Improving the Road Network of Small Cities

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Abstract: The transport system is an important part in human activity and is an integral part of the successful functioning of an urbanized territory. The historical relationship between the size of the city and the development of urban transport is traced very well. With the growth of the city's population and its territory, there is an increase in vehicles and traffic volume. The mobility of the population is increasing (the average number of transport trips per resident per year), while the travel distance is also increasing. This requires the appropriate development of transport, increasing traffic speed, and increasing the capacity of the road network. The article is devoted to environmental problems of motor transport in small cities, where it is impossible to apply large and expensive solutions. Two problematic intersections in similar cities were considered in Apatity and Elabuga and measures for the reconstruction of these sections were proposed (applying adequate road markings and changing traffic lights modes). Performing a computer experiment on constructed simulation models showed that there is a significant potential for improving the parameters of traffic flow in these areas and reducing the negative impact on the environment.

1 INTRODUCTION

The global urbanization affects all countries of the world. The population and economy are concentrated mainly in large cities, and the number of such cities is constantly growing. One of the consequences of urbanization is the high mobility of the population and, as a consequence, high motorization. Along with the positive effect of increasing motorization, traffic intensity increases. There is a strong and complex interaction between urbanization, motorization, and air pollution. Everything is developing within the framework of a number of urban restrictions that are inevitable from a political and regulatory viewpoint, where the environmental problem is becoming increasingly important. The fact that transport and regional planning influence each other and determine air pollution is a reality that needs to be recognized in order to consider development alternatives as soon as possible (Farid, 2015). With the population growth of the city and its territory there is an increase in the number of vehicles and volume of traffic. This requires appropriate development of transport and the road network (CRN) (Makarova, 2017).

Problems of increasing the capacity of public roads, which are the cause of non-compliance of traffic conditions with standards, are one of the main and urgent problems today.

The decrease in the capacity of suburban roads is accompanied by processes of urbanization and suburbanization-the causes of sprawl and growth of cities with a continuous increase in the level of motorization, the number of vehicles per thousand inhabitants. As a result, the city's road network is far from regulatory requirements.

One of the consequences of motorization is traffic jams, which have a negative impact on people and the economy, causing a decline in living standards in urban settings, additional business costs, loss of productivity, and so on. According to the 2011 urban mobility Report, the annual waiting time in traffic has

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increased from 14 hours per capita to 34 hours per capita since 1982. The annual financial cost of traffic jams was more than $ 100 billion, almost $ 750 per commuter train in the United States (Turcu, 2012). Motor transport is the largest source of air pollution. In Russia, starting from 2012, the volume of emissions from motor vehicles continued to increase and by 2018 increased from 12679 thousand tons to 15108 thousand tons (Ministry of Natural Resources and Environment of the Russian Federation, 2019). To some extent, this is due to the age of vehicles in service, which increased from 11.5 years in 2010 to 13.4 in 2019 (Timerkhanov, 2020).

According to the world health organization, noise is the second most important environmental problem for human health after air quality. Noise from traffic flows is extremely dangerous for human health, as it is a source of constant noise in the immediate vicinity of their places of residence (National Institute for Public Health and the Environment, 2014).

All these facts have a negative impact on the overall level of accidents, environmental safety, and ultimately on the world economy. This article attempts to suggest measures to reduce road tensions in small cities.

2 PROBLEM STATUS: EXISTING METHODS AND SOLUTIONS

2.1 Reduced Environmental Load Due to Energy-Efficient Vehicles

Technical measures aimed at reducing emissions from vehicles associated with the use of alternative energy sources. One of the most promising strategies to reduce CO2 emissions in urban territories is to focus on the electric vehicles use (Hofer, 2018, Gabsalikhova, 2018).

However, the power reserve of these vehicles is not very high and the rapidly increasing battery load can cause various reliability problems and peak demand in electric power systems. Therefore, the authors in the article «Probabilistic reliability evaluation of distribution systems considering the spatial and temporal distribution of electric vehicles» (Anand, 2020) propose a new probabilistic approach for assessing the impact of electric vehicles on the reliability of power distribution systems.

