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USING THE AGENT-ORIENTED SIMULATION MODEL FINDING ROUTE PARAMETERS IN AN AUTOMATED PUBLIC TRANSPORT MANAGEMENT SYSTEM

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Анотація. *Громадський транспорт є важливою складовою частиною інфраструктури будь-якого міста. Рівень розвитку транспорту, зокрема, рівень розвитку таких екологічних видів транспорту, як тролейбуси і трамваї, впливає на економічну і екологічну ситуацію в місті, а також на його туристичну привабливість. З часом розгалуженість маршрутів громадського транспорту і обсяги пасажирських перевезень, які він обслуговує, значно зростають. Управління такою інфраструктурою стає складним завданням і в такому випадку необхідно застосовувати автоматизовані системи управління. На даний момент існує значна кількість автоматизованих систем управління громадським транспортом, але більшість із них не має у своєму складі такої важливої функції, як пошук прийнятних параметрів маршруту. Сьогодні існує досить багато підходів щодо визначення прийнятних параметрів маршруту, які не є універсальними, і для кожної транспортної системи необхідно підбирати свій набір методів. У даній роботі проведено аналіз і запропоновано автоматизовану систему управління громадським транспортом, яка дозволяє відстежувати поточну позицію одиниць громадського транспорту, оплачувати проїзд і проводити пошук прийнятних параметрів маршрутів громадського транспорту. Пошук прийнятних параметрів маршруту досягається за рахунок запропонованої імітаційної агентно-орієнтованої моделі з такими параметрами, як інтервал руху одиниць громадського транспорту та кількість одиниць транспорту на кожному з маршрутів. На прикладі одного з маршрутів громадського транспорту продемонстрована можливість пошуку прийнятних параметрів маршруту таким чином, щоб кількість пасажирів на зупинках прямувала до нуля. Проведені експерименти підтвердили ефективність запропонованої моделі при вирішенні задач пошуку прийнятних параметрів маршруту за рахунок організації обслуговування таким чином, щоб кількість пасажирів на зупинках була близькою до нуля. Перспективи подальших досліджень полягають у розширенні розробленої системи за рахунок збільшення кількості вхідних параметрів та її інтеграції з іншими комплексами управління громадським транспортом.*

Ключові слова: *автоматизована система управління, метод імітаційного моделювання, агентно-орієнтований підхід, прийнятні параметри маршруту.*

Аннотация. *Общественный транспорт является важной составляющей частью инфраструктуры любого города. Уровень развития транспорта, а именно уровень развития таких экологичных видов транспорта, как троллейбусы и трамваи, влияет на экономическую и экологическую ситуацию в городе, а также на его туристическую привлекательность. Со временем разветвленность маршрутов общественного транспорта и объемы пассажирских перевозок, которые он обслуживает, значительно возрастают. Управление такой инфраструктурой становится сложным заданием и в таком случае необходимо использовать автоматизированные системы управления. На данный момент существует большое количество автоматизированных систем управления общественным транспортом, но большинство из них не предоставляет такой важной функции, как поиск приемлемых параметров маршрута. На сегодняшний день существует множество вариантов поиска приемлемых параметров маршрута, которые не являются универсальными, и для каждой транспортной системы необходимо подбирать свой набор методов. В данной работе проведен анализ и предложена автоматизированная система управления общественным транспортом, которая позволяет отслеживать текущую позицию единиц общественного транспорта, оплачивать проезд и производить поиск приемлемых параметров маршрутов общественного транспорта. Поиск приемлемых параметров маршрутов достигается за счет предложенной агентно-*

