traffic flow, urban, model, simulation, microscopic,
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# A COMPARISON OF MICROSCOPIC TRAFFIC FLOW SIMULATION SYSTEMS FOR AN URBAN AREA

**Summary.** The paper compares the results of an application of three selected systems (TRANSIMS, SUMO, and VISSIM) to the microscopic simulation of traffic flow for a fragment of a real urban road network. First, the problem of traffic flow modeling and simulation was described, and the selected systems were introduced. Afterwards, model construction and simulation were presented. The authors discussed an issue of model calibration, and then conducted a comparative result analysis for the three systems, with a reference to the real traffic. The paper ends with a summary of the conducted research.

# PORÓWNANIE SYSTEMÓW MIKROSKOPOWEJ SYMULACJI PRZEPŁYWU RUCHU DROGOWEGO DLA OBSZARU MIEJSKIEGO

**Streszczenie.** W artykule porównano wyniki zastosowania trzech wybranych systemów (TRANSIMS, SUMO i VISSIM) do przeprowadzania mikroskopowej symulacji przepływu ruchu drogowego dla rzeczywistego fragmentu miejskiej sieci drogowej. W pierwszej kolejności nakreślono zagadnienie modelowania i symulacji ruchu oraz przedstawiono wybrane systemy. W dalszej części opisano przebieg prac nad modelami, a następnie wyniki symulacji wraz z omówieniem procesu kalibracji modeli. Następnie autorzy dokonali krótkiej analizy porównawczej wyników i odnieśli je do rzeczywistego ruchu drogowego. Artykuł kończy podsumowanie zrealizowanych prac.

## 1. INTRODUCTION

A reliable description of traffic flow is a nontrivial problem. A lot of models have been proposed so far, unfortunately, none of them can be considered as an ideal or, at least, universal one. In general, traffic flow models can be grouped into four main categories depending on the level of detail [1]: macroscopic [2], mesoscopic, microscopic [3], and submicroscopic. On the one hand, macroscopic models have application when detailed information about behavior of a single vehicle is not required but only a general evaluation of traffic flows in a network. These models are often used for regional transportation planning. On the other hand, microscopic models deliver estimated, but reliable and detailed, information about a behavior of each single vehicle. For this reason, they can be applied mainly to narrow-range transportation systems, however, with a much higher level of detail.

## 2. MICROSCOPIC SIMULATORS

### 2.1. TRANSIMS

TRANSIMS (TRansportation ANalysis and SIMulation System) [4] is a free integrated simulation system that enables a regional analysis of transportation systems. It supports the whole process of transportation modeling and simulation from population synthesis, through activity generation to traffic microsimulation. The process is usually run iteratively in order to obtain system equilibrium according to the first Wardrop's principle [5]. Additionally, it is possible to perform estimation of emissions on the basis of microsimulation results.

TRANSIMS consists of several modules, one of them is Traffic Microsimulator that is responsible for microscopic simulation of traffic and only this module was used in the study. It is based on cellular automata (CA) theory and uses the commonly recognized Nagel-Schreckenberg model [6] which, in an extended form, encompasses car following models, lane change models and so on. The main feature of CA based models is time and space discretization. For this reason each link is segmented into small cells of equal length (in TRANSIMS the default size is 7.5 m). Each cell can be in one of two states: occupied (by a vehicle) or empty. The space discretization causes discretization of vehicle parameters (i.e. length, maximum velocity) and vehicle state variables (i.e. position, velocity). In consequence, assuming the cell size of 7.5 m, all space and space-derivative parameters and state variables are discretized with a step value of 7.5 as well. Despite significant simplifications, CA models are able to express the first and the second order properties of macroscopic traffic flow models. Moreover, due to their relative simplicity, compared to other microscopic models, the cellular automata models are computationally effective and as such they can be practically applied to the simulation of large and complex regional or even countrywide networks [7]. The research was carried out with TRANSIMS version 4.0.6.01 (containing Traffic Microsimulator module version 4.0.75).

