Information Technology and Management Science
doi: 10.2478/v10313-012-0026-3
2012 /15

# The Development of an Integrated Geosimulation Environment for Public Transit Analysis and Planning

Arnis Lektauers[1], Julija Petuhova[2], Artis Teilans[3], Arnis Kleins[4], [1-4] *Riga Technical University*

***Abstract* – This paper describes an integrated software environment for multi-modal public transit simulation based on the principles of geosimulation that integrates the capabilities of multi-agent systems, GIS and interactive visualization. The goal of the presented research is to explore possibilities of population in one of Latvia's planning regions, called Vidzeme, to access state/municipal and other services by using public transport. In order to achieve the defined goal, an integrated simulation environment for public transit analysis and planning is developed.**

***Keywords* – geosimulation, public transit, multi-agent systems**

## I. Introduction

In recent years, new forms of simulation have come into popular use in urban, environmental and transportation research, supported by an array of interdisciplinary advances in many scientific areas, especially in the geographical and computer sciences. These models are most commonly based on Multi-Agent System (MAS) formalisms and are often applied to the simulation of spatial systems in dynamic and high-resolution contexts [1]. The modelling of system behaviour with explicit dependency on the geographic space requires the geographic information support that is usually accomplished with Geographic Information Systems (GIS).

A relatively new alternative for the research of urban systems is geosimulation [2], which tightly couples spatial data with process models within a single, integrated framework.

In the area of passenger transportation, there has been a tendency in recent years to increase investments in public transit projects and to reduce them in road construction [3]. Public transit systems or public transportation systems are increasingly complex systems incorporating diverse travel modes and services. The need to integrate and efficiently operate these systems poses a challenge to planners and operators [4]. By using new technologies and applications, as well as development assistance and evaluation tools prior to field implementation in public transportation systems, it is possible to find a solution to this complex problem.

Simulation models have been established as the primary tool for transportation system evaluation at a local operational level [5]. However, traditionally, simulation methods have not played a major role at the regional planning level, but several tools and models developed in recent years [4][6][7] can assist the decision process and help produce transportation infrastructure designs that can be used by the transportation planners for further evaluation.

The domain of traffic and transportation systems is well suited to an agent-based approach because of its geographically distributed nature and its alternating busy-idle operating characteristics [8].

This paper describes an integrated software environment for multi-modal public transit simulation based on the principles of geosimulation that integrates the capabilities of multi-agent simulation, GIS and interactive visualization. In comparison with commercially available public transit simulation tools [9], the proposed simulation system for modellers, planners and stakeholders provides flexibility, scalability and extensibility together with open architecture, computational efficiency and multi-platform support.

The goal of the presented research is to explore possibilities of population in one of Latvia's planning regions, called Vidzeme, to access state/municipal and other services by using public transport. It is also necessary to provide recommendations for public transit network development possibilities.

In order to achieve the defined goal, an integrated simulation environment for public transit analysis and planning is developed. It allows analysing the current public transport routing network optimality in Vidzeme by taking into account the population requirements, as well the available resources of public transit service providers.

## II. Geosimulation System

For a simulation to be useful for transportation analysis and planning, it must not only support a wide variety of features, but it must also be applicable to large-scale, real-world applications.

The developed simulation system implements the agent-based simulation concept, allowing explicit modelling of each transport participant, such as a vehicle or passenger, at a micro-level.

Public transit models developed with the proposed software system can be interactively explored in a multi-scenario mode at different simulation time intervals. Currently, the simulator supports two configurable simulation time modes regarding transit routes and trips used by transit operators during summer school holidays or school time.

The following list gives an overview of the main features of the developed transit simulation system:

• Multi-modal simulation of regional and intercity bus and train traffic.

• GIS based infrastructure for spatial data processing.

• Graphical user interface for simulation data preparation, visualization and analysis.

• Interactive real-time simulation and visualization with possibilities to speed-up the simulation runs by different time scales.