The driving style control (human factor) contributes to reducing emissions from road vehicles (Cindie, 2012, Ho, 2015). So, in Melbourne and Sydney, a tests series were carried out using the MetroScan-TI integrated assessment system to study how changes in driver behavior can affect emissions (Stanley, 2018). In the research course (Mensing, 2014), the author found that the formation of economic as well as environmental behavior in the eco-driving field shows a significant reduction in energy consumption due to the choice of a rational speed and acceleration. Thus, training drivers to be competent in road behavior (eco-driving) will reduce emissions from vehicles.

2.2 Reduced Environmental Load Due to Management Decisions

As urbanization increases, municipalities around the world are becoming aware of the negative effects of road transport, including traffic jams and air pollution. As a result, tolling schemes were introduced in several cities to prevent vehicles from entering the inner city (Zhang, 2019). In the article «Intelligent traffic control for autonomous vehicle systems based on machine learning» (Lee, 2020), the authors developed a traffic management system based on machine learning predictions and a routing method that dynamically determines routes with reduced congestion rates and predicted congestion for critical bottlenecks and used forecasts for adaptive routing management of all vehicles to avoid congestion.

In the article «Judicious selection of available rail steels to reduce life-cycle costs» (Bevan, 2020), the authors study the performance of automobile connections at intersections in the presence of interference, when the communication system implements the Non-orthogonal multiple access (NOMA) scheme. This scheme allows you to achieve a safer passage of intersections by vehicles. In New York city, the most important feature of building a traffic management strategy and developing its most complex CRN is that the municipal authorities and the Department of transportation strive to reduce the number of personal vehicles per capita as much as possible. This is achievable only if the residents of the city have a well-built public transport network. Due to the allocation of huge funds (about $ 10 billion in 2008), invested in the daily use of public transport, the city encourages residents to abandon the use of personal transport and switch to public transport.

In Sochi, a unique Integrated Traffic Management Scheme was developed and implemented. This scheme covers a wide range of tasks for improving road safety and is aimed at obtaining a program for the development of the city's CRN in the long term. During the preparation and holding of the 2014 winter Olympic Games, using transport modeling, the current road situation was analyzed, the main parameters were obtained and the desired capacity limits were calculated, which are achievable for the city's CRN when implementing a set of interrelated measures. Thus, New York, Sochi and London are quite successful in solving similar problems, but using different methods.

The article (Turcu, 2012) suggests an approach based on the Internet-of-Things to solve some of the problems that arise due to traffic jams. Moreover, this approach provides tools for monitoring a set of environmental parameters, including air quality, and for early warning and warning when critical levels are reached. This approach offers a solution for increasing traffic-related pollution (which has a negative impact on the environment and human health), economic losses, and other problems caused by traffic jams. The authors of the article (Mraihi, 201)) describe the study of the stability of road transport systems in the Metropolitan areas of Tunisia, where the density of the urban population is high, and the negative consequences have become a serious problem for the population. The authors investigated the relationship between income and several environmental and social negative effects of road traffic in Tunisia during the period 1989-2008 using The Kuznets Environmental curve. They found a monotonously increasing relationship between carbon dioxide (CO_2) and income, and a downward L-shaped curve for nitrogen dioxide (NO_2). The rest of the negative externalities are characterized by a monotonously growing ratio of energy consumption to income and an inverted U-shape ratio for accidents, as well as a monotonously growing ratio of income and use of private vehicles.

The Article (Palconit, 2017) shows that public transport contributes significantly to total CO2 emissions. The data collected indicate a 33% difference in CO2 emissions between climbs and declivitys, 16–27% between slopes and flat roads, and 10–20% between flat and mountainous roads. In addition, for the lowest level of CO2 emission, the optimum speed is from 40 to 50 km/h. The most unfavorable operating vehicle modes are low speeds and engine “idling”, when pollutants are emitted into the atmosphere in quantities significantly exceeding the emission under load conditions. Therefore, it is necessary to avoid traffic jams in which the movement parameters is characterized as “stop-and-go”.