### 2.2. SUMO

SUMO (Simulation for Urban MObility) [8] is a free microscopic traffic flow simulation system developed by German Aerospace Center (*DLR*). It includes the safe distance car following Krauss model [9], an extension of the Gipps model [10], and the Krajzewicz model of lane change [11]. As opposed to the space-discrete time-discrete CA based simulation, SUMO supports space-continuous time-discrete approach. The system enables simulation for various vehicle types, various intersections with or without traffic signals, for networks with a number of links exceeding 10,000. Moreover, SUMO includes procedures for dynamic traffic assignment proposed by Gawron [12] and a graphical application that provides 2D graphical visualization of traffic simulation. The research was conducted with SUMO version 0.11.1.

### 2.3. VISSIM

VISSIM is a commercial system for microscopic traffic simulation by PTV [13]. For car following modeling purposes, it uses the Wiedemann psycho-physical driver behaviour model [14] that takes into consideration an influence of driver's perception on velocity control. A rule-based lane selection model also originates from the research of Wiedemann [15].

In VISSIM, a classical representation of a road network as a graph of nodes (vertices) and links (edges) is replaced by a structure of one-way links connected with connectors. This approach enables modeling of road systems of almost any structure, including roundabouts, which is practically impossible to be done precisely by means of the classical graph representation. VISSIM has lots of functionality options for modeling traffic signal controllers. Besides availability of fixed-time and traffic-actuated controllers, it can also collaborate with external hardware controllers.

Not only does VISSIM facilitate very precise modeling of road infrastructure but also offers great possibilities for adjustments of vehicle properties. It allows the simulation of two-wheeled vehicles, trams, and even pedestrians, which is rather rare for microscopic simulators. Moreover, it is possible to perform an iterative procedure of dynamic traffic assignment [16]. Last but not least, VISSIM has huge graphical capabilities enabling the creation of 2D/3D animations with a high level of detail.

## 3. ROAD NETWORK

The comparison of microsimulation systems was based on a fragment of a road network of Grunwald, a south-western district of Poznan city. The considered fragment consisted of the following high traffic streets (Fig. 1) [17]:

- ul. Krzysztofa Arciszewskiego,
- ul. Głogowska,
- ul. Hetmańska,
- ul. Macieja Palacza,
- ul. Piotra Ściegiennego.

These streets cross as 6 signalized intersections.


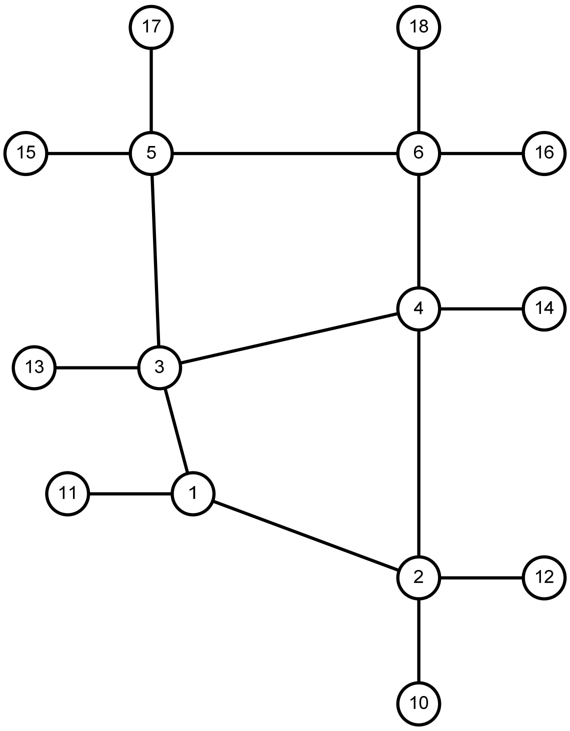


Fig. 1. Fragment of Poznań road network and its model
Rys. 1. Fragment sieci drogowej Poznania oraz schemat modelu

## 4. MODEL

### 4.1. Road network

The model of the road network consisted only of the major streets listed above. As the network is localized in a residential area without commercial or public buildings that generate high traffic, all minor streets were excluded from further considerations because of low traffic. Furthermore, tram communication along Hetmańska and Głogowska streets was not taken into account due to the lack of support for this means of transportation in TRANSIMS and SUMO.

