Information technologies and management of transport systems development of the approach to assessing adaptation of the intersection transport model

A Novikov¹, S Glagolev², I Novikov² and A Shevtsova²

¹Orel State University, 95 Komsomolskaya Street, Orel, 302026, Russia
²Belgorod State Technological University named after V. G. Shukhov, 46 Kostyukova Street, Belgorod, 308012, Russia

E-mail: shevcova-anastasiya@mail.ru

Abstract. In the work the authors touch upon the main approaches to assessment of adequacy of modeling of the transport system. They study the main parameters which can be used during assessment of adequacy of a transport model. The object of the research is a process of movement of vehicles at controlled intersections. The subject of the research is the technique of assessment of adequacy of the transport model using certain parameters of traffic flow (intensity, delays, motion speed, queue length). During the research the authors have developed the algorithm of assessment of adequacy of a certain parameter modeling.

1. Introduction

Modeling of transport processes is creation of the working model of the traffic corresponding to the actual traffic on highways. The transport model is a mathematical model, that is, it has a rather high accuracy to implement different tasks connected with forecasts, optimization and imitation of traffic flows. Such model can be used as the instrument of support of decision-making and as storage of statistical information on the constructed transport system.

Russian and foreign researchers dealt with issues of transport modeling [1-3]. The first macroscopic model in which the movement of traffic flow was considered from positions of mechanics of the continuous environment was offered in 1955 by Ligthill and Whitham [3]. They show that methods of the description of processes of transfer in continuous environments can be used for the description of modeling of congestions.

Any model has to conform to certain requirements such as: adequacy, accuracy, universality, profitability. To be sure of reliability of a model of a real object there is a concept “adequacy of model and assessment of adequacy”. Adequacy assessment is check of compliance of the model to the real system. Assessment of adequacy is an element of creation of the road network model. It is necessary to construct a model with such parameters of roads, cars, means of the organization of traffic so that it could provide compliance to actual data [4].

When modeling the transport systems an important condition is adequate work of the model. The adequacy characterizes the accuracy of the received model. For assessment of adequacy there are three methods of comparison of rated and experimental data: 1) comparison of intensity of the movement and speed of vehicles in control points of networks: correlation, dispersive analyses; 2) dependence between intensity, density, speed; 3) dependence between time of a trip and a stop on the basis of two-component
models of the kinetic theory of traffic flow. These methods are quite complicated but during assessment of modeling efficiency they give approximately identical results. For assessment of adequacy we use the method: U coefficient – of Zeyl's statistics (the correlation analysis) which consists in use of the second criterion - covariance coefficient. Having chosen a method for assessment of model adequacy we need to determine the parameters of comparison of a model and a real object. In this regard, the main purpose of the study is to develop a method to verify the adequacy of the model with the real site, taking into account changes in the main characteristics of the traffic flow.

2. Determination of the main parameters for assessment of modeling adequacy

The transport model has input and output parameters. Parameters which allow to change result of the work of a model are considered as input ones. Output parameters are the parameters which are subject to control for assessment of the current situation.

Parameters which characterize trip time are connected with characteristics of traffic flows: intensity, speed, delay time and queue length.

The traffic flow intensity is the number of cars passing through road section in unit of time (year, month, day, hour, minute). The intensity can be of two types: actual and brought. The actual intensity established on the basis of data of movement accounting is subdivided into hour intensity, aut./h, taking into account duration of time of its registration; daily intensity, aut./days; month intensity aut./month and year intensity, aut./y. [5,6].

Speed of the movement is an important indicator of the movement of traffic flow. According to the sectoral road methodical document, speed of the movement is divided into: designed, instant, operational, technical speed and free movement speed.

The general losses of time for traffic flow are estimated on the following formula:

\[ T_\Delta = N_a t_\Delta T \]  

where \( N_a \) is a given intensity of traffic flow, aut./h; \( t_\Delta \) is an average total delay of one car, s; \( T \) is an observation duration, per hour.

Transport delays on certain sites and the road networks nodes:

\[ K_z = \frac{t_f}{t_p} \]  

where \( t_f \) is the actual vehicle travelling time; \( t_p \) is designed travelling time.

For definition of delays at controlled intersection we compare time of vehicle passing intersection and a certain intensity of the movement and the working traffic light object. The intensity of the movement is close to zero and passing must be done at a green signal. Another way of definition of a delay at the intersection is the calculation of a number of vehicles standing on an intersection entrance at regular intervals.

Average delay of vehicles at the controlled intersection:

\[ t_{\Delta j} = \frac{n_{tru} t_{int}}{n_{tr}} \]  

where \( j \) – number of driving direction; \( n_{tru} \) – total number of the vehicles which stopped before the intersection during an interval (15 s) during 5 minutes; \( n_{tr} \) – total number of the vehicles which passed the intersection without stopping during 5 minutes; \( t_{int} \) – an interval of measurements, 15 sec.

