Types of Computer Models in Spatial Planning

Elżbieta Litwińska
Wrocław University of Technology, Wrocław, Poland

The complex nature of cities and regions need proper tools to explain how a particular phenomenon comes about or to help in building plans. Such a tool is a computer model that is able to simulate different aspects of processes occuring both in urban areas and in regions. The first attempt to apply computer modeling was in the 1960s. The aim of the paper is presentation the following types of models: transport-allocation models, cellular automata, multi-agent models and models related to Geographic Information Systems (GIS).

The development of information technology has made it possible to carry out the simulation of processes and phenomena occurring in the reality.

Phenomena, which refer to spatial planning and spatial economy include the movement of people in the city, migrations and spatial growth. Simulations reflect processes now occurring as well as those which will take place in the future.

The first simulation models appeared at the turn of 50s and 60s to solve the problems of transport in cities. Then simulations were related to increasingly wider issues e.g. searching mechanisms that shape concentrations of activities, an identification of factors controlling the distribution of services, development of spatial systems, localization problem etc.

In the article it was decided to discuss transport-allocation models, cellular automata and multi-agent models. The importance of Geographic Information Systems will be highlighted.

At the beginning transport-allocation models will be discussed.

1. TRANSPORT-ALLOCATION MODELS

Although transport-allocation models have different theoretical bases and the degree of complexity, all of them were created on the assumption that there is a feedback between land use and transport system.

The basic module of these models simulates the spatial interactions (contacts) [14]. Contacts are reflected by trips from home to work, journeys to services and trade etc. And so, for example the contact home-work reflects the relationship between housing and those activities, in which places of work are located. The contact may also be understood more widely, as the impact of one activity on location of another one. For instance distribution of the population without doubt affects the localization of commercial centres.

The interaction between transport network and settlement system means that on the one hand the modernization of transport network improves the accessibility of certain spatial units what increases their attractiveness and causes development. On the other hand activities generating various contacts reveal weakness of transport network and show a need for its modernization.

The contacts play a key role in shaping and functioning of settlement systems so models of contacts can be applied to simulate the development of these systems [13, 24].

In the group of transport-allocation models there are *transport models*, which are used to solve transport problems, and *allocation models*, which search the best location for activities.

These models apply different rules describing the spatial interactions between elements of urban or regional systems. The most important among them there are the gravity rule and the intervening opportunity rule.

1.1. GRAVITY MODEL

The gravity model is based on an analogy with the Newton's law of gravitation. The law says that the gravitational force between two bodies is directly proportional to their size and vice versa to the function of the distance between them. The earliest applications of the gravity model used a formulation in the form:

$$T_{ij} = G \cdot P_i \cdot P_j / d_{ij}^{\beta}$$

where:

T_{ij} trips (interactions) between areas *i* and *j*,

P_i, P_j mass of the two areas, for instance their population,

d_{ij} distance between areas *i* and *j*,

G a constant to be determined at calibration,

β distance exponent.

Therefore the number of trips from home to work between two areas is directly proportional to the population of the first area and the number of jobs in the second one, and inversely proportional to the function of the distance between them.

Such models were widely applied in migration and shopping studies from the late 1920s, before . Further empirical work on interregional flows, particularly in transportation, has improved the model.

Gravity models have been widely used to establish the basic characteristics of existing patterns of movement migrations, trips to work, to shop etc. and to predict future patterns.

It is worth mentioning that A. G. Wilson [20], by using the concept of entropy, received the formula for the number of contacts, which form is similar to the Newton's law.

1.2. INTERVENING OPPORTUNITIES MODEL

An alternative approach is represented by the intervening opportunities idea, first developed by S.A.Stouffer [16], which says that the presence of closer destinations (opportunities) diminishes the attractiveness of even slightly better but more distant ones. The number of contacts (movements) from an origin zone to a destination zone depends not only on the number of the purposes of the latter, but also on the intervening opportunities, situated between two zones.

The model was refined for the journey-to-work by M.Schneider (1959) for the Chicago Transportation Study [6]. In his model the number of trips between origin zone *i* and destination zone *j* (T_{ij}) is given as:

$$T_{ij} = O_i \cdot [e^{-sd} \quad e^{-s(d + dj)}]$$

where:

O_i the number of trips originating in zone *i*,

d the number of destinations situated closer to origin *i* than destinations in zone *j*,

d_j the number of destinations in zone *j*,

s the parameter of trip selectivity. This parameter expresses the fastidiousness of trip-maker, the type of need causing the trip and variety of potential destinations.

All distances in this model are measured by the number of neglected destinations. This leads to deformation of geographic space into so-called economic space.

A typical sequence of proceeding in transport simulations (not only based on the idea of intervening opportunities) is presented in Fig. 1.

