Optimization of Autonomous Vehicles Movement in Urban Intersection Management System

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Abstract—**With the growing number of cars in the world, there are corresponding problems that society needs to solve. In metropolises, intersections are generators of traffic jams and traffic accidents. The introduction of unmanned autonomous vehicles is one of the solutions, however, it is necessary to optimize their movement. In this paper, authors propose a model of the functioning of the intersection management system. The aim of the system is to organize a conflict-free, safe and optimal traversal of unmanned vehicles within the framework of the intelligent transport system of a smart city. The model assumes that at each intersection there are objects of transport infrastructure responsible for building routes at the intersection. To assess the feasibility of the presented model, the authors developed a software simulator of a network of urban intersections and conducted experiments. Based on simulation experiments, the use of the developed model can significantly reduce the time spent by unmanned vehicles to overcome the intersection compared to a traffic lights.**

I. Introduction

In recent years, technological advances in the automobile industry have led to cheaper and widespread private cars. According to ACEA [1], in 2018, 40.4 million passenger cars were sold worldwide, which is 3.7% more than in 2017, while only one of the 60 cars sold in the European Union runs on electricity.

The annual mortality rate in traffic accidents, traffic jams and the depressing state of the environment in major cities force the society to take measures to resolve these issues. If air pollution can be managed through a gradual transition to electric cars, reducing mortality in road accidents and congestion on roads requires more comprehensive measures. For example, in Sweden, since 1997, the program Vision Zero [2] has been implemented in order to reduce fatal accidents. The program is based on the statement that no matter how ideal a driver is, he can always be mistaken, and those who design, build and maintain roads, as well as car manufacturers, must bear responsibility. The result of the program was the reduction of fatal accidents from 1997 to 2017 by 46.7%.

In the context of the development of intelligent transport system (ITS), mechanisms are actively developed and applied that are capable of dynamical adjusting to the current situation on the road and regulate traffic depending on it. For example, methods such as Mainline Control, Ramp Control, Variable Speed Limits (VSL), etc. are used. VSL is one of the main components of traffic control on highways. The purpose of VSL is adaptive regulation of vehicle speed depending on weather conditions, road repairs, highway congestions, etc. However, the study [3] showed that the use of such a system does not cause any significant changes in the traffic situation both immediately after use and after several-month implementation.

However, contrary to popular belief that traffic jams are associated only with the narrowing of the roadway due to the appearance of "bottlenecks", e.g. accidents, repairs, tunnel entrances, etc., congestion on the highway can appear literally from nowhere. In the work [4], the authors experimentally prove that traffic jams may appear due to a decrease in speed by one of the vehicles, which causes a chain reaction of all other vehicles on the highway in case of absence of bottlenecks.

One of the ways to combat traffic jams is the introduction of unmanned autonomous vehicles (AVs). In the work [5], the authors describe a phenomenon called "Traffic Wave", which arises as a result of exceeding the maximum capacity of the road segment by vehicles. To combat such situations, a method for introducing a Cognitive and Autonomous Test (CAT) Vehicle into a stream that is able to use special mathematical algorithms to control traffic is presented and experimentally tested. The authors emphasize that even the introduction of a single CAT Vehicle into a stream of 20 human-driven vehicles helps increase the capacity of a section of the road, reduce fuel consumption and reduce the number of situations in which vehicles need to brake.

In this article, autonomous cars are considered in the context of developing the smart city concept, where systems of interconnected objects function, based on the data transmitted by communication channels and obtained directly from the environment.

As part of the urban transport infrastructure, there are often intersections of one or more carriageways. Such intersections are the main bottlenecks in the city and are generators of emergency situations and traffic jams. This is due to the limited throughput of the intersection and the decussation of the trajectories of several vehicles at once. The use of traffic lights, in particular, adaptive to the current traffic situation, helps to improve the situation at intersections. However, in the framework of building ITS using AVs, the use of traffic lights is inefficient compared to using the Intersection Management system, which has been experimentally proven in studies [6], [7], [8], [9], [10].

In this paper, the authors propose to develop a model for organizing the concept of intersection management system for AVs at intersections in order to optimize the intersection throughput and improve traffic safety within the concept of a smart city. The authors propose the introduction of a variety of transport infrastructure objects (OTIs), located one at each intersection and able to communicate with each other. Working as a distributed system (in the system there is no central element responsible for the distribution and solution of problems), each OTIs solves the problem of optimizing only its own intersection. Failure of one of the OTIs will not affect the performance of the others.

