Managing an Urban Transport System in Enhancing the Area Stability

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Abstract: The urbanized mankind is faced with vulnerability of urban systems, migration and concentration of population, low quality of habitat, loss of fertile land, and necessity of waste disposal. In large cities, a significant contribution to atmospheric pollution with sulphur dioxide, nitrogen and carbon oxides, and industrial dust comes from the motor transport. The motor traffic growth inevitably affects the human health by causing road and transport traumatism, respiratory diseases and diseases caused by physical inactivity. The proposed solution is based on optimization of a city transport system parameters. This was achieved by via simulation modelling taking into account a large number of parameters, both within and outside the system, many of the latter being stochastic. The recommendations include rearranging of the public transport routes and changing over to vehicles running on gas motor fuel.

1 INTRODUCTION

Transition to “green” economy is unique for each country, being affected by various interrelated factors. However, the main trends and challenges have been shaped by global processes and are relevant for both developed and developing countries. One of those is urbanization, which is an objective process triggered by social demands, modes of production, and character of the social system. As a consequence, a precipitous growth of urban population, especially in recent decades, has depleted the reproductive capacity of the environment in major cities.

As reported by the European Commission (Eurostat, 2008), transport in 27 EU countries is a major source of greenhouse gas (GG) emissions, second after the industry, and their dynamics is higher than that of any other energy-generating sector (Transport and its infrastructure).With that, the share of automotive transport exhaust is over 90% of direct transport exhaust (Eurostat, 2009), and it is increasing in most countries due to growing transportation volumes. In large cities, the atmospheric pollution comes mainly from automotive transport. Thus, in Moscow and other Russian megacities the share of automobile exhaust is over 90% of total emissions to the atmosphere. The share of vehicle exhaust in less industrialized cities is but a little smaller (about 80-90). On the average in Russia, the vehicle emissions account for 42% of the total (Konstantinov, 2012).

One of Russia’s priorities on the way to sustainable development of the socio-economic system is transition to low-carbon fuels. More economical and environmentally friendly vehicles will facilitate «green» growth, diminish the environmental loads and increase the processing depth of natural resources. Considering the public concern regarding the sustainability of urban territories and increasing human migration to cities worldwide, there has been developed a project concept of a system of city management taking into account both the mobility needs of population and environmental factors.

In compliance with the “road map” given by the European Economic Commission to intelligent transport systems for the period of 2012-2020 (ITS for sustainable mobility, 2012) there have been identified 20 lines of activities promoting the use of ITS. They incorporate both activities on developing of uniform terminology and understanding of the ITS essence and objectives, and measures on introduction of ITS-related developments. This concerns both the technical component (development of road-to-vehicle and vehicle-to-vehicle communication; integration of different kinds of transport) and activities on improving of

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management and safety of the transport system, including the environmental safety, as well as analytical work and development of various methodologies. Since optimizing of transport system parameters may follow along two lines, i.e. by regulating the transport density and by improving the environmental safety of transport means, pathways for achieving the best values are being developed in two directions. It is evident that the ITS plays an important role in optimization of the transport system operations. It promotes the sustainability of the environment (Fengqi, 2010), diminishes the negative impact of the transport complex on the environment and also the energy consumption (Gkritza, 2013). Nowadays the ITS has turned into tool in transport planning being used for surveying, decreasing of traffic congestions (Harb, 2011), and planning of shared vehicle use. Since the ITS is a technology for creating applications and systems for traffic management and forestalling of accidents, they diminish the workload on motorists (Jarašūniene, 2013).

2 EXPERIMENTAL METHODS

2.1 Intelligent Transport Systems

Since the transport system belongs to the class of major systems, optimizing of its processes involves processing of great bodies of data and modeling of processes by using IT technologies. This kind of research is joined by a common term “intelligent transport systems”. Alongside with artificial intellect systems this area is dynamically developing and embraces different classes of problems.

The sustainability of transport systems in major cities, including megacities, depends on the stability of subsystems and links connecting them, which in turn depends on the quality of management. Nowadays controlling of large systems, such as the transport one, is effected by using the systems of solution support, expert systems, and information systems of control. Such systems are created for both strategic and local, tactical, control. Efficient management not only improves the economic performance of the system; it also assists socially, by improving the transport service and reducing the negative impact of the transport complex on the environment.