ориентированной модели с такими параметрами, как интервал движения единиц общественного транспорта и количество единиц транспорта на каждом из маршрутов. На примере одного из маршрутов общественного транспорта продемонстрирована возможность поиска приемлемых параметров маршрутов таким образом, чтобы количество пассажиров на остановках стремилось к нулю. Проведенные эксперименты подтвердили эффективность предложенной модели при решении задачи поиска приемлемых параметров маршрута за счет организации обслуживания таким образом, чтоб количество пассажиров на остановках стремилось к нулю. Перспективы дальнейших исследований возможны в сторону расширения разработанной системы за счет увеличения количества входных параметров и ее интеграции с другими комплексами управления общественным транспортом.
Ключевые слова: *автоматизированная система управления, метод имитационного моделирования, агентно-ориентированный подход, допустимые параметры маршрута.*

Abstract. *Public transport is an important part of the infrastructure of any city. The level of development of transport, in particular the level of development of such ecological modes of transport, as trolleybuses and trams, affects the economic and environmental situation, as well as its tourist attractiveness. Over the time branching of public transport routes and the volume of passenger traffic which it serves increase significantly. Management of such infrastructure is becoming difficult task and, in such case, it is necessary to use automated management system. At present, there are a significant number of automated public transport management systems, but most of them do not have such an important function as finding of acceptable route parameters. Today, there are quite a lot of approaches to determining acceptable route parameters that are not universal and for each transport system it is necessary to choose their own set of methods. In current paper an analysis has been performed and automated public transport management system, which allows tracking the current position of public transport units, pay fare and search for acceptable parameters of public transport routes, has been proposed. Finding of acceptable route parameters is achieved by using of proposed simulation agent-oriented model with such parameters as the traffic interval and the amount of public transport vehicles on the route. The possibility of finding acceptable parameters of the route in such a way that the number of passengers at stops went to zero has been demonstrated on an example of one of the public transport routes. Performed experiments confirmed the effectiveness of the proposed model for solving problem of finding acceptable parameters of the route due to the organization of maintenance in such a way that the number of passengers at the stops was close to zero. Perspectives for further research are the extension of the developed system by increasing the number of input parameters and integrating it with other public transport management systems.*
Keywords: *automated control system, simulation method, agent-oriented approach, acceptable route parameters.*

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1. Introduction

With the development of cities, branching of public transport routes and the number of passengers it serves is increasing significantly. The infrastructure management is a complicated task, stimulating continuous development and improvement of automated systems.

The relevance of this study rests on the need of development of the automated public transport management systems capable of taking into account more parameters determining their utilization.

The object of the study is the automated public transport management system.

The subject of the study is the methods of finding acceptable public transport route parameters.

The purpose of the research is the development of the automated public transport management system able to find acceptable route parameters using the simulation agent-oriented model. The developed system should enable its users to track the current position of the public transport vehicles, to pay fare electronically and to find acceptable route parameters (quantity of public transport vehicles featuring specified passenger capacity on the route and their traffic intervals).

2. Problem statement

Let the public transport network be represented by number of public transport stops *STOP={stopi1, stopi2,…,stopiN}*. The public transport vehicles move according to their routes with the given traffic interval *d*. A range of public transport vehicles *TRANSPORT={transporti1, transporti2,…,transportik}* provides passenger service using transport network, and each vehicle can transport its maximum number of passengers *capacity*. Passenger capacity of public transport is given by the vector *CAPACITY=(capacity1, capacity2,…,capacityh)*, where *capacityh* is the passenger capacity of the vehicle, capable of transporting the largest possible number of passengers. At any specific time, there is a certain number of passengers at the stops along the route. It is represented by the number of passengers vector *QUANTITY=(quantityin1, quantityin2,…, quantityinN)*. The task of finding acceptable route parameters involves finding for each route from the range *R* such acceptable parameters *k* of the given passenger capacity *capacity* with such traffic interval *d* using the agent model *AM={STOP, I, TRANSPORT, CAPACITY, QUANTITY}*, that the number of passengers at each stop along the *i*-route is minimal according to the acceptability criterion represented by the formula:

$$\min QUANTITY_i = \sum_{n=1}^{N} quantity_n \ . \tag{1}$$

Furthermore, the developed system should enable users to track the current position of the public transport vehicles, to pay fare electronically and to find acceptable route parameters (quantity of public transport vehicles featuring specified passenger capacity on the route and their traffic intervals).

