

# Moscow traffic jam is under attack of an intelligent agent-based model

**Abstract.** The paper deals with conceptual description of an agent-based model for Moscow city transportation system. The model was created in the framework of the project dealing with strategy of city development till the year 2025. The study aims at presenting a solution to transportation problem in Moscow, which is one of the serious issues in all megapolises. As is shown below, development of calculation packages and specialized software, used for practical realization of agent-based model, allows computing a solution to the problem.

**Keywords:** agent-based model, transportation system.

## Introduction

In the first part of the paper we'll see how a work of a megapolis transportation system (the example of Moscow city) can be represented as an agent-based model, realized as a 2-D application created by AnyLogic 6.0 Karpov, 2006). A number of alternative programming tools, e.g. VISSIM and VISUM from PTV company (Gomes, May, Horowitz, 2004) should also be noted in this regard. Yet, AnyLogic offers extra opportunities for implementing agents' subsystems, which may be introduced in corresponding environment – «transportation system». The developed model allows assessing the work of the whole transportation system. This is realized through the following mechanisms on a city agglomeration scale:

- introduction of new radial or circular highways;
- construction of new residential zones or putting facilities that attract traffic flows into operation (e.g., shopping malls);
- short-term closure or liquidation of an element of a transportation system;
- new fees (highway fees, fees for entering city center, etc.).

The second part of the paper presents computational simulations that led us to finding the most efficient way of coping with traffic jams.

The third, final part of the study described the conceptual solution which we discovered in the course of research. It deals with replacing the used «environment» for moving agents from the existing sub-layer (realized in the form of a drawing) to GIS city map. The map presents a number of layers, which contain information about houses and street location, number of inhabitants in houses etc.

Development of these hybrids, uniting agent-based models and GIS maps is implemented by researchers (Longley, 2005; Maguire, 2005), who use GIS as a

database for replenishing the knowledge of the agents. As iterative interactions between a large number of agents and GIS provide for constant changes of GIS data and agents' actions, the work of the models becomes unstable (Castle, Crooks, 2006). This may be largely explained by insufficient capacities of personal computers, as well as by the fact, that initially GIS were created for purposes, not related to interactions between large numbers of agents.

This research attempts at constructing a transportation system with GIS and a relatively small number of agents. Therefore, the work at this stage does not create conceptual barriers for further analysis in this field.

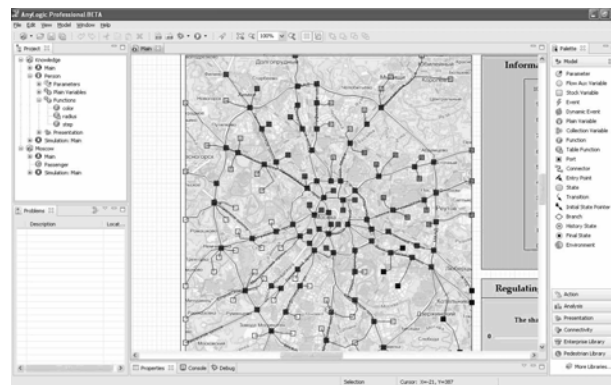
## I. Modelling transportation system of a megapolis using agent-based models.

### 1.1. Technical issues

There are three types of agents in the model: 1) an individual willing to get from point A to point B; 2) a car carrying 2 people on average; 3) a public conveyance carrying 150 people.

Agents of the first type choose means of transportation (i.e. agents of the second or the third type) considering a number of factors that will be addressed later on. Agents of the second and the third type are linked to the real-time animated diagram and their representations (i.e. their velocity and position at the moment  $t$ ) depend on the current situation.

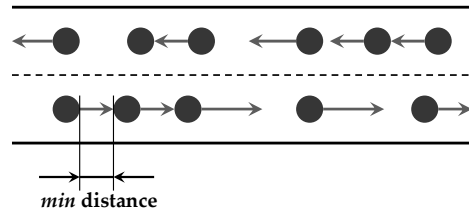
Animated diagram represents a city map (of Moscow in this instance which is not crucial though) zoomed down to the level of large highways (Fig. 1).



