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THE ROLE OF TRAFFIC FLOW MODELING IN SOLVING CURRENT PROBLEMS OF TRANSPORT PLANNING IN UKRAINE

Abstract. *The main current problems of the transport and planning infrastructure of Ukraine are identified. A brief description of traffic flows as an object of the street-road network is given including all off the factors that are affecting its functionality and the main reasons for the difficulty of studying them are listed and divided in. Modelling is proposed as one of the most effective tool in dealing with modern traffic problems with application of informational technologies. A brief history of the development of urban transport planning and modelling is given, highlighting its four most significant time periods with the description of notable changes during that time. Description of basic principles of transport modelling is structured and formalized. Four-stage computerized transport model is highlighted as the most common used and flexible, its basic assumptions and principles is mentioned. Various transport modeling techniques are proposed for consideration as one of the ways to aid in traffic flows managing. Definition of macromodelling, micromodelling, mesomodelling with its area of research, types of problems it is used to solve, basic advantages and disadvantages is given. The main software packages used today to solve various transport and planning tasks are listed, divided by the level of modelling it is capable to effectively perform. The main transport modelling software packages development companies is named with mentioning of its country-of-origin year of establishing and the most popular products. Along with that, a brief overview for the company's production is given taking into account their advantages and disadvantages and ability to be capable of working in different modelling levels at the same time. Conclusions are drawn summarizing the modern state of urban transport modelling in Ukraine with application of classical paradigm of traffic flow management and regarding further directions of research in this area for the most optimal use of modeling in issues of transport planning, such as creating of hybrid systems that make it possible to simultaneously study various characteristics of traffic flows at several levels of abstraction.*

Keywords: Traffic flow; simulation; street-road network; urban transportation planning; micro modelling; macro modelling

Introduction

The transport problems of Ukraine are well known and are still quite relevant – the increase in the level of motorization and, as a result, the steadily increasing intensity of traffic, the exhaustion of the capacity of highways and road network and traffic jams during peak hours at its key nodes, etc. For a long time, problems of this kind were solved extensively – by expanding the existing transport infrastructure, but in modern realities this is becoming a less rational option and there is an urgent need to use other approaches, aimed primarily at increasing the efficiency of managing traffic flows and applying new automation algorithms to them for the most effective result.

Related Works

The basis for this scientific work was the works and publications of national domestic and foreign scientists, which can be thematically divided as follows:

– Devoted to the issues of the connection of transport and the city – V. E. Bakutis, G. F. Bogatsky, G. A. Golts, H. D. Dubelira, M. M. Dyomin, G. A. Zablotskyi, E. E. Klyushnichenko, A. E. Kudryavtskyi;

– Development of theories and adequate models of traffic flow – J.B. Whitham, D.S. Gazis, O.V. Hasnikova, D. Drew, L. Elefteriadou, V. G. Zhivoglyadova, M. J. Lighthill, A. D. May, L. A. Pipes, P. I. Richards, R. V. Rothera, V. V. Semenov, T. V. Forbes, F. Heit, R. Herman, R. E. Chandler, J. K. Batchelor, H. Birkhoff;

– Problems of organization, management and modeling of the transport planning system and transport flow in particular – V. R. Vuchic, L. S. Abramova, V. F. Babkova, S. A. Boxilla, G. Yu. Vasylieva, V. I. Huk, S. V. Dubova, E. M. Dubrovina, S. Ezell, H. Inose, Y. V. Karasya, V. K. Kittelson, G. I. Klinkovshtein, V. I. Konoplyanka, Y. S. Lanzberga, Ye. M. Lobanova, O. O. Lobashova, E. A. Merkulova, O. Yu. Mykhaylova, M. M. Ossetrina, H. Rakha, E. O. Reitsena, D. S. Samoilova, A. V. Sigaeva, M. S. Fishelson, T. Hamad, Y. V. Khomiak, V. A. Cherepanova, V. V. Sheshtokas.