In order to achieve the main purpose of this work the following tasks need solving:

1. To create the agent-oriented simulation model of the public transport routes.

2. To develop the method for finding acceptable route parameters using the created agent-oriented simulation model of public transport routes.

3. To develop the architecture of the public transport management system, this includes the subsystem monitoring the position of each vehicle, the subsystem of fare payment and the subsystem of finding acceptable route parameters.

4. To determine the ways of further improvement of the created automated system of the PTMS.

3. Related works

Different works give methods of solving the problem of finding acceptable route parameters for public transport.

The work [1] describes the ways of optimization of parameters in highly branched transport networks and their optimal timetables development. In addition, it offers the methodology that helps to solve the mentioned problems. The given methodology offers to represent the branched transport network as a range of street nodes, interconnected by the range of street segments.

The work [3] deals with the task of synchronizing the timetables of several routes in order to increase the comfort of movement of passengers. The result of the simulation is the timetable for the public transport vehicles on the route optimized for the change using genetic algorithms.

The work [4] considers another mathematical model used to optimize the timetable for public transport vehicles on the route, which might deviate from the timetable. The special feature of the given model is taking into account the checkpoints on the route where a driver must arrive at a sharply defined time. To implement this model, the authors suggest using the Monte Carlo method.

Consequently, most works connected with finding acceptable route parameters and timetables, offer mathematical models with a set of algorithms. However, the offered models solve highly specialized tasks, lacking the possibility to add new parameters in order to increase their adequacy or to simulate the parameters.

The works [5–8] offer to use the agent-oriented approach in modeling complex social-oriented systems. In the works [5–8], authors use a simulation modeling method with the agent-oriented approach to research the dependence of changing the parameters of a complex city system. Among the investigated parameters there is quantity of police patrols in the given city district, each patrol's traffic interval and quantity of thefts. The feature of object-oriented models is that each their element demonstrating certain conduct is represented as a separate object. This allows providing each object with unique conduct that differs from other objects and positively affects the adequacy of the model. The authors of the work [5] describe in details the agents involved in modeling, in the work [6] they explain how they are created and how the rules of conduct are formulated, and in the work [7] the authors determine the tools used to construct the agent models. The work [8] presents agent-oriented models for generating crime data in the given region. This approach was chosen to determine the acceptable route parameters as the one that suits best for complex social-oriented systems.

The above given existing automated public transport management systems lack the function of finding acceptable route parameters. The ones featuring this function use various mathematical models, which do not allow adding any new parameters for increasing adequacy or continuing their modeling. Accordingly, the chosen direction of the research is still at its initial stage and has some prospects for the further development.

4. Materials and methods

Most modern cities implemented automated systems accounting fare payment in public transport thus having created conditions for improving the quality of passenger service on transport followed by active development of such systems and their commissioning.

One of such systems is DozoR [9] – the system providing information about routes and stops of public transport in Ukraine's cities. The system allows tracking on the map the position of the public transport vehicles a user is interested in and determining the time of arrival of the vehicle at the certain stop. However, the system has following faults: it does not encompass all Ukraine's cities and lacks the fare payment subsystem as well as ability to find acceptable route parameters.

Clipper [10] is a versatile system of contactless payment for transport services used in San Francisco. It allows paying fares for many means of transport such as buses, trolleybuses, subway and cell trains. Most stations in San Francisco are equipped with dynamic electronic displays demonstrating arrival time of the next vehicle linked to its route. Public transport users can take a map of the routes with their timetables free of charge. However, the system lacks the function of finding acceptable route parameters.

The company «CARD-SYSTEMS» developed the automated fare payment system CS-Trans [11]. The system provides high level of control over the fare payment process, helps to monitor privileged passengers in order to give them compensation, eliminates the possibility of counterfeiting means of payment and allows using single ticket. This management system offers its users a large number of useful functions; nevertheless, it lacks the function of finding acceptable route parameters.

