APPLICATION OF THE MICROSCOPIC MODELS AS A PART OF THE DECISION SUPPORT SYSTEM AT ALL STAGES OF TRANSPORTATION SYSTEM EVOLUTION

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ABSTRACT

This paper refers to the consideration of a problem related to urban transport system (UTS) operation and management on the basis of the Decision Support System (DSS). Considering the DSS as a complex system, which consists of a data management system, a users' interface system, a knowledge-based management system, a model management system [3]. The main attention is being paid to the latter. The model management system represents a repository of models, used for consideration of different scenarios of UTS planning and functioning, and may include different types of UTS models: the models based on macroscopic, mesoscopic and microscopic approaches. This paper considers the role of the microscopic models in DSS: what tasks can be solved by them, what kind of data they need, data requirements, what kind of results they can provide and use at different levels of decision making. For example, the experience of application of microscopic models is demonstrated for solving of some transport system problems in Riga.

Keywords: *urban transport system, decision support system, modelling, simulation, optimisation, microscopic simulation tools*

INTRODUCTION

The contemporary tendencies of the world economic globalization involve distribution of production, thereby contributing to the increase of transportation of resources and goods. As a result the mankind has faced the problems of congestion, pollution, accidents, financial deficits and so on. That's why the planning and management of UTS have a significant impact on the entire processes running in states, regions, towns or cities. However, it is necessary to point out that this is a complex task, because the UTS can be classified as a complex, large, integrated open system (CLIOS) [1]. Normally, systems of such type are counterintuitive in their behaviour, defying description and analysis. Moreover, UTS optimization is a multiple criteria problem, because the transportation planning problem implies involvement of different stakeholders (inhabitants, shippers, government, transport system operators etc.), whereas each of them has its own interests and vision of optimal planning. That's why the decision making relating to the UTS planning and operation should anticipate a system approach. There are several approaches decisions based on master plans, a normative decision theory, a behavioural decision theory, group decision making, adaptive decision making and the mixed-mode decision-making strategies. The latter is one of the most usable approaches and combines all other approaches. Modelling often plays an important role in this case [1, 2]. It allows analyzing the present state of the system under consideration, predicting the future condition and testing different scenarios of solving of the existing problem. This paper considers an application of the simulation modelling as a part of the DSS in the field of UTS management. Specific attention was paid to application of the microscopic simulation at all stages of the TS evolution, as demonstrated in several case studies of UTS modelling in Riga.

PROBLEM OF CONTINUOUS UTS PLANNING AND CONTROL

The UTS planning has to meet certain requirements for people and goods movements for different travel purposes, at any time of a day and of a year using various modes, providing UTS with a certain operating capacity [2]. That's why the UTS study and optimisation should be carried out continuously all the time, taking into account all and any changes, which might happen within a respective period. Such approach supports the mixed-mode decision-making style and includes the following stages [2]:

- formulation of the problem referred to the objectives, standards and constraints;
- data collection about the present state of UTS. This phase is closely connected with the model development;
- construction of an analytical and *simulation* model of the system under consideration, which involves specification estimation and calibration of its parameters and validating of its performance. The original scheme does not include the simulation models, but, in our opinion, this approach also might be included into this scheme;
- generation of solution for testing;
- forecasting of the future values of the planning variables, which are used as inputs to the model;
- testing the model and solution using different scenarios. The model is also used for simulation of different solutions and estimation of their performance;
- evaluation of solution;
- implementation of the solution and search for another problem to tackle;
- monitoring function provides the continuous planning of UTS and checks the validity of data, variables, models, strategy and plans, considered during the study.

The framework of such approach is presented in Figure 1.