The paper is organized as follows. The second section presents an overview of scientific research in the field of organization of AV control, examines the work of existing models and schemes for organizing the movement of AVs at the intersection. The model description, and the criteria for the operation of the intersection control system, are presented in section three. The fourth section describes the software simulator developed and the conditions of the experiments. Section five presents the main conclusions on the work done and tasks for future research.

II. Related Work

A. Overview of Autonomous Transport Development

The first trials of integrating AVs began in the 1980s, when DARPA (Defense Advanced Research Projects Agency) organized funds to support the research of AVs. In 2004, 2005 and 2007 DARPA held Grand Challenges, intended to demonstrate achievements in this field by dint of competitions among robotic cars [11].

In 1996 ARGO project was started at University of Parma dedicated to elaboration of car unmanned management system [12]. The vehicle prototype perceived and analyzed the environmental factors by dint of two low cost synchronized cameras, speedometer. ARGO car allowed three driving modes:

- manual: monitoring and logging driver’s actions;
- supervised: warning driver in dangerous situations;
- automatic: full system’s control without driver’s intervention.

In 2009 Google initiated the project related to self-driving cars [13]. Their systems use Google Street View and process data from there in artificial intelligence software. This software includes video cameras, LIDAR (Light Detection and Ranging Laser Imaging Detection and Ranging) position estimators, distance sensors.

The work [14] states prospects for the nearest several years relatively to the realization of AVs:

- Ford, Baidu, BMW and Volkswagen announced the release of AVs by 2021;
- Japanese government invested SIP-ADUS program, whose milestone by 2020 is elaboration of automated highway driving system;
- Tesla Inc. plans to develop a hardware platform for fully autonomous cars in 2020-2025.

In the boundaries of the smart city concept, it is vital to provide conflict absence among all the objects belonging to the system and optimized traffic in the roads. This paper considers conflict resolution and states the optimization task during passing the intersection.

B. Approaches to Intersection Management Tasks

One of the most widespread methods for intersection management is centralized control by dint of stop signs and traffic lights changing permitting and prohibiting signals during the determined time slots. The work [15] suggests Vehicle-to-Infrastructure (V2I) communication, where traffic light controllers, based on information provided by individual vehicles, adjust the signals to avoid traffic delays and collisions.

However, processing data from multiple vehicles and centralized decision-making can provoke significant lags in the infrastructure work. Thus, the authors of [16] offer intersection protocols built on Vehicle-to-Vehicle (V2V) communication:

- Maximum Progression Intersection Protocol (MP-IP): states the task of increasing the intersection throughput and determines the passage safety as a primary goal; in case this goal is not violated, even potentially conflicting cars can pass through the intersection.
- Advanced Maximum Progression Intersection Protocol (AMP-IP): is based on the MP-IP with a possibility of allowing low-priority cars to overcome the intersection before the arrival of higher-priority vehicles to the cell of conflict.

Another V2V system was elaborated in [17]. The authors proposed conflict resolution algorithm that is more flexible in comparison with the protocols above. The vehicles approaching to the intersection share information about desired time to occupy the conflict zones. The flexibility consists in the opportunity of choosing the speed profile and, based on it and data obtained from other cars, recalculate estimated time of conflict zone occupation avoiding delays and collisions. By dint of these local decisions, the global solution for passing intersection is generated.

In 2004, Dresner and Stone in [18] for the first time presented a mechanism, based on the reservation of space-time sections by system agents. The results of the experiments showed that such a mechanism for organizing traffic allows two to three hundred times to exceed traffic lights. The authors continued to engage in active research in the field of unmanned vehicles, their ideas are represented in a series of works [19], [20], [21], [22], [23] on traffic control at intersections. A complete final formal description of their scheme was found in the work [9] which described an intersection management system in terms of a multi-agent approach. The authors also described the developed protocol for data transfer between AVs and infrastructure objects. The results of experiments presented in the paper allow us to conclude that the use of the reservation-based mechanism contributes to a significant increase in intersection throughput. Also, the authors have provided additions to their algorithm, with the help of which it is possible to introduce human-drivers and emergency vehicles into the system.