Another system for obtaining information about public transport and navigation is a free mobile application Moovit [12], developed in scope of Israeli startup Tranzmate. Moovit provides real-time public transport information. Users can see all nearest stops on the map and plan trips considering real-time data about all means of transport. The application receives data collected by users of the system in real time. Whenever the users travel by public transport with the background application, it transfers speed and location data.

So, one of the main functions of automated transport management system is to find acceptable route parameters such as amount of public transport vehicles on the route, their passenger capacity and traffic intervals.

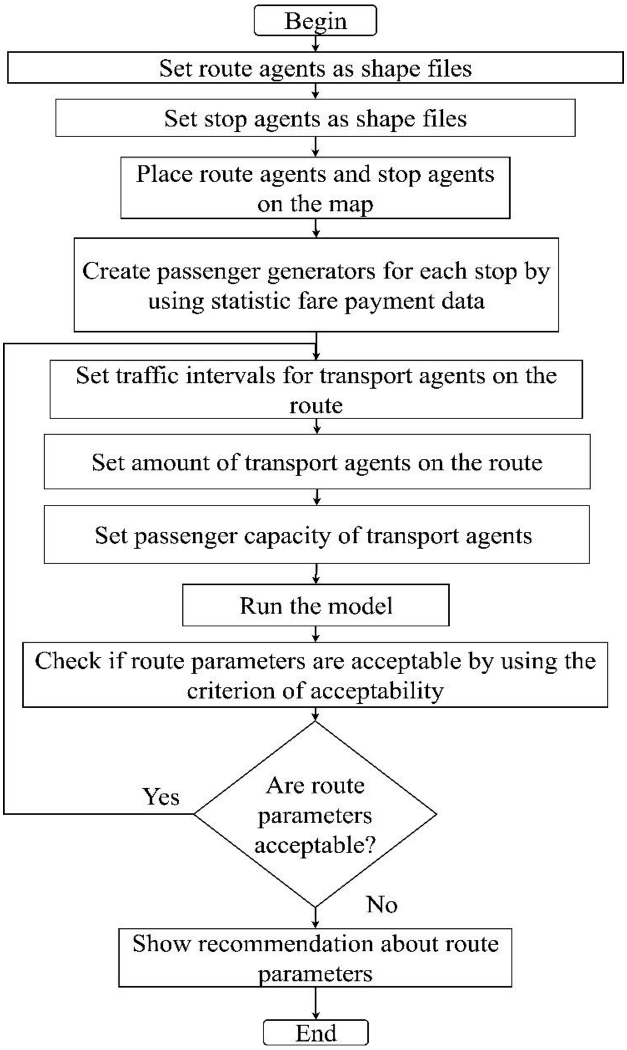

Figure 1 – The algorithm of creating the agent-oriented route model

A simulation model based on the agent approach was created to find acceptable route parameters. The main elements of the simulation model are public transport vehicle agents, public transport stop agents and public transport passenger agents. Each agent performs its own task. For public transport vehicle agents, it is moving along the given route, stopping movement at the designated points while its passengers are getting off/on and continuing movement along the route. If a public transport vehicle agent does not have vacancies and no passenger needs to get off at the stop, the agent can continue moving without stopping. Public transport stop agents generate passengers according to the collected statistics. Fig. 1 describes the algorithm of the method of finding acceptable route parameters using agent-oriented simulation model.

At the first stage, we need to create shape files with routes and stops for future displaying them at the city map as stop agents and route agents. At the second stage, we need to use statistic data from the payment statistics gathering module to create passenger generators at the stops on the route. The generators are created to make the simulation model as close as possible to the real system from the point of intensity of passenger flows at different stops on the routes. At the third stage, we need to change such parameters of the simulation model as amount of public transport vehicle agents on the route, their passenger capacity and traffic interval until they are acceptable. In this case the simplest criterion of acceptability for each route can be for example minimal amount of passengers at all stops on the route:

$$\min QUANTITY_i = \sum_{n=1}^{N} quantity_n \qquad (2)$$

If we consider the criterion within all routes of the simulation model, the criterion of acceptability will look as follows:

$$\min QUANTITY_G = \sum_{i=1}^{m} QUANTITY_i \,. \qquad (3)$$

At the fourth stage, when acceptable parameters of the route are defined, the recommendations related to changing route parameters need providing.