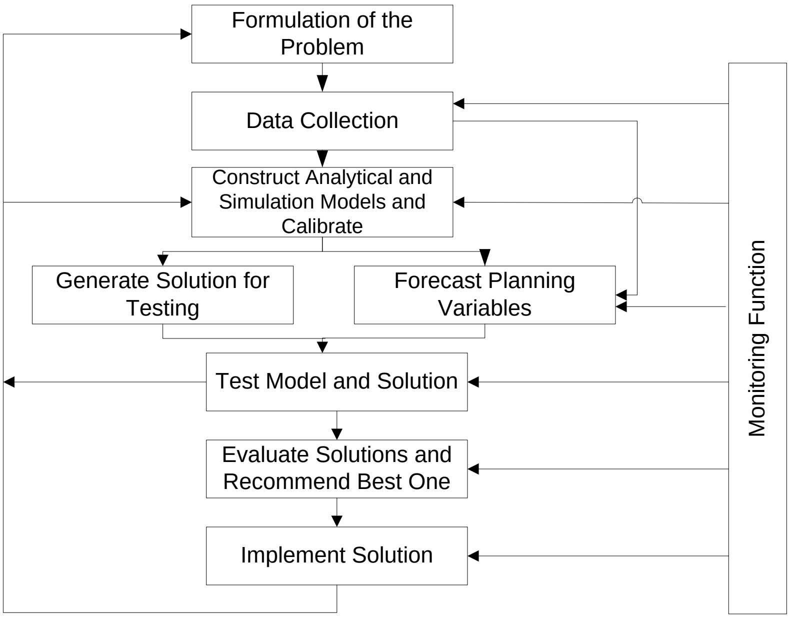


Figure 1 – Continuous decision making of UTS planning and monitoring using models [2]

This approach might be involved in the UTS life cycle, which includes the following stages (Figure 2):

- functioning, UTS monitoring and measures of efficiency (MOE) estimation;
- operation control based;
- tactical planning and control;
- strategic planning and UTS reconstruction or expansion.

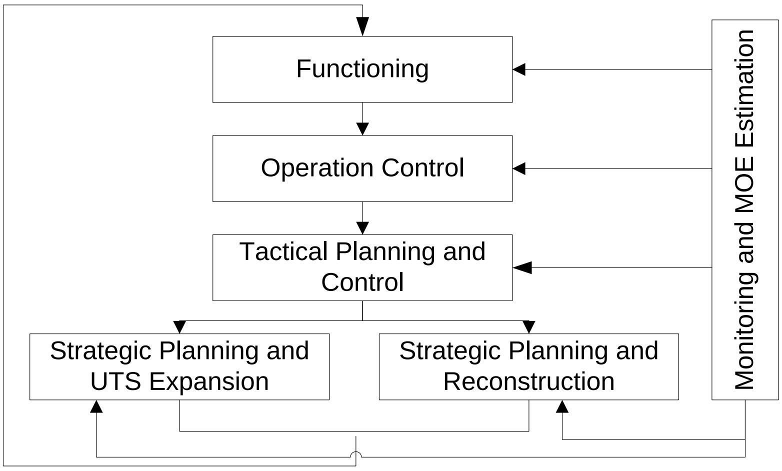


Figure 2 – UTS evolution life cycle

All stages of UTS evolution life cycle are based on the continuous monitoring and MOE estimation. The examples of possible decisions at the operational, tactical and strategic level are presented in Table 1.

Table 1 – Examples of possible decision at all stages of UTS development

Level of decision making	Examples of proposed solution
Operation level	• light signal control • traffic control (velocity, direction, routing etc.)
Tactical level	• reversible traffic control; • road lanes number changing; • traffic direction changing and rerouting; • traffic rerouting taking into account the possible the roads repair works, accidents, bad weather condition etc.
Strategic level	• reconstruction of crossroads, UTS fragments, interchanges etc. and • new UTS fragment and infrastructure creation and UTS expansion because of new points of attraction (business, shopping, entertainment centres, micro-districts) appearing.

The decision making at all these stages is a complex process and should be based on the analysis of its implementation results at all levels of the UTS functioning. The DSS is applied in order to find the best solution, taking into account all constraints and interconnections.

Unfortunately the UTS planning and management in Riga has neither systematic nor continuous character. Most of decisions are of fragmentary nature and are not considered as a whole. Quite often the proposed local solutions are not considered in the context of their influence on the whole transportation system. That’s why the implementation of DSS for Riga TS planning and management plays an extremely important role.