Transport flows as an object of research

The above-mentioned problem of the exponential increase in the level of motorization in modern cities exacerbates the issue of optimizing the management (and effective distribution) of traffic on road networks. As a result, urban transport flows, as the main component of the city’s traffic flows, become a very difficult object to study and formalize, as they are aggravated by the following features [1]:

1. Stochastic behavior – the characteristics of the traffic flows can be predicted only taking into account the probability. The traffic flow moves through a network, which also ensures good quality, allowing for a more or less strict description.
2. Non-stationarity – a characteristic of changes in oscillations in at least three cycles: daily, weekly and seasonal.
3. Incomplete controllability, the essence of which is that even with complete information about flows and the ability to inform drivers about current actions, these requirements are advisory in nature. Consequently, achieving a global extremum for any control criterion becomes very problematic.
4. Multiplicity of such qualities as: travel delay, average speed, predicted number of accidents, amount of harmful environmental indicators in the environment, etc. Most of the differences are in characteristics; it is not possible to single out and isolate any one thing from them.
5. Complexity (and sometimes impossibility) of measuring even the main characteristic that determines the quality of management. Thus, the traffic restriction measurement parameter requires either digital sensors that provide flows in all directions of movement, or the use of aerial photography data, or a manual survey.

It is also necessary to note the fundamental impossibility of conducting large-scale field experiments in the field of traffic control. This is predetermined by the need to ensure traffic safety, the material and labor costs of conducting the experiment (changing the markings and location of road signs) and the fact that serious changes in the complex traffic management scheme affect the interests of a large number of people – traffic participants.

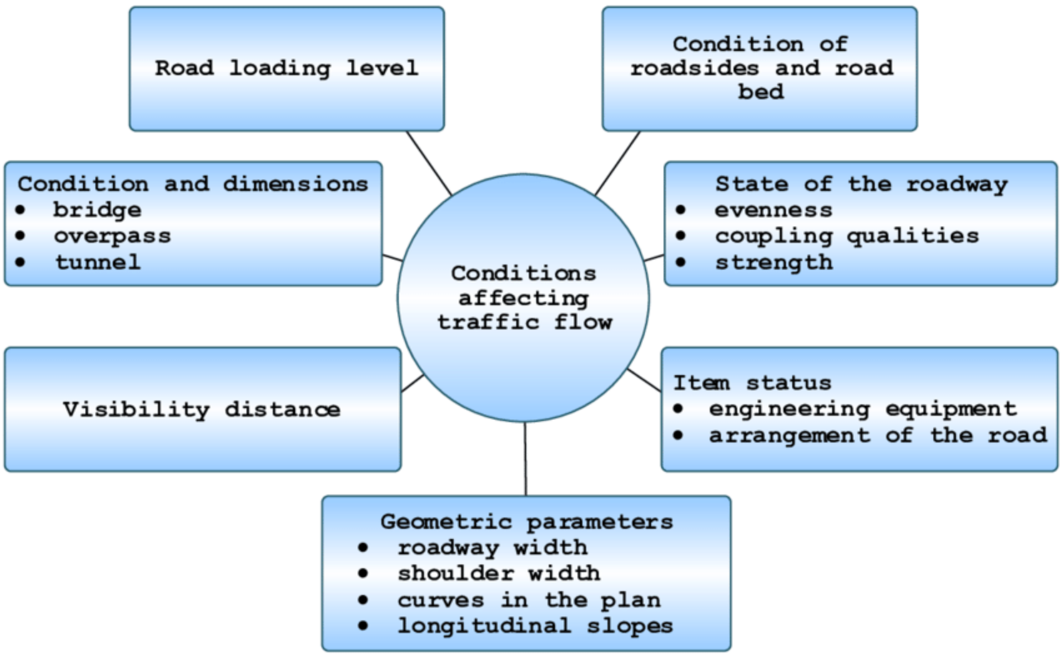

Figure 1 – The variety of road condition affecting traffic flows

Thus, the difficulties of formalizing the processes of traffic flow have become a serious reason for the lag of the results of scientific research from the requirements of practice, and this leads to the need for a fundamentally more modern, information-based approach to solving problems. One of the ways to study this problem may be a generalized approach to the object of study, in particular, the application of new principles for the development of the theory of transport modeling.