In [24], the authors described a method for optimizing traffic at a crossroads using vehicles equipped with a cooperative adaptive cruise control (CACC) system. The paper describes

s_{1}	s_{2}	s_{3}	s_{4}	s_{5}	s_{6}	s_{7}	s_{8}	s_{9}	s_{10}
s_{11}	s_{12}	s_{13}	s_{14}	s_{15}	s_{16}	s_{17}	s_{18}	s_{19}	s_{20}
s_{21}	s_{22}	s_{23}	s_{24}	s_{25}	s_{26}	s_{27}	s_{28}	s_{29}	s_{30}
s_{31}	s_{32}	s_{33}	s_{34}	s_{35}	s_{36}	s_{37}	s_{38}	s_{39}	s_{40}
s_{41}	s_{42}	s_{43}	s_{44}	s_{45}	s_{46}	s_{47}	s_{48}	s_{49}	s_{50}
s_{51}	s_{52}	s_{53}	s_{54}	s_{55}	s_{56}	s_{57}	s_{58}	s_{59}	s_{60}
s_{61}	s_{62}	s_{63}	s_{64}	s_{65}	s_{66}	s_{67}	s_{68}	s_{69}	s_{70}
s_{71}	s_{72}	s_{73}	s_{74}	s_{75}	s_{76}	s_{77}	s_{78}	s_{79}	s_{80}
s_{81}	s_{82}	s_{83}	s_{84}	s_{85}	s_{86}	s_{87}	s_{88}	s_{89}	s_{90}
s_{91}	s_{92}	s_{93}	s_{94}	s_{95}	s_{96}	s_{97}	s_{98}	s_{99}	s_{100}

Fig. 1. Example of splitting an intersection into elementary sections

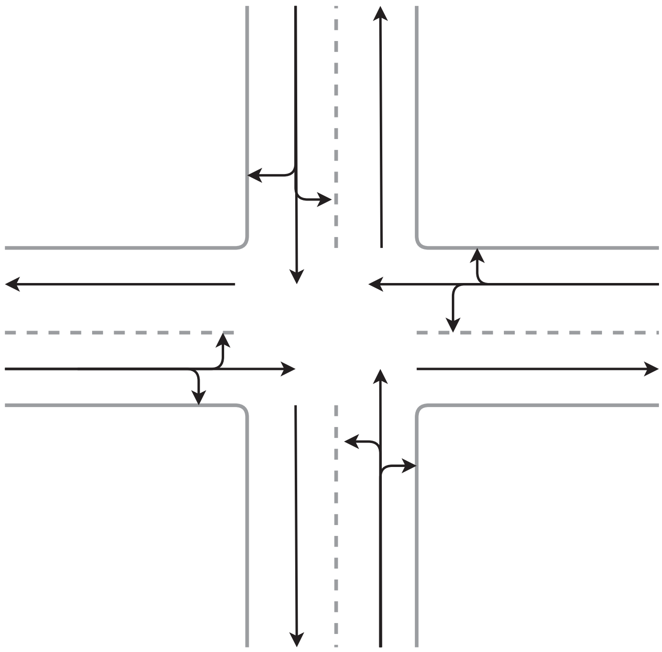

Fig. 2. Scheme of traffic organization at an intersection

in detail the scheme using the developed approach, the ways of communication among vehicles and objects, which allow real-time control of traffic at the intersection. In addition, the authors also presented mechanisms that give a possibility to simulate the influence of weather conditions on the current traffic situation. The results of the experiments showed that the use of CACC compared to the intersection, adjustable by traffic lights and all-way stop control can significantly reduce the time spent by vehicles on travel and fuel consumption.

An interesting solution, based on economics and the use of auctions suggested in the work [25]. The basis is the method of reserving sections of the space of time, presented in [9]. The authors presented a description of the developed method both for the case with one intersection, and for the case with a network of intersections using decentralized mechanisms. The price policy of elementary sections at intersections depends on its capacity, the higher it is, the higher the price of the bid for a vehicle to reserve it is. Experiments with a network of intersections have shown that using the auction allows to more evenly distribute vehicles on the road network, which helps to balance the load and reduce the time spent on overcoming the loaded intersections.