**Fig. 1.** Representation of Moscow transportation network with AnyLogic 6.0

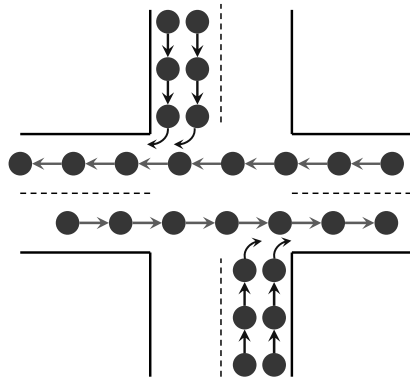
Animated diagram represents a city map (of Moscow in this instance which is not crucial though) zoomed down to the level of large highways (Fig. 1).

The map of the city is a *Bitmap* image (Fig. 1) which the transportation network laid upon it and its elements are the instances of the corresponding *Java*-classes. The speed values of conveyances depend on the overall number of conveyances and if the number is too high it may result in traffic jams at the most busy crossings. The programmed transportation network consists of nodes (initial and final routes for the agents of the first type; seen as colored squares on Fig. 1) and paths of agents of the second and the third types. To make it more plausible a certain distance is to be kept between the moving agents. Fig. 2 illustrates how agents of the second and the third type move among the nodes of the network. The distance between animated images of these agents is to be no less than a given minimum value. This behavior nuance becomes the major impediment for programming realization. Helbing (2007) and Deguchi (2004) share a similar point of view.



**Fig. 2.** Agents keep distance while moving along a highway

When the number of conveyances is high traffic jams occur at crossings due to agents' inability to keep moving (Fig. 3).



**Fig. 3.** Emergence of a traffic jam at a crossing

## 1.2. Processing data for the model

The number of agents of the first type equals to the number of people living in city districts.

The *gravitation model* is used to estimate the flows between districts. The model is based on the assumption that a flow from one district to another is proportionate to the living capacity of a home and destination district and inversely proportionate to the distance between the districts (Shvetsov 2007). The general form of the gravitation model is the following:

$$F_{ij} = \frac{(\alpha_i \cdot D_i) \cdot (\beta_j \cdot A_j)}{\exp(\lambda \cdot S_{ij})} \quad (1)$$

where  $D_i$  is the number of people departed from district  $i$ ;

$A_j$  is the number of people arrived at district  $j$ ;

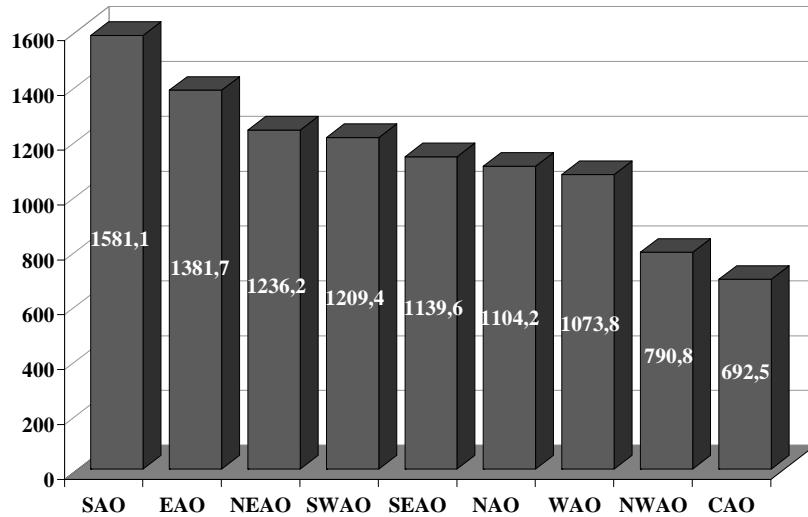
$S_{ij}$  is the distance between district  $i$  and district  $j$ ;

$\alpha_i, \beta_j$  are the balancing coefficients.

The matrix of the flows between the districts has called for the following data:

- district departure capacity (within the model this implies the working age population that commutes to work on workdays);
- district job capacity;
- costs of moving to a district from any other district measured in kilometers.

The model deals with 9 large districts – administrative *okrugs* (AO) of Moscow (Fig. 4): 1) Southern (SAO); 2) Eastern (EAO); 3) North-eastern (NEAO); 4) South-western (SWAO); 5) South-eastern (SEAO); 6) Northern (NAO); 7) Western (WAO); 8) North-western (NWAO); 9) Central (CAO).