A brief history of the development of urban transport planning

In the development of transport models, 4 periods can be distinguished [2]:

1. In 1950 – 1960 development in response to the construction of highways and the improvement of computers;
2. In 1970 – 1980 development in response to criticism of integrated methods;
3. In 1980 – 1990 development in response to criticism of static route analysis methods (trip analysis);
4. In the 1990s. – support in response to environmental pollution and transport demand management policies.

Until the 1950s, metered data was used to analyze events. This approach was only adequate when considering daily periods; any forecasts were rough and based on trends. In the 1950s, road construction, especially in the United States, accelerated, and with it the need for more sophisticated predictive tools and economic forecasts increased.

The first comprehensive study of an urban transport system was carried out in the United States in 1953 in Detroit, and then in 1956 in Chicago. Since then, the general approach to the research has not changed at its core – it was a aggregate four-stage computerized transport model [3], first proposed by Vukan Vucic:

– Level 1 – relationships between the city and the transport system;
– Level 2 – intermodal coordination;
– Level 3 – type of transport or route network;
– Level 4 – individual infrastructure facilities.

The basic assumptions of the four-stage model were the following statements:

1. Forecasting future land use patterns is possible regardless of changes in the transport system.
2. Driver behavior can be predicted based on household data collected from a specific area (urban area).
3. The relationship between household characteristics and driving behavior will remain constant over time.
4. Drivers choose a travel route, trying to minimize travel time and cost.

Connections between urban areas, average characteristics of a typical weekday and peak hours allow us to create an adequate picture for the purpose of improving the transport system.