The network model with node identifiers is presented in Fig. 1, on the right. Links from node 10 to 18 represent ul. Głogowska. Nodes 1,…,6 are intersections with traffic lights, and 10,…,18 are boundary nodes, where each route starts and ends. Nodes 1-6 are connected with links of length equal to the real one, whereas links leading from/to the boundary nodes are 300 m long.

According to the specific modeling approach, the model built in VISSIM was not directly constructed with nodes. As stated earlier, the link-connector architecture allows the construction of realistic models of complex road systems. This representation turned out to be superior to the classical node-link one. For illustration, Fig. 2 shows an aerial photography [18] and a VISSIM model of intersection 5. As it is easy to see, the two marked left turn maneuvers can be executed in two steps and even not necessarily within a single traffic light cycle. In TRANSISM and SUMO models, these two left turns can be performed only as one indivisible operation.

Fig. 2. Intersection 5 – an aerial photography and the model in VISSIM
Rys. 2. Skrzyżowanie 5 – zdjęcie lotnicze oraz model w VISSIM

### 4.2. Traffic signals

Detailed information on traffic lights programs was derived from road measurements presented in [19]. A few intersections have traffic signal controllers with a high priority for trams. In these cases, since tram communication was beyond consideration, the measurement was conducted in periods when no tram was awaiting the green light. It is worth mentioning that TRANSIMS and SUMO do not allow modeling of the red/amber signal between the red and the green. Therefore, instead of red/amber signals, duration of all red signals had to be respectively extended.

### 4.3. Traffic measurements

In order to estimate the volume and distribution of traffic, series of measurements were made on each intersection (nodes 1-6). The measurements were performed manually for each intersection inlet with the distinction of a vehicle type (P – passenger car, L – light duty truck, H – heavy duty truck, Ht – heavy duty truck with a trailer, C – bus/coach, M – motorbike, and B – bicycle) and a maneuver (L – left turn, S – straight ahead, and R – right turn).

The traffic volume was counted on a working day (April 21, 2009) during the afternoon rush hour (from 14:00 to 18:00) in good weather conditions. As the counts were made during high traffic, the obtained traffic flows were close to the capacities of the intersections.

Obviously, there were small discrepancies in traffic flow on individual links in the measurement data. They consist in differences between a number of vehicles entering a given link at one intersection (through intersection outlets) and a number of vehicles exiting this link at the successive intersection (through intersection inlets). The reasons were twofold: impossibility of conducting manual measurements for all the intersections at once, and exclusion of small local streets from the consideration. However, the discrepancies were of minor importance.

### 4.4. Traffic generation

The measured traffic flows at the intersections (nodes 1-6) were used for the generation of vehicles and their routes. Because there is no uniform method of traffic generation for the selected microscopic simulators, several steps had to be taken in order to ensure maximum mutual conformity of the planned routes for each model. Therefore, for each simulator a specific generation procedure was proposed according to the following assumptions.

The first assumption was that each vehicle enters the network in one of the boundary nodes (nodes 10-18) and then traverses the network until reaching any of the boundary nodes where it exits the network. During the traversal on each of the six intersections a driver selects one of possible maneuvers. The selection is stochastic and depends on the measured turning ratios.

Secondly, vehicle flow, regarding both its volume and vehicle type distribution, incoming from each boundary node was assumed to be equal to the measured flow at a respective input link of the nearest intersection.

The traffic generation procedure in SUMO is quite straightforward. Among many other route generation programs, the system offers JTRROUTER (Junction Turning Ratios ROUTER) that facilitates route generation on the basis of turning ratios and incoming flows.

A different approach, but also easy to apply, is available in VISSIM and consists in graphical definition of incoming flows (using vehicle generators) and intersection turning ratios (with route decisions).

Unfortunately, despite great functionality and versatility of TRANSIMS, it does not contain a tool that performs traffic generation on the basis of turning ratios. Due to this limitation, a special procedure, functionally similar to JTRROUTER, was implemented in Java. More detailed information about this procedure can be found in [20].

