Imitation and analytical approaches to assessment of condition and modeling of city transport system nodes

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Abstract. The issues of the city transport system and transport nodes assessment concerning the possibilities of express assessment by analytic methods and accurate forecast of its development by transport (imitation) models are discussed. Localization of the assessments for the transport services consumers and transport companies enables to implement the functions of the city transport regulation by the municipality. The social and economic factors of the city transport development for increasing the transport quality and public access are considered.

1. Introduction

The organization of rational city transport system is based on the use of the analytical and imitational approaches allowing to assess and forecast basic parameters of the transport operation, consider the interest of the transport process members as well as assess the influence of the transport system infrastructure development level on the implementation of social and economic purposes of the municipality and city population. Recently, in the Russian Federation Traffic Management Complex Schemes (TMCS) are developed for settlements, urban agglomerations, and regions based on the transport flows modeling. For the assessment of the taken measures results, the different levels models shall be developed, including express assessment models for the transport system operation which enables to quickly determine the efficiency and performance as well as to calculate basic traffic parameters and provide fast assessment and correction of the changes results.

The issues of the city transport processes modeling are addressed at many works, including the discussion of the particular aspects of the city transport system stability improvement by intellectualization of public transport and provision of its priority at the road (Makarova et al., 2016), use of alternative means of transport for the public transportation (Gorbachev, 2017), increase of the traffic safety (Batishecheva et al., 2017, Safiullin et al., 2018), improvement of the throughput functionality due to crossroads optimization (Chubukov et al., 2017), and issues of an ecological burden caused by transport flows (Yakimov, 2017, Yakimov et al., 2018).

The issue of the absence of any accurate assessment criteria for the transport system management (Sharov et al., 2014) shall be solved at the state level by classifying the cities and regions by the number of population, economic links development level (Konovalova et al., 2017), the transport flows laid across the settlement considering modern requirements to delivery chains organization (Mikhaylyk et al., 2019).
Use of the imitation modeling is predetermined by the necessity to select rational traffic schemes and change of the road net configuration (Makarova et al., 2014, Zulfadly et al., 2014).

2. Methods
The development of the assessment system and measures for the development of the city transport shall take into consideration the trends and values which significantly affect at the strategic management level such as:
- grow of the automobilization level (both individual and commercial cargo transport), transit cargo traffic, transport traffic intensiveness and necessity of the car parking places;
- increase of street and road network load;
- decrease of the road safety level;
- provision of the transport availability to the population;
- decrease of the average travel time and etc.

Significant infrastructure projects are specific in their methodological approaches to the consistency analysis and efficiency assessment.

Firstly, the transport which covers the demand for «now and here» transportation services requires adequate forecasting of the future market. Errors in the forecasts to greater or smaller limit influence the final price of products and thus reduce their compatibility. In addition, large transport companies and industry have no methods of direct influence on the transportation services market.

Secondly, the transport systems are widely-distributed and their elements are significant under the condition of the balanced power and resources distribution for effective transportation organization. The narrow places in the transport network can influence on global throughput capacity and barrier its development.

Thirdly, transport system development issues delegated to state (regional, municipal) management level include financial and business elements presented by large transport companies, the «holders» of the public transport infrastructure. In addition, the single transport infrastructure (single transport network) is one of dominants of stable development of interindustry an interregional connections.

These and other factors, connected with the methods of decision taking determine the peculiarities of strategic decisions taking and assessment of their efficiency at the different stages of implementation, see table 1.

The algorithm of the strategic decision taking concerning city transport includes large transport companies and holdings forming basic cargo flows, federal and regional administrations with their financial, economic and social responsibility zones as well as the system of territory planning and town-planning policy determining the structure and scheme of passenger traffic flow.
Table 1. First stages of infrastructure projects implementation for the city transport.

| Stage of decision taking | Basic tasks | Stage implementation participants | Used methods and tools |
|--------------------------|-------------|-----------------------------------|------------------------|
| 1. Design basis memorandum | Determination of the project and pre-analysis of the change of technical and operational values of the transport system | Initiative group, organization. | Foresight-methods, expert analysis, SWOT-analysis and etc. |
| 2. Technical assignment for project validation | Technical evaluation of the project feasibility and cost effectiveness indicator | Customers-initiators of the project and consulting organizations | Technical requirements to the project basing on GOSTs, OSTs, SNiPs, TU and other normative acts for designing. |
| 3. Calculations of project validation | Qualitative assessment of the technical properties and feasibility of the project | Design and scientific and consulting institutions | Analytic and statistical methods, imitational modeling |
| 4. Investments justification | Assessment and justification | Consulting group representing the interests of the project agents and market | Economic and finance analysis, projects management methods |
| 5. Economic assessment of investments efficiency | Assessment of economic efficiency of investments | Companies and organizations participating in the project | Methods of investments efficiency assessment (industry and interindustry) |
| 6. Development of investments project business plan | Presentation of the project with its attractiveness assessment for all agents (business, capital, state structures) | Consulting group or organization which develop business-plan on contractual basis | Methods of investments project business-plan development |

Main feature of the first stage of taking the decision concerning the city transport system development is associated with an uncertainty of future condition and the necessity to achieve adequate forecast. Methodological apparatus of this stage includes expert and cause-consequence analysis, statistical methods, foresight-methods with a following common feature: assessment basing on benchmarking and comparative analysis of trends, schematically implemented in the diagrams (Ishikawa, Gantt, Pareto diagram), matrices (SWOT, BCG, Shell/DPM, Ansoff, McKinsey, Arthur D. Little), graphs (tasks pyramids, strategic plans) and etc.

