Mobility and Road Safety Improvement by Optimizing Smart City Infrastructure Parameters: A Case Study

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Abstract. Accelerating urbanization leads to an increase in transport fleets. The road infrastructure does not have time to develop at the same pace, it gives rise to problematic situations in the field of organization and road safety. In order to solve these problems, an information managerial system has been developed. It aggregates information from several databases (information on traffic intensity, statistics of road traffic accidents, location and characteristics of infrastructure objects). Decisions are made on the basis of multivariate data analysis and computer experiments on simulated micro-models of the road network problem areas. The practical significance of the system lies in the ability to calculate the effects of the implementation of the proposed solutions at the stage of development of projects for the modernization and reconstruction of the road network parameters. The system can also be used for operational management decisions in the event of extreme situations in the city transport system (lockdown, public events).

Keywords: Information managerial system · Road mobility · Road safety · Simulation · Smart city

1 Introduction

The United Nations estimates that by 2050, 67% of the world’s population will live in cities [1]. Accelerating urbanization leads to an increase in the number of commercial and personal vehicles. At the same time, the road infrastructure does not keep pace with the increase in the vehicle fleet, which causes the appearance of problematic situations in road organization and safety. All of the above problems require changes in the organization of transport systems of urbanized territories, which are reflected in the Smart City concept.

Smart City is a system in which the existing city services resources are used in the best way, ensuring maximum safety of city life. The main goal of developing the idea of Smart City is to create a sustainable model for the development of cities and preserve...
the quality of their citizens’ life [2], therefore, a deeply integrated system is needed that meets the general concept of a “smart city”, which will take into account both the current needs of various city services and development prospects, taking into account all external factors.

According to the definition given by Institute of Electrical and Electronics Engineers [3], Smart City combines technology, government, and society to provide the following features: smart economy, smart mobility, smart environment, smart people, smart life, and smart management. The use of such technologies is aimed at improving the management of urban flows and quick response to complex tasks. Therefore, Smart City is more prepared for solving problems than with traditional relations with its citizens.

In accordance with the indicated problems, the article first highlights the features inherent in transport management in Smart City, as well as advanced approaches and methods for managing the transport system, ensuring increased mobility and, at the same time, the safety of its participants. Next, the concept of the proposed information managerial system, its structure and functionality is described. Finally, the results of testing the proposed system in the selected city is presented.

2 Problem Status: Existing Methods to Improve Mobility and Transport Security

2.1 Transport Management in Smart City

Intelligent traffic planning, the development and promotion of public transport, and improving the interconnectedness of all road users in citywide infrastructure are the main components of Smart City mobility [4].

Smart City is data driven, and data management enables municipal services to improve the quality of citizens’ life. In the ecosystem of smart roads, analysts include solutions for collecting and processing data about vehicles and road infrastructure in order to make decisions, including traffic flow detectors, adaptive (smart) traffic lights, means of automatic recording of traffic violations, electronic means of non-stop fare payment, parking meters, connected information boards, automated lighting control systems, other connected objects (for example, automatic road weather stations, road controllers, etc.) [5].

Many government departments have already accumulated quite large amounts of data (information on the qualitative and quantitative structure of transport fleets, drivers, traffic intensity, traffic violations, open data on road accidents and congestion) and now can use them for improving the quality of decisions [6].

There are smartphone applications that provide drivers with real-time traffic information, while other applications use communication between vehicles and transport infrastructure or provide special vehicle sharing services (so-called car-sharing and bicycle -sharing), which help to improve efficiency and safety on the road. The spread of the Internet also contributes to a decrease in traffic: the practice of remote work from home is becoming more widespread, online trading platforms are gaining popularity, and distance learning technologies are developing [7]. However, for online platforms to
be able to replace regular travel to work and study, good communication quality is necessary. At the same time, as the recent events associated with quarantine measures due to COVID-19 have shown, the quality of training during its transfer to a distance form was not properly ensured due to the lack of communication channels to high loads [8]. If we talk about the organization of a single information interaction between infrastructure, vehicles and pedestrians, then the tools and technologies that provide them, due to their high cost [6], will not soon be introduced into medium and small urban settlements, especially in developing countries. On the other hand, measures aimed at popularization of public transport may not give the desired effect, since the citizen make final decision on the choice of the vehicle type.

In this regard, the use of organizational and managerial tools that regulate and optimize the “soft” parameters of the transport system is available and dependent only on the decision of local authorities. Thus, increasing mobility and transport security should be carried out not only through the development of information services, but also through the introduction of tools and methods that allow performing intelligent data analysis and making decisions based on it.

### 2.2 Prospective Approaches and Methods for Managing the Transport System

The transport management system is an open complex system, its efficiency and safety is influenced by many factors [9]. Therefore, the construction of its conceptual model is a non-trivial task. There are many studies devoted to this issue.