DSS FOR UTS AND MODELLING APPLICATION

The idea of DSS application for UTS was considered in different works (J.Barcelo, A.Uliead & A.Esquius, HoungY.Soo & Dusan Teodorovic & J.Collura, J.Ortuzar etc.) Authors consider application of DSS for UTS control using a modelling approach as a part of DSS. J.Barcelo in several papers considered the DSS for Madrid UTS management using the models implemented in AIMSUN and GERTRAM. Authors A.Uliead & A.Esquius (“Developing Advanced Decision-Support Systems (DSS): an open and networked Transport DSS for Europe”) considered the framework of DSS for the European transport system management and controlling. Some works consider the application telematics for intelligence traffic control within the bounds of DSS. For example, Houng Y. Soo, Dusan Teodorovic, J.Collura (“A DSS framework for advanced traffic signal control system investment planning”) presented the DSS framework provided a holistic framework to perform analytical assessments of integrated emergency vehicle pre-emption and transit priority systems. Juan de Dios Ortuzar in his monograph (2008) describes the role of DSS in transportation system management and planning, and he paid special attention to the modelling application as a part of decision making.

Generally, DSS can partially automate some procedures, like data collection, pre-processing and processing; models running and MOE estimation, comparative analysis implementation;

data processing, models simulation results presentation; user graphical interface supporting etc. A possible scheme of DSS is presented in Figure 3.

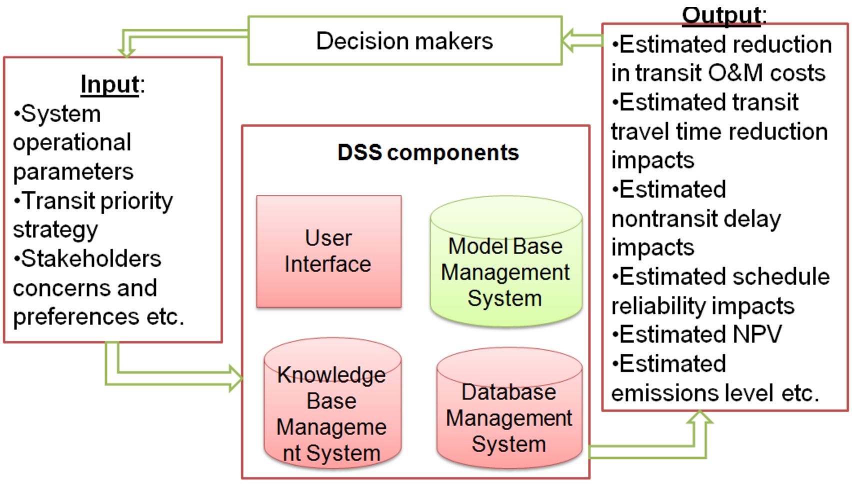


Figure 3 – Scheme of DSS for UTS Planning and Controlling [6]

One of the DSS parts is a model-based management system (Figure 4), comprised of the model base, model directory, model execution, integration and command processor, model - based management system (data management, interface management and knowledge based subsystems).

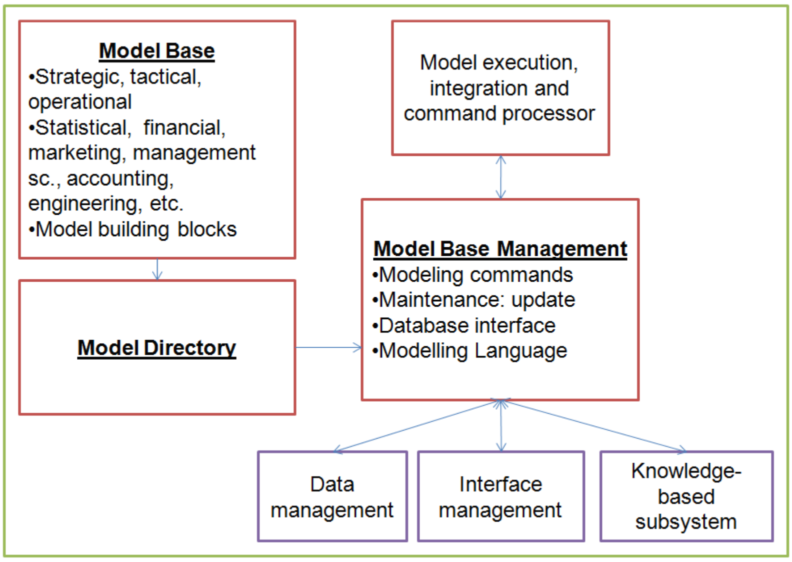


Figure 4 – Framework of model base management system

The DSS models repository might include the following types of models [3]:

- Algorithm-based models,
- Statistic-based models,
- Linear programming models,
- Graphical models,
- Quantitative models,
- Qualitative models,
- Simulation models.