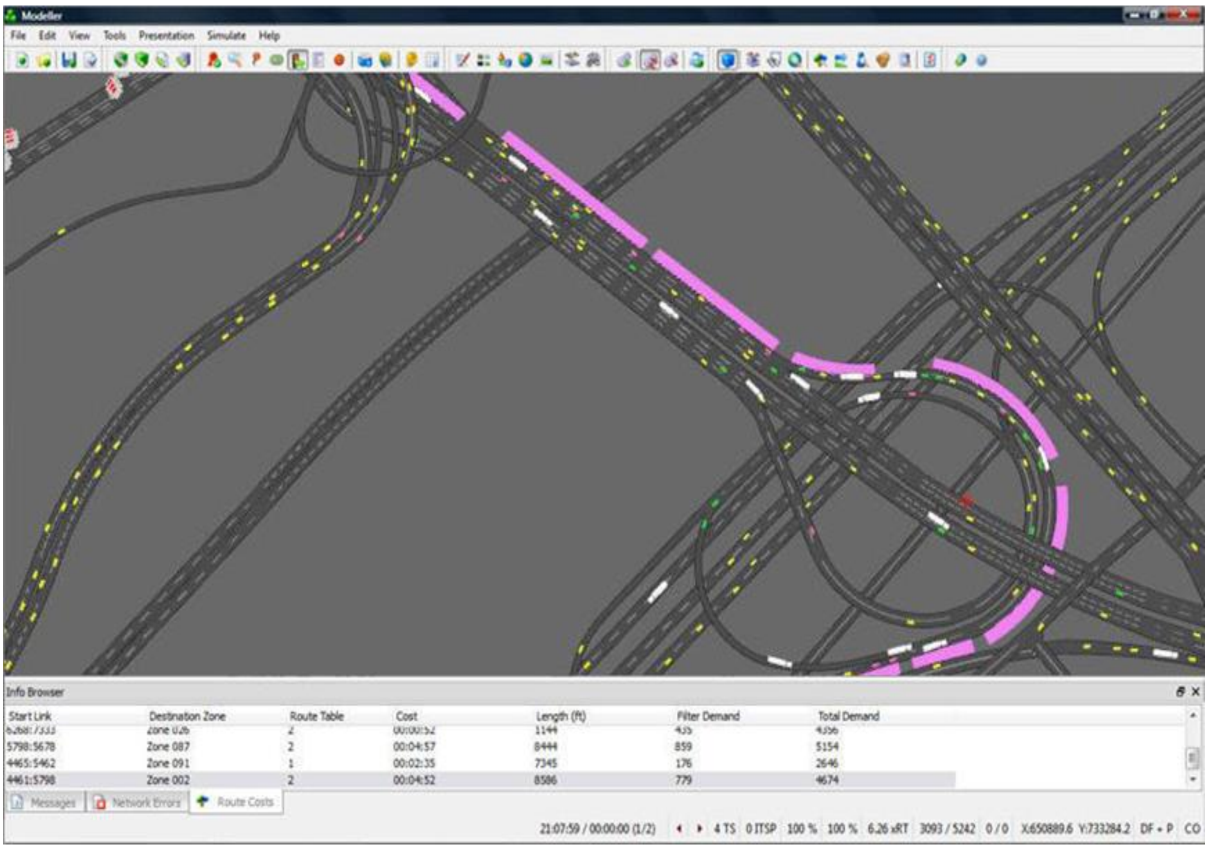

Figure 2 – Screenshot of the Paramics 6.7 Demo software package

The development of computers during this time period provided the means to process the large volumes of data needed to model the entire urban system. The developers of the first models were mainly engineers with "positivistic" views, who used physical laws to plan urban systems (for example, gravitational interaction was used to model the distribution of traffic flows along a network).

In the 1970s a new approach to research was proposed, driven by various historical and social changes – less computer-dependent, more open to public participation, which included a wider range of different evaluation criteria (environmental for instance) as in the previous period attention was focused largely on economic assessments. Seven fundamental shortcomings were highlighted: excessive complexity, large volumes of input data, computational crudeness, high cost, discrepancy between the theory used in the models and the actual behavior of road users, the need to adjust the model to obtain realistic results and difficulties of its interpreting. As a result, three new analytical methods were invented and implemented:

1) models of interaction between transport and land use, describing the mutual influence of transport and land use;

2) disaggregation of methods – building route selection models based on individual travel purposes, rather than zoning of the territory;

3) microsimulation methods – improvement of a complex demand distribution procedure taking into account driver behavior at the level of an individual vehicle or a small group of vehicles/

Despite improvements in modeling technology in the 1970s and early 1980s, the complex of four-stage models, which were mentioned above, are continued to be used in practice as they were in the 1950s. It was only in 1986 that the question of redundancy, inefficiency and wastefulness of the main methods in transport planning was raised. In the 1980s and 1990s, new modeling tools were developed in response to these criticisms:

– Dynamic methods;
– Intermodal coordination.

Modeling the distribution of traffic flows today

Modern models usually consist of the following interconnected structural blocks:

– models of transport demand volumes;
– models of the structure of transport demand;
– models of traffic flows on the road network.

Modeling of the movement parameters of transport and passenger flows on public and individual passenger transport routes is based on data on the structure of transport demand, travel purposes, types of transportation and time periods.

Despite the differences in the mathematical apparatus used, most modern transport models involve performing standard operations and calculations:

1. Zoning of the study area;
2. Construction of graphs of the road network and route networks of public transport;
3. Determination of the total volumes of transport demand by transport areas for various travel purposes;
4. Modeling the structure of transport demand by travel destination, time of day, mode of transport;
5. Calculation of performance indicators of road transport;
6. Modeling the distribution of traffic flows along the road network of the study area and calculating the parameters of traffic flows.

Programs for modeling traffic flows are usually divided into programs related to micro-, meso- and macro- levels of modeling, as well as programs that support several levels at once [4].

At the micro level, vehicles are viewed as individual entities with their own characteristics and behavior. Here the "reasonable driver" models predominate, in which the acceleration of a car is described by some function of the speed of this car, the distance to the car in front and the speed relative to the leader [5]. At the meso level, individual cars are not modeled, but the behavioral characteristics of drivers are taken into account. This level includes cluster models that operate with groups of cars moving at the same speed at a short distance from each other approximately, and models that use probability distributions to describe the speeds of vehicles on certain sections of the road [6].

At the macro level, the transport network is considered as a single whole, and vehicle flows are considered as particle flows in liquid media [7]. In such commercial packages as CORSIM (development began more than 30 years ago through the efforts of the Federal Highway Administration), Paramics Modeller (Quadstone Paramics, UK), Aimsun (TSS – Transport Simulation Systems, Spain, Barcelona), SimTraffic (Trafficware Corporation, USA), PTV Vision (PTV Group, Germany; the main components of PTV Vision are the VISUM and VISSIM software products) the source code is not available for modification or research, and these packages are implemented, as a rule, for the Windows operating system. In such academic developments as the SUMO package (Germany; a package designed for modeling broadband highways), the source code is available for downloading, modification, and there are versions of the package for a number of popular operating systems.