The goals pursued in the creation and implementation of transport managerial systems (ensuring an acceptable level of mobility and maximum safety while moving) are sometimes in opposition. In this regard, they must be considered comprehensively.

With increasing mobility, the main task is to reduce the movement time. It is solved, among other things, through the optimization of the route network of urban public transport [10], the parameters of the traffic lights [11]. Active research and development is being carried out in the field of creating intelligent transport systems. In particular, we can give an example of the digital platform RITM3, in which one can perform a wide range of tasks: visualization of data obtained in real time in various representations, their modeling and forecasting of the development of the transport situation. However, the system does not implement the modules for monitoring the situation and data mining [12].

The problem of ensuring the safety of the pedestrians, cyclists, motorists movement is currently especially acute. Given the large number of road traffic accidents occurring in the world and the number of people injured in them, it is important to identify the main factors influencing their occurrence in order to reduce the damage done to human lives and national assets. As for the methods and models used for the analysis of road traffic accidents, it should be noted that machine learning [13] and data mining [14] have become widespread in recent years: bagging, association rules, naive Bayesian classifier, cluster analysis, neural networks, hybrid combination of decision trees.

The most significant factors are the movement speed and the vehicle type, psychophysiological characteristics of road users, weather conditions, alcohol consumption, driver fatigue [15], the presence of road safety barriers, visibility conditions [16],
etc. Currently, such a phenomenon as uberization has been actively developed. There are also fleets of connected taxis (as an example, we can cite the announcement of the startup AutoX about the launch of a robotic taxi service through the Amap mobile application in Shanghai [17]. In this regard, research on the study of factors affecting road transport accidents for taxi drivers has acquired particular relevance. [18] Lack of data is a common limitation in examining and identifying dependencies. Accident reports are often incomplete because responsible employees are not required to complete all fields [19].

To improve traffic safety, various measures are also proposed, consisting in optimizing the design of unsafe road sections [20], introducing systems for monitoring traffic violations [21] and driver fatigue [22], using real-time systems to predict road safety indicators [23] and decision support systems based on data mining [19].

3 Concept of the Proposed Managerial Information System

To solve these problems, an information managerial system is proposed. Since decision-making should be based on real data on the urban transport system, for analysis and strategic decision-making, information was aggregated in a data warehouse containing data from several databases (flow rate, traffic accident statistics, location and characteristics of infrastructure objects). The purpose of building a repository is the integration, updating and coordination of operational data from heterogeneous sources to form a single consistent view of the control object as a whole. For the correct reproduction of real situations, operational information is used, which can come from various sources: from video cameras [24, 25], equipment for operational monitoring of the traffic situation (GPS/Glonass devices). To assess the dynamics of the road network parameters according to different measurements (number of vehicles, road section, season, average speed, traffic lights, etc.), a multidimensional intelligent data model (online analytical processing cube (OLAP)) is used, which makes it possible to predict possible changes situation on the city roads in subsequent periods. Decisions are made on the basis of multivariate data analysis and computer experiments on simulated micro-models of the road network problem areas [26], which make it possible to assess, among other things, the ecological load on the territory (Fig. 1).

To identify problem areas, traffic patterns in cities are studied, complex areas are selected where congestion and traffic jams are observed, as well as places where traffic accidents are concentrated. Then, for the selected areas, based on the processing of data from stationary video cameras, the parameters of traffic flows during hours, critical from the standpoint of mobility and safety, are calculated. They serve as input data when building a simulation model for the “as is” situation. After that, an experiment is carried out on the model for the purpose of its verification and validation. Modeling options for possible solutions with varying system parameters allows to choose the best of them and form the knowledge base of the best solutions with fixed parameters of the traffic flow and the environment.
The practical significance of the system lies in the ability to calculate the effects of the implementation of the proposed solutions at the stage of developing projects for the modernization and reconstruction of the parameters of the road network: increasing the road segment capacity, reducing the movement time by traffic participants, changes in the average speed, reducing the volume of exhaust gases. The system can also be used for operational management decisions in the event of extreme situations in the transport system of the city (lockdown, public events).

4 Discussions and Results of Applying the Proposed System

For practical testing of the proposed system, the Elabuga city was chosen due to the small size of its population (74 thousand people). In small cities, the parameters of traffic flows are more stable and there are not so many critical sections, so it is possible to successfully use simulation micromodels to reproduce the “what-if” situation on them.

With the constructed OLAP-cube, the places of road accidents concentration with the largest number of injured were identified, which were considered in the context of day time and week days (Fig. 2).