### *A. System Architecture*

In Fig. 1, a general architecture of the developed public transit simulation system is shown. The geosimulation system uses open source software components based on Java programming tools providing a unified development environment for different operating systems, for example, Windows, MacOS or Linux.

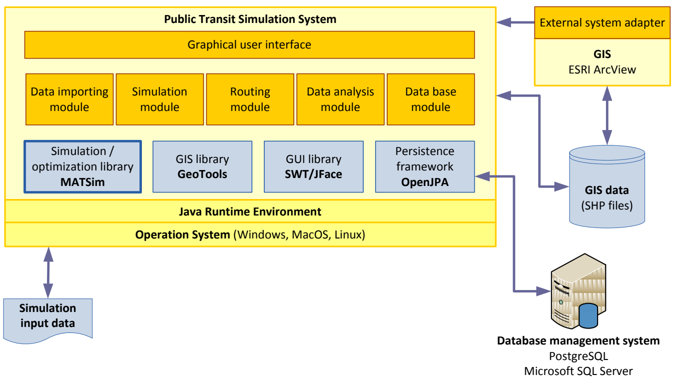


Fig. 1. Architecture of the public transit simulation system

As the main system component, the MATSim (*Multi-Agent Transport Simulation Toolkit*) [6], [10] toolkit has been used that is an open source agent-based transport simulation framework for handling of large transport simulation scenarios with millions of agents within a useful amount of time. Initially, MATSim has been limited to simulate only private car traffic. However, in the latest versions MATSim has been extended to support additional modes of transportation, for example, public transit [11]. The public transit simulation has been implemented as a detailed simulation of schedule-based transit into the existing private car simulation. A mode choice model has been integrated into the iterative structure of the simulation framework, effectively combining mode choice, departure-time choice and route choice together with the traffic assignment in the simulation.

For geospatial data processing, visualization and analysis, the GIS library called GeoTools [12] has been used in the research. GeoTools is an open source Java GIS toolkit implementing many Open Geospatial Consortium (OGC) specifications, including features for vector and raster data access available in different file formats and coordinate reference systems.

The system includes several integrated interactive analysis features:

- Assessment of route network traffic intensity;
- Assessment of availability of public transport stops;
- Assessment of settlement accessibility.

### *B. Simulation Data*

Each simulation needs some initial data that in the case of transportation simulation usually means a transportation network and the so-called “initial demand”. The initial demand describes the initial day plans of all simulated transportation system participants.

The model database contains both the spatial and non-spatial data of different bus and railway routes. The route data is stored and processed in a combination with transit schedules, fares and vehicle types.

The non-spatial relational database contains 19 tables that store all the necessary information about public transit routes, trip schedules, transit agencies, vehicles, stop facilities, fares, planned passenger counts and transit time modes. For the universal object-relational access to different possible database management systems, the OpenJPA [13] data persistence framework has been used. OpenJPA implements the JPA (Java Persistence API) specification that combines features from such existing persistence mechanisms as JDBC (Java Database Connectivity), ORM (Object-Relational Mapping), EJB (Enterprise Java Beans), and JDO (Java Data Objects).

### *C. Simulation Process*

The simulation process (Fig. 2) begins with the building of a road network. The simulation system contains a module that on the basis of the available GIS data automatically generates the network data in the MATSim supported format.