Methodologically, the ITS development is based on systemic approach, meaning that ITS are created as systems, not as individual modules (services). The process involves forming of a unified, open architecture of the system, protocols of information exchange, forms of transportation documents, standardization of parameters of communication, control and management technologies, management procedures, etc.

Intellectualization enhances the transport system’s safety and efficiency both due to information services and the means and methods affording to perform intelligent data analyses and make decisions on their basis. Regarding ITS as an information service, the authors of work have found that such systems are mainly needed for informing a driver of the transport flow parameters along his route. The ITS tools are also used to ensure the safety of traffic participants, i.e. in intelligent onboard systems (safety shields) and pedestrian recognition systems (Truong Cong, 2011). The development of alerting systems is connected with developing of communication technologies and infrastructure applied in traffic control. Several studies have been devoted to the analysis of trends and future evolution of ITS (Ran, 2012;).

2.2 Decision Support Systems in Management of Transport Flows

Since the quality of decisions in managing of large systems depends on the quality of information, adequately selected methods of its analysis, and effective tools, this calls for creating of decision support systems. The structure of DSS essentially depends on the kind of objectives to be tackled, on the available data, information and knowledge and also on the system’s users. Therefore a DSS consists of three main parts:

1. A data system for collecting and storing of information obtainable from internal and external sources; as a rule it is a data storage.
2. A dialogue system affording the user to set the data to be selected and methods for their processing.
3. A system of models, i.e. ideas, algorithms and procedures permitting to process and analyse the data.

Since decision making is based on the real data of the object under management, both analysis and adopting of strategic decisions require aggregate information available from a specially created data storage (DS). Data storages contain the information collected from several operative databases of an on-line transaction processing systems (OLTP). The core of a road situation control center is a multi-dimensional intelligent data model (an OLAP cube) which collects, stores and formalizes the road network parameters (Fig. 1).

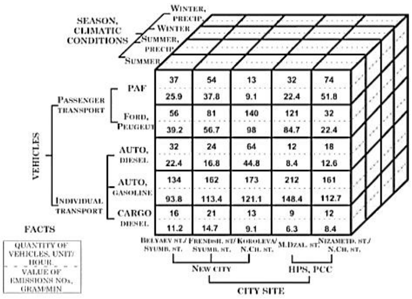


Figure 1: OLAP cube: the “kind of transport” dimension.

Storing of information as an OLAP cube and its subsequent processing will make it possible to precisely assess the dynamics of street road network parameters in different dimensions (number of transport vehicles, road section, season, of the year, average speed, availability of traffic lights, etc.). By analyzing the information on varying road parameters within the day time, week day, and month it is possible to forecast probable changes in road situations in the future.

Besides, modeling of variants of possible solutions with varying system parameters allows to select the optimal parameters and create a database of best solutions at fixed parameters of the transport flow and external environment. Such bases serve for operative decision making in the case of transport emergencies. The intellectual core of the DSS is often composed by simulation models, which affords not only to make a qualitative analysis of the processes but to investigate the consequences of variations and select the variant satisfying all preset limitations to obtain the system parameters optimal for the preset conditions (Makarova, 2013).

3 RESULTS AND DISCUSSION

3.1 Field Studies of Transport Flows

Improving the performance of a transport system presupposes examining of its current state, revealing of problem areas, developing of a package of measures, aimed at alleviating the negative factors, and implementing the measures while controlling the parameters in order to assess the solutions efficiency. Therefore the following objectives have been set:

- To carry out field studies of the transport flows, including their intensity and sites with frequently occurring accidents;
- To carry out field studies on pollutants distribution in atmospheric air;
- To develop a software module for feeding, storing and analyzing of the obtained statistical data;
- Developing of a model simulating the city’s traffic infrastructure;
- Input and systematization of obtained information and of a database by using a software complex;
- Analysis of information on the traffic infrastructure parameters by using the statistical analysis of obtained information;
- Model studies of the impact of vehicles powered by natural-gas motor fuel on the air quality.