Introductory data describe existing or forecasted transport network and determine the size of activities in every zone (e.g. expressed by the number of people and the number of work places). In addition, the model parameters are given. At the beginnig contacts (trips, migrations) are simulated. The result is the origin-destination matrix (O-D matrix), which returns the number of contacts between each pair of zones. Fig. 1. presents only two bundles of traffic. (In this example the area was divided into four zones so six bundles must be taken into consideration). The visualization of the origin-destination matrix (width of the line corresponds to the number of trips between zones) allows to draw some conclusions.

Then number of trips are apportioned to various modes of transport (e.g. automobile or public transport) modal split. In the next stage trips are assigned to segments of network. As a result, we obtain the traffic on the lines of network usually expressed in vehicles in peak hours.

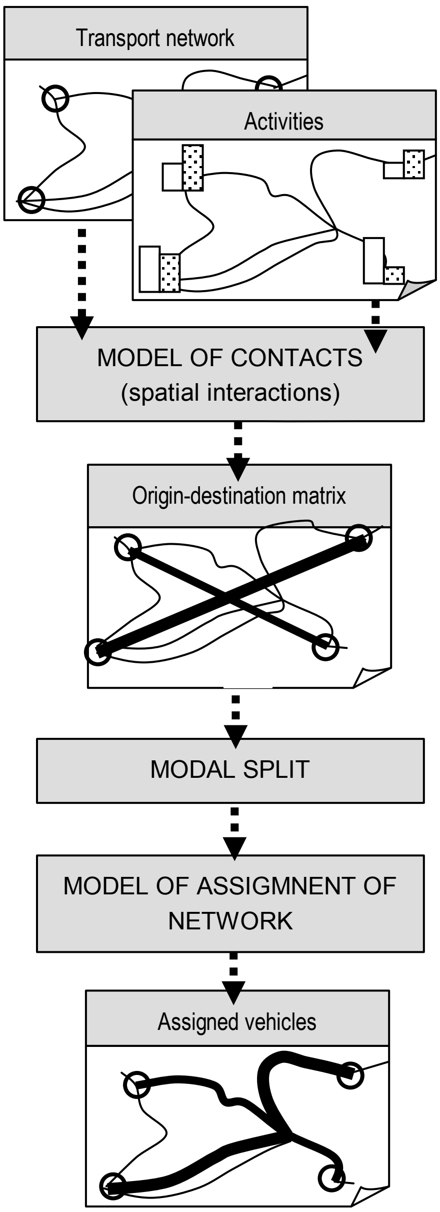
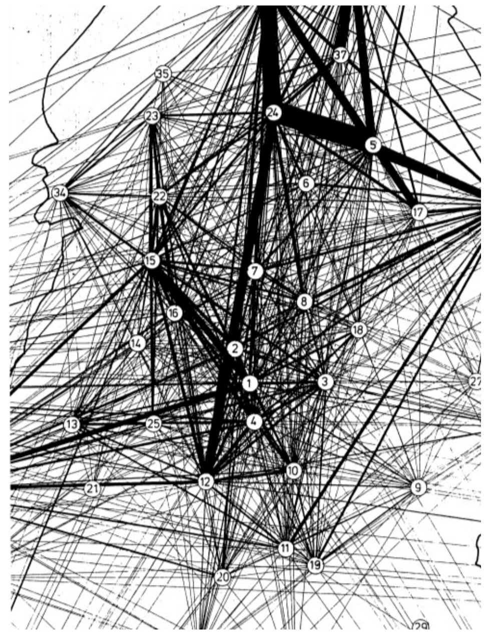


Fig. 1. The typical scheme of transport simulations
Source: develop your own

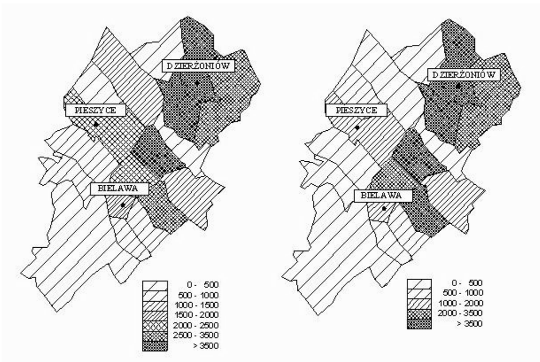
The visualization of the O-D matrix (Fig.2) shows that even for a relatively small number of zones the image becomes unreadable, especially in the middle, because there are many crossing bundles, what makes it difficult to interpret the results.



the O-D matrix for trips from home to work. The result of simulation by using the intervening opportunities model
Source: [21]

model has been creatively developed by T. Zipser, who built a series of both transport and allocation models. Some of them are used to solve transport problems, other to find the optimum location of activities and to simulate development of cities and regions [11, 22, 24]. Among allocation models there are *shifting models*: shifting of destinations, shifting of origins, general shifting, versions with constrains and ORION model. The shifting models allow to find the state of equilibrium of settlement systems defined as balance between the number of arrivals and destinations in every zone of the area. Such defined equilibrium means that needs of trip-makers can be satisfied.