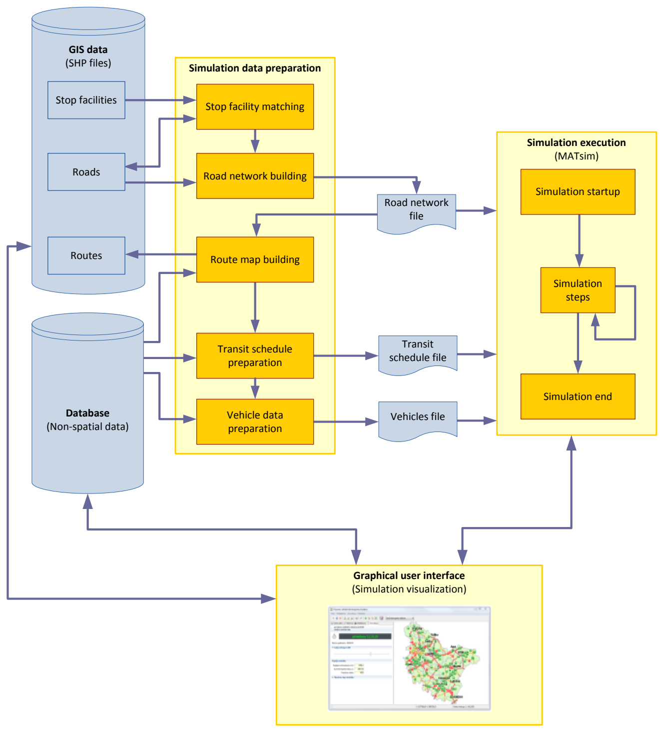


Fig. 2. Data preparation and simulation execution steps

For public transit simulation purposes, the MATSim simulation engine requires at least three specific XML-based input files – road network file, transit schedule file and vehicle file. These files are automatically generated by the simulation system, when the spatial or non-spatial data that is stored in the database or in shape files is changed. This is the simulation data preparation process.

During the simulation execution process also called mobility simulation, at the lowest technical level the discrete time simulation approach has been used in the present research. The mobility simulation is responsible for the execution of the day plans of transportation participants in a physical environment.

The road network is a graph consisting of links representing road segments and nodes representing road crossing or road type change point. Links are modelled as first-in, first-out (FIFO) queues. Vehicles in the queue cannot leave the queue before the corresponding free flow travel time of the link has passed. In addition, only a limited number of vehicles can leave a link per time step, corresponding to the flow capacity of a link. Nodes do not have a lot of internal logic – in each time step, the foremost vehicles of each incoming link are moved over the node to the next link in their route.

Also the public transport stop facilities are represented by nodes in the road network. Therefore, a special module for the conversion of stop facility location data into network nodes is implemented.

During the system development, there has been a problem that the necessary geographical transit route schemes have not been available. To solve this problem, an auto-router module implementing the Dijkstra routing algorithm has been used for route map building applying the available transit schedules.

Then transit schedule data stored in the database has been converted to XML format using transit schedule preparation module. Similarly, the vehicle data stored in the database has been converted to vehicle file by the vehicle data preparation module.

The management of simulation data preparation and simulation execution is managed through the graphical user interface (GUI) (Fig. 3). The GUI is based on the concept of single document interface (SDI), and is developed using the Eclipse rich client platform [14].

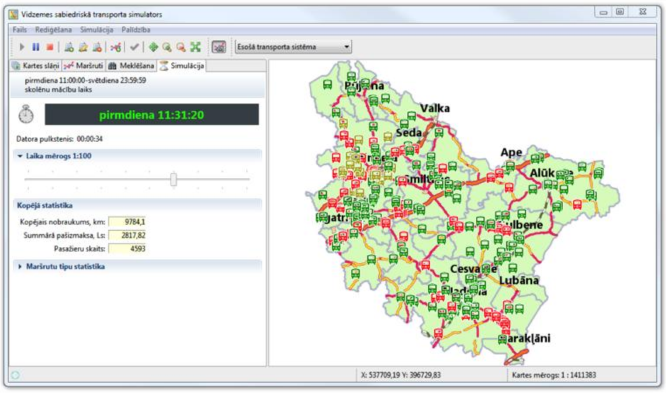


Fig. 3. Geosimulation system user interface

## III. Simulation Scenarios

This section describes how the transit simulation has been applied to Vidzeme region in Latvia, detailing the steps for data preparation, as well as for configuring and running the simulation. It then analyses the computational performance of the large-scale application and estimates the optimization possibilities and directions of the regional public transit network.