**Fig. 4.** Number of citizens in the administrative districts of Moscow (thousands)

The gravitation function  $\exp(\lambda \cdot S_{ij})$  has inverse effect on the intensity of flows between districts and its value depends on the distance between the districts and coefficient  $\lambda$ , which determines the gravity force resulting from the purpose of a trip. The value of this parameter for business trips is usually smaller than for any other trip (entertainment trip, etc.). In the current version of the model  $\lambda = 0,09$ .

The balancing coefficients  $\alpha_i$  are defined in a way that the number of people departed to various districts ( $j$ ) from district  $i$  equals to the total number of departures from district  $i$ , i.e.

$$\sum_j F_{ij} = D_i \quad (2)$$

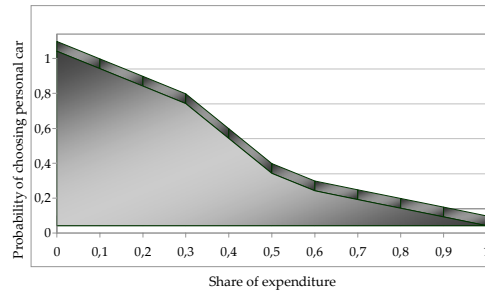
The balancing coefficients  $\beta_j$  for people arriving at district  $j$  are selected in the same way:

$$\sum_i F_{ij} = A_j \quad (3)$$

These coefficients were calculated by an *MS Excel* tool - the «Solver».

### 1.3. Specification of agents

The two major factors affecting the conveyance choice are of different nature: economic and psychological. The psychological factor implies that comfort perceived while driving a private car outweighs a displeasure from rising costs for the time being. The affect of economic factor is described by empirically obtained function (Fig. 5) that treats the probability of taking a private car as a dependent variable and the share of private car costs in the total costs as an independent variable. Hence, an agent of the first type chooses a conveyance with consideration of the expected costs.



**Fig. 5.** Probability of choosing a private car as a function of its maintenance costs

The agent-based model described in this paper was used to deal with the problem of traffic jams in Moscow.

## II. Computer simulations: figuring out the efficient ways of coping with traffic jams in Moscow

### 2.1. Current situation on the roads of Moscow

Currently traffic in Moscow is jammed almost 24 hours a day which dramatically lowers the efficiency of public transportation system and hampers the work of the emergency services. The number of minor accidents and violations of road laws (driving along tramlines, in the oncoming lanes and on the sidewalks) keeps rising. Cars running idle while in a jam pollute air heavily (more than 80% of air pollution is produced by vehicles). In fact, the failure of ground transport drives passengers under the ground where the subway already faces the maximum of its capacity.

Last year (from spring 2006 until spring 2007) Moscow saw 650 jams a day on average. During summer 2007 their number reached 670 and 850 – during autumn 2007. Autumn jams consume more time than summer ones (on average – 1 hour 20 minutes in autumn and 1 hour and 8 minutes in summer) but are less lengthy. The average length of an autumn jam was 2,8 kilometers, and 2,9 kilometers – of a summer jam. If the traffic situation worsens at the same rate then it'll be impossible to drive in Moscow during rush hours on 4 out of 5 workdays in 2 or 3 years.