One should note that both SUMO and TRANSIMS procedures do not provide the distinction of a vehicle type in turning ratio definitions. Therefore, in all three cases (also in VISSIM) all turning ratios were normalized to so-called vehicle units using weights typical for signalized intersections in Poland [21]. Because SUMO and TRANSIMS simulators do not enable simulation of two-wheeled vehicles, like bicycles or bikes, these means of transportation were excluded from simulations in all three models. However, two-wheeled vehicle traffic made up only a small portion (0.8%) of the total traffic, and therefore, the omission had no significant influence on the results.

## 5. SIMULATION

### 5.1. General approach to model calibration

In order to obtain reliable simulation results, it is extremely important to carry out a thorough calibration process that leads to identification of the model structure and its parameters. Usually, the calibration process is iterative and strongly depends on model properties.

In the conducted research, each of the three models was calibrated separately. There were many conditions of model correctness considered during the calibration. First of all, running the simulation with the measured traffic flow values should not cause traffic congestion since the intersection capacities should be at least as high as the measured flows. Moreover, simulation output should be consistent with the real traffic, particularly when analyzing bottlenecks for increased traffic volumes, for instance 110% or 120% of the initial traffic flow level. The calibration process was conducted on the basis of vehicle counts per link and per network, queue lengths, and visual assessment of the simulation.

In this section, the most interesting issues of calibration and simulation for each of the selected systems were presented. More detailed information can be found in papers concerning simulation in TRANSIMS [22], SUMO [23], and VISSIM [24] individually.

### 5.2. TRANSIMS

In the case of TRANSIMS, a lot of emphasis was laid on the adjustment of a cell size. The default cell size is 7.5 m, but this results in coarse-grained vehicle parameters and state variables (i.e. velocity, acceleration). Therefore, the only possible values of velocity are 0, 7.5, and 15 m/s, and vehicle maximum acceleration/deceleration is at least equal to $\pm 7.5$ m/s$^2$.

Because of this impreciseness, additional simulations were run for smaller cell sizes, like 3.75 m (twice as small), and 1.5 m (five times smaller). The decrease of the cell size did not cause any significant changes in simulations carried out for small traffic volumes. However, when increasing the traffic flow, some instabilities (resulting in sudden traffic congestion) occurred during simulations. In general, the higher the traffic and the smaller the cell, then the more probable the occurrence of instabilities. For a cell size of 3.75 m, sudden congestion was likely to happen when the traffic flow was greater than 100% of the measured flow. But in the case of 1.5 m long cells, such instabilities started to appear for 65-70% of the initial traffic volume.

Fig.3 shows the influence of traffic volume on a degree of congestion in the network (a number of vehicles in the network) during the simulation. For comparative purposes the figure includes results for the two first variants of the cell size (7.5 and 3.75 m). As it is shown, for the default cell size, smooth traffic flow is possible even after an increase of its volume to 140%. The issue of cell size adjustment should be investigated in the future, however, the authors suggest not to use too small cell sizes as simulation seems more stable and reliable with the default size of 7.5 m.