The average maximum delay of one vehicle shouldn't exceed two minutes. If the delay exceeds two minutes then the condition of the movement of traffic flow refers to congestion.

Queue length before controlled intersection implies number of vehicles on one approach with two phases of signals. For planning queue length can be evaluated considering the average density of cars in the queue:

\[ QL = \frac{T_{(v-c)}}{Nd_s} \]  

where \( T_{(v-c)} \) – duration of delay in traffic flow, s; \( N \) – average density of cars in the queue, aut./km; \( d_s \) – characteristic delay at intersection,
where $QL$ – queue length (km); $T$ – analysis period duration (hour); $v$ – request for traffic (aut./h); $c$ – the flow capacity (aut./h); $N$ – quantity of lanes; $d_s$ – the average density of cars in a queue (aut./km/lane).

Transport models have input and output parameters. For assessment of adequate work of the simulated intersection it is necessary to compare such parameters as: intensity, speed, delay time and queue length. Having compared parameters of model and real intersection by means of a correlation method, it will be possible to draw a conclusion on adequate work of the constructed object.

3. Experiment and results
To define the main parameter for assessment of adequacy an experiment was carried out. For this research we chose Belgorod site of the road network as an object: crossing of Nikolay Chumichov Street and Belgorod Avenue (Figure 1-2).

![Figure 1. The satellite image of the intersection of N. Chumichov St. and Belgorod Avenue.](image)

![Figure 2. Creation of transport model of the intersection of N. Chumichov St. and Belgorod Avenue.](image)

To perform any operations on movement reorganization for the purpose of saving of time, it is recommended to construct models. The main question in case of creation of a model of a real section of road network is assessment of adequacy of a modeled object. For determination of this parameter we use a method of correlation analysis - U Coefficient – Zeyl's statistics [7-9]. The 563 cars passed Belgorod Avenue within an hour in evening hour "peak" during the full-scale researches, 210 aut/h
passed N. Chumichov St. In the Aimsun software the intensity of the model in Belgorod Avenue was 627 aut/h, in N. Chumichov St. – 233 aut/h. There are insignificant differences between model intensity and real object intensity so it is necessary to check adequacy of the model using correlation coefficient.

Correlation coefficient characterizes the relation of the experimental and calculated data. The coefficient evaluates a residual error, namely an error between model parameters and real object parameters (Table 1-2).

Table 1. Correlation coefficient (intensity) of Belgorod Avenue

| Time series | 15 min. | 30 min. | 45 min. | 60 min. |
|-------------|---------|---------|---------|---------|
| Actual intensity | 140 | 112 | 150 | 161 |
| Model intensity | 156 | 140 | 161 | 170 |
| Correlation coefficient | 0.89 | 0.80 | 0.93 | 0.95 |

Table 2. Coefficient of correlation (intensity) of N. Chumichov St.

| Time series | 15 min. | 30 min. | 45 min. | 60 min. |
|-------------|---------|---------|---------|---------|
| Actual intensity | 59 | 58 | 49 | 50 |
| Model intensity | 61 | 61 | 56 | 55 |
| Correlation coefficient | 0.97 | 0.95 | 0.87 | 0.91 |

As we can see in tables 1 and 2 the coefficient of correlation is close to one and it is within an interval from 0.80 to 0.95. So we may conclude that it is rational to use such parameter as intensity for assessment of adequacy of modeling.

Average speed at the intersection of Belgorod Avenue and N. Chumichov St. is 11 km/h, in Belgorod Avenue – 13 km/h, in N. Chumichov St. – 9 km/h. In the Aimsun software, in Belgorod Avenue – 21 km/h, in N. Chumichov St. – 11 km/h. The correlation coefficient on both directions gives low value as it is within an interval from 0.5 to 0.75. Therefore, this parameter gives small deviations, and the model works in a different way. This parameter can be used as a secondary parameter at adequacy assessment.

The maximum queue length in natural research in Belgorod Avenue makes 3 cars, in N. Chumichov St. – 1 car. During modeling the following results were received: in Belgorod Avenue – 4 cars. In N. Chumichov St. there were no vehicles in one approach with two phases of signals. The correlation coefficient in Belgorod Avenue is within an interval from 0.7 to 0.8, in N. Chumichov St. the coefficient is absent as when modeling queue length isn’t observed. When modeling the maximum queue length gives small deviations and the model works differently. This parameter can be used as a secondary parameter during adequacy assessment.

The average conventional delay of one vehicle in the intersection is 20 s. In Belgorod Avenue a conventional delay is 22 s, in N. Chumichov St. it is 15 s. In the Aimsun software a conventional delay in Belgorod Avenue –16 s, in N. Chumichov St. – 11 s. The correlation coefficient in both directions is within an interval from 0.60 to 0.75. The parameter shows deviations and the model works in a different way. The vehicle delay can be used as the secondary parameter for adequacy assessment.