5. The architecture of the automated public transport management system applying the proposed model

The developed automated city transport management system combines capabilities of several different systems. On the one hand, the proposed system has the function of public transport fare payment by the aid of RFID cards and it offers flexible payment mechanisms with different types of discounts. On the other hand, the proposed system allows a customer to track the position of a public transport vehicle and determine its time of arrival. The most important feature of the system is ability to find acceptable public transport route parameters by using the agent-oriented simulation model. The feature makes it possible to change dynamically such parameters of the routes as traffic interval and passenger capacity of vehicles. Furthermore, this feature allows researching possibility of changing the routes and combining several routes in one. Fig. 2 demonstrates the architecture of the transport management system.

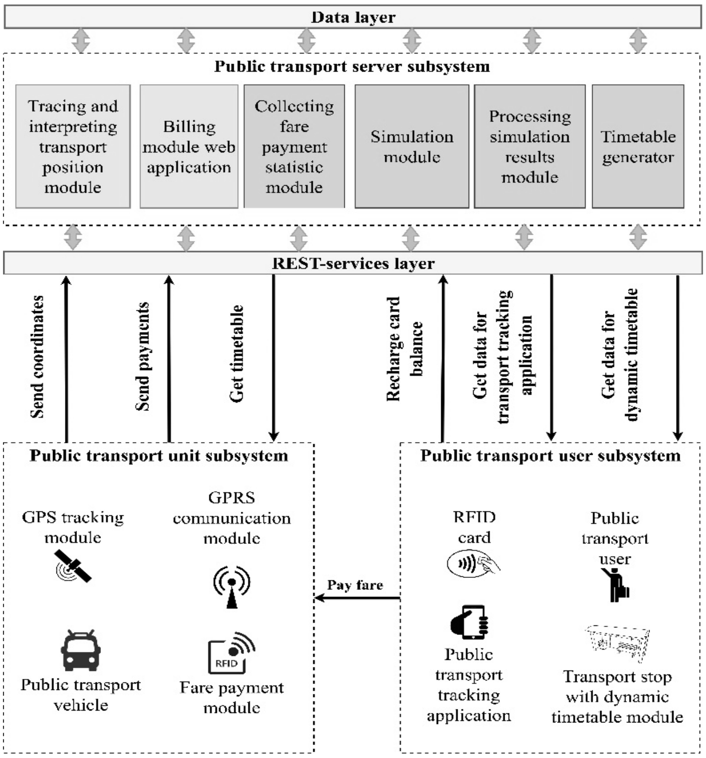

Figure 2 – The architecture of the automated transport management system

The automated city transport management system has distributed architecture and contains following main subsystems.

Public transport vehicle subsystem contains GPS tracking module, GPRS communication module and fare payment module using RFID card. GPS module identifies the current position of a vehicle and transfers it to the server in real time using GPRS module. Fare payment data are transferred to the server using GPRS as well; however, the frequency of data transfer is lower than the frequency of transferring current vehicle position.

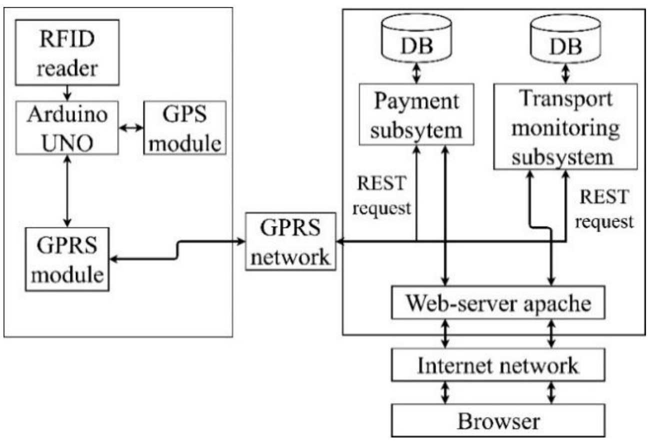

Figure 3 – The architecture of the public transport vehicle subsystem based on Arduino platform

The architecture of public transport vehicle subsystem rests on Arduino platform described in Fig. 3.

