UDC 519.872

On modeling the traffic of vehicles through the road intersection of a smart city

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The relevance of the research topic is determined by the increasing role of information and communication technology (ICT) systems and services usage in all spheres of life - culture, education, healthcare, transport and trade. We live in a society where mobile, broadband and cloud computing change the structure of society and promise the great opportunities for its inhabitants. The development of the human activity field will depend on the progress achieved through the information and communication technology (ICT) systems and services usage. ICTs can play a key role in smart transport management; utilities and electricity supplying; measuring pollution levels; health care and education management, innovative management of agriculture. All of the above-mentioned systems form a "smart" society. By 2050, a significant part of the world's population will be living in cities, and the proportion of urban residents will reach approximately 70%. For the timely provision of quality urban services requires the introduction of various information systems.

Key words and phrases: infocommunication system analysis, smart city, traffic flow, transport network, traffic flow modeling.

In: K. E. Samouylov, L. A. Sevastianov, D. S. Kulyabov (eds.): Selected Papers of the 12th International Workshop on Applied Problems in Theory of Probabilities and Mathematical Statistics (Summer Session) in the framework of the Conference "Information and Telecommunication Technologies and Mathematical Modeling of High-Tech Systems", Lisbon, Portugal, October 22–27, 2018, published at http://ceur-ws.org

1. Introduction

The phrase "smart society" is often used as a term describing the vision of a plan for the future of a nation or region to achieve a developed information society. An analysis of the various approaches to the definition of "smart" society shows that in this diversity the emphasis is placed on different aspects. Let's give some examples:

Society 5.0 is a society that will contribute to the prosperity of humanity. This society is able to provide the necessary data and services to people at a given time and only in the right quantity; society, capable of engaging a wide range of social needs; a society in which all people can easily receive high-quality services, despite their age, gender, region and language, as well as live an energetic and comfortable life [1].

The term "smart" means a society that is economically and environmentally sustainable without sacrificing the comfort and quality of life of its citizens. It is a convergence of physical and digital infrastructure, where the use of ICT makes life more efficient and sustainable.

The majority of the world's population lives in cities, which leads to the creation of a complex urban environment with complex processes. It is precisely these difficulties and the importance of their solution that determine such attention to the concept of smart cities.

Smart Sustainable City is an innovative city that uses information and communication technologies and other means to improve the quality of life, work efficiency, service and competitiveness, while meeting the needs of city residents in relation to economic, social and environmental aspects.

The trend of urbanization and the increase in the planet population leads to problems that can be solved through the effective resources allocation and the urban system rational management. Thus, many countries set themselves the task of implementing an intelligent society projects.

Congestion can completely paralyze the movement of vehicles in a large area and on a single road. Owners of cars and passengers of public transport suffer from traffic jams. The problem of car congestion negatively affects on the economic and environmental situation, as well as the health of people.

There are several causes of traffic jams: the number of vehicles exceeds the capacity of the road; the road network inefficient operation (road markings, signs, operation mode of traffic lights), inconvenient road interchanges, the lack of overhead/underground passages and detours for freight transport; violation of traffic rules by vehicles and pedestrians; repair and construction work; accidents and inadequate technical condition of cars and poor road conditions; lack of parking spaces; adverse weather conditions [2].

The transport flow is considered as the result of the interaction of vehicles on the elements of the transport network in mathematical models. Due to the rigid nature of network restrictions and the massive passage in a traffic flow, distinct patterns of queue formation and intervals, loads along the road lanes etc. are defined.

Thanks to transport modeling, rational management of the urban system, construction of new and reconstruction of existing roads are possible. In this case, the queueing theory is used to build a mathematical model of a regulated intersection. Although, automobile traffic has been studied for half a century, but these studies are not often used in practice due to instability, the diversity of traffic flow and the need to expand the number of parameters [3]. To obtain the optimal solution of transport issues, specialized equipment and software are required, which makes it difficult to quickly implement such systems in Russia.

