabilities of modern information technologies, including applied programs. Therefore, the use of simulation models in the creation and management of the public transport route network is an urgent task.

Analysis of recent research and publications. Many works have been devoted to the application of simulation models in the creation, organization and management of various systems, including urban public transport.

Author [1] notes that simulation when studying complex systems is practically the main available method for obtaining information about the behavior of a system under conditions of uncertainty. Among the characteristic features of large systems stand out: a significant number of elements, the relationship and interaction between the elements, the hierarchy of the management structure and human participation in management, the need to make decisions under conditions of uncertainty.

Katalevsky D. [2] emphasizes that agent-based modeling can introduce irrational moments in decision-making. In this regard, simulation is becoming a powerful decision support tool for a manager. In some programs, such as AnyLogic, it is possible to include network analysis in simulation modeling in order to more accurately assess the dynamics of interaction and customer response to a new product or service.

According to the author [3], methods of mathematical and simulation modeling can make a huge contribution to the development of changes in the traffic patterns of public transport in connection with the introduction of new ones. In the field of passenger traffic modeling, PTV Vision software systems are mainly used. In such packages, for example, it is impossible to simulate the logic of a dispatcher deciding whether to leave a vehicle when there is a strong delay in schedule. Also, when modeling, the researcher is forced to divide the territory of the city into microdistricts, without taking into account the correspondence within them. Thus, it is limited by the capabilities provided by the developer.

Gizem Gunesh [4] emphasizes simulation model is a copy of a real world system on computer and can be used to see results of different scenarios without nothing changes in the real world. But we have to not forget that models aren't represent to real system exactly. Because real systems are more complex than the models. So simulation modeling typically requires some training and learning, in a conclusion it's harder than mathematical models. While an AB simulation is modeling, agents, agents' behavior, environment and relationship between each other are determined generally. AnyLogic makes modeling AB easier about creating or deleting an agent, relationship or any description. AnyLogic based on object-oriented that means everything in system is built on objects (that means agents in AB simulation). Two of the strongest point of the object-oriented are 10 expressing reality (that means a real system is abstracted as you modeled) and managing change. In addition, AnyLogic simulation software uses Java programming language. So, it helps to understand how we can model easily.

Purpose of the article is to develop a logical diagram of a simulation model of a bus route or a model of a bus route network to observe the influence of management decisions on changing the mode of movement of vehicles.

Presentation of the main material. It is known that models can be different: physical, mental, template, algorithmic, computer, etc. The main difference and advantage of computer models from other models is that they can represent any problem in a flexible virtual format.

Almost everyone is touched by some form of transportation every day of their lives. We rely on both public and private systems to get us to work, school, shopping, or to our favorite form of recreation. We take for granted the underlying system supporting this complex network of roadways, rail, and public transit routes. And these systems are very complex. They consist of miles of road surface and track with multiple control mechanisms to regulate the flow of vehicles. The systems have become

so complex that a seemingly minor adjustment to the timing of a traffic light in one part of the city can have a drastic effect on traffic movement miles away. Traffic engineers employ simulation to test these adjustments for just this reason. It is far better to see the results in a simulation and watch traffic back up there than it is to have hundreds of frustrated motorists wasting valuable time traveling at a speed far below their expectation. Large-scale regional traffic simulations, known as Macroscopic Traffic Simulations, are capable of showing the effects of these changes on very complex networks of roadways covering large regional areas [5].

There are six main benefits of simulation [6]:

1. Simulation models allow you to analyze the system and find solutions when methods such as analytical reports, linear programming, etc. are not effective or do not give any results.
2. Development of a simulation model after choosing the appropriate abstraction stage is a simpler process than analytical modeling.
3. The structure of the simulation model more naturally reflects the structure of the real system. The main reason for this is that simulation models are developed primarily using visual languages.
4. In the simulation model, you can observe any creature not lower than the level of abstraction and measure any value. In addition, measurements and statistical analysis can be added at any time.
5. The main advantage of simulation is the ability to track the behavior of the system at any time in the form of animation. Animation is used not only for displaying the results, but also for checking and correcting.
6. Simulation models are more attractive and convincing than spreadsheets. Presentation of simulation models is more effective than presentations that consist only of figures and tables.