In [26], the authors draw attention to the fact that using the multi-agent approach and the first-in-first-out (FIFO) mechanism, you can further improve the efficiency of the system by optimizing the sequence of the vehicle arrival for the time-reserved sections at the intersection. The paper describes the system operation scheme and the system of planning a vehicle trajectory, based on previous studies by the authors, as well as a description of the work and the criteria for optimal scheduling approach. Simulation results using SUMO (Simulation of Urban Mobility) illustrated that using the developed approach can significantly reduce the time spent by vehicles to cross the intersection compared to a simple FIFO.

Another interesting approach using the collective strategy for managing a group of vehicles when passing through the intersection, was presented in [27]. The authors also used a multi-agent approach and divided groups of cars approaching the intersection into small groups called "platoons" in the work. The first car entering the communication zone is defined as the leader vehicle agent (LVA). The rest of the vehicles approaching the intersection join the group headed by the LVA, transfer their data to it and obey the commands received from it. The LVA, in its turn, communicates with the intersection manager, transmits data on all vehicles of the group and receives information on the reservation of space-time sections for the group at the intersection. The simulation results showed that the presented scheme helps to significantly reduce the load on the communication channel, compared with the scheme, when the intersection manager communicates directly with each vehicle.

In this paper, the system of AVs is proposed allowing V2I/I2V and V2V communication. The optimization task includes several parameters and is adapted for functioning in the grid of connected intersections within the smart city.

III. Intersection Management System Mathematical Model

The elaborated model includes vehicles and infrastructure elements, determined as $V = \{v_1, v_2, ..., v_n\}$ and $I = \{i_1, i_2, ..., i_m\}$, respectively. Each infrastructure object can interact with multiple vehicles, at the same time, meanwhile a particular vehicle v_j can interact with only one infrastructure object i_h.

The city is divided into regions, and for each one a separate infrastructure object responsible for this region's control is set. Entering to a particular region, the vehicle communicates with its infrastructure facility and this facility gets information about the vehicle from another infrastructure objects.

During the motion process, to provide operative reaction to the emergency situations, vehicles inside the determined radius at the end of each conditional time discrete transmit data to each other containing information about their technical state I_{cts}, planned route I_{route} and environment I_{env}. The information possessed by i^{th} vehicle can be classified as own and acquired. Directly before information exchange, in the z^{th} time period, the vehicles' knowledge is represented, as in (1) and (2):

$$I_{\text{own}_i} = I_{\text{cts}_{[t_{z-1},t_z]_i}} \cup I_{\text{route}_{[t_{z-1},t_{z+d}]_i}} \tag{1}$$

$$I_{\text{acquired}} = I_{\text{env}_{[t_{z-1},t_z]_i}}, \tag{2}$$

where $i \in [1, N]$, N is the number of vehicles in the determined radius in the z^{th} time discrete, d - discrete amount covering the planned route.

After the information exchange process, each vehicle, as part of the acquired data, has records gathered by other cars. It is illustrated by (3):

$$\begin{aligned} I_{\text{acquired}_i} &= I_{\text{env}_{[t_{z-1},t_z]_i}} \\ &\cup \left(\cup_{j=1}^{N, i \neq j} \left(I_{\text{env}_{[t_{z-1},t_z]_j}} \cup I_{\text{cts}_{[t_{z-1},t_z]_j}} \right) \right) \end{aligned} \tag{3}$$

The total area of passage sectors can be represented as sum $S = s_1 + s_2 + ... + s_k$, where s_a, $a \in [1, k]$ is area of the a^{th} sector. An example can be seen in Fig. 1. There are two variants of allocating these elementary sectors in the city:

1) $s_a \cap s_b = \varnothing$, $a \neq b$
2) $s_a \cap s_b \neq \varnothing$, $a \neq b$

The research task statement consists in organizing the movement of AV within the city and building the optimal route, in which the factual time t_v of the vehicles movement tends to minimum $t_v \to min$. The etalon time $\widetilde{t_v}$ is the vehicle's movement time in case of absence of obstacles. Thus, $t_v \to \widetilde{t_v}$ $\forall\ v \in V$.

Factual movement conditions that include obstacle presence can be described, as following: t_z – z^{th} time point, $P_{v_i} = \left\{ p_{v_i}^1, p_{v_i}^2, ..., p_{v_i}^l \right\}$ – the distance traveled by the vehicle during its travel time t_v. Then $\exists t_w : P_{v_i}^{t_z} \cap P_{v_j}^{t_z}$.