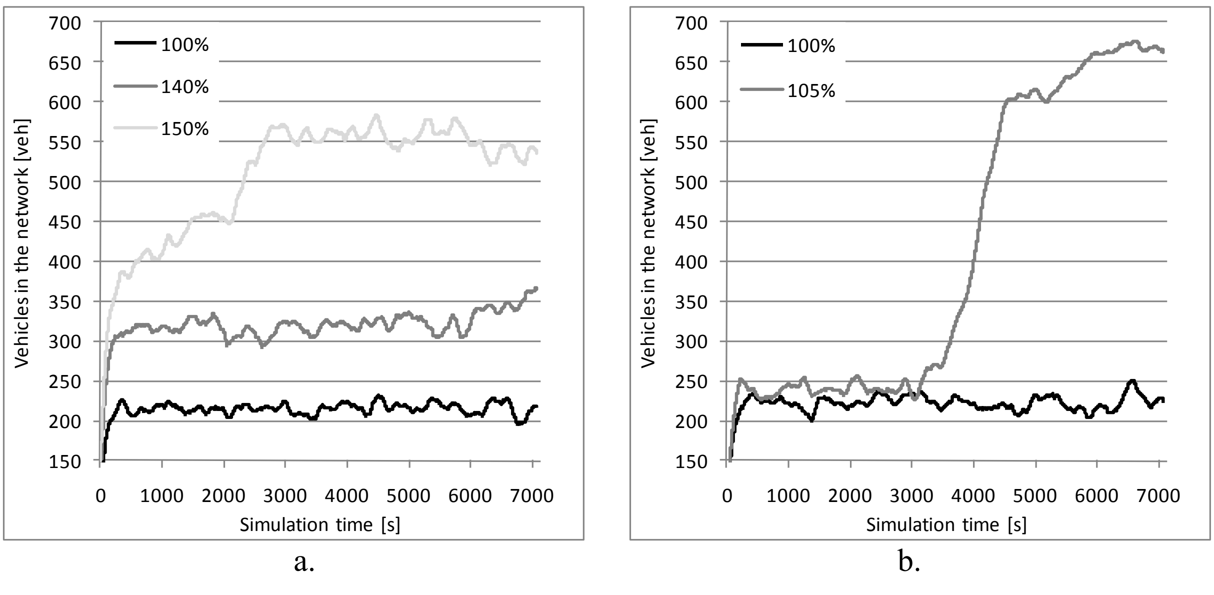


Fig. 3. An influence of traffic volume on a number of vehicles in the network during a two-hour simulation (a – cell 7.5 m, b – cell 3.75 m)

Rys. 3. Wpływ wielkości natężenia ruchu na liczbę pojazdów w sieci w trakcie dwugodzinnej symulacji (a – komórka 7,5 m, b – komórka 3,75 m)

### 5.3. SUMO

Quite different simulation results were obtained with the model implemented in SUMO. In contrast to the model in TRANSIMS, the main problem lay in the insufficient capacity of the network, and particularly of the intersections. For the default vehicle parameters, only when the traffic volume was equal to 90% of the measured one, or smaller, there were no vehicle queues lengthening during the whole simulation. As the network was incapable of serving traffic of the initial (100%) volume, the goal of the calibration process was to identify the model parameters that would increase the network capacity.

In SUMO version 0.11.1, a lot of parameters, regarding lane change model and others, are not directly accessible to a user in configuration files. Therefore, these parameters were not considered during the calibration process. A special attention was paid to vehicle and driver parameters of the car following model, which were:

- *accel* – acceleration ability [$m/s^2$],
- *decel* – deceleration ability [$m/s^2$],
- *sigma* – driver imperfection (real value between 0 and 1 inclusive),
- *length* – vehicle length (increased by a typical gap distance between stopped vehicles) [m],
- *maxspeed* – vehicle maximum velocity [m/s],
- *tau* – driver's reaction time [s].

Tab. 1 contains the identified values of parameters for each type of vehicles (abbreviations according to Section 4.3). Only these values guaranteed no congestion at 100% volume level, and even small changes to many of the parameters significantly worsened the network capacity. Nevertheless, this set, as well as any other set, did not enable to run the simulation for an increased traffic volume without increasing congestion. What is interesting, the determined parameter values differ much from the originally proposed by Krauss and the default values used in SUMO.

Table 1

Vehicle parameters after the calibration

| | ***accel*** | ***decel*** | ***sigma*** | ***length*** | ***maxspeed*** | ***tau*** |
|---|---|---|---|---|---|---|
| **P** | 3.0 | 5.5 | 0.1 | 7 | 50 | 1 |
| **L** | 2.5 | 5.0 | 0.1 | 10 | 40 | 1 |
| **H** | 2.0 | 4.0 | 0.1 | 15 | 35 | 1 |
| **Ht** | 1.5 | 4.0 | 0.1 | 21 | 30 | 1 |
| **C** | 1.0 | 4.0 | 0.1 | 15 | 25 | 1 |

Fig.4 shows the influence of changes in accel (±0.5 m/s2) and sigma parameters (0, and 0.3) on deterioration of the network capacity. In the case of the left chart, a dotted line was used to include vehicles that were unable to enter the network due to the spread of congestion up to boundary nodes 16 and 18.