Lifestyle and workflow change due to technological advances. More and more, physical and virtual areas of our life are becoming intertwined due to the introduction of the interconnection of machines (Internet of Things, M2M, wearable technology, intelligent live and wireless computing).

In addition to things that can be connected to each other, neural networks will play a special role - technologies that are capable of self-learning, receiving the necessary information from the Internet. The Internet, based on artificial neural networks, is called neuronet.

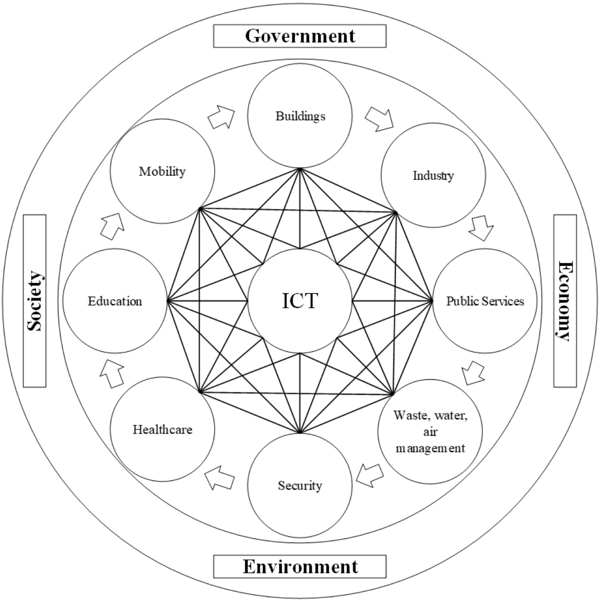

Figure 1. The lifecycle of the city

Data prediction, analytics, large data sets, open data, data availability and management, data security, mobile broadband, wireless sensor networks - all these aspects have become essential in society.

Due to the significant role of ICT in solving the problems of creating smart cities and, moreover, smart societies, it is necessary to emphasize the important role of software tools used to introduce relevant services. The criteria for such applications include the following: expediency, reliability, security, confidentiality, practicality.

The above four pillars work through the physical and service infrastructures that form the lifecycle of the city (Fig. 1).

Nowadays, the rapid growth of cars leads to the decrease in the capacity of the road network. For many large cities, this problem is the painful one and that is why it requires an urgent solution [4]. The main reasons of traffic jams are improper operation of traffic lights and inconvenient interchanges, as well as adverse weather conditions that make driving difficult.

That is why, this task is relevant in the framework of the well-known concept of the smart city [5]. The definition of "smart" transport system is related to the system that consists of separately modeled sections, which are then compiled and transported into a single knowledge base. Due to the continuous monitoring and incoming information from the road management services, the information and mathematical model is periodically adjusted and the level of service provision in cities increases. The simulation allows to evaluate the effectiveness of the city's transport network management and identify potentially problematic areas for their repid elimination [6]. This paper gives a brief overview of the method and numerical analysis, which will then be used in further studies on the optimization of traffic flows in a smart city [7].

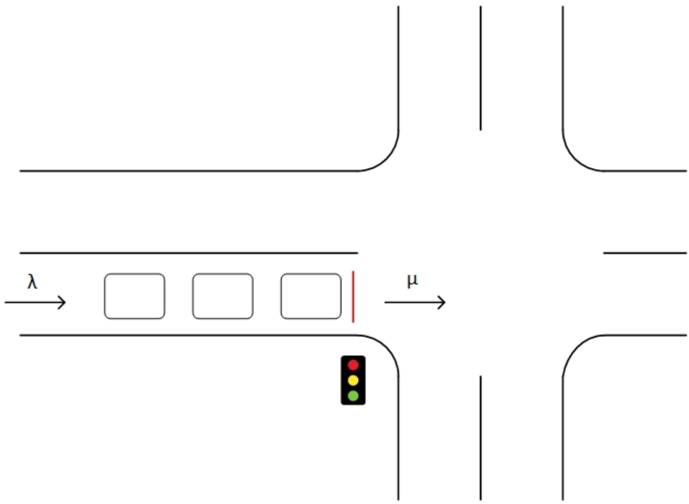

Figure 2. Stream of cars at a crossroad

2. Main section

In this article a model that describes the vehicles passage through a regulated intersection as a queuing system with variable service intensity and a limited queue is described (Fig. 2).