Nowadays, the growth of city population and development of residential construction continuously lead to the expansion of cities borders. This is the reason for a large number of «narrow places» – conflicting routes, insufficiency of the throughput capacity of the neighboring roads, great number of pedestrian and motor roads crossings, traffic speed limits and stops at the traffic lights, increase of the negative impact on the environment. Due to the grow of the railway traffic intensity and speed and absence of grade-separated crossings the costs of motor transport and accidents risk also increase (Mamaev E.A. et al., 2014; Mamaev E.A. et al., 2018).

Basic loss associated with the complications of street and road network shall be determined considering the use of the analytical imitational mathematic models.
Analytical models are the dependences and equations allowing to take decision on the parameters characteristics of the studied model for the determination of the rational operation of the studied facility (for maximum and average loads).

The main difference between the imitational and the analytical models is the description of the system behavior by a set of the elements behavior algorithms (probable implemented in different environments, but linked together) which describes the system processes.

The use of the imitational models is considered reasonable for the assessment of the condition and determination of vehicles movement speed within a railway crossing.

Analytical method of assessment of time loss by the vehicles at a single level crossing shall be presented as following. Average value of time loss by commercial vehicles $V$ at «narrow places» zone consists of two elements:

$$ V = (V_{\text{speed}} + V_{\text{delay}}) \cdot 265, \quad (1) $$

where $V_{\text{speed}}$ is time loss by vehicles due to traffic speed reduction, hours per day;

$V_{\text{delay}}$ is time loss by vehicles due to the delay caused by waiting an opportunity for passing, hours per day;

$265$ – number of working days.

During the pass through the «narrow places», the transport traffic speed reduces resulting in the delay of the whole traffic flow.

$$ T_{\text{кор}} = N_{\text{AT}} \cdot \left( \frac{S}{V_0} - \frac{S}{V_1} \right), \quad (2) $$

where $N_{\text{AT}}$ – vehicle traffic intensity at the zone under consideration, units per day;

$S$ – average length of the «narrow place», including slowing-down and acceleration zones, km;

$V_0$ – vehicles speed in the «narrow place», km/h;

$V_1$ – normative vehicle speed, km/h.

Time loss by vehicles due to the delay caused by waiting an opportunity for passing is directly related to the traffic intensity, speed, road crossing type, traffic participants. Average delay of vehicles:

$$ T_{\text{зад перес}} = N_{\text{перес}} \cdot \left( \frac{t_{\text{ct}} \cdot N_{\text{AT}}}{24 \cdot 120} + \frac{t_{\text{ct}}}{2} \right), \quad (3) $$

where $N_{\text{перес}}$ – average number of stops due to flows crossings and stop-overs;

$T_{\text{CT}}$ – average stop time while waiting for the traffic pass, hours.

Combination of the imitational and analytical methods is the basics of the assessment methods for the transport infrastructure projects and methods used in TMCS, based on the use of the results of imitation experiment in analytical calculations of the city transportation support and specific regions and nodes.

3. Main part

The abovementioned efficiency assessment model for the traffic organization on the example of the railway crossing can be implemented with the use of imitational transport modeling (Chislov et al., 2016). One of the most popular tools of imitational transport modeling is PTV Vissim, which enables to simplify the required researches by avoiding the necessity to intrude into road traffic.

Let’s consider the application of the abovementioned approach to the multilevel railway and motor road junction at the street and road network in Rostov-on-Don at one of the crossings, Figure 1. To increase the road safety and vehicles time loss at this road section, the possibility of the construction of the multilevel railway and motor road junction according to the scheme on Figure 1 is considered.

The imitation model of this Rostov-on-Don transport network is created.

During the rush-hour, the traffic intensity at this crossroad is 1500–1700 vehicles/hour, $N_{\text{AT}} = 7000$ units/day., $S = 0.2 \text{ km}$. 
Based on the statistical surveys and implementation of imitational model of the transport network node the following values were determined: $V_0 = 11.92 \text{ km/h}$ and $V_0 = 40.21 \text{ km/h}$, Figure 1.

**Figure 1.** PTV Vissim model of multilevel railway and motor road junction.

The traffic characteristics in the railway crossing at different crossing types are analysed.

**Figure 2.** Analysis of imitation modelling results.

Figure 2 shows the average traffic speed (km/h) in railroad crossing before and after the project implementation.

The values are calculated at $t_c=4 \text{ min}$, $N_{perc}=60$.

Using the vehicles speed obtained by imitational modelling the time loss by the vehicles at the railway crossing with single and multi level crossing is calculated.

As seen from Figure 2, the loss before the project implementation are 160 thou. vehicles h/year.

4. **Conclusions**

Consequently, the combination of the analytical and imitational methods during the analysis of city transport networks is an efficient and adequate tool for strategic decisions taking.

The changes of city transport network shall be made for the consecutive development of the throughput capacity and optimal scheme of traffic organization as well as for the city and agglomeration development.
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