The latter one includes three types:

- macroscopic – usually is used at a strategic level with the purpose to analyze and planning large UTS (UTS fragments of urban districts or the whole UTS);
- mesoscopic – usually is aimed at modelling the UTS fragments (urban districts, several connected intersections etc).
- microscopic – is used for the analysis and optimization of crossroads and minor UTS fragments.

The models repository includes all these model types for application at different levels of decision making. This paper considers the application of the microscopic models for the UTS fragments monitoring, controlling and optimisation. Such models might constitute the DSS models repository and might be used for different scenarios analysis: light signal regulation, traffic speed, direction management, traffic rerouting, crossroads redesign etc.

PROBLEMS OF VALIDATION AND CALIBRATION MODELS AND REQUIREMENTS FOR DATA

An important role in the modelling application during decision - making belongs to its quality. A model should be valid and creditable. In order to get this status a process of model validation and calibration is used. The idea of the model validation and calibration is presented in Figure 5.

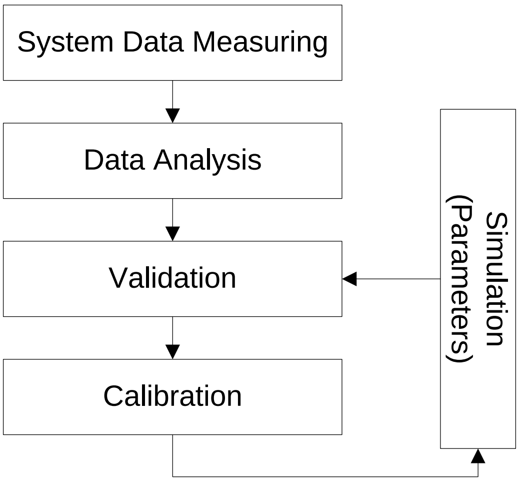


Figure 5 – Framework of data processing and model validation & calibration

Validation and calibration are two interconnected processes. Validation examines the model validity on the basis of real data and measured under model (travel time, travel delays, traffic density, queue length on the intersections etc.). This process means the application of the graphical analyses, statistical methods (ANOVA, homogeneity analysis, naive or novel tests etc.), Turing test etc.

The calibration is aimed at précising the values of the model parameters so that the modelling results will be creditable. Two groups of the parameters require calibration in microsimulation: the driving behaviour parameters and the travel behaviour parameters. The driving behaviour includes acceleration, lane changing, and intersections models. The major components of travel behaviour are the origin–destination (O-D) flows and the route choice model [11]. Usually this process starts from the driving behaviour models parameters calibration and then continuous with the travel behaviour parameter calibration. In literature there are being considered the disaggregated and aggregated model parameters calibration using the classical optimisation methods and heuristic algorithms (for example, the genetic algorithms) (Toledo, J.Barcelo, M.E.Ben-Akiva etc.).

As in the case of validation, in calibration process an important role refers to the quality of data. The relevant and correct data are needed to formalize the model and its environment, including the parameter fitting, calibration and validating of the model, so we can have the meaningful and credible simulation results (Ören 2001). Generally, the main sources of the data might be:

- online data gathered by telematics in the real system;
- historical data stored in the data warehouse;
- estimated or predicted data on the basis of mathematical or statistical models.

The data should satisfy the data requirements as regards the homogeneity, relevancy and actuality. Since it is not possible to employ the rough measurements directly for modelling, processing and analysis of the measured data in parallel with the simulation the modelling process is required. The main tasks of data processing are:

- outliers recognition and excluding;
- samples homogeneity analyses;
- distribution functions and parameters fitting;
- correlation analysis.

In some cases when it is necessary to predict some values the interpolation and extrapolation models, regression models and time series are used. With the purpose to adapt the models to real UTS usually the dynamic data-driven approach is used. The study in these fields are presented in [7, 8, 9, 10].

Sometimes there exists a problem with the actual data collection. For example, in Riga the systematic data collection process is lacking. As a result there is no information about the traffic intensity on crossroads and the UTS fragments, precise distribution of flows (routing) etc. One of the ways to solve this problem refers to using the data of macroscopic models. For example, the results of macroscopic modelling might be used as input data for the microscopic approach: it allows to estimate the local traffic intensity and find out what will happen if a new attraction point appears in some districts of the city; as a result we can estimate the traffic routing, density, velocity and intensity in some fragments; the obtained information might be taken as input data (the resulted intensity and routing) for a microscopic model, which allow to analyze what will happen with some fragments of crossroads more precisely and to make some decisions to solve possible problems according to the possible traffic increasing at the operational or strategic level.