The road network of Vidzeme planning region that is dynamically generated from the available GIS data contains 137521 arcs and 62183 nodes (Fig. 4). The public transportation system of Vidzeme planning region is characterised by the following statistical data:

- 2993 bus stops;
- 2173 bus stop facilities assigned to the existing public transit routes;
- 33 railway stations and stops;
- 78 regional intercity routes;
- 222 regional local routes;
- 36 city routes;
- 316 regional intercity trips;
- 1230 regional local trips;
- 162 city trips;
- >74 school bus trips;
- 16 railway trips.

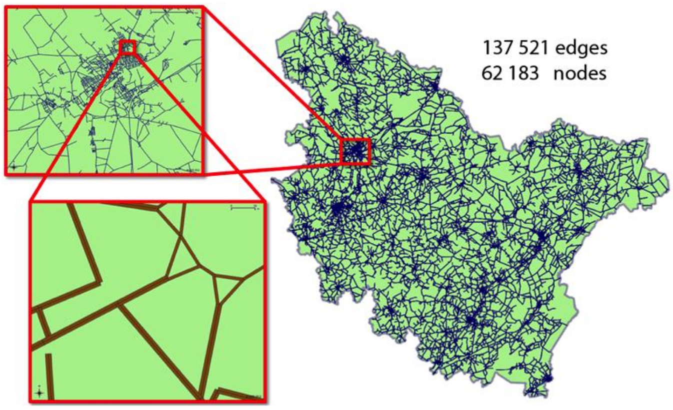


Fig. 4. Road network of Vidzeme planning region

Public transport network design corresponds to the first step of the public transport planning process. From a passenger's perspective, the public transport network should cover a large service area, be highly accessible, offer numerous direct-through trips, hardly deviated from the shortest paths, and should globally be able to meet the demand [15]. There are numerous performance and service criteria used in the public transport route evaluation process. These criteria serve as indicators that assess the quality and quantity of service offered by public transport system bus routes [16]. The presented study is primarily focused on the evaluation of public transport routes at the network level based on the transportation social aspect.

### *A. Route Traffic Intensity and Public Transport Availability*

One of the most important public transportation network efficiency indicators is the trip count per route during a working day or the route traffic intensity. The developed software system contains a module for the assessment of route traffic intensity.

By analysing the public transit route traffic intensity in Vidzeme region, the following results have been obtained:

- 566 bus route kilometres, where route traffic intensity is less than 2 per working day.
- 199 stop facilities where trip count is less than 2 per working day.

Another important indicator for assessment of the public transport quality is the public transport availability. Availability means that the public transport service is within a reasonable distance from where it is and where people want it to be. The presented simulation system calculates public transport availability $A_D$ (%) for each district $D$ located in the Vidzeme planning region using the following GIS-oriented equation:

$$A_D = \frac{\sum_{p\in P}\sum_{d\in D}\left(BUFFER(p,R)\cap P_d\right)\cdot\delta_d}{I_D}, \qquad (1)$$

where

$p=\left(x_p, y_p\right)\in P$ - the set of region stop facility coordinates;

$d\in D$ - the set of district sub-territories, for example, parishes, where the density of population is known;

$P_d$ - the area of district sub-territory (m$^2$);

$\delta_d$ - the density of people in district sub-territory (people/m$^2$);

$R$ - the stop facility availability distance (m);

$BUFFER(p,R)$ - spatial distance circular buffer operator with centre located at $p$ and the given radius $R$;

$I_D=\sum_{d\in D} P_d\cdot\delta_d$ - the number of inhabitants in the district (people).

The performed analysis using public transport availability calculation functionality implemented in the simulation system shows that 59 % of the Vidzeme region inhabitants live, on average, within a 2 km radius from public transit stop facilities. This result is smaller than the availability of public transport stops in other planning regions of the Republic of Latvia. In Fig. 5, the map of public transport availability buffer zones located at centres of stop facilities is shown.

### *B. Accessibility*

Accessibility is a key element to transport geography [17], since it is a direct expression of mobility either in terms of people, freight or information. Accessibility is defined as the measure of the capacity of a location to be reached by, or to reach different locations [18]. Therefore, the capacity and the structure of transport infrastructure are key elements in the determination of accessibility.