There are 3 main types of simulation: system dynamics, discrete event simulation, and agent-based simulation. Among these agent-based modeling is the most suitable for modeling the bus route network [7].

Agents are intelligent objects that means they can make decision. They can change their decision as their experiment. They can control themselves, for that situation we say agents are decentralised. They have parameters and variables differently and communicate each other and their environment. Agents' reactions depend on their state. In a system, it's not obligated that all agents have to be same object. So, one agent can be a car and another agent can be a customer. In this case vehicles and passengers act as agents.

Modeling the operation of the bus route network allows you to control the process by changing indicators, road conditions with changing passenger flows and modes of bus movement. Simulation models allow for specific process characteristics. This includes the description and analysis of probabilistic processes.

A bus route simulation model can be created in *Anylogic 8.5.1* or *8.5.2* in the **Road** library using the *CarSource*, *CarMovieto*, *CarDispose*, *BusStop*, *Delay* tools. One of the main advantages of the program is that you can pre-specify the intervals between buses, the number of buses, the number and location of stops like on a real bus route. At the same time using the statistics of existing bus routes the program can use numbers from *MS Excel* files as data [1, 2, 8].

In a simulation model the nature of changes in the number of passengers arriving at a stop can be taken into account using the *Pedestrian* library. The influence of this parameter is taken into account in the bus schedule by the time of stopping at stops.

It is known that the simultaneous arrival of more than 3 buses is not recommended at bus stops. In this case it is advisable to scatter the stops along the routes. Stops on city routes can have intense (more than 15 passengers, including pick-up and drop-off intervals), medium (5-15 passengers) and low (up to 5 passengers) passenger traffic. Due to the high traffic volume of buses on different routes, they interfere with each other at stops. In such cases routes are scattered by dividing routes into two or more groups. The scattering of stops is carried out in each direction in the following sequence [9]:

1. The average (estimated) interval I of movement of all routes passing through the parking lot is calculated.
2. The average delay time of the bus t_{land} due to the embarkation and disembarkation of passengers is determined.
3. The condition $t_{land} < I$ is checked. If this condition is not met, there will be significant delays and the scattering of stops will be important. If I is 8 times greater than t_{land} no scattering is required.

4. The probability $p(t_i)$ of exceeding the delay of the bus a certain value is determined (for example, 1 minute):

$$p(t_i > 1) = \frac{t_{land}}{I} e^{-\left(\frac{1}{t_{land}} - \frac{1}{I}\right)}$$

The expediency of scattering the scattering according to the established probability is substantiated. If the probability is greater than 0.2, the dispersion is considered appropriate.

An example of a scheme for creating bus routes using *Anylogic* software for buses departing from the same starting stop is shown in Figure 1. In this case the *SelectOutput* agent is used. The bus is entered into the road library using the *CarSource* tool. Bus selected as vehicle type.