Otherwise, considering some decisions of traffic controlling or crossroads reconstruction at the microscopic level it is necessary to analyze how the proposed decision at the microscopic level will influence on the whole UTS.

The idea of application of data transition from the macroscopic to microscopic level and otherwise was mentioned in the works of T.Toledo, J.Barcelo etc.

CASE STUDY

The presented case studies demonstrate the application of the microscopic modelling for decision making at different stages of the TS life cycle. All models were implemented by using a simulation modelling tool PTV Vision VISSIM. The first case study demonstrates the application of the microscopic modelling at the stage of re-planning the existing UTS fragment, taking into account the appearance of a new point of attraction. In this case the data for simulation were collected during the special transport system survey initiated by the Riga City Council in 2005 and the data predicted by using the coefficient of extrapolation [4]. The second case study demonstrates the application of the simulation modelling at the stage at the tactical planning. In this case the data derived partially from the macroscopic models and partially from the expert's estimation were used. The latter one demonstrates the application of modelling at the stage of Riga crossroad reconstruction with prediction of the future state of Riga transportation system fragment. In this case the data from the macroscopic model were used as well.

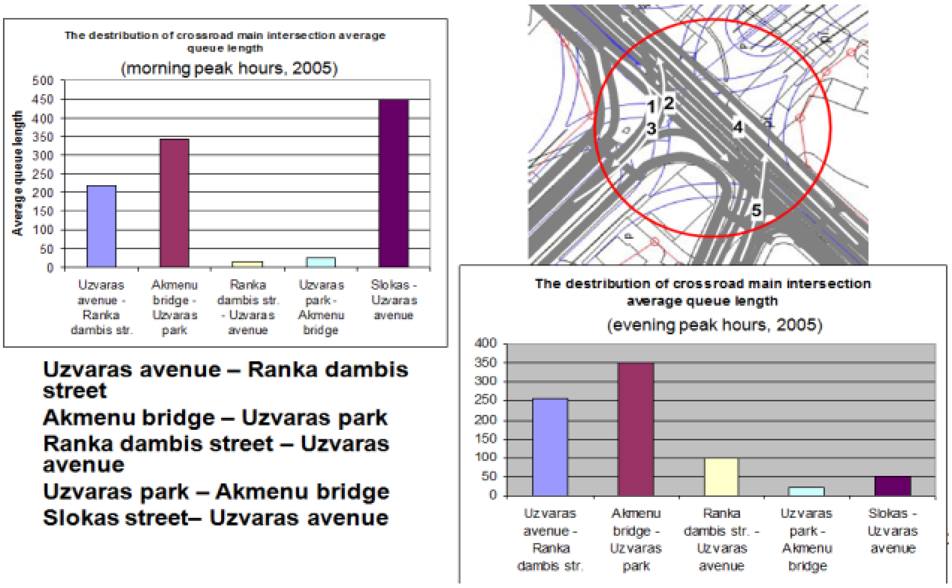
Case study 1: Investigation of TS fragment “Sloka-Uzvaras-Ranka dambis” current capacity, - implying a possibility of occurrence of some new attractive zones

The Riga TS fragment which is located across three main streets: Sloka, Ranka dambis and Uzvaras in Pardaugava district of Riga – was chosen as a subject of the research. This TS fragment was chosen, because the Riga City Council has decided to move the administrative centre from the downtown to Pardaugava district. This re-planning is expected to reduce the congested traffic of the city centre and to alleviate the bridge capacity problem [3]; however, it might increase the traffic flow within the TS fragment examined. That's why it was necessary to analyze carefully the current and the future condition of this TS fragment, which includes 9 crossroads and where the public and private transport operates.

According to the ICU standard, the level of congestion of the majority of crossroads presently complies with a respective standard. The research goals were as follows: analysis of the capacity of the transport node under the existing conditions; revealing its bottlenecks and carrying out a number of experiments with the view of forecasting the intensity of traffic until 2010. An example of the constructed model is presented in Figure 6.

Figure 6 – Example of implemented model fragments

The first analysis was based on the data of 2005. During simulation, a few most problematic intersections were distinguished. The information on queues length is presented in Figure 7.