The document (Ullo, 2018) presents the project idea to reating an innovative public transport system. The proposed system is based on the use of small vehicles with low emissions following flexible routes that will be adapted in real time to meet customer needs, taking into account traffic congestion and the other transport services availability. To implement this system, it is important to have information on the vehicles positions, other public transit supply types, traffic and environmental conditions in real time.

However, these methods are not suitable for every city or locality, because they entail huge financial costs, and it will be difficult for the city administration to cover such costs, and for some cities with a small population it is impossible at all. Therefore, for small cities, it is necessary to look for more budgetary ways and methods of solving the existing environmental and transport problems.

So in the article (Sun, 2020) Langfang, a typical medium-sized city bordering two megacities (Beijing and Tianjin), is the target area for vehicle emissions research. Studies have shown that from 2018 to 2025, emissions in Langfang will increase faster than in Beijing and Tianjin, indicating that medium-sized cities may become a significant source of air pollution in China. In the document (Villagra, 2020) the authors focus on using existing infrastructure (traffic lights) to address these negative issues, instead of investing in expensive new ones. Appropriate planning of traffic lights improves the flow of vehicles, and at the same time-this improvement is achieved without any additional costs and without requiring the use of specialized applications by drivers. And in the article (Kang, 2014) the authors propose an approach to coordinating emergency vehicle signals, which is designed to provide a "green wave" for emergency vehicles.

2.3 Application of Modern Methods of Intellectualization and Modeling to Search for Effective Solutions

The study (Nourani, 2020) presents a model based on artificial intelligence (AI). The authors first applied the emotional artificial neural network, which was calibrated using real data obtained in Nicosia (Cyprus). The model can be used to provide higher accuracy in predicting traffic noise. An analysis of the input parameters sensitivity showed that the total traffic volume is the most significant factor affecting traffic noise in the study area. The authors conclude that AI-based models have shown better capabilities than traditional multilinear regression models and empirical models.

In the article (Dev, 2020) modeling is used to evaluate the effectiveness of circular logistics in Industry 4.0 from the economics and ecology point of view The virtual world effectiveness in the I4.0

environment is studied using a reverse logistics simulation model, including operations such as inventory policies and production planning, family-based dispatching rules of remanufacturing and additive production. The remanufacturing model explores the trade-off between setup delays and the availability of green mobility.

Reducing the vehicles environmental load in urban conditions largely depends on the rational traffic routes choice. To assess the such solutions effectiveness using simulation models. So, the article authors (Pratama, 2019) performed an analysis of the road network characteristics using the Vissim simulation software, and they used the EnViver software to analyze vehicles exhaust emissions.

Improving the effectiveness of traffic management systems (TMS) remains an actual and complex problem in view of this task importance - control over the transport infrastructure. Review (Djahel, 2015) is devoted to a comprehensive study of the modern TMS development: an analysis of the main problems and shortcomings of existing systems and directions for increasing their effectiveness in smart cities. The review presents various technologies for collecting traffic data, including new technologies that can significantly improve the data collected accuracy. Review authors presented the routing protocols used by Vehicular ad-hoc networks (VANET) to distribute the collected data between vehicles, and showed their respective advantages and disadvantages. The authors investigate route planning and traffic forecasting services with the main focus on identifying the limitations of existing algorithms and suggesting alternative directions for increasing accuracy and efficiency, using the capabilities of an intelligent vehicle and advanced parking systems to achieve the desired accuracy level and traffic control.

With the intelligent transport systems development, the need for reliable changes recording in travel time of road network sections in real time grows. This is necessary to improve the accuracy of traffic parameters forecasts in real time. The study (Du, 2012) proposes an adaptive model based on an iterative combination of past information for the current day with travel time information available at specific points in time to predict the distribution of a particular section road's travel time. To determine the model of adaptive information integration, the authors use the nonlinear programming formula with an emphasis on information quality. The model adapts good information, weighing it higher and protecting the consequences of bad information, reducing its weight. Numerical experiments show that the proposed model adequately represents the distribution of the short sections transit time in terms of accuracy and reliability, while ensuring compliance with the surrounding traffic flow's conditions.