The field studies were conducted using the following methods of monitoring the traffic infrastructure: revealing the regularities of transport flows formation; evaluating the most congested road sections and sites of frequent accidents. First, the city map was split into squares to reveal the potentially problematic sites (narrowing sections of thoroughfares and streets, traffic confluence, complecated road junction with lots "conflicts points", etc.), with account for peculiarities of the city’s street-road network (SRN) pattern.

When identifying the sites with higher than average traffic intensity, we analysed the transport police data and revealed the places with a high rate of road traffic accidents. It was hypothesized that the high accident rates were caused by increased traffic loads on the SRN. The experiment included registering by vehicle dash cameras and video cameras and computer processing of the images. Measurements were performed at the cross roads that had been found as the greatest loaded, potentially dangerous and most in need of optimization. In order to reveal the peak loads on SRN, the measurements were performed during the week days and included the following periods: 1) 07:00–09:00 am; 2) 11:30–13:30 pm; 3) 16:30–18:30 pm. The following parameters were recorded: vehicle model, brand and type; traffic direction; average current velocity.

3.2 Studies of the Atmospheric Air Pollution

Having analyzed the road layout, the purpose of motor roads, and information about the traffic load, we selected the following 5 road portions for instrumental measurement of ambient air pollution on the following roadside clear zones. Sampling of atmospheric air was carried out in the immediate vicinity of roads, mainly from downwind, during the morning and evening rush hours. For each site there were obtained 2 duplicate samples, so that the total number of samples was 600. Both the initial working solutions (600) and 300 blank solutions were prepared for analysis at a chromatograph with a photoionization detector and photometer. Analysis for the presence of carbon monoxide has required the obtaining and processing of more than 300 chromatograms.

Company's fixed contamination sources of Naberezhnye Chelny city are outside the city, therefore motor transport is the main source of emissions. We made the environmental analysis, determined locations of high concentrations of pollutants and calculated emissions of motor transport by using certified methodologies: in this calculation traffic volume was considered. The volume was determined by making field surveys. Maps of pollutants (CO, NO_X, C_XH_Y, soot, SO_2, formaldehyde, benzopyrene) were made by using Integral Ecolog 3.0 software. The analysis of these maps showed that the highest levels of concentration of polluting substances are located on the crossroads. Field surveys showed, that maximal density of traffic cause increasing of concentration of polluting substance. We have ascertain, that non-optimum traffic light control is one of the cause of this situation. Further research is aimed at searching for optimal parameters of traffic light control by using simulation models and at the elaborations of recommendations for optimization of road traffic.

3.3 Developing of Decision Support System

Using the maps of pollutant dispersion from stationary sources, derived as a result of field observations (Figure 2), we highlighted the problem areas, one of which is a complex junction formed by intersecting Mira, Druzhba Narodov and Syuyumbike Avenues.

Figure 2: Dispersion of carbon monoxide map.

As shown statistically, this site is characterized by a higher than average rate of vehicle accidents, which cumbers the traffic and deteriorates the atmosphere by frequently occurring congestions. For more detailed analysis of the area, we constructed a simulation model using the AnyLogic software (Russia). The following factors were taken into account: geometry of the road network portion; traffic density; intensity of pedestrian traffic along traffic lanes; pollutants actually emitted by motor vehicles emission quotas; modes of traffic lights operation at road portions preceding and following the portion being analyzed. A constraint for the model was the value of the emission quota that was not to be exceeded. This system of simulation modeling makes possible to examine the effect of varying transport flow parameters on the city atmosphere and select the environmentally optimal parameter values.

The input data were systematized in tables and then fed into a database using the developed input forms. Account was made for the transport flow parameters (its composition and intensity) and the data on the emission of noxious substances into the atmosphere. The site for the field study represented a confluence of two major avenues and accommodated several public transport routes connecting the city’s newer and older parts. Therefore optimizing of the traffic current parameters primarily involved the route network. Another approach consisted in using of buses with greater capacity, which would both diminish the traffic current density and reduce emissions of harmful substances. Similar methods are described in works (Saharidis, 2013). The optimization experiment on a simulation model was carried out using an OptQuest device and metaheuristic methods.

At the first stage of the experiment, we determined the optimal parameters for the traffic current, such as density, intensity and speed, falling within the quota for pollutant emissions.

Table 1: Point sizes and type styles.