During determination of the parameter of modeling necessary for check of assessment of adequacy and identification of the rational approach within an object of a research of a real intersection we will develop an algorithm of check of adequacy (Figure 3).
The developed algorithm of check of adequacy (fig. 3) shows that transport model assessment requires several stages. First, it is necessary to construct a model using software for modeling of traffic flows (in this research the Aimsun software was used), stages of creation of a model are described in the item "Creation of Model of an Object of a Research in the Program Environment Aimsun", Second, the most suitable out of two offered methods should be chosen and adequacy assessment should be carried out. Method 1 - Two-component models of the kinetic theory of traffic flows - is suitable for the intersections which are in city entries and exits. Method 2 - U - Zeyl's statistics (the correlation analysis) - consists in a research of dependences between sizes. As the intersection Belgorod Avenue and N. Chumichov St. is in the downtown we choose method 2 for assessment of the constructed intersection.

For a method of the correlation analysis we investigate the following sizes: intensity of TF, vehicle speed, time of a delay and maximum queue length. During the research in the item "Assessment of adequacy of model taking into account key parameters (intensity, speed, delay, queue length)" we calculated the coefficient of correlation of each parameter. The greatest correlation is observed with the intensity parameter: \( r = 0.8 \ldots 0.99 \), other parameters have \( r = 0.5 \ldots 0.8 \). Therefore, for further calculations it is rational to use intensity as a primary parameter and vehicle speed, time of a delay and the maximum queue length as secondary parameters.

Having determined the primary parameter, we will find covariance share coefficient which estimates a residual mistake. The model is considered adequate if \( U_c > 0.8 \). In this intersection both directions have \( U_c > 0.8 \) that corresponds to the condition.

4. Conclusion
Modeling of the transport systems is one of stages when holding actions for the organization of traffic. The organization of traffic is the actions connected with carrying out certain works on roads for the purpose of improvement of a transport situation. The process of modeling helps to choose the most optimal solution for the transport infrastructure and is an integral part in the field of the intellectual transport systems [10-12].

During the search, the algorithm for check of adequacy of the model of the controlled inter section is developed. This algorithm shows under what conditions it is possible to conduct organization and reorganization of traffic. There are two methods of assessment of adequacy, one of which is U - Zeyl's
statistics (the correlation analysis). The correlation analysis consists in a research and comparison of dependences between sizes of model and real object. Comparisons were carried out on such parameters as: intensity, speed, delay time, maximum queue length. To find out the best research parameter, it is necessary to calculate correlation coefficient. During calculations intensity showed the greatest correlation, therefore, it must be used as a primary parameter. Speed, delay time, the maximum queue length are secondary parameters. After determination of a primary parameter we found the coefficient of a share of covariance $U_c$ which estimates a residual mistake. The model is considered adequate if $U_c > 0.8$; therefore, it is possible to conduct the organization and reorganization.

The article is prepared within the program of development of the key university on the basis of BSTU named after V.G. Shukhov.

References

[1] Greenberg H 1959 An analysis of traffic flow. Operations Research. 7 79–85
[2] Yakimov M 2013 Transport planning: creation of transport models of the cities: monograph. (Moscow: Lagos) 21–23
[3] Kislyakov V, Filippov V, Shkolyarenko I 1979 Mathematical modeling and assessment of traffic conditions of cars and pedestrians (Moscow: Transport) p. 200.
[4] Zyryanov V 2013 Methods of assessment of adequacy of results of modeling. Eng. Bulletin of Don. 25(2) 132
[5] Borovskoy A, Shevtsova A 2013 Development of a method of collection of information on intensity of traffic. Topical issues of the innovative development of a transport complex, materials of the 3rd International scientific and practical conference pp. 253–260
[6] Shevtsova A, Medvedev M 2013 The overview of the existing methods of a research of intensity of the movement. The international scientific and technical conference of young scientists of BSTU named after V.G. Shukhov devoted to the 160 anniversary of V.G. Shukhov birth, pp. 1307–1312
[7] Industry road methodical document 218.2.020-2012 Methodical recommendations about assessment of flow capacity of roads
[8] Toledo T, Koutsopoulos H N 2004 Statistical validation of traffic simulation models. Transportation Research Board Annual Meeting Proceedings. TRB. (Washington DC)
[9] Barcelo J 2004 Methodological notes on the calibration and validation of microscopic simulation models. Transportation Research Board Annual Meeting Proceedings. TRB (Washington, D.C)
[10] Novikov A, Novikov I, Katunin A, Shevtsova A 2017 Adaptation capacity of the traffic lights control system (TSCS) of as to changing parameters of traffic flows within intellectual transport systems (ITS). Transportation Research Procedia 20 455–462
[11] Novikov A, Novikov I, Katunin A, Shevtsova A 2017 Research of influence of dynamic characteristics for options controlled intersection. Procedia Eng. 187 664–671
[12] Borovskoj A, Novikov I, Shevtsova A 2013 Implementation of intelligent transportation systems within national programs of increase in traffic safety. Bulletin of the Kharkiv national automobile and road university. 61-62 279–283