3 RESULTS AND DISCUSSION

Earlier, we already conducted similar studies using microscopic simulation (Makarova, 2019). These studies were carried out in medium-sized cities, where the load at intersections is greater, especially during peak hours, and where there are more options for improving traffic and unloading problem sections of roads. As a literary review in small cities showed, environmental problems of motorization are also relevant.

For the research, 2 cities were selected: Apatity, which are located in the Murmansk region, and the city of Elabuga, located in the Republic of Tatarstan. Both cities have almost the same population (55,000 people live in Apatity, 74,000 people in Elabuga), and they are similar in structure and construction. Both cities have an identical shape. The difference is the fact that Elabuga is located on a flat terrain in the mean climatic, Apatity near a mountain range in the northern climatic zone.

We have identified the main problem areas in selected cities and suggested possible ways to address them or minimize them. To analyze the effectiveness of the proposed activities, simulation models of sections of the road network in the AnyLogic software package were built. AnyLogic simulation modeling provides a Road Traffic Library, enabling traffic flow simulation with the power to deliver the most efficient road traffic engineering and design. Clear visualizations quickly aid development, with density maps highlighting congestion, and animations demonstrating traffic flow and bottlenecks. The freedom to experiment, and the ability to optimize accurate models, with traffic simulation software, provides the best platform for success in road traffic planning and engineering.

Having analyzed the map of traffic accidents, we selected one of the most emergency intersections in Elabuga - this is the intersection of st. Mir– st. Molodezhnaya. A weighty argument in choosing the intersection was the fact that it is located almost in the center of the city and has dense buildings around itself and, as a result, has a high concentration of vehicles and pedestrians for the city, especially during rush hours.

To analyze the condition of the road section the field surveys had been made. The field surveys consist in fixing a specific conditions and indicators of traffic actually occurring during a predetermined time period. The field surveys are the only way to obtain reliable information about the condition of the roads and allow an accurate characterization of existing traffic and pedestrian flows. Field surveys were carried out in accordance with the interstate standard GOST 32965-2014 (Standardinform, 2019). The following data were collected: the number of vehicles in each direction of movement and the percentage of possible options for traffic from each direction, the average, maximum and minimum speed of vehicles when crossing an intersection, the number of pedestrians and the average speed of the pedestrian flow, the operating time of each section of the traffic light. The data collected contributed to a more detailed simulation of the problem area (Figure 1). The model is built on the basis of a discrete-event simulation modeling using libraries of modeling processes, flows and traffic. The block diagram of the model is shown in Figure 2.

The main problem of this intersection is the different width of the dividing strip on st. Mir before and after crossing with st. Molodezhnaya. It is this factor that influenced the increased number of accidents in this section of the road and, as a result, the increase in pollutant emissions from vehicles.

The problem is further aggravated by the fact that the markings are erased at the intersection, so it becomes more difficult to notice a change in the direction of the lane, and under unfavorable weather conditions or limited visibility it is impossible to notice the curvature of road.

The most obvious way to solve this problem was to mark the intersection. The results of experiments on simulation models without marking (Figure 3) and with marking (Figure 4) showed that when there is marking on the road, the number of dangerous and conflict situations in this section of the road decreased, the amount of harmful substances decreased by 11.8% at the entire intersection, and decrease in average travel time.

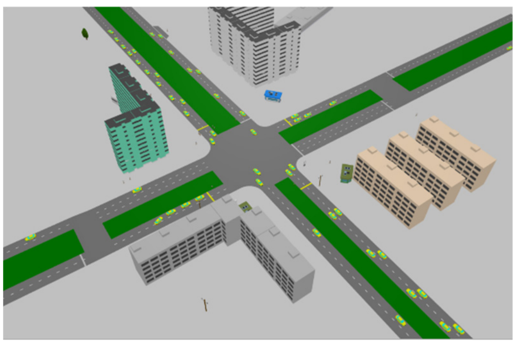

Figure 1: View of the simulation model of the section of the road network of the city of Elabuga.