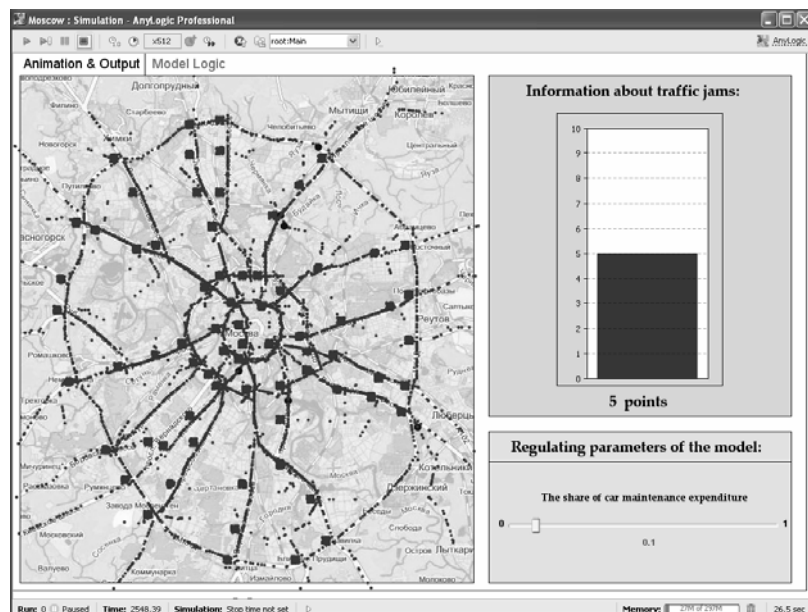


Fig. 6. Model in action – 5-point jams

On the whole, we are facing a *force majeure* situation which requires an urgent and certainly comprehensive solution. It is one of the topical city problems that hampers its strategic development. Fig. 6 mirrors a typical weekday situation showing traffic jams at the crossings of large highways. The number of points measuring a road congestion is calculated as the ratio of the number of cars in a jam to the total number of cars in the transportation system. Therefore, a 5 point jam suggests that 50% of cars are stuck in jams.

## 2.2. Known ways of coping with traffic jams

Let us examine basic mechanisms used by other countries to address the problem of traffic jams.

**1) Singapore.** Solution: *Limitation of the number of cars, i.e. limitation of the number of cars sold through quotas (in force since 1990).* Only well-off people can afford cars given this considerable financial burden. The number of vehicles in the city grows at a fixed rate of 3% a year which allows to sustain a relatively low level of approximately 180 cars per 1000 citizens. Outcome: *Singapore is considered to be one of the most successful megapolises in terms of road traffic.*

**2) London.** Solution: *Fees for entering downtown (since 2003).* Outcome: The monitoring system costed the city budget \$400 million. According to the official estimates of the Department for Transport *the number of cars downtown London has dropped by 10 – 15%, while London Underground and other public conveyances haven't seen significantly more passengers.*

**3) Athens.** Solution: *Cars are allowed on certain dates only (since 1982).* Cars whose number plates end with an even digit are allowed to drive in on the even dates only and the rest of the cars are free to drive in on the odd dates only. Outcome: The obtained result was rather a contrary one: families went on buying their second and third cars (mostly used ones) specially for overcoming the restriction which *had no effect on the traffic* but aggravated the ecological and parking problems.

**4) Rome.** Solution: *Administrative restriction on entering downtown (since 1994).* The limited traffic zone – *Zone a Traffico Limitato* – is part of the historic center of Rome located to the east of Tiber covering area of 4,6 sq. km. The restriction is in force on workdays from 6.30 till 18.00 and on Saturday from 14.00 till 18.00. Outcome: According to the official data, the traffic intensity in ZTL has dropped by 20% after the introduction of an electronic monitoring system. At the same time the demand for public transport rose by 6%.

**5) Vienna.** Solution: *Parking lot restrictions, parking time limitations, a system of intercepting parkings (since early 1990s).* The authorities attempted to solve the traffic problem in Vienna via parking restrictions. They believed that the road capacity could be increased by taking cars off the roadsides. Outcome: According to the official data *the traffic burden on the citycenter has decreased by 20%* and has transferred the traffic to periphery roads.

**6) Washington.** Solution: *Introduction of the reversible lanes (since 1993).* The idea of this approach is simple: one or two lanes in the middle of the road change their direction reflecting the increase of the number of cars in the morning and in the evening. Outcome: *If well thought out reversible lanes may be of a great help in rush*

hours. Unsafety is the only drawback of this method. A lot of drivers are reported to neglect reverse traffic lights which results in head-on collisions (with the fewest chances for survival).

As a matter of fact, the analysis of the above and other measures to deal with traffic jams allows us to conclude that this problem cannot be solved by the development of road network alone (not to mention that this approach may result in costly and sometimes unaesthetic solutions). A better road network will attract still more vehicles. *Administrative and economic measures turn out to be more effective.*

### 2.3. Coping with traffic jams by developing road network

Let us use our model to test the above statement about insufficiency of road network development measures. To do this we will amend the existing transportation system by a new circular road which is to attract some traffic. The new highway is highlighted by a dotted line on Fig. 7.