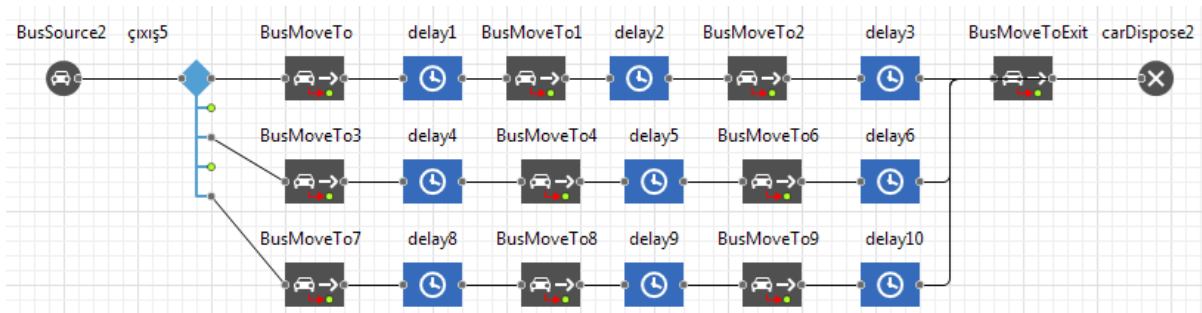


Fig 1 – Construction of an algorithm for simulating routes leaving the same initial stop

If the number of routes leaving the same start stop is less than 5, the probability of the corresponding exit in the *Probability* cell is 0.

When constructing a simulation model for routes that exit from different initial stops and have several coincident stops, the logical diagram of which is shown in Figure 2, the capacity of these stops must be considered.

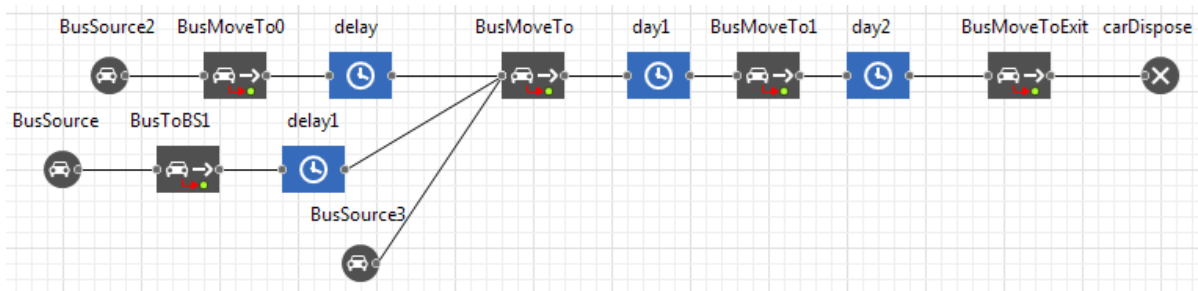


Fig 2 – Building a simulation algorithm for routes with coincident stops

To study the work of public transport moving in a general flow, you can use software to include traffic flows and their intensity by direction. In this case, it is possible to determine the nature of public transport management, both in a specialized lane and in the general flow.

The proposed methodology for creating a simulation model of the bus route network in the *Anylogic 6.0* environment [3] describes the movement of vehicles on the network, but does not cover the work in the general transport network. It is known that a bus passes through streets with different numbers of lanes, different traffic intensities, stops at traffic lights with different operating modes [10]. Therefore, we use elements of the road library to describe the operation of buses in the route network. For more efficient process management, you can simplify the task and divide the city into microdistricts.

To create a simulation model we use the tools of the program. To enter the parameters of bus routes and traffic flow we use *Road*, *CarSource*, *CarMoveTo*, *BusStop*, *Delay*, *Queue*, *Pickup* and *Dropoff* and to enter the parameters of movement of passengers *Ped source*, *Restangular area*, *Ped wait* tools from the *Pedestrian* Library [11].

In one direction on the road bus stops and areas for embarking and disembarking passengers are created. Then a logical model is created to allow passengers to board the bus (Figure 3).