We consider that the traffic light has two states: the red light is on, then the passage is prohibited, and the green light is on. The number of service channels is determined based on the number of lanes for the intersection passage in one direction and is equal to one.

The model has a limited capacity N that can fit throughout the selected quarter. In this way,

$$N = \frac{L}{l} m$$

where L – is the length of the block, l – is the average length of the car, m – is the number of lanes. The number of places in the queue varies from 10 to 30 cars on average. It should be considered that the car, which has occupied the whole quarter, will leave the system.

The main parameters of the system are: T - the length of the full traffic light cycle (the length of the "green" phase $\tau = \frac{T}{2}$); λ is the intensity of the arrival stream; μ_0 is the intensity of the service flow in the "green" phase; N is the maximum queue length. For instance, the service intensity $\mu(t)$ has an periodical form and shown in Figure 3:

$$\mu(t) = \begin{cases} \mu_0 & , kT \le t < kT + \tau, \\ 0 & , kT + \tau \le t < kT + T. \end{cases}$$

where $k = k(t) = [t/T]$ – the quantity of traffic light cycles, $[x]$ – the integer part of number x, μ_0 – an intensity of passage through intersection on a green traffic signal.

According to the fact that the service intensity is piecewise constant, the Queuing System can be in different states:

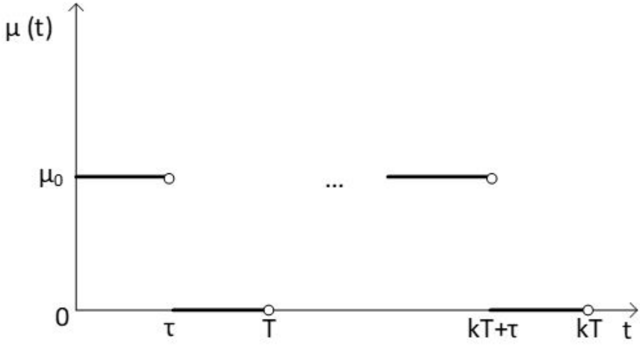

Figure 3. The intensity of the car passage through the intersection

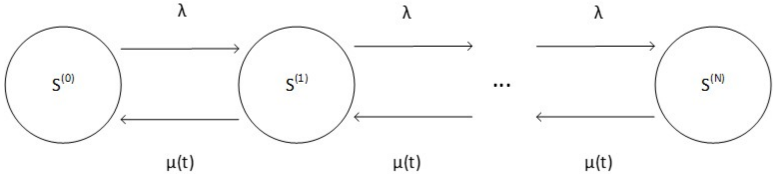

Figure 4. System state graph for the one direction

$S^{(0)}$ – there are no cars in front of the stop line,
$S^{(1)}$ – one car drives through a crossroads,
$S^{(2)}$ – one car drives through a crossroads, one is in front of the stop line and so on,
$S^{(N)}$ – all places in the queue are occupied.
The state graph of the system is shown in the Figure 4.

The probability of the n-th state of the system S at a t moment of time is denoted as $p_n(t)$. In this case, the normalization condition $p_0(t) + p_1(t) + ... + p_N(t) = 1$ is necessarily satisfied. The system can be solved numerically for different input data using well-known software tools, and the main characteristics of the Queueing System can be determined for it at a given operation mode of a traffic light.