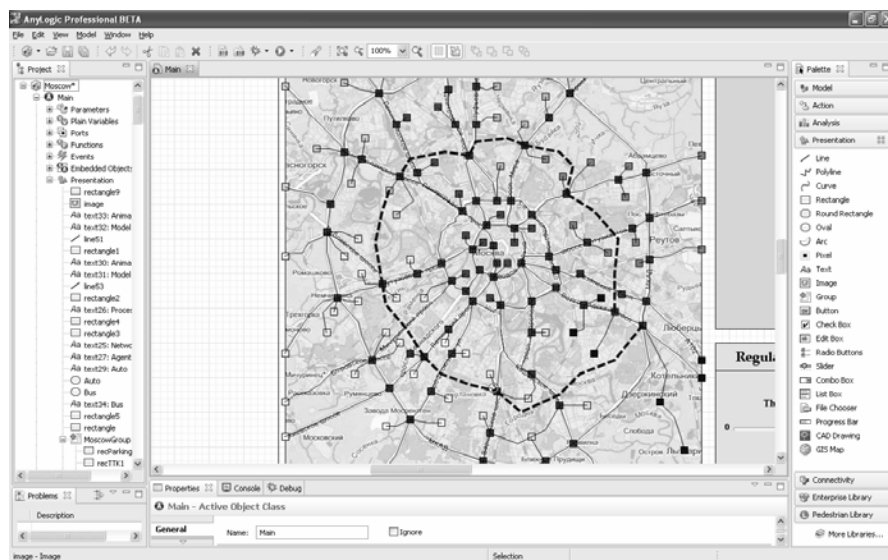


Fig. 7. Building new roads

Running the model with the number of vehicles fixed suggested that this measure was ineffective (Fig. 8).

Conclusion: it is necessary to demotivate and destimulate passenger flow in general and car traffic in particular. Demotivation through city planning (bringing closer places of work and living, building stores «in the walkable vicinity», etc.) and through IT development and the like is a tricky task in the short and middle-run.

Therefore, only economic and administrative measures remain when a fast and effective solution of the traffic jam problem is required.