The described simulation system calculates public transport accessibility in terms of time necessary to reach a chosen destination. By combining the calculated stop facility availability data with public transport traffic intensity, it is possible to estimate settlement accessibility time.

The analysis of Vidzeme city accessibility using the developed simulation systems shows that the territory of Vidzeme planning region can be divided into 2 geographical areas (Fig. 6). The first area is formed by the cities Valmiera, Cēsis and Valka, where up to 60% of inhabitants have the city accessibility of 45 minutes. The second area is formed by Alūksne, Madona and Gulbene, where the accessibility within 45 minutes is available to 25-35% of inhabitants. Between these geographical areas there is a gap, where the quality and quantity of the public transport traffic should be enhanced.

The visualization of accessibility time implemented in the simulation system is conceptually based on the principles presented in [19].

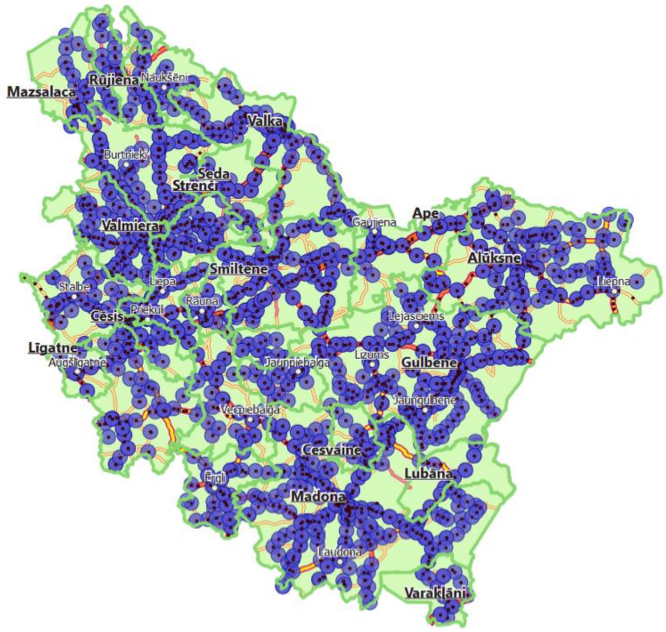


Fig. 5. Map of public transport availability buffer zones located at centres of stop facilities and having 2 km radius

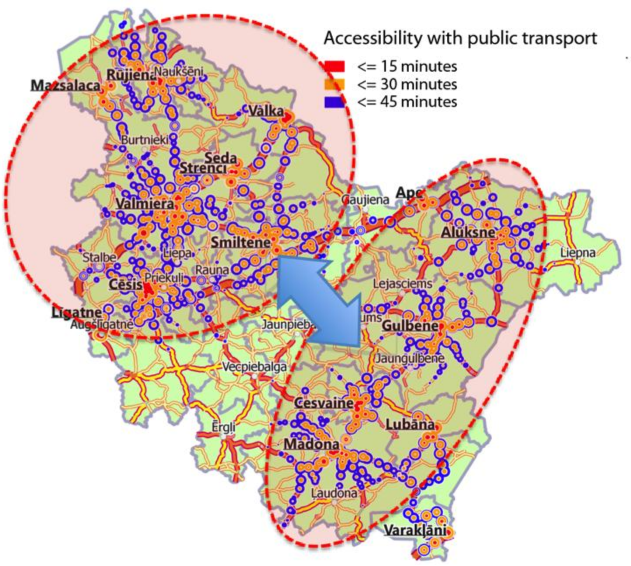


Fig. 6. City accessibility with public transport in Vidzeme region

## IV. Simulation-Based Optimization Possibilities

In this research, four optimization alternatives are defined. The initial alternative is to use the existing public transport infrastructure without changes. The second alternative is related to the improvement of the road quality and the public transit network density. The third alternative is to increase the count and diversity of public transport vehicles.