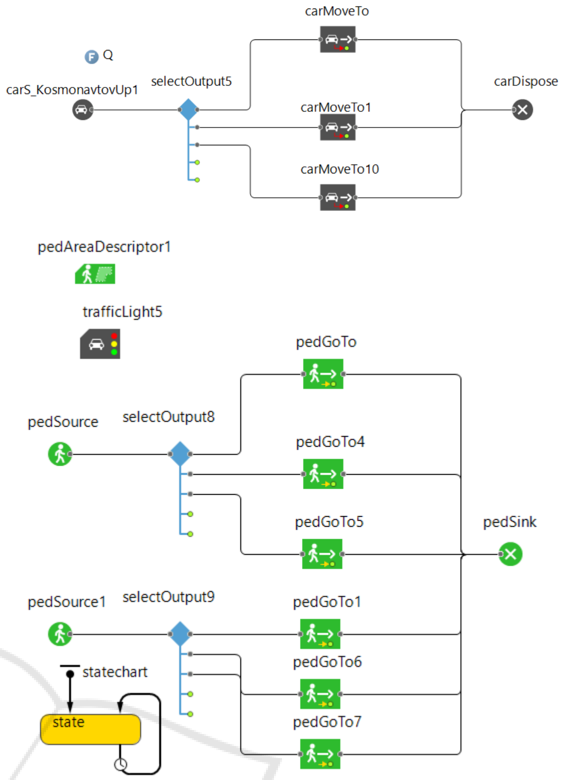

Figure 2: The block diagram of the model.

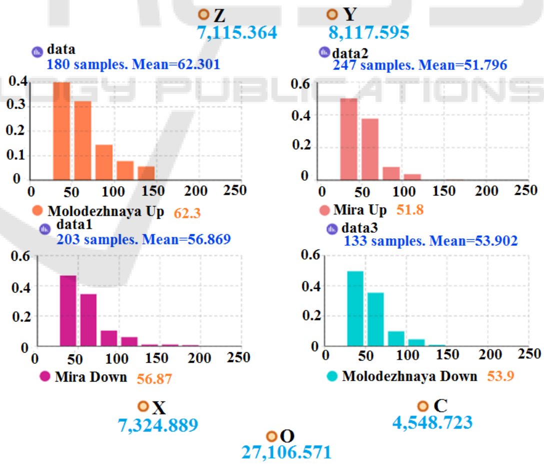

Figure 3: The results of the experiment on the model before any changes (along the abscissa axis - the travel time of the car along the site, along the ordinate axis - the number of cars in % of the total number driving through the intersection).

In the city of Apatity, for modeling was selected the intersection of st. Lenin - st. Kosmonavtov (Figure 5), since it is located, like the intersection in Elabuga, near the center, the administration building is also nearby, and during peak hours there is a large concentration of vehicles.

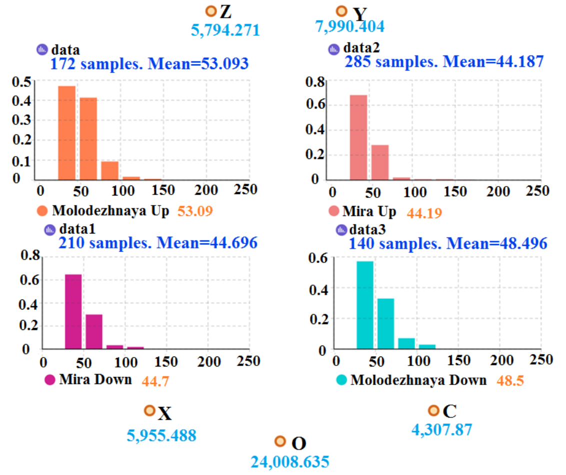

Figure 4: The results of the experiment on the model after changes.

Figure 5: View of the simulation model of the road network section of Apatity.