The considered queuing system makes three quality decisions: 1. Free passage in a given direction. The mode is characterized by high probabilities of states S_0 and S_1 at the end of the green phase $N_1 < N_2$.

2. Difficult passage. The mode is characterized by a low probability state $S_(n+1)$ at the beginning of the inhibit signal $N_1 = N_2$.

3. Clogging. The mode is characterized by a high probability of the state S_n at the beginning of the inhibit signal $N_1 > N_2$.

$$N_1 = \lambda T$$

$$N_2 = \mu\tau$$

N_1 - the average number of approaching cars for a full cycle,

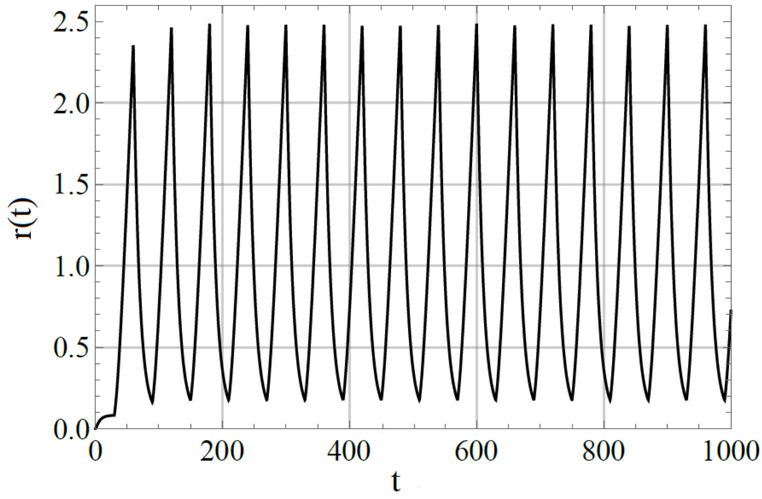

Figure 5. The average number of cars in the queue at $\tau = 30$

N_2 - the average number of cars driving on the green light.

The paper also provides an example of numerical analysis. The average length of the machine queue at the intersection

$$r(t) = \sum_{n=1}^{N} (n-1)p_n(t),$$

was calculated. To do so, the system of Kolmogorov's differential equations was solved and a stationary distribution was found.

To calculate the parameters of the model, the closed to real life baseline data were taken. The intensity of the arrival stream is $\lambda = 0.15$ cars per second, the average time of the intersection passage equals to $(\mu)^{-1} = 2.5$ seconds, the length of a full cycle of traffic lights is T=60 seconds, the permissible queue length of cars is $N = 10$.

In order to investigate the dependence of the queue length on time, several cases with different duration of the green phase were considered. In the first case, let‘s consider that the green phase is $\tau = 30$ seconds.

At the same time, at the initial moment of time the quarter is empty, therefore the initial probability distribution of the systems states: $p(0) = (1, 0, ..., 0)^T$.

Figure 5 presents the results of finding the main characteristics of the system - the average number of cars waiting to travel through the intersection.

In the second case, by changing the duration of the green signal to $\tau = 0.8T = 48$ seconds, the average queue length will decrease. So, it does not go beyond the limits of one car, as can be clearly seen in Figure 6.

The last considered case ($\tau = 0.2T = 12$ seconds) shows that cars have not enough time to cross the road in such a short period of time. This leads to a blockade of cars at the intersection, forming a traffic jam that consists of 6-8 cars in average (Fig. 7).