A real-life application of these two optimization variants requires relatively large financial investments.

During the development of public transit geosimulation system, optimization experiments and scenarios are performed on the basis of the fourth alternative that is related to the improvement of the multimodal public transport infrastructure. This includes the coordination of the railway and bus traffic, planning of the public transport stop layout, modification of the existing routes and optimization of the vehicle trip count. The main goal of the proposed optimization scenarios is to fulfil the social aspect of public transport.

The first proposed optimization scenario is related to the adaptation of the public transport capacity to the number of passengers. The performed data analysis and simulation experiments have shown that in Vidzeme region there are 166 regional trips of local importance, where the expected number of passengers per trip is less than 25. Therefore, in these trips it is possible to use buses with smaller capacity and at the same time with lower fuel consumption (Table ).

TABLE I

Calculated Fuel Consumption Costs for 7 Working Days

| **Scenario** | **Costs** (LVL) | **Cost Savings** (%) |
|---|---|---|
| Initial alternative: Buses with consumption of 30 l/100 km usage | 80153 | |
| Buses with consumption of 25 l/100 km usage | 75174 | 6.2% |
| Buses with consumption of 20 l/100 km usage | 70188 | 12.4% |

The second optimization scenario is to increase the trip count in routes, where the existing trip count per working day is smaller than 2. In the model, 18 new trips are added to 293 bus route kilometres, therefore improving the quality of public transport support in these road segments.

The third possible optimization scenario is to improve the accessibility of the region cities by decreasing the stop count within the existing trips. By decreasing route stop count per trip and at the same time by increasing the distance between stops, on average, from 4 to 6 kilometres, it is possible to improve the accessibility up to 10%. This alternative can be practically implemented in a real life by using partly express buses.

## V. Conclusions

This paper has presented an integrated geosimulation system for public transit analysis and planning that is a novel solution in the context of transportation planning in Latvia. The developed solution is considered to be a useful tool in assisting decision-makers in development planning allowing them to evaluate alternative public transit scenarios and planning options.

The future of the proposed simulation system will include the increasing level of dynamics and accuracy of the modelled transportation infrastructure. The application of modern Web technologies will expand the availability of the public transport simulation to a wide range of users with different levels of knowledge, skills and experience.