### 5.4. VISSIM

Due to very precise models of vehicles and drivers available in VISSIM, calibration efforts were concentrated mainly on adjustments of geometry and parameters of the road network. A lot of attention was given to the proper localization of all road transportation infrastructure elements (links, connectors, signal heads, etc.), and logical elements (vehicle generators, route decisions, etc.). Also, it was very important to correctly define conflict areas, particularly when running simulations with high traffic volumes.

Despite very detailed models of vehicles, VISSIM does not have a light duty truck class among available vehicle classes by default. Therefore, such a class was created and adequately parameterized prior to the simulation tests.

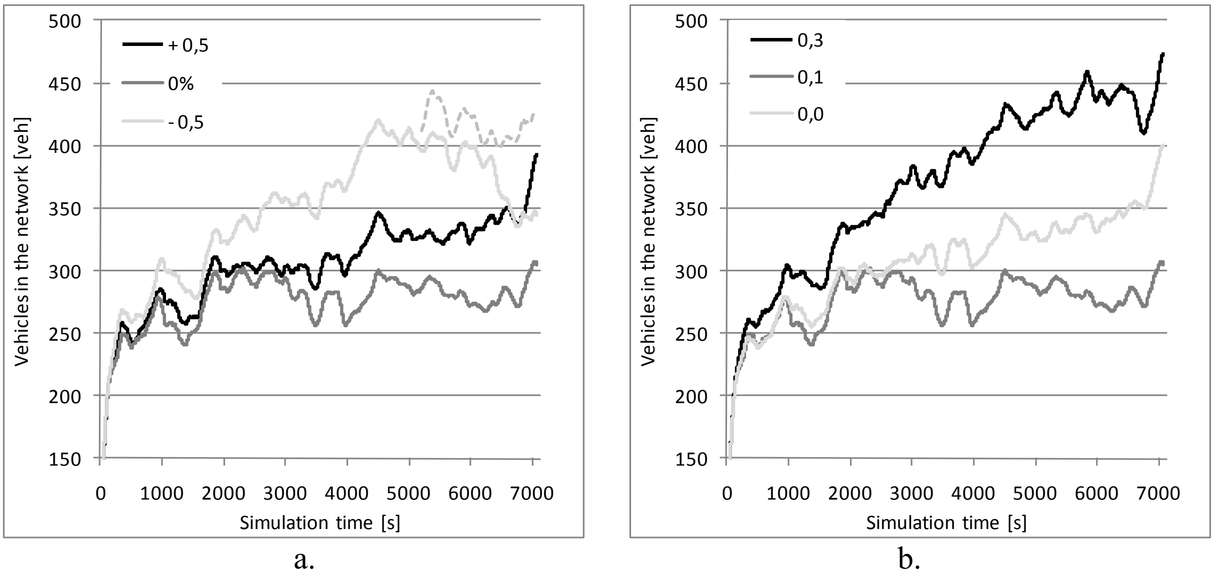


Fig. 4. An influence of adjustment of parameter values on a number of vehicles in the network during a two-hour simulation (a – *accel*, b – *sigma*)
Rys. 4. Wpływ doboru wartości parametrów na liczbę pojazdów w sieci w trakcie dwugodzinnej symulacji (a – *accel*, b – *sigma*)

Fig.5 shows simulation results for different levels of traffic volume (100%, 130%, and 140% of the initial volume). Up to the 130% level, traffic was smooth and there were no long queues at all intersections inlets. However, the network capacity was not enough to service any further increase in traffic amounts. In the case of the 140% level, vehicles were unable to enter the network due to the propagation of queues up to two boundary nodes (nodes 16 and 18). Therefore, a dotted line was used to show both running and awaiting vehicles.