Neighboring infrastructure objects interact with each other, and generate a route for the vehicle v_i, in the zone under infrastructure facility i_h, i_h takes information from the neighboring i_g, which v_i passed before.

The authors of this article identified the following criteria for overcoming a group of connected intersections by AVs:

- the number of cars waiting for crossing the intersection tends to minimum at each intersection;
- the factual vehicle's speed is close to the expected when driving in the city and when passing the intersection;
- the area of occupied space s_{occ} at the intersection tends to minimum;
- the time for a vehicle to cross an intersection at real speed tends to minimum;
- the total time spent on overcoming the constructed route with factual speed tends to minimum.

The enumerated points can be expressed in (4), respectively:

$$\begin{cases} n_{\text{waiting}} \to min \\ speed_i^{\text{factual}} \to speed_i^{\text{expected}}, i \in [1, n] \\ \sum_{u=1}^{U} s_{occ_u} \to min \\ t_{\text{intersection}_i} \to min, i \in [1, n] \\ t_{\text{route}_i} \to min, i \in [1, n] \end{cases}, \tag{4}$$

where U is amount of elementary sectors at the intersection.

Thus, AVs and OTIs perform interdependent functions. AVs collect and exchange data about their technical condition, movement and environmental state, store a plan of the city zone, along which the route passes. OTIs accumulate information about the system, develop a plan for local and global optimal plans for the movement of vehicles in the city, monitor the performance of tasks by means of transport, and control the activities of other infrastructure objects if the city or vehicles they control are common.

IV. Experiment Setup and Results

There are many different software solutions for simulating the behavior of traffic control systems. Most of the tools for professional modeling are paid and are mainly suitable for commercial use with free trial demo-versions. Such products are not quite suitable for achieving the goal in the course of this study, namely, to compare the effectiveness of the proposed traffic control model at the intersection with traffic lights using affordable methods. Such paid solutions have broad functionality and are actively used in transportation engineering for proper planning during the construction of new roads and highways as well as modeling possible scenarios for traffic changes during the development of urban areas. Some of the simulators (PTV Visum [28], Aimsun Next [29], etc.) allow to create models of the inter-modal transport network with two or more modes of transport, which is a necessary function when assessing the impact of different models connected to each other and working simultaneously. It is worth noting that some paid products are developing rapidly and regularly add new features. For example, in Aimsun Next and PTV products, the possibility of introducing AVs into the system along with human-drivers to simulate road traffic recently appeared [30], [31].

There are also a number of free tools that allow to simulate road traffic. However, such tools do not always provide the possibility of in-depth analysis of data in both microscopic and macroscopic mode, the ability to implement own variables and characteristics of vehicle movement, separation logic and motion optimization parameters. Against the background of free solutions stand out SUMO (Simulator of Urban Mobility) [32]. In future studies, the authors plan to use SUMO for a comparative analysis of the effectiveness of the presented

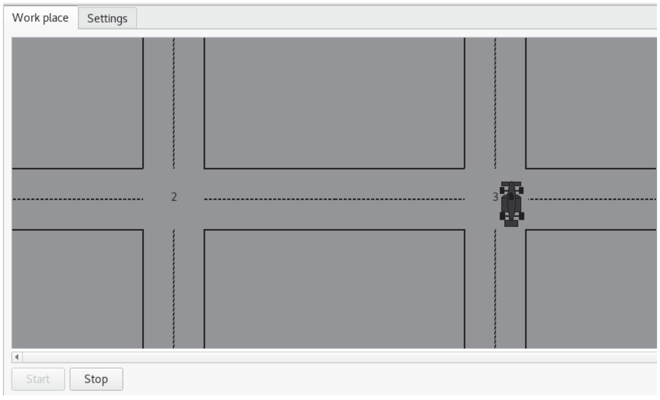

Fig. 3. General view of the graphical interface of the simulator

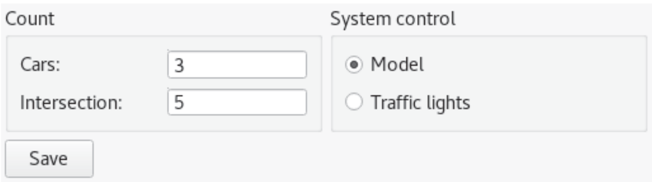

Fig. 4. An example of the settings entered for the simulation

model of a traffic control system at an intersection with other existing models.