## References

[1] J. Ferber, Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence. Addison-Wesley, 1999, p. 528.
[2] I. Benenson and P. M. Torrens, Geosimulation: Automata-Based Modeling of Urban Phenomena. West Sussex: John Wiley & Sons, 2004, p. 312.
[3] G. Laporte, J. A. Mesa, F. A. Ortega, and F. Perea, Planning Rapid Transit Networks, Socio-Economic Planning Sciences, vol. 45, no. 3, pp. 95–104, Sep. 2011.
[4] T. Toledo, O. Cats, W. Burghout, and H. N. Koutsopoulos, Mesoscopic Simulation for Transit Operations, Transportation Research Part C: Emerging Technologies, vol. 18, no. 6, pp. 896–908, Dec. 2010.
[5] C. E. Cortés, V. Burgos, and R. Fernández, Modelling passengers, buses and stops in traffic microsimulation: review and extensions, Journal of Advanced Transportation, vol. 44, no. 2, pp. 72–88, Apr. 2010.
[6] MATSim: Multi-Agent Transport Simulation Toolkit. [Online]. Available: www.matsim.org. [Accessed: 17-Sep-2012].
[7] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, SUMO - Simulation of Urban MObility: An Overview, in SIMUL 2011, The Third International Conference on Advances in System Simulation, 2011, pp. 63–68.
[8] B. Chen, A Review of the Applications of Agent Technology in Traffic and Transportation Systems, IEEE Transactions on Intelligent Transportation Systems, vol. 11, pp. 485–497, 2010.
[9] H. Xiao, R. Ambadipudi, J. Hourdakis, and P. Michalopoulos, Methodology for Selecting Microscopic Simulators: Comparative Evaluation of AIMSUN and VISSIM, 2005.
[10] M. Balmer, M. Rieser, K. Meister, D. Charypar, N. Lefebvre, and K. Nagel, MATSim-T: Architecture and Simulation Times, in Multi-Agent Systems for Traffic and Transportation Engineering, A. L. C. Bazzan and F. Klugl, Eds. Information Science Reference, 2009, pp. 57–78.
[11] M. Rieser, Adding Transit to an Agent-Based Transportation Simulation, PhD Thesis, Technische Universität Berlin, 2010.
[12] OGC, GeoTools - The Open Source Java GIS Toolkit. [Online]. Available: http://geotools.org. [Accessed: 17-Sep-2012].
[13] The Apache Software Foundation, Apache OpenJPA project. [Online]. Available: http://openjpa.apache.org. [Accessed: 17-Sep-2012].
[14] The Eclipse Foundation, Eclipse Rich Client Platform. [Online]. Available: http://www.eclipse.org. [Accessed: 17-Sep-2012].
[15] V. Guihaire and J.-K. Hao, Transit Network Design and Scheduling: A Global Review, Transportation Research Part A: Policy and Practice, vol. 42, no. 10, pp. 1251–1273, 2008.
[16] H. P. Benn, Bus Route Evaluation Standards. Washington D.C.: National Academic Press, 1995, p. 63.
[17] C. Curtis and S. Jan, Planning for Sustainable Accessibility: The Implementation Challenge, Transport Policy, vol. 15, no. 2, pp. 104–112, Mar. 2008.
[18] J.-P. Rodrigue, C. Comtois, and B. Slack, The Geography of Transport Systems, 2nd ed. Abingdon, Oxon, New York: Routledge, 2009, p. 352.
[19] MySociety, Travel-time Maps and their Uses. [Online]. Available: http://www.mysociety.org/2006/travel-time-maps.

**Arnis Lektauers** received the Dr.sc.ing. Degree (2008) in Information Technology from Riga Technical University (RTU), Riga, Latvia. His research interests include interactive hybrid modelling and simulation, and their application to complex system design, as well as industrial, economic, ecological and sustainable development problems.

From 1996 to 2009, he worked for software development and technology companies in Latvia. Since 2001 Arnis Lektauers has served in various staff appointments at Riga Technical University including a Research Assistant, Lecturer, and currently, an Assistant Professor at the Department of Modelling and Simulation, the Faculty of Computer Science, RTU.

He is the Secretary of Latvian Section for the Institute of Electrical and Electronics Engineers (IEEE), and a member of Latvian Simulation Society, System Dynamics Society and European Social Simulation Association (ESSA).

E-mail: arnis.lektauers@rtu.lv

**Julija Petuhova** is a Doctor of Engineering, Lecturer of the Institute of Information Technology at Riga Technical University. Her research interests include simulation methodology of logistics systems, supply chain dynamics, practical applications of simulation modelling, training and education via simulation-based business games.

She is a member of the Latvian Simulation Society and has a wide experience in performing research projects in the simulation area at a national level. She is a member of Latvian Simulation Society (LSS) since 2002 and a member of Technical Program Committee (TPC) of the International Conference on “Computer as a Tool (EUROCON)” (2007). She is the author of 20 scientific publications, including 1 book and 1 international journal.

E-mail: julija.petuhova@rtu.lv

**Artis Teilans** was born in Riga, Latvia and graduated from Riga Technical University, where he studied automatic and remote control and obtained his Doctoral Degree in 1999.

He works in the software industry at Exigen Services Latvia. He is a Senior Researcher at Riga Technical University and a Professor at Rezekne University College, as well. His professional interests include techniques of system modelling and discrete-event simulation.

E-mail: artis.teilans@rtu.lv

**Arnis Kleins** was born in Riga, Latvia and graduated from Riga Technical University, where he studied information technology. He obtained his Master Degree in 1996.

He works at Exigen Services in Riga. From 2010 he is a doctorsl student at Riga Technical University. His professional interests include methodology of system modelling and discrete-event simulation.