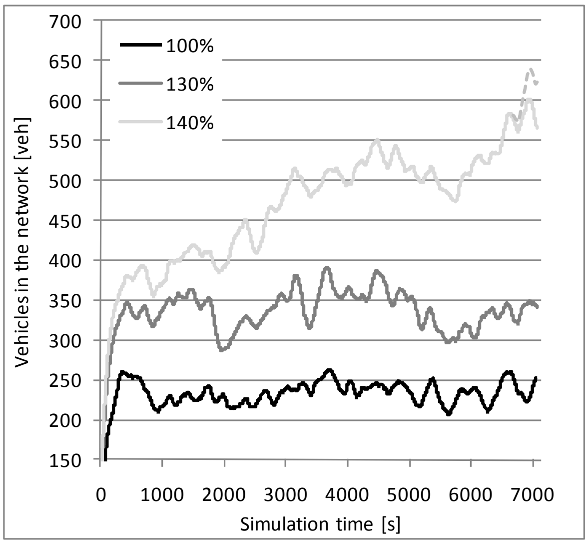


Fig. 5. A number of vehicles in the network during a two-hour simulation
Rys. 5. Liczba pojazdów w sieci w trakcie dwugodzinnej symulacji

## 6. A COMPARISON

### 6.1. System properties

The compared systems represent different approaches to modeling and simulation of traffic flow. In general, VISSIM enables most precise modeling and simulation, with an emphasis on providing a high level of realism, concerning both a network and vehicles/drivers. However, such precision is at a price of low simulation speed, and, ultimately, very limited territorial scope. At the opposite pole is TRANSIMS whose traffic flow model belongs to the most coarse-grained microsimulation models, but, at the same time, offers high speed simulation and supports multiprocessing. Therefore, it is indispensable for regionwide traffic simulation with a huge number of vehicles. An alternative to these two systems is SUMO that can be considered as a reasonable compromise. It uses a space-continuous car following model, and enables simulation for large, even regional, networks.

From user's point of view, VISSIM is very user-friendly, offers powerful and intuitive graphical environment supporting network edition in 2D mode, and simulation visualization in 2D/3D modes. Therefore it seems to be a good solution for both beginners and experienced users. On the other hand, both SUMO and TRANSIMS, as open-source software, allow programmers to view, analyze and modify the code, which enables much easier integration with external software. Last but not least, SUMO and TRANSIMS are both available for free whereas VISSIM is expensive commercial software.

Tab. 2 presents a more detailed comparison between the selected systems. It includes all factors that influenced the course of modeling and simulation, and the final results.

Table 2

A comparison of the selected systems

| | **TRANSIMS** | **SUMO** | **VISSIM** |
|---|---|---|---|
| **Space domain** | discrete | continuous | continuous |
| **Car following model** | Nagel-Schreckenberg (cellular-automata) | Krauss (safe distance) | Wiedemann (psycho-physiological) |
| **Realism level of vehicle dynamics** | low | medium | high |
| **Two-wheeled vehicles** | no | no | yes |
| **Trams** | no | no | yes |
| **Pedestrians** | no | no | yes |
| **Network representation** | links & nodes | links & nodes | links & connectors |
| **Modeling of roundabouts and complex intersections** | with limited precision (esp. for large cells) | with limited precision | very precise |
| **Simulation speed** | high | medium | low |
| **Maximum scope area** | region/country | city/region | city district |
| **Model edition** | via text files | via XML files | graphical |
| **Route generation according to turning ratios** | not included (external application required) | yes (JTRRouter) | yes (route decision points) |
| **Visualization of simulation** | off-line, 2D (external application required) | on-line, 2D, low details | on-line, 2D & 3D, high details |
| **Software category** | free | free | commercial |

### 6.2. Simulation results

When comparing the results obtained with the three systems, one can see some similarities, but also some differences. The most significant relationships concerned the network capacity (Fig. 6). The model in SUMO had its capacity maximally at a level of 100% of the measured rate of traffic flow, however, it required thorough calibration of vehicle parameters, otherwise the capacity oscillated between 85 and 95%. In contrast, the VISSIM as well as the TRANSIMS models, had much higher and comparable capacity equal to 130% and 140%, respectively, of the initial flow.

With an equal volume of traffic, the model in SUMO had a considerably greater number of vehicles concurrently traversing the network than the other models. For the measured volume of traffic (100%), it was oscillating between 250 and 300 whereas traffic in both the remaining models was characterized by smaller numbers, ranging from 200 to 250. However, for these two models, at the highest (without congestion) levels of traffic, the number of active vehicles in the network fluctuated between 300 and 400 (VISSIM, 130%), and between 300 and 350 (TRANSIMS, 140%), respectively.