MySQL database stores user data concerning RFID card balance, the performed operations, personal data and the data necessary for the site to function. A user puts an RFID card on RFID reader. The RFID reader reads user's token and unique number and transfers the data to Arduino UNO. Arduino UNO sends REST request via GPRS module to APS (Automation Payment System). The Automation Payment System has fare amount in its configurations and makes SQL request to MySQL server to withdraw the defined amount of money from user's account.

After successful payment, the Automation Payment System sends response to Arduino UNO, which informs the user about the successful operation by means of the green indicator and one beep and if operation was unsuccessful, – by means of the red indicator and double beep. The user can open the site deployed on server using a browser and perform following operations: refill RFID card balance, check card balance and history of operations with the card, read site news and contact with the support office.

The public transport user subsystem contains a public transport tracking application, RFID cards and module for displaying dynamically time of arrival of vehicles. Public transport users can track current position of the vehicles they are interested in using the mobile application.

The components of public transport vehicle subsystem and public transport user subsystem are distributed over a distance and are used primarily for collecting and displaying data. Unlike these subsystems, the public transport server subsystem is designed to collect and process the data received from the public transport vehicle subsystem and public transport user subsystem.

The public transport server subsystem contains following components:

– tracing and interpreting transport position module;

– billing module web application;

– collecting fare payment statistics module;

In addition, simulation module, processing simulation results module and timetable generator belong to this subsystem.

Tracing and interpreting transport position module allows recording the position of a public transport vehicle to data source and transferring the data to the mobile application for public transport tracking.

Functions of billing module web application include updating and checking the balance of the RFID card, viewing the history of payment with the link to the position on the map where it was made and blocking RFID card. Collecting fare payment statistics module is designed for collecting the records of fare payment with the link to the public transport stops thus making it possible to use the records for adjusting public transport load simulation models.

Simulation module is used to model public transport load simulation. Results of the simulation are transferred to processing simulation results module used for finding acceptable route parameters.

The timetable generator uses the data from the processing simulation results module to schedule transport vehicles on the route and sends the timetable to public transport drivers.

6. Simulation results

Simulation results are used in processing simulation results module to schedule public transport vehicles. Fig. 4 demonstrates graphic representation of agent-oriented simulation model of public transport load on the route. Squares represent stops and triangles represent public transport vehicle agents.

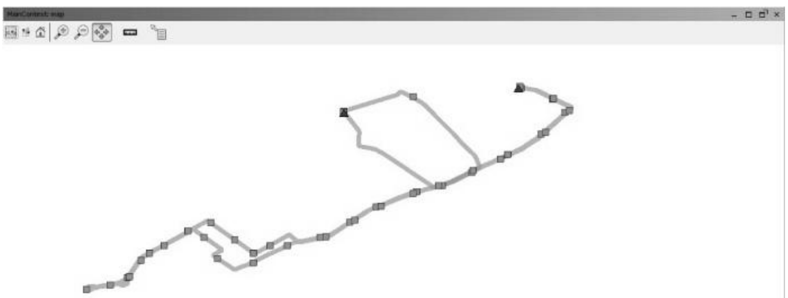

Figure 4 – Graphic representation of the agent-oriented simulation model of urban traffic on the route

The presented model was tested several times to find acceptable route parameters such as amount of public transport vehicle agents on the route, their passenger capacity and traffic intervals. Chernihiv trolleybus route #1 was chosen for performing the experiments. Let us set the ters for the first experiment. The quantity of vehicles is 3 trolleybuses, their passenger capacity – 20 people, and their traffic interval – 30 minutes. Fig. 5 demonstrates the diagram of number of passenger at all stops on the route in the first experiment.