Packages for macro- and meso- modeling allows to solve such problems as planning transport infrastructure and public transport, graphical processing of the network, analysis and assessment of transport networks, forecasting planned activities, creating a platform for transport information systems. Microsimulation packages for traffic flows are rapidly developing due to the increase in computing power, 3D visualization capabilities and processing of large amounts of available data collected from millions of vehicles. This allows to receive and take into account data on vehicle speeds and routes.

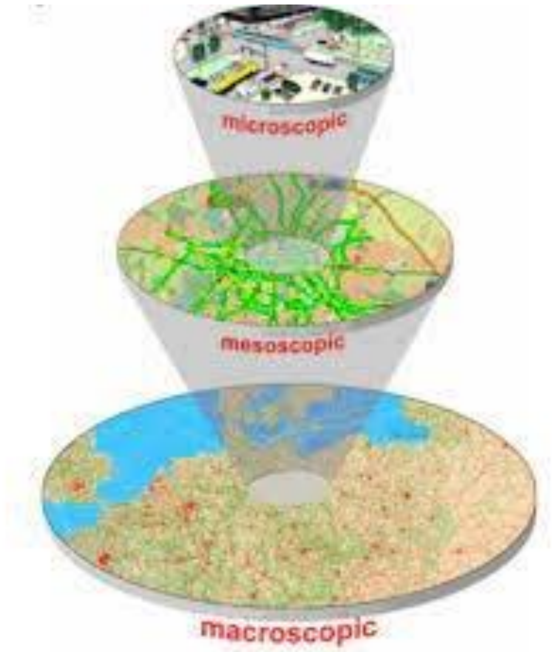

Figure 3 – Levels of traffic flow modelling

Table – ***Packages for modeling transport flows at macro, meso and micro levels [8]***

Macromodeling	Aimsun, DYNEV, Emme, OmniTRANS, OREMS, TransCAD, TransModeler, VISUM, CUBE VOYAGER
Mesomodeling	Aimsun, Cube, Dynameq, DynusT, DYNASMART, TRANSIMS, TransModeler
Micromodeling	Aimsun, CORSIM, CityTrafficSimulator, CORSIM, DRACULA, DYNASIM, MATSim, Quadstone Paramics, Sidra Intersection, Sidra Trip, SimTraffic, SIAS Paramics, TransModeler, SUMO, VISSIM

Many packages that support microsimulation that allow to create transport diagrams and overlay them on maps (these maps serve as background images on which the transport networks of cities are plotted). Particularly noteworthy in this area are the capabilities of the Aimsun package. In most microsimulation packages, it is possible to set maximum and minimum driving speeds, types of road sections, their capacity, etc.

A brief comparative overview of software companies [9 – 10]

– **Kaskeo, 2002** – VISSIM, CORSIM, SimTraffic.

The simulation compared three types of objects: highways, interchanges, and highways with signal coordination. It is concluded that CORSIM is the most mature and widely used package, and VISSIM is the most powerful and versatile. The study also showed that VISSIM has the least user-friendly interface and requires additional effort to post-process the results. SimTraffic turned out to be the easiest to use.

– **Hardy, Wunderlich, 2007** (30 software packages, including VISSIM, Cube, HEADSUP, ETIS, OREMS, Paramics PCDYNEV, TransCAD, TRANSIMS).

The review examines the capabilities of the packages in studying emergency situations and modeling evacuation plans. Twenty-eight packages are used for evacuation planning at the macro-simulation level. Among the non-macromodeling packages, the CUBE package is recommended.

– **Trueblood, 2001** – CORSIM, SimTraffic.

The results of the review showed little difference between the systems when simulating highways with low and moderate traffic. The article establishes the need for detailed analysis of models and the importance of the model validation procedure.

– **Barrios, 2001** – CORSIM, VISSIM, PARAMICS, SimTraffic.

Packages were evaluated based on their visualization (animation) capabilities. In particular, the packages were tested to simulate bus traffic. Ultimately, the authors chose the VISSIM package, which supports extensive 3-D visualization of traffic flows.