E-mail: arnis.kleins@exigenservices.com

**Arnis Lektauers, Jūlija Petuhova, Artis Teilāns, Arnis Kleins. Integrētas ģeosimulācijas sistēmas izstrāde sabiedriskā transporta analīzei un plānošanai**

Rakstā ir piedāvāta autoru izstrādāta integrēta interaktīva programmatūras vide multimodālai sabiedriskā transporta imitācijas modelēšanai, balstoties uz ģeoimitācijas modelēšanas principiem, kas apvieno daudzaģentu sistēmu, ģeogrāfisko informācijas sistēmu un interaktīvas vizualizācijas iespējas. Sabiedriskā transporta imitācijas modelēšanas sistēmas izveides mērķis ir piedāvāt dinamiskas modelēšanas instrumentu transporta plānotājiem, ļaujot noskaidrot iedzīvotāju iespējas saņemt valsts/pašvaldību un citus pakalpojumus, izmantojot sabiedrisko transportu. Dotā mērķa sasniegšanai ir izstrādāta integrēta imitācijas modelēšanas vide, kas nodrošina sabiedriskā transporta maršrutu tīkla analīzes iespējas, ņemot vērā iedzīvotāju vajadzības, kā arī sabiedriskā transporta pakalpojumu sniedzēju iespējas. Salīdzinot ar eksistējošiem transporta modelēšanas risinājumiem, aprakstītais programmlīdzeklis modelēšanas speciālistiem, plānotājiem un lēmumu pieņēmējiem nodrošina elastīgas, mērogojamas un paplašināmas reģionāla mēroga transporta modeļu veidošanas iespējas mijiedarbībā ar atvērtu sistēmas arhitektūru, datorresursu izmantošanas efektivitāti un daudzplatformu atbalstu. Imitācijas modelēšanas sistēma ir balstīta uz MATSim simulācijas bibliotēku, realizējot daudzaģentu balstītus transporta sistēmu mikrosimulācijas principus uz ģeogrāfiskās informācijas bāzes. Izstrādātā programmatūra ir praktiski aprobēta lielākajā Latvijas administratīvi teritoriālajā apgabalā – Vidzemes plānošanas reģionā, apliecinot tās lietderību un potenciālu sabiedriskā transporta plānošanas procesā.

**Арнис Лектауэрс, Юлия Петухова, Артис Тейланс, Арнис Клейнс. Разработка интегрированной системы геоимитационного моделирования для анализа и планирования общественного транспорта**

В статье предлагается разработанная авторами интегрированная интерактивная программная среда для мультимодального имитационного моделирования общественного транспорта, основанная на принципах геоимитационного моделирования, которое объединяет возможности мультиагентных систем, географических информационных систем и интерактивную визуализацию. Целью разработки системы имитационного моделирования общественного транспорта является предложить инструмент динамического моделирования для планировщиков транспорта, разрешающий анализировать возможности жителей получить государственные/муниципальные и другие сервисы, используя общественный транспорт. Для достижения данной цели разработана интегрированная среда имитационного моделирования, которая обеспечивает возможности анализа маршрутной сети общественного транспорта с учетом потребностей населения, а также государственных поставщиков транспортных услуг. По сравнению с существующими решениями транспортного моделирования, предложенное программное средство обеспечивает для специалистов моделирования, планировщиков и лиц, принимающих решения, гибкие, масштабируемые и расширяемые возможности разработки транспортных моделей регионального уровня во взаимодействии с открытой архитектурой системы, эффективным использованием вычислительных ресурсов и мульти-платформенной поддержкой. Разработанная система имитационного моделирования базирована на библиотеке моделирования MATSim, реализуя принципы микро-имитационного моделирования транспортных систем на базе географической информации. Разработанное программное обеспечение практически апробировано в административно-территориальной единице Латвии – в Видземском регионе планирования, подтверждая свою полезность и потенциал в процессе планирования общественного транспорта.