So, the first experiment demonstrates that there are many passengers waiting for the trolleybus at the stops. This indicates that the route parameters are not acceptable and need changing.

Let us set the route parameters for the second experiment. Let the quantity of vehicles be 4 trolleybuses, their passenger capacity – 40 people and their traffic interval – 20 minutes. Fig. 6 demonstrates the diagram of number of passengers at all stops of route in the second experiment.

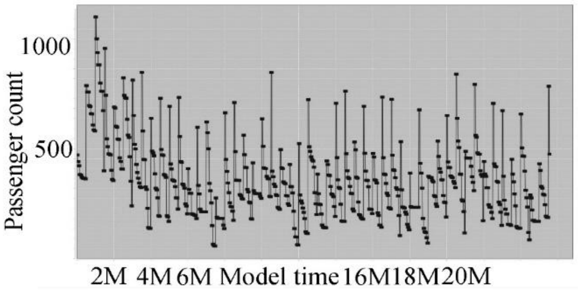

Figure 5 – The diagram of number of passengers at all stops on the route in the first experiment

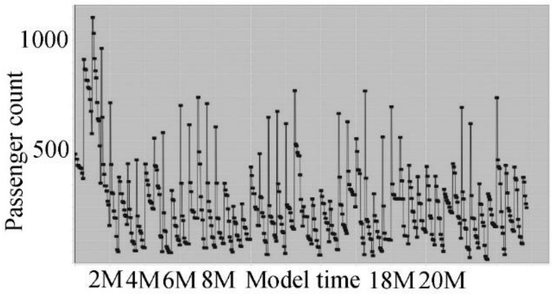

Figure 6 – The diagram of number of passengers at all stops on the route in the second experiment

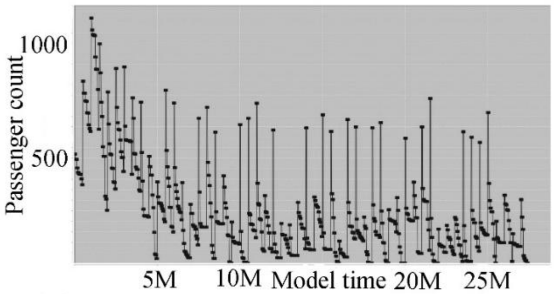

Figure 7 – The diagram of number of passengers at all stops on the route in the third experiment

In the second experiment, the number of passengers waiting for the transport at the stops reduced in comparison with the first one. Consequently, the route parameters for the second experiment are better than the route parameters for the first one but they still can be improved.

Let us set route parameters for the third experiment. Let the quantity of vehicles be 6 trolleybuses, their passenger capacity – 45 people, and their traffic interval – 35 minutes. Fig 7 demonstrates the diagram of number of passengers at all stops on the route in the third experiment.

In the third experiment, the number of passengers waiting for the transport goes to zero. Consequently, the route parameters for the third experiment are the most acceptable among all the experiments.

7. Conclusions

The work solves the actual task of developing the automated public transport management system using the agent-oriented model. In addition, it offers the architecture of the automated public transport management system and creates the agent-oriented simulation model of public transport routes.

The scientific novelty of the work is in the development of the method of finding the acceptable route parameters, which, in contrast to existing methods, uses the agent-oriented simulation model that allows reducing waiting times for passengers, costs of its use and the number of passengers at stops.

The practical value of the results obtained is that the developed automated system of city transport management allows saving money by optimizing the number of passengers and passenger capacity of public transport vehicles, while improving the quality of passenger service.

The system can be used by any city having public transport.

Further development of the proposed automated system and the models is possible in the direction of applying other more informative criteria of acceptability while modeling the parameters of public transport routes.

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