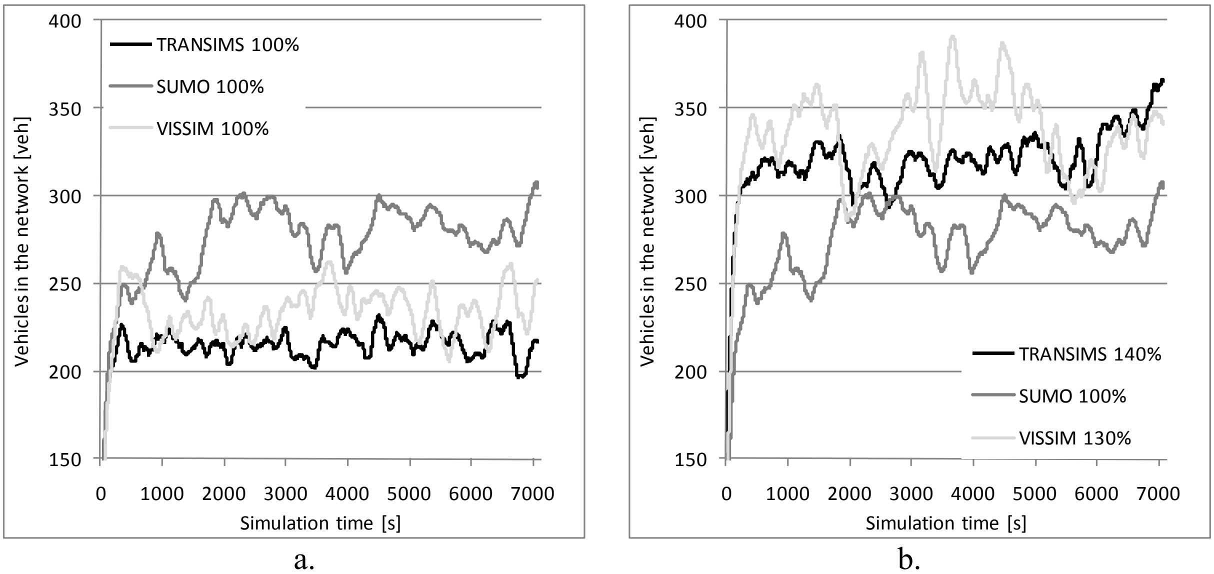


Fig. 6. A number of vehicles in the network during a two-hour simulation (a – the measured traffic flow, b – the maximal traffic flow without congestion)

Rys. 6. Liczba pojazdów w sieci w trakcie dwugodzinnej symulacji (a – zmierzone natężenie ruchu, b – maksymane natężenie ruchu bez kongestii)

Despite some dissimilarities in the network capacity, overall pictures of the simulations, regardless of a model, were analogous. In all cases, with an increase of traffic volume, problems with the insufficient capacity appeared first at intersection 5 and were caused by left-turning vehicles from link 6→5 towards node 3. As a result, for all three models, after exceeding the respective maximum traffic flow levels, vehicles blocked link 6→5, and, in consequence, gridlock appeared at intersection 6.

## 7. CONCLUSIONS

The goal of the conducted research was to provide a comparison of selected microsimulation systems on a fragment of a real urban network. Although a lot of effort was made to ensure consistency among the models, the results revealed some dissimilarities expressed, for example, in statistics showing the number of running vehicles. In general, it seems that the model in SUMO had too low capacity as compared to the real network capacity, but, on the other hand, it is difficult to assess whether the capacities of both VISSIM and TRANSIMS models were consistent with, or higher than the real one. However, despite some discrepancies in quantitative measures, similar effects in traffic flow propagation (i.e. appearance of network bottlenecks and gridlock effects) were observed in all three models.

The study gave a lot of interesting insights that require detailed examination. Further research will be concentrated on the application of mesoscopic or macroscopic models to the considered fragment of a network, as well as consideration of non-signalized intersections in an urban network.

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