– **Middelton, Cooner, 1999** – CORSIM (FRESIM component), FREQ and INTEGRATION.

Packages, that were studied to simulate traffic flow on a freeway. All packages showed adequate results for the problem under study. Important to mention that the packages under study cannot be used for modeling under traffic congestion conditions.

– **Bloomberg, 2003** – CORSIM, VISSIM, INTEGRATION, PARAMICS, MITSIMLab, WATSIM.

All six systems were examined based on their potential for use in modeling signalized intersections and freeways. The study showed that all models provide adequate results.

Results and conclusion

Improving modeling techniques can become an important milestone in the long process of overcoming the current problems of the transport and planning infrastructure of Ukraine. To find effective strategies for managing traffic flows in a metropolis, optimal solutions for designing the road network and organizing traffic, it is necessary to take into account a wide range of characteristics of traffic flow, patterns of influence of external and internal factors on the dynamic characteristics of mixed traffic flow. Modern software used to support decision-making in the design and management of traffic flows does not yet cover all their parameters and characteristics, offering only a simplified representation of the research object with an emphasis on its various aspects. Particular attention, depending on the tasks, is paid to the level (coarseness) of the model, the quality of the available data, the capabilities of calibration and verification of the model, as well as visual interface tools.

The classical paradigm of the theory of traffic flows, mathematically defined as the functional dependence of the traffic flow intensity on its density still remains the defining heuristic principle for the development of the theory of model construction. However, an analysis of the fundamental principles of the theory of traffic flows and a comparison with the requirements of practice indicate the need to apply new principles for the development of the theory of transport modeling. The most promising task at the moment seems to be the creation of hybrid systems that make it possible to simultaneously study various characteristics of traffic flows at several levels of abstraction. To develop the scientific and technical basis of such software, a more detailed study and comparison of modeling and calculation algorithms is necessary. Our research confirms that in different situations one or another approach has its advantages and disadvantages; only their complex application can lead to the most optimal result.