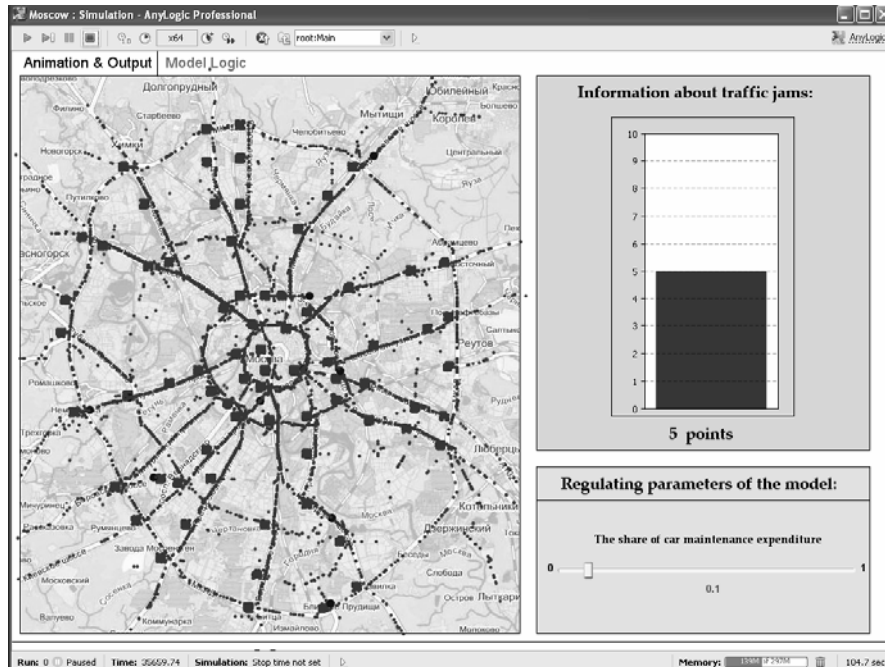


Fig. 8. Introducing an extra highway – still 5-point jams

#### 2.4. Coping with traffic jams by using economic sanctions

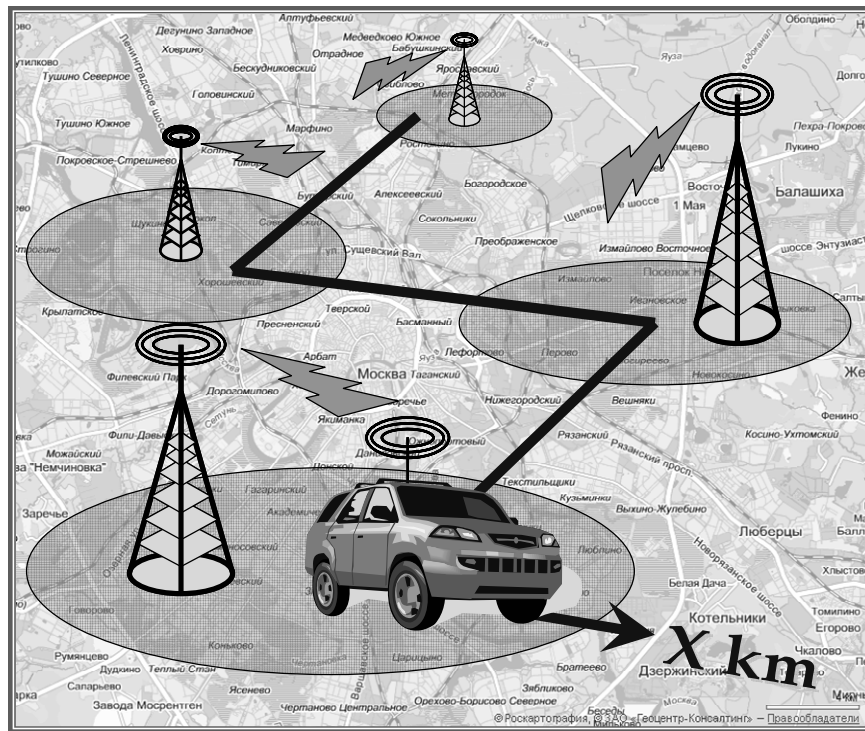
To destimulate with economic measures we propose to *introduce fees for driving within the city*.

Technically this proposal could be implemented by fixing electronic markers on cars. The marker will be automatically recognized at certain city-points (the more frequently – the better) as in a cellular network. The concept of this solution is presented in Fig. 9 on which a car equipped with the marker is located by the base stations that process the signal.

Signal processing will give us a piecewise linear trajectory. After that the car owner can be charged depending on the current fee and the total length of linear segments. At the same time:

- fees may vary with the city zone, with the time of day, with the level of road congestion, with the size, engine capacity, age and other car characteristics, etc.;
- fixing markers on cars may be fit into car registration or maintenance checkup;
- to promote using of markers we can lower transportation tax, introduce gas buying benefits, etc.;
- if a car is registered in another city then the driver could be offered to buy an entrance ticket or to fix a marker on his car right away;

- funds accumulated in such a way could be used for compensation of benefits, environmental improvements, etc;
- the expected reduction of traffic flows will raise the number of passengers in public transport. Less congested roads will let a public transportation system improve its work. And the revival of taxi services can compensate for inconveniences.