1. **Uzvaras avenue – Ranka dambis street**
2. **Akmenu bridge – Uzvaras park**
3. **Ranka dambis street – Uzvaras avenue**
4. **Uzvaras park – Akmenu bridge**
5. **Slokas street– Uzvaras avenue**

Figure 7 - Distribution of Average Queue Length on Crossroad Main Intersection (morning peak and evening peak hours, 2005)

Furthermore, a forecast of future situation with this fragment was made, taking into account the traffic intensity forecasted for 2006, 2007, 2008, 2009, and 2010. The simulation results are presented in Figure 8.

The result shows that the future increase of motorization of the Riga population will lead to the junctions increase and the transport node capacity will be insufficient in the future. The analysis of the other transport node crossroads demonstrates that they will be overloaded too. This fact should be taken into account when accepting plans of developing a new business centre in this district. Evidently, it is necessary to carry out the entire transport node reconstruction.

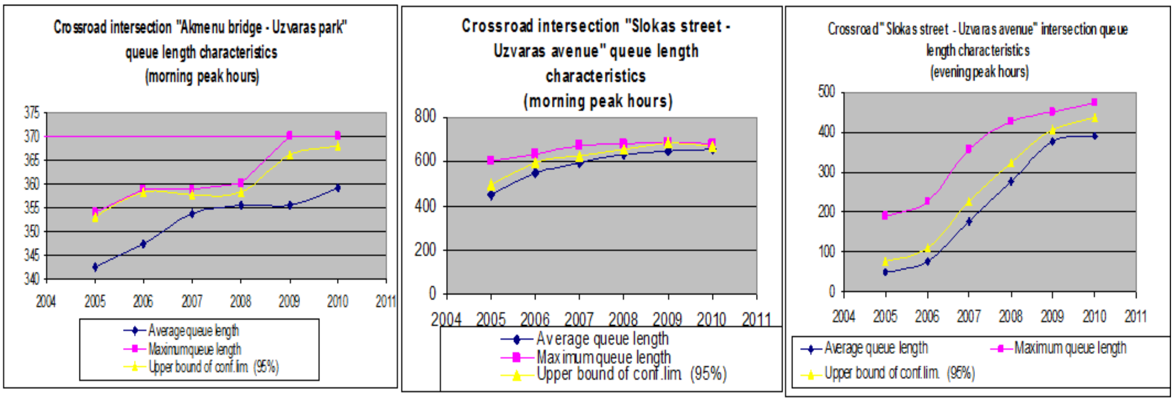


Figure 8 – Results of future situation forecast

Case study 2: Optimization of Riga TS fragment "Slavu-Krasta-Maskavas" organization at the stage of tactical planning

The object of research refers to the transport hub (complex junction of crossroads Maskavas – Slavu – Krasta) characterized by the permanent traffic jams. The scheme of this TS fragment is presented in Figure 5. The main tasks of modelling: the choice of the optimal movement organization and the estimation of capacity for each version of movement; optimization of operation of signal heads [4].

It was supposed that a number of offered changes would give a positive effect on the transport traffic organization and would raise the capacity of the considered area. One of the suggestions was: to bring out the roadway directly from Krasta Street to Slavu Bridge (on the bridge) across the currently existing parking territory (Figure 6, on the right). Thus, the system of three signal heads is replaced by two.

Figure 4 - The studied junction Maskavas–Slavu bridge–Krasta (the old scheme on the left, the new design of network – on the right)

The results of the model experiment before and after the reconstruction are presented on the Box&Whisker diagrams in Figure 6, where the mean, standard error and the standard deviation of crossing time with respect to the three main routes shaping the crossroad are mapped.

One can see that the average values of crossing times were more than halved. Those visualized results were confirmed by the statistical criterion.

This case study illustrates the results of the microscopic modelling application at the stage when it was necessary to find a solution of the existing problems. But the obtained result wasn't taken into account by the municipality. One year later, the municipality started a project of a new bridge construction and the reconstruction of the neighbouring transportation infrastructure (including Slavu-Krasta-Maskavas interchange). The following case study demonstrates an example when the simulation models were used later than necessary, and the problems that should have been really solved were not settled in time [5].