A feature of this intersection is the separation of traffic and pedestrian flows. First, vehicles move along st. Kosmonavtov, after them there is movement along st. Lenin. In the third phase of the traffic light, all vehicles are standing, pedestrians cross the road. In our opinion, this is precisely the fact that influenced the creation of traffic jams on st. Kosmonavtov. The situation is aggravated by the fact that the road in this direction is single-lane, and traffic is carried out in three directions. It is impossible to increase the number of lanes due to the lack of sufficient space due to the dense development of houses along st. Kosmonavtov.

Having studied in detail the structure of the intersection, a solution was proposed to combine pedestrian and traffic flows and make 2 sections of the traffic light instead of 3 for the movement of pedestrians and vehicles. The experiments on the model showed a positive trend: the average travel time decreased by 24.8% (by 20% in the problematic direction), the intersection throughput increased accordingly, the total amount of pollutant emissions decreased by 21.1%. The experimental results are presented in Figures 6 and Figures 7.

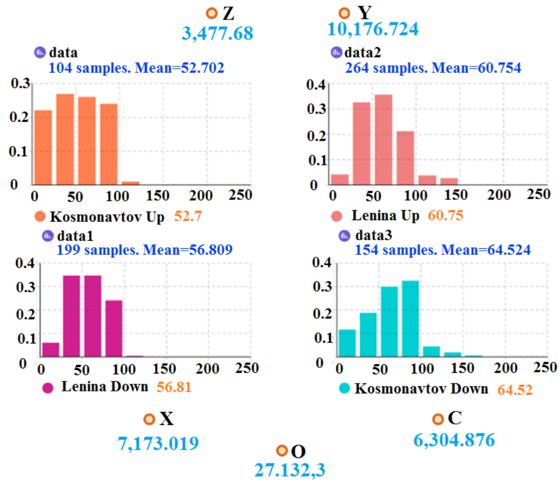

Figure 6: The results of the experiment on the model before any changes.

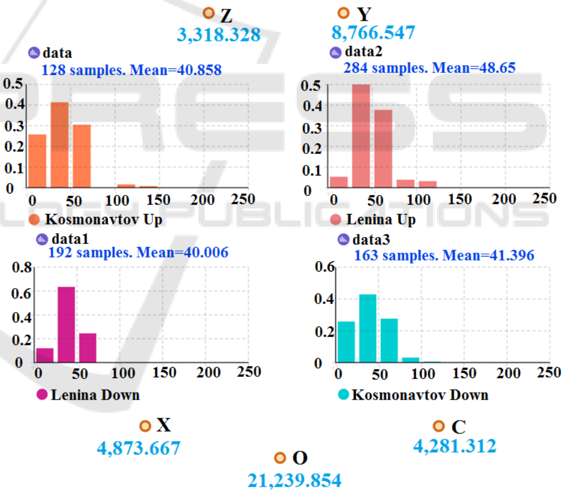

Figure 7: The results of the experiment on the model after changes.

4 CONCLUSIONS

The problem of the negative impact of the motorization process is extremely urgent, especially in small cities, since the solution to this problem is complicated by the lower availability of budgetary funds to improve transport infrastructure compared to large cities. Therefore, in small cities should be applied, first of all, more affordable methods and solutions. The development of simulation models of sections of the road network and the implementation of a series of experiments on it is one of such methods. The article studies the possibility of improving the road network of small cities on the example of the city of Elabuga and the city of Apatity. Measures were proposed to improve sections of the road network. Calculations on the constructed simulation models showed that for the city of Apatity, the average travel time of cars in the problem road section decreased by 24.8%, the volume of emissions decreased by 21.1%. For the city of Elabuga, the decrease was 15.1% and 11.8%, respectively. To obtain more complete results, it is necessary to offer a study of these cities to take into account the climatic factor in order to assess the influence of the geographical position of urbanized territories on possible solutions to improve the road network. Since these cities are located in different climatic zones with a significant difference in the duration and characteristics of the winter period, when traffic is difficult, the proposed models will help in finding the best solution to problems.

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