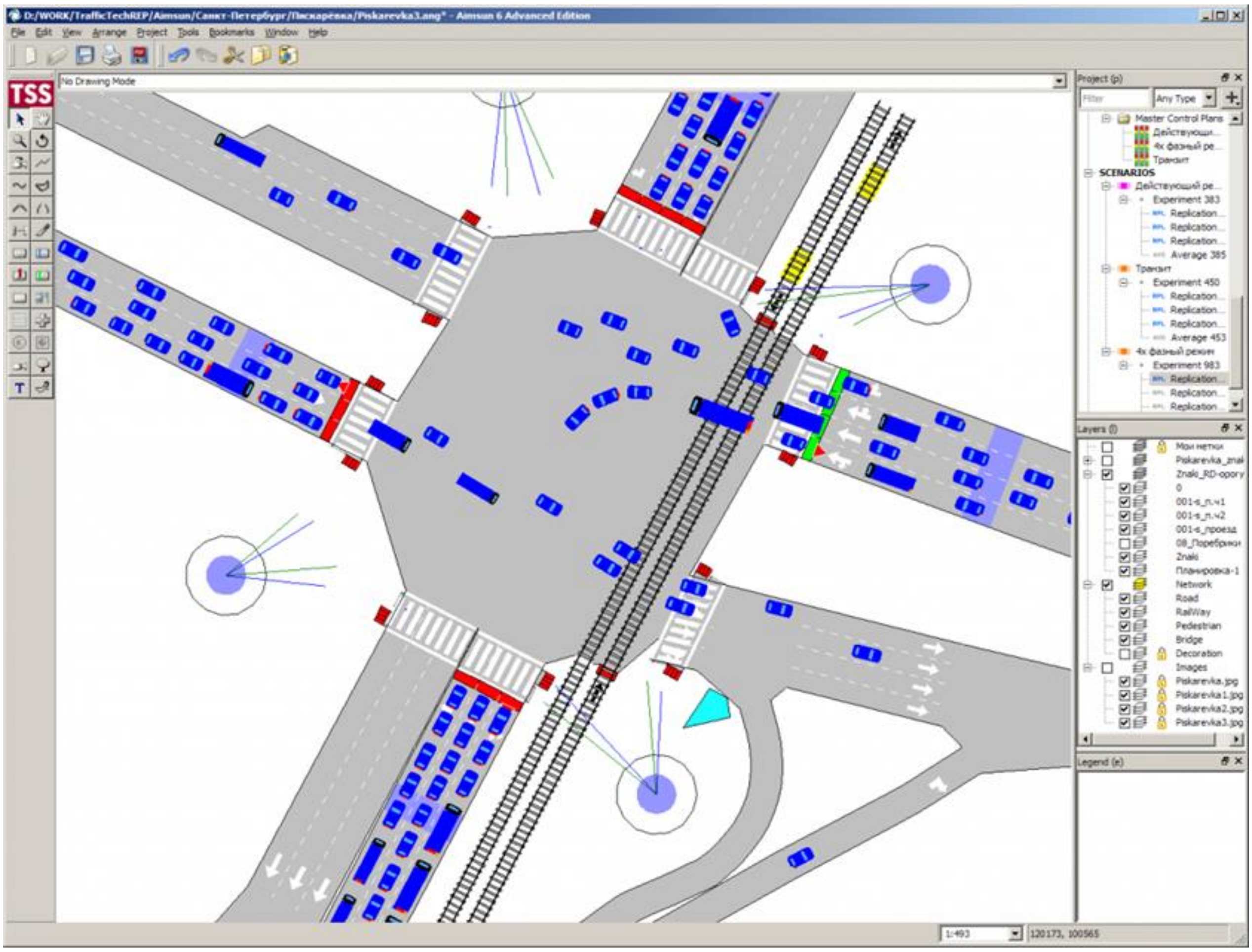

Figure 4 – Screenshot of the AIMSUM Demo software package

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РОЛЬ МОДЕЛЮВАННЯ ТРАНСПОРТНИХ ПОТОКІВ У ВИРІШЕННІ АКТУАЛЬНИХ ТРАНСПОРТНО-ПЛАНУВАЛЬНИХ ПРОБЛЕМ УКРАЇНИ

Анотація. *Визначено основні актуальні проблеми транспортно-планувальної інфраструктури України. Дано коротку характеристику транспортних потоків як об’єкта вулично-дорожньої мережі, враховано всі фактори, які впливають на їхню функціональність, перелічено основні причини ускладнення їх вивчення. Моделювання запропоновано як один із найбільш ефективних інструментів для подолання сучасних транспортних проблем, що залучає інформаційні технології. Надано стислу історію розвитку планування та моделювання міського пасажирського транспорту із зазначенням чотирьох найбільш значущих періодів та описом найважливіших змін впродовж тих часів. Структуровано і формалізовано основні принципи транспортного моделювання. Чотиристадійна комп’ютеризована транспортна модель визначена як найбільш застосовувана і гнучка, вказано її основні допущення та принципи. Запропоновано до розгляду різноманітні методики транспортного моделювання як шляхи вирішення поставлених завдань. Дано визначення макромоделюванню, мікромоделюванню та мезомоделюванню із зазначенням сфери досліджень та різновидів проблем, які долаються їх використанням із вказанням всіх переваг і недоліків. Наведено основні програмні пакети, що використовуються нині для вирішення різноманітних транспортно-планувальних завдань і поділені відповідно до рівня моделювання, який вони спроможні виконувати. Названо основні компанії-виробники сучасного програмного забезпечення для моделювання транспортних потоків із зазначенням їхньої країни походження, року заснування та найбільш вживаних програмних продуктів. Також дано стислий огляд з урахуванням їх преваг і недоліків та спроможності працювати одночасно на декількох рівнях моделювання. Зроблено висновки щодо сучасного стану моделювання міського пасажирського транспорту в контексті застосування класичної парадигми управління транспортними потоками та стосовно подальших напрямів досліджень в цій галузі для найбільш оптимального застосування технологій моделювання в питаннях транспортного планування, таких як створення гібридних систем, спроможних одночасно вивчати різноманітні характеристики транспортних потоків на декількох рівнях абстракції.*

Ключові слова: транспортний потік; симуляція; вулично-дорожня мережа; міське транспортне планування; мікромоделювання; макромоделювання; мезомоделювання

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