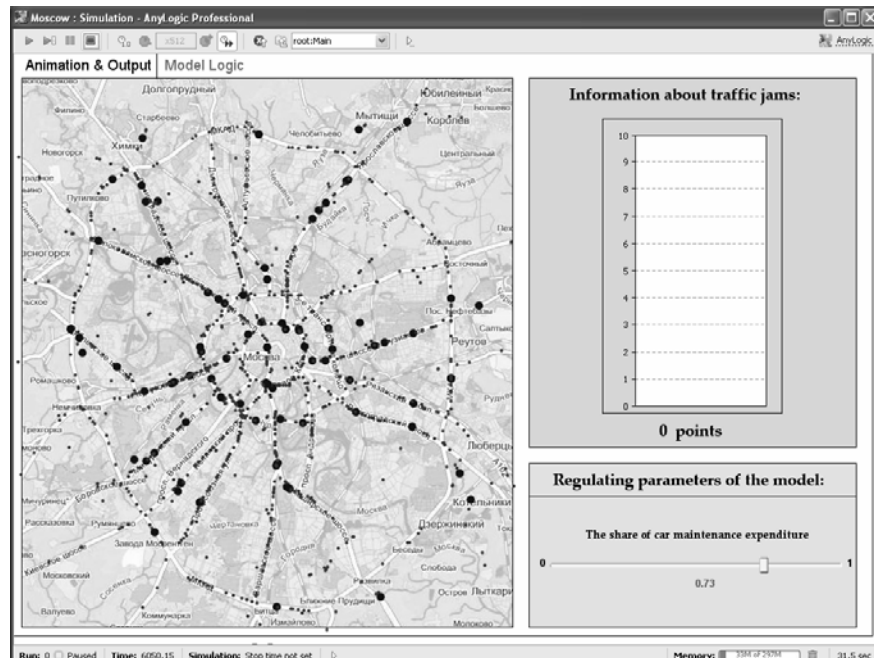


**Fig. 9.** The technology of monitoring car mileage (cellular network principle) – a conceptual view

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Changing one of the controlling parameters of the model – tariff on using a personal car (per 1 kilometer of trip) gives us the costs of using a car which depend on monthly mileage. The share of these costs in total expenditures of an individual directly affects his decision making through empirically obtained function (Fig. 5).

We've run two simulations with this average share increased from 0.1 (Fig. 6) to 0.7 (Fig. 10). In the first case we've had 5-point jams on average (on a 10-point scale), in the second case we have witnessed no jams at all, i.e. most of the city population resorted to public transport. Fig. 6 demonstrates that all the roads are "flooded" with red circles and numerous jams are observed at highway crossings impeding public transport. And Fig. 10 shows that the roads are free while public transport (large blue circles) carries the same number of passengers as in the first case.



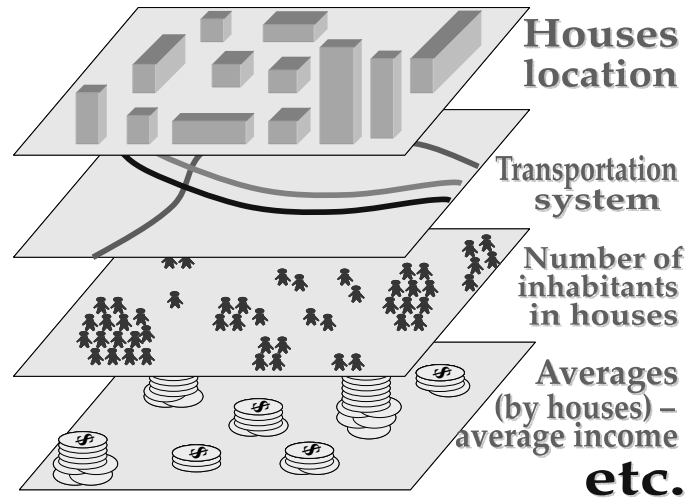
**Fig. 10.** Implementation of economic measures for congestion regulation – no traffic jams

The current model makes it possible to run a virtual experiment of moving enterprises and organizations outside the city in order to minimize daily commuting flows (into the city in the morning and back to suburbs in the evening). However, this solution will cost more compared to the economic measures discussed previously.

To sum up, the using of agent-based model that takes into account individual behavior of citizens allows us to consider various scenarios and track changes in road congestion. Same result could hardly be achieved by just examining aggregate indicators that feature a few equations.

### III. Further development of the model

Currently we are working on the “environment” for movement of the second and the third type agents. The current bottom layer (represented on the drawing) is planned to be replaced by the geo information city map. This GIS map will incorporate information on houses and streets location, and on the number of residents in houses. Conceptual description of the GIS is shown on Fig. 11.



**Fig. 11.** Conceptual view at GIS

The current prototype model sets the movement for the second and third level agents as a sequence of steps of certain duration. Prior to agent's making another step, an event «On before step» with the following code is implemented (general description):

```

PoliticalArea area =
get_Main().gisMap.geyLayers[0].findPoliticalArea (X, Y)
// Search for the domain, where the point with agent's
coordinates (X, Y) is situated. This requires an access
to the corresponding GIS map layer.

if (area.traffic != false) // if this domain is not
restricted for traffic

{

moveTo (X, Y) // agent moves to the preset point

else // otherwise

implementation of a certain alternative action, dealing
with movement to the allowed domain and with further
search for trajectory, connected to the destination
point.

}

```

Fig. 12 demonstrates the window of ArcGis 9.3 package, which projects one of the city districts.