Substance name	The volume of emissions		
	100% fleet on diesel fuel	50% fleet on gas motor fuel	100% fleet on gas motor fuel
CO	1.036	0.870	0.691
NOx	0.974	0.907	0.830
CH	0.499	0.437	0.386
Soot	0.581	0.102	0.043
SO2	0.578	0.422	0.361
formaldehyde	0.681	0.663	0.627
Benzapyrene	0.579	0.514	0.489

At the second stage, volumes of vehicular emissions were determined. While preserving the original parameters, we replaced a part of the public transport with more environmentally friendly vehicles. This considerably reduced the volumes of emitted pollutants (Table 1).

The city is crossed by a longitudinal thoroughfare comprising the Musa Djalil, Naberezhnochelninsky, and Mira Avenues. The traffic intensity, the highest among the city streets, is 3000 veh/h at a capacity of 3500 veh/h. During the rush hours the vehicle flow gets stuck, the traffic gets congested, with frequently occurring bottlenecks. Maneuvering within the vehicle current is hindered at turnarounds. There is an dangerous area adjoining the “Pedinstitut” bus stop, where the roadway narrows from three to two lanes, after crossing with Nizametdinov street, as a result of which vehicles are forced to change lines immediately after the crossroads. At the nearest road sections, inadequate traffic management has resulted in even more dangerous situations. Thus, of the city total of 472 vehicle crashes during 8 months of 2015, 37 in this avenue.

For more detailed analysis, we designed a simulation model of the road section that took into account the following parameters: the section geometry, traffic flow density, intensity of pedestrian flow, signalization modes at preceding and succeeding sections, and the phase number in traffic signals. As revealed by simulation experiments, the traffic is negatively affected by such factors as great density, inappropriate section geometry, and numerous infrastructural elements (such as public transport stops and turnarounds). It was also proved that the flow density at Naberezhnochelninsky Avenue is affected by two unregulated turnarounds.

To reduce the aforementioned impacts, we proposed a scheme of optimization of the crossing layout, which included elimination of the nearest U-turn with the lowest discharge capacity and using of an alternative number of phases in the crossing regulation, that is the combination of main and intermediate regulation cycles. Correspondingly, for changing of phase number we proposed to change the time intervals between the signals.

Using the enumerative technique based on metaheuristics, we determined the most appropriate infrastructure for traffic signalization. A conventional traffic light with two operation modes and each phase of 148 seconds was substituted for a multiphase timing signal automatically correcting the phases and time of coordination of a set of signalizing objects adapting to the traffic situation.

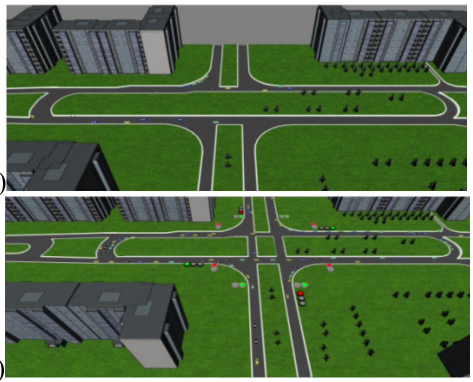
To set the adaptive mode in a traffic light, the model processed the situations at several regulated turnarounds located in the immediate proximity of the road section and inter-influenced by the traffic flow. The model registered the speed and density of the traffic flow at each section. By analyzing these characteristics, coming in real-time regime as feedback from succeeding road system sections, and it is possible to correct the length of green signal for all directions according to optimal regimes established in the model. Table 2 presents changing of signal phases with adaptive control depending on the traffic flow density. Adaptive regulation will permit to smoothly relieve all sections of the road-street system by responding to critical flow parameters at individual sections and so forestalling congestions and bottlenecks at succeeding sections.

Table 2: Variation of signal phase depending on flow density.