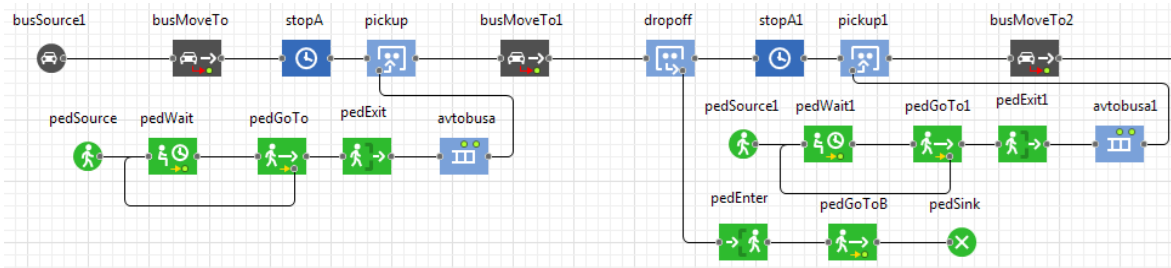


Fig 3 – Logical model of passengers boarding the bus

Bus stop parameters are entered through the *Delay* (stop) tool.

To enter the parameters of waiting for passengers at stops, in the *Action* area, enter the following code lines in the appropriate cells:

```
On enter: pedWait.freeAll ();
On exit: goToBoarding.cancellAll ();
```

If *All available agents* are selected in the window with the *Pickup* tool parameters, then the bus will pick up all passengers at the stop. *All available agents* in the *Dropoff* tool settings selected. This serves to send passengers to the *Pedestrian* library to allow re-entry.

The regularity of the passengers' approach to the stop can be taken into account in the features of the *PedSource* tool.

The bus routes on the network run along different streets. The number of lanes and the amount of traffic on these streets vary. Traffic at intersections is organized in different ways. Since the duration of permitting and prohibiting signals at controlled intersections is different. With the help of software we can track the movement of buses along the route in various conditions, reflecting this situation in the model [4, 12].

Anylogic software tools allow you to view the simulation model in 3D. To do this select the *3D Window* tool from the *Presentation* toolbar. The *Camera* tool makes it possible to track any area in particular in the created bus route network. On the logical model created by the simulation model you can see the statistics of changes in traffic and passenger flows (Figure 4).

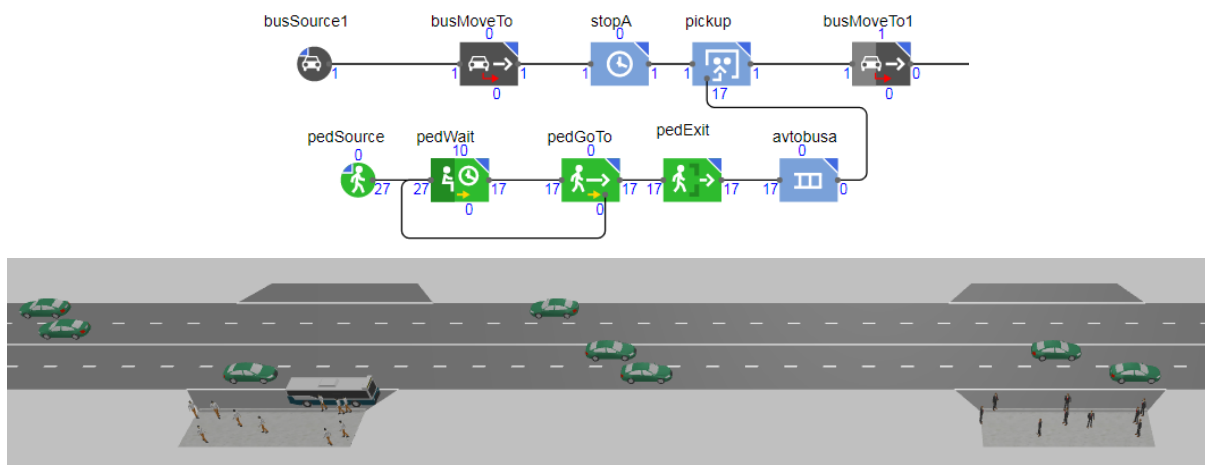


Fig. 4 – Simulation model of the bus route section

Conclusions

Thus, by creating an agent-based simulation model of the bus route network, it is possible to enter the parameters of the movement of buses and passengers along the network for vehicles moving along different streets (network points) and passing through bus stops (peaks), to observe the nature of

the bus operation in the route network. By identifying shortcomings at the next stage, you can select optimization criteria. The creation of such a model makes it possible to identify real obstacles throughout the network or in its sections, causing delays in the passage of buses on the road network with different traffic conditions (number of lanes, traffic intensity, intersections, etc.).