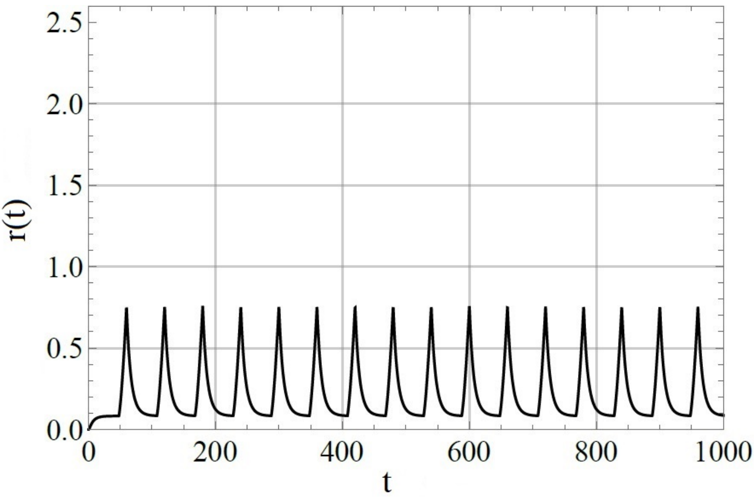

Figure 6. The average number of cars in the queue at $\tau = 48$

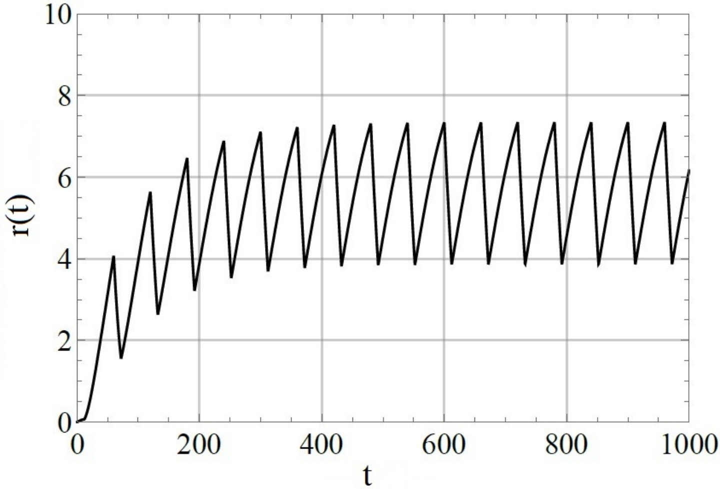

Figure 7. The average number of cars in the queue at $\tau = 12$

3. Conclusions

Traffic modelling plays an important role in improving the traffic situation. The paper presents the results of monitoring the time distribution of the intersection crossing by cars. It depends on the time elapsed from the beginning of the enabling signal. Also, the methods of mathematical modeling were used. In the future, it is planned to study models that allow creating routes which takes into consideration the indication of stopping places, overtaking. Moreover, the team would like to implement a data processing system and coordinating schedules [8, 9].

It is impossible to create an intellectual society without using digital inclusion technologies. They allow to achieve maximum efficiency by combining vast distances in order to bring in a sustainable way the knowledge, help and resources to those who need it.

It is expected that such a society will develop and implement an environment in which people, robots and artificial intelligence will coexist and work to improve the quality of life, offering finely differentiated personalized services that meet the diverse needs of users. The trend of urbanization and the increase in the population of the planet leads to problems that can be solved through the effective allocation of resources and the rational management of the urban system. But every year the development of cities faces a lot of problems: provision of water, electricity, transport, etc. Thus, many countries set themselves the task of implementing projects of an intelligent society.

Summing up the research on “smart” services, we concluded that despite the great interest of scientists in this issue, not all countries are ready to provide an adequate level of infocommunication support and a legislative framework for the introduction of modern technologies into life. The main obstacles to the development of this issue are: firstly, the lack of clearly defined economic goals and objectives of innovation, secondly, the insignificant involvement of universities and research centers for the implementation of plans, and thirdly, the lack of a working process management system and the development of the digital economy. However, we are on the right track, and the development of the future depends on our ability to build an information-friendly culture, support the development of digitalization and invest in key infrastructure elements to create new open platforms and markets.

Acknowledgments

The publication has been prepared with the support of the “RUDN University Program 5-100” and funded by RFBR according to the research projects No. 18-00-01555, 19-07-00933.

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