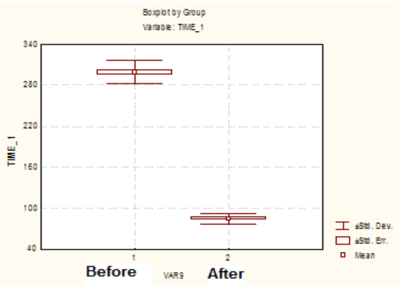
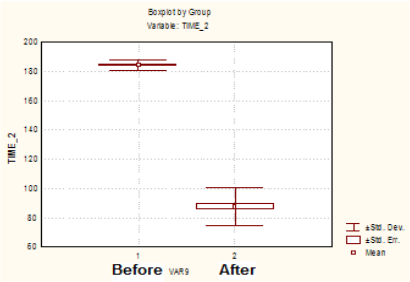
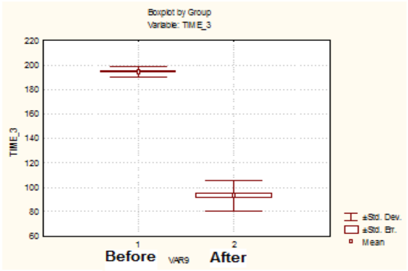
Krasta-Slāvu	Maskavas-Krasta	Maskavas-Slāvu
		

Figure 5 - Box&Whisker diagrams for the parameters of transport junction crossing time

Case study 3: Study of the efficiency of a new project on the Riga TS fragment "Slavu-Krasta-Maskavas" reconstruction

The transport hub was the same as in the previous case study and the main goal of the study was to perform a comparative year-on-year analysis of the considered interchange throughput capacity - as it was in 2004 and as it will be in 2012, when the project of transport network reconstruction around the Southern Bridge will be completed. The simulation model of the new trestle design Slavu-Krasta-Maskavas (SKM) was implemented and based on the real traffic measurements performed in this area, and on the forecast data describing the traffic volume in 2012. The traffic characteristics of the renovated transport hub were studied and compared to the traffic characteristics of this hub in 2004. The fragments of the implemented model are presented in Figure 7.

Figure 6 - View on the three-level flyover model fragments in 3D Animation (on the left) and the average delay time in the problem zones for 2004 and 2012 (on the right)

Two pilot plans were performed: new "SKM" interchange throughput capacity study with the traffic flow forecast for 2012; the study of the efficiency of the proposed decision aimed at suppression of a negative effect of the non-optimal organization of one of the crossroads.

The obtained results have demonstrated that the proposed new design of the transport hub SKM will enhance its throughput capacity. The average speed will be increased by 19%, the average vehicle stop delay will be decreased by 46%. But the specific analysis of several fragments of the interchange demonstrates that the improvement of the throughput capacity will be fragmentary. Comparison between the states of the 3 areas of concern in terms of vehicles delay makes it possible to note the change in architecture of this transport hub; changing the traffic intensity and redistribution of streams resulted in reducing temporal delay on segments N1 and N3, but did not have any positive effect on the segment N2 (Figure 7, on the right).

The reason for this situation is the pedestrians' light signal disposition in this area. The hypothesis was proposed that omitting this light signal (which is possible due to the pedestrian subway being constructed) would reduce the saturation level in this transport system segment. This hypothesis was tested by simulation of a new model with the pedestrians' light signal omitted and the experimental results have demonstrated that the proposed reconstruction will be helpful and will resolve the existing problem. The average speed increased by 34%; the average delay time decreased by 53%.

CONCLUSION

Obviously, the permanent UTS monitoring, management and optimisation play an essential role in the contemporary economics. The principal role in this process belongs to DSS, which accompanies all stages of the decision making at all levels of UTS life cycle. The models might be used as the tools for testing hypotheses suggested to find the best way of solving the problems related to the existing transportation network. An important role in this process belongs to the data and validation & calibration process. Firstly, the data quality should satisfy the requirements. Secondly, the model must be plausible. The latter one was achieved during the special procedures of validation and calibration.

The three above-mentioned case studies illustrate the achieved advantages of the microscopic models application (1) - at the stage of TS current situation analyses/ prediction of future states; (2) – at the stage of tactical planning of transportation network optimisation and (3) - strategic decision making concerning reconstruction. The performed study demonstrates application of modelling under different conditions with real data availability and rigorously proves the necessity of applying simulation at all stages of the transport system life cycle. The obtained results have demonstrated that the timely applied simulation can resolve the current crossroad problems at the stage of its design, and can cut costs associated with removing it now.

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