References:

1. Remezova E.M. *Imitatsionnoe modelirovanie v srede AnyLogic* [Simulation modeling in the AnyLogic environment]. Vladimir, VIGU Publ., 2017. 87 p. (Rus.)
2. Katalevskii D.Iu. *Osnovy imitatsionnogo modelirovaniia i sistemnogo analiza v upravlenii: uchebnik* [Basics of simulation and systems analysis in management: textbook]. Moscow, «Delo» RANKHiGS Publ., 2015. 496 p. (Rus.)
3. Lipenkov A.V., Maslova O.A., Eliseev M.E. Modelirovanie marshruta passazhirskogo avtobusa v Anylogic. *Materialy V Vseros. nauch.-prakt. konf. «Imitatsionnoe modelirovanie. Teoriia i praktika»* [Passenger bus route simulation in Anylogic. Proceedings of the V-th All-Russ. Sci.-Pract. Conf. «Simulation modeling. Theory and practice»]. St. Petersburg, 2011, vol. 2, pp. 137-141. (Rus.)
4. Gizem Gunesh. Agent-based simulation and an example in anylogic. İstanbul, 2014. 36 p.
5. Sokolowski John A., Banks Catherine M. Principles of Modeling and Simulation. John Wiley & Sons, Inc. Publ., 2009. 280 p. doi: 10.1002/9780470403563.
6. Borshchev A. The Big Book of simulation Modeling. Multimethod Modeling with AnyLogic 6. 2013. 614 p.
7. Dashdamirov F.S. Simulation modeling of the route network in the Anylogic environment. *Professional education and human capital*, 2020, vol. 3, no. 2, pp. 73-77.
8. Malikov R.F. *Praktikum po imitatsionnomu modelirovaniuu slozhnykh sistem v AnyLogic 6: uchebnoe posobie* [Practical Simulation of Complex Systems in AnyLogic 6: Tutorial]. Ufa, BGPU Publ., 2013. 296 p. (Rus.)
9. Dashdamirov F.S., Sharifov A.C. Urban and suburban passenger transport: textbook. Baku, AzTU Publ., 2019. 205 p.
10. Dashdamirov F. Coordination of the work of buses in city routes. *Transport Problems*, 2013, vol. 8, iss. 4, pp. 77-82.
11. Dashdamirov F.S. Build an agent-based simulation model for the bus network. Materials of the Republ. Sci. and Tech. Conf. dedicated to the 70th anniversary of the Azerbaijan Technical University «Technological prospects of the fourth industrial revolution: industrial internet, cyber-physical systems and intelligent technologies», 2020 Available at: www.aztu.edu.az/azp/yubiley/az/down/B%C3%B6lm%C9%99%201.pdf.
12. Help – AnyLogic Simulation Software Available at: www.help.anylogic.ru/index.jsp (accessed 25 July 2020).

Перелік використаних джерел:

1. Ремезова Е.М. Имитационное моделирование в среде AnyLogic: лаб. практикум / Е.М. Ремезова; Владимир. гос. ун-т им. А.Г. и Н.Г. Столетовых. – Владимир : Изд-во ВлГУ, 2017. – 87 с.
2. Каталевский Д.Ю. Основы имитационного моделирования и системного анализа в управлении: учебник / Д.Ю. Каталевский. – 2-е изд., перераб. и доп. – М. : Издательский дом «Дело» РАНХиГС, 2015. – 496 с.
3. Липенков А.В. Моделирование маршрута пассажирского автобуса в Anylogic / А.В. Липенков, О.А. Маслова, М.Е. Елисеев // Имитационное моделирование. Теория и практика: материалы V Всерос. науч.-практ. конф. (19-21 октября 2011 г.; г. Санкт-Петербург). – СПб., 2011. – Т. 2. – С. 137-141.
4. Gizem Gunesh. Agent-based simulation and an example in anylogic / Gizem Gunesh; Yildiz technical university. – İstanbul, 2014. – 36 p.
5. Sokolowski John A. Principles of Modeling and Simulation / John A. Sokolowski, Catherine M. Banks. – John Wiley & Sons, Inc., 2009. – 280 p. – Mode of access: DOI: 10.1002/9780470403563.
6. Borshchev A. The Big Book of simulation Modeling. Multimethod Modeling with AnyLogic 6 / A. Borshchev. – 2013. – 614 p.

7. Dashdamirov F.S. Simulation modeling of the route network in the Anylogic environment / F.S. Dashdamirov // Professional education and human capital. – 2020. – Vol. 3, no. 2. – Pp. 73-77.
8. Маликов Р.Ф. Практикум по имитационному моделюванню складних систем в AnyLogic 6: учебное пособие / Р.Ф. Маликов. – Уфа : Изд-во БГПУ, 2013. – 296 с.
9. Dashdamirov F.S. Urban and suburban passenger transport: textbook / F.S. Dashdamirov, A.C. Sharifov. – Baku : AzTU, 2019. – 205 p.
10. Dashdamirov F. Coordination of the work of buses in city routes / F. Dashdamirov // Transport Problems. – 2013. – Vol. 8, iss. 4. – Pp. 77-82.
11. Dashdamirov F.S. Build an agent-based simulation model for the bus network / F.S. Dashdamirov // Technological prospects of the fourth industrial revolution: industrial internet, cyber-physical systems and intelligent technologies: materials of the Republ. Sci. and Tech. Conf. dedicated to the 70th anniversary of the Azerbaijan Technical University. – 2020. – Режим доступу: www.aztu.edu.az/azp/yubiley/az/down/B%C3%B6lm%C9%99%201.pdf.
12. Help – AnyLogic Simulation Software [Electronic resource]: [Website]. – Electronic data. – Mode of access: www.help.anylogic.ru/index.jsp.

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ОСОБЛИВОСТІ ФУНКЦІОНАЛЬНИХ МОЖЛИВОСТЕЙ І ТЕЛЕМАТИЧНОГО ЗАБЕЗПЕЧЕННЯ СИСТЕМИ «КОЛІСНІ ТРАНСПОРТНІ ЗАСОБИ-ІНФРАСТРУКТУРА»

Представлена розробка функціональних можливостей і системного забезпечення інформаційної телематичної системи «Колісні транспортні засоби-Інфраструктура», як системи супутникового моніторингу і управління транспортними засобами в умовах інфраструктури. Показані основні інформаційні складові телематичного забезпечення системи у взаємодії зі встановленими морфологічними структурами.

Ключові слова: автомобільний транспорт, телематична система, колісний транспортний засіб, інфраструктура, моніторинг.

R.V. Symonenko. Features of functional possibilities and telematic support of the system «Wheeled vehicles-Infrastructure». The development of functional capabilities and system support of the information telematics system «Wheeled vehicles-Infrastructure» as a system of satellite monitoring and vehicles control in the conditions of infrastructure is presented. Application in the conditions of practical activity of the system motor transport is presented as specialized software and hardware complex for remote control of the parameters of a wheeled vehicle power plant technical condition, for control of a power plant operating conditions and transmission of a wheeled vehicle, as well as performing of the given law of movement of the wheeled vehicle in the given conditions of the infrastructural environment. It has been shown that the system «Wheeled vehicles-Infrastructure» is designed to solve scientific and production problems of road transport in terms of optimizing the operation of the wheeled vehicle and is a comprehensive solution for monitoring and control of the parameters of their technical condition and traffic.

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