The analysis of road traffic accidents statistical data in the Elabuga city made it possible to choose one of the most emergency intersections which is unregulated. Since the intersection has a different number of lanes, and there is no traffic light regulation, congestion and conflict situations arise, road users create obstacles to each other, the probability of an accident and the crossing time increase.
The factors that significantly affect the road traffic accidents severity are found out, but it should be said that in different countries the research results may be different (sometimes even contradictory), even if the same method was used [11]. In this regard, it is necessary to conduct independent research for each territory, which was done. As a result of the analysis of variance, it was found that the factors that most affect the number of injured in an accident are kind of accident, the intoxication degree, the traffic violation type, month, hour, number of lanes (Fig. 3a) [27]. Associative rules were used to reveal hidden connections between factors and accidents with serious consequences. As a result, the influence of weather conditions, quality of road infrastructure and markings were established (Table 1) [28]. Also, with the help of decision trees, it was found that the consequences severity at regulated intersections is lower than at unregulated ones, therefore, the introduction and adjustment of traffic light operating modes should have a positive effect on improving road safety (Fig. 3b) [29]. It should be noted that, according to the zero mortality concept, roundabouts reduce the consequences severity more than traffic light regulation [30], however, within the urban area, the organization of roundabout traffic is problematic due to the insufficient area of the territory.

The adequacy of the proposed assumption was tested on a simulation model of this site. Data aggregation made it possible to establish that the largest number of accidents with victims occurred on this section of the road network on Friday in the time interval from 17:30 to 18:30, therefore, for building the model the traffic intensity measurements were carried out in this time.
To implement the simulation model and conduct optimization experiments, the AnyLogic software package was used. It has a built-in traffic library and an OptQuest optimizer. The structure of the model is shown in Fig. 4a. When optimizing the operating mode of a traffic light, transport delays at the intersection and the average length of congestion at the intersection are analyzed. We determined the logic of the traffic light: a two-phase cycle, in which the first phase is a green light for driving along the Okruzhnoye Highway in all permitted directions, and the second is a green light for entering the intersection from Neftyanikov Avenue and from the Tanaevskoye Highway. When determining the optimal parameters, we proceeded from the fact that infrastructure changes would be minimal and would consist in optimizing the operation of the installed traffic light. Therefore, the target function is the average travel time of the road section, and the influencing parameters are the phase time of the green and red traffic light signals, due to the change of which, the traffic light operation is optimized. The optimal values obtained during the simulation experiment are shown in Fig. 4b. In the process of optimization, the best value of the functional was obtained, at which

![Fig. 3. a) factors importance graph; b) bar diagram of the average number of wounded.](image)

Table 1. The most informative association rules.

| Antecedent                                         | Consequent                                              | Support | Confidence | Lift  |
|----------------------------------------------------|---------------------------------------------------------|---------|------------|-------|
| September                                          | Rain                                                    | 4.11    | 60         | 5.475 |
| Ground stripe                                      | Mira street                                             | 5.48    | 66.7       | 6.083 |
| February                                           | Lacks of winter street cleaning and Snowfall and Curb Width – 30 m | 5.48    | 66.7       | 9.733 |
| Public transport stop And Lack, poor distinguishability of horizontal marking of the carriageway | Improper usage, poor visibility of road signs            | 5.48    | 80         | 8.343 |
| Lack of pedestrian fences in the required places   | Adjustable intersection                                  | 8.22    | 60         | 3.65  |
| Adjustable pedestrian crossing                      | Lack of pedestrian fences in the required places         | 11      | 61.5       | 4.492 |
congestion on the considered section of the road traffic system would be reduced, the probability of an accident and negative impact on the environment would decrease. The average time of crossing a given intersection in each direction will decrease, and the average speed will increase (Fig. 5).

5 Conclusions

Urban growth raises many challenges that threaten the sustainability of urban development. In this sense, Smart City is an example of the concept of a modern city, within which more innovative solutions and complex approaches are being developed and implemented, supported by advanced technologies and innovative scientific knowledge. The analysis showed the lack of a unified standard for building transport control systems. Concerning, the paper proposes an information managerial system, a conceptual model of which is built on the basis that when creating a city’s transport system, it is necessary to comprehensively solve the problems of increasing mobility and road safety. Before introducing certain means to reduce road accidents and injuries,
it is necessary to identify significant factors and check how they will affect traffic on a specific section and the entire road network as a whole. For this, it is proposed to use tools for multidimensional and intelligent data analysis and simulation micro-models of the road network problem areas. As an example, the application of the system in the Elabuga city was considered, the influencing factors were found, and the problematic section of the road network was identified. The option of installing a traffic light at a selected intersection is considered. Two series of experiments were carried out, during which the number of traffic light phases and their duration were varied, the optimal duration of the operating modes was found, which ensured the minimum travel time of the section by vehicles. Thus, the system allows to develop recommendations for the rational management of the transport system of urbanized territories both at the strategic level (for example, when determining constant traffic light settings) and during operational management (changing the duration of phases depending on various parameters), integrating simulation models of problem areas into the proposed information managerial system of the city transport system.

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