Flow density at the section	Total phase time, sec.	Red signal (main cycle), sec.	Green signal (main cycle), sec.	Red and yellow signal, sec.	Yellow signal, sec.	Green with yellow signal, sec.
95%	112	40	64	2	4	2
82%	112	42	62	2	4	2
74%	86	43	35	2	4	2
61%	86	48	30	2	4	2

Another problem area in the city of Naberezhnye Chelny is located at the intersection of Chulman and Druzhba Narodov Avenues (Figure 3a). According to the traffic police data, it is a place with a high concentration of road crashes, which both prevents the normal operation of the transport system and affects the environment. For more detailed analysis, we designed a simulation model taking into account the road section geometry, the intensity of pedestrian flow, and traffic light modes at preceding and succeeding sections. The target function was the average speed of vehicles since the frequent road crashes here are caused by high speed. The simulation results have revealed that the traffic quality at this section is affected by the following factors: high flow density, high average speed of vehicles, and the presence of an unregulated pedestrian crosswalk.

The results of the road section survey can be seen in Table 3. The data indicate to the possibility of radical improvement of the traffic parameters.



a) b)

Figure 3: Simulation model: a) before optimizations; б) after optimizations.

Table 3: Calculated parameters of the road section of interest.

Parameter name	Value before modification	Value after modification
Traffic flow parameters		
Average speed, km/h at the section	12	27
Number of stops per unit of time, pcs	4	1
Flow density relatively the road, %	92	67
Average time needed to traverse the section, min	4	1,4
Air pollutants concentration		
CO	1.042	0.879
NOx	0.972	0.937
CH	0.495	0.458
Soot	0.583	0.122
SO_2	0.574	0.428

To reduce the negative impacts, we proposed a new intersection layout, involving a signal control. After the model was modified (Figure 3b), experiments showed that using the proposed variant will diminish the likelihood of road crashes and stabilize the parameters of vehicular and pedestrian flows.

The proposed plan of reconstruction of crossroad allowed both to decrease accident hazard of the site significantly at a lower cost and to decrease negative impact on the environment. Also optimal traffic light mode was determined which allowed to increase pedestrian safety. Traffic police approved the proposed solution and the reconstruction of the crossroad had been carried out.

4 CONCLUSIONS

The research findings have demonstrated a considerable contribution of automotive transportation to urban air pollution. It has been established that the problem should be approached comprehensively. Simulation modelling can help to identify the optimal parameters for the transport flow and find rational managerial solutions.

REFERENCES

Eurostat, 2008. *Energy and Transport in Figures*. Luxembourg: EC.

Eurostat, 2009. Eurostat database. http://www.ec.europa.eu/eurostat (accessed 18.12.2015).

Fengqi, Z., Jun, S., 2010. Deploying an Intelligent Transportation System in Chongming County. *Shanghai Journal of Urban Technology,* Vol.17, Iss.3, p. 39-51.

Gkritza, K., Karlaftis, M.G., 2013. Intelligent Transportation Systems Applications for the Environment and Energy Conservation (Part 1). *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*. Vol. 17, Iss.1, p. 1-2.

Harb, R., Radwan, E., Abdel-Aty, M., Su, X., 2011. Two Simplified Intelligent Transportation System-Based Lane Management Strategies for Short-Term Work Zones. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations,* Vol. 15, Iss.1, p. 52-61.

ITS for sustainable mobility, 2012. http://www.unece.org/trans/publications/its_sustainable_mobility.html (accessed 18.12.2015).

Jarašūniene, A., Batarlienė, N., 2013 Lithuanian road safety solutions based on intelligent transport systems, *Transport,* Vol. 28, Iss. 1, p. 97-107.

Konstantinov, A.P, 2012. Ecology and health: risks mythical and real. *Ecology and life*, № 9, p. 82–86.

Makarova, I., Khabibullin, R., 2013. Intellectualization of transport systems for the benefit of safety and the sustainable development of territories. *Journal of International Scientific Publications: Ecology&Safety*, Vol. 7, P. 3, p.189-199.

Ran, B., 2012. Perspectives on Future Transportation Research: Impact of Intelligent Transportation System Technologies on Next-Generation Transportation Modeling. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*. Vol. 16, Iss. 4, p. 226-242.

Saharidis, G.K.D., Dimitropoulos, C., Skordilis, E., 2013. Minimizing waiting times at transitional nodes for public bus transportation in Greece. *An International Journal "Operational Research"*. Vol. 13.

Truong Cong, D., Khoudour, L., Achard, C., Bruyelle, J., 2011. Intelligent Distributed Surveillance System for People Reidentification in a Transportation Environment. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, Vol. 15, Iss. 3, p. 133-146.