A. *Simulator Description*

In order to assess the feasibility of the presented model, the authors developed a software simulator of the intersection management system. The main goal of the work is to evaluate the effectiveness of the developed model both at one intersection and immediately at a set of interconnected intersections. The developed simulator allows to generate several interconnected intersections of the urban road network, vary the current load on the road network, save data on the traffic intersection (the amount of time spent by all AVs on overcoming the route). Figure 2 shows schematically the organization of traffic at the intersection. As a traffic control system at the intersection, the simulator gives a possibility to use both traffic lights and the developed model.

The main window of the simulator is shown in Fig. 3. Before starting the simulation, it is necessary to configure the settings: enter the number of intersections and the load on each of them (Fig. 4), as well as select the method of traffic control. According to the results of the work, the simulator allows to obtain data on the travel time of intersections by all AVs (Fig.5) and upload them to the database.

When starting the simulator, a window is created, as well as tabs are created (main tab and settings tab). In the main window, a field is created for displaying intersections, the ”Start”, ”Stop” buttons and ”Label” button to show the results of the simulator. In the settings section, it is possible to enter the conditions of the simulation: the load on the intersections, the number of intersections and choose the traffic control system used.

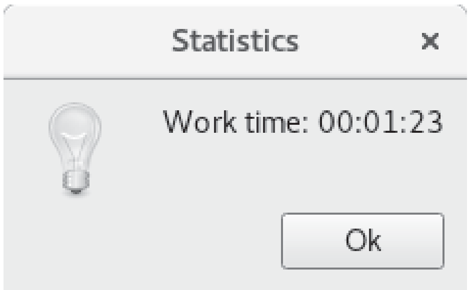

Fig. 5. Simulation data window

B. *Description of the experiment and simulation conditions*

As a comparison with the traditional traffic control system - traffic lights, two real intersections connected together were taken. Intersections are located in Russia, Petrozavodsk: the intersection of Lenin Ave. and st. Kirov [33] and the intersection of Lenin Ave. and st. Kuibyshev [34] (see Fig. 6 and 7). These intersections are marked on the map presented in Fig. 8. These intersections were chosen because of the high-quality web cameras installed on them and the ability to view the archive of videos over the past few days. The load on each intersection was assessed. In the interval for the assessment, the peak morning hour was chosen from 08:00 to 09:00, 05.02.2019. According to the camera records, it was empirically determined the load of intersections Q. At the intersection of Lenin Ave. and st. Kirov $Q_1 = 2404$ vehicles per hour (veh/hr), at the intersection of Lenin Ave. and st. Kuibyshev $Q_2 = 2531$ veh/hr. Traffic lights at intersections have the following work cycles. For the convenience of describing the cycles, the roads on the intersection are named A, B, C, and D (Fig. 6 and 7). At the intersection of Lenin Ave. and st. Kirov:

- B→C: 18 seconds of green light phase. For other directions - red signal;
- A→C, C→A, D→C, C→D: 30 seconds of green light phase. For other directions - red signal;
- D→B, B→D, A→D, D→A: 32 seconds of green light phase. For other directions - red signal.

At the intersection of Lenin Ave. and st. Kuibyshev:

- C→B, B→C: 20 seconds of green light phase. For other directions - red signal;
- A→C, C→A, A→B, C→D: 27 seconds of green light phase. For other directions - red signal;
- B→A, B→D, D→B, D→A, A→D: 35 seconds of green light phase. For other directions - red signal.

It is worth noting that at each of the intersections there is a 2 seconds of yellow phase between the red and green signals and between the green and red signals.

To enable the experiment and assess the effectiveness of the model, the following assumptions were introduced:

- AVs move strictly according to certain rules of the road;
- the field model is spatially limited;

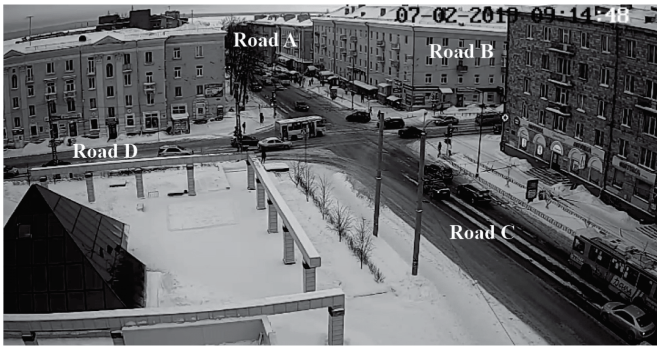

Fig. 6. View of the intersection of Lenin Ave. and st. Kirov

Fig. 7. View of the intersection of Lenin Ave. and st. Kuibyshev

- only one AV can occupy one elementary section;
- in the event of a conflict, when two cars pretend to one elementary section, the cars drive off according to the following criteria (5):

$$\begin{cases} Y = \dfrac{\sum_{l=1}^{L}\sum_{j=1}^{N}\sum_{i=1}^{M} n_{lji}}{M} \\ n_{lij} = \begin{cases} 1, \text{if } j^{\text{th}} \text{ AV is situated at the } i^{\text{th}} \text{ time discrete on the } l^{\text{th}} \\ \text{elementary sector, } n_{lji-1} \neq n_{lji} \\ 0, \text{otherwise} \end{cases}, \\ Y \to max \end{cases} \quad (5)$$

  where N is number of AVs, passing the intersection; L – number of elementary sections at the intersection; M – amount of time discretes, for which N AVs passed the intersection;
- it is assumed that communication channel is ideal i.e. at each intersection there is a OTI installed, and informational messages from the AVs to the OTIs and backwards are delivered without delays, interference and errors.

C. Simulation process and results

For safety reasons, a speed limit of 32,4 km/h was taken as a speed limit at intersections (this number was determined on the basis of the experiments performed). Average AV's length was defined as 4,5 meters. After a series of experiments, data on traveling time t of all vehicles at the intersection was obtained. The time was received in seconds and converted to minutes. Comparison of time with real intersections is given in Table I. Thus, within the framework of this study, it can be concluded that the developed model is appropriate. The system allows to pre-allocate routes between the AVs at the intersections, thus reducing the likelihood of moments when vehicles need to slow down at the intersection.

Fig. 8. Crossroads of Lenin Ave. and st. Kirov (upper circle) and Lenin Ave. and st. Kuibyshev (lower circle) in Petrozavodsk, Russia

TABLE I. COMPARISON OF THE RESULTS OBTAINED IN THE SIMULATION WITH REAL INTERSECTIONS

Q (veh/hr)	t (min), traffic lights	t (min), model	Improvement
$Q_1 = 2404$	60	20,016	66,6%
$Q_2 = 2531$	60	21,1	64,8%

Due to the fact that all AVs move in accordance with the developed model on optimal, predetermined routes, they do not waste time stopping at the intersections and skipping other AVs, since they also have defined optimal conflict-free routes. During the experiment, it was also determined that it is possible to increase the throughput of Q on one intersection. In the developed simulator, one intersection can pass through an average of $Q = 7198$ AVs per hour, which is more than 60% more than at real intersections with traffic lights.

V. CONCLUSIONS AND FUTURE PROSPECTS

This paper presents a description of the functioning model of intersection management system within the ITS of a smart city. The main goal of the developed model is to ensure a conflict-free and optimal traversal of AVs at the intersection, and provide a balanced load among all the intersections within the city. The authors developed and described a mathematical model, conditions and performance characteristics. To evaluate the effectiveness of the intersections controlled on the basis of the model, a software simulator was developed. The proposed model was compared to the model of traffic light control. The comparison results led to the conclusion that the use of the developed system in the framework of this study can significantly reduce the time spent by AVs on the passage of the intersection and support a balanced road loading in the boundaries of the smart city.

It is obvious that the simulator requires significant refinement for the accuracy of the data obtained and the approximation of experiments to real conditions. In future studies, the authors plan to improve the simulator to organize more realistic and detailed experiments (adding traffic signs, road marking, increasing road lanes, more realistic behavior of AVs), elaborating information security functions for the system and the possibility of conducting experiments with more realistic communication protocols. The authors also plan to compare the performance of the presented model with other existing models and conduct experiments in various traffic simulators.

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