These models were used in the following issues: searching the optimal localization of services, jobs (Fig. 3.), testing different variants for the development of agglomeration, an analysis of the impact of location of Katowice steel works on the functional-spatial structure of region and the forecast of spatial structure of Poland for the years 1990-2000 [11, 24].



ielawa, Pieszyce.
The real and simulated distribution of workplaces
Source: [8]

The most sophisticated model created by T.Zipser is ORION model, which allows simultaneous allocation of various activities in cities and regions (e.g. housing, industry, shopping, services). Contacts and conflicts between them as well as attractiveness of a given area are taken into consideration.

In ORION model the simulation of contacts is based on the intervening opportunities formula. ORION model has been applied many times to simulate settlement systems of different size. It has mainly been used for forecasting the development of settlement structure in Poland, in regions (e.g. Legnica-
agglomera

Although in general dynamics is not characteristic of transport-allocation models, it is worth underlining that as well shifting models as ORION model are able to simulate the dynamics of settlement system changes. This is the result of the fact that during modelling the solution is achieved step by step (iteratively).

1.3. TRANUS MODEL

Another example of the land use and transport models is TRANUS model (Fig. 4.) which integrates the economic and spatial interactions between activities, the real estate market and the transport system. This model includes an input-output analysis to represent the economy of a spatial system and the formation of prices. The gravity rule is used in simulating contacts.

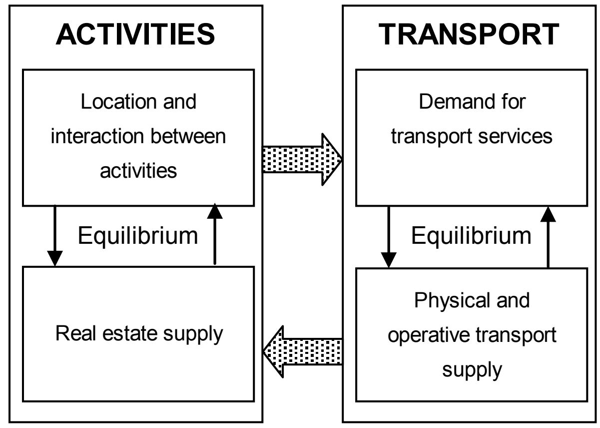


Fig. 4. The general schema for TRANUS model
Source: www.modelistica.com/gral_description.htm

TRANUS model was applied to evaluate the impact of the implementation of Regional Express Rail Network (RER) project in Brussels Region on the creation of a new wave of *urban sprawl* in this area [7].

Urban sprawl is a multi-dimensional phenomenon. It is usually assumed to refer to uncoordinated growth of cities, particularly around their edges or peripheries. Urban sprawl causes the loss of agricultural land and open space, increases the cost of infrastructure and public services, especially public transport, contributes to the decay of downtown areas etc. This phenomenon is a serious problem for authorities and city planners.

In this study seven types of households, thirteen activities and three types of land use were considered. In simulations either the existing transport system or the future one (incl. regional railway) were taken into consideration. Also some variants of modelling reflected trials of limitation of urban sprawl by introduction different systems for parking fees and tariffs in public transport. The result was the number of households and places of work in Brussels and in the region, the distribution of the length of journey to work for population groups with different incomes, the share of public transport in the morning peak hour etc.

2. CELLULAR AUTOMATA (CA) MODELS

The cellular automata (CA) models are of a completely different nature. These models consist of four elements: cells, neighbourhoods, states and transition rules. The cellular-based data structure is composed of cells (or pixels) of equal size arranged in columns and rows. Cells are the smallest spatial units. Relationships among the cells are defined within neighbourhoods. The neighbourhood is a set of adjacent cells. The most popular are the Moore and the von Neumann neighbourhood (Fig. 5.). In the first case eight cells are taken into account, in the second one four. It is obvious that the shape of the neighbourhood and its size (and thus the extent of impact) affects the results of modelling.

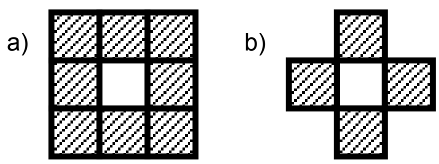


Fig. 5. a) The Moore and b) von Neumann neighbourhood

For a given time step (t = 1, 2,...) state of the system is described by value of attributes in every cell. The transition rules say how to modify the value of the atribute of the cell what is determined by the state of its neighbouring cells.

example. The attribute of cell is: developed or not developed. Suppose that at the beginning (t = 1) only the central cell is developed (Fig. 6.a). The transition rule says that if there is one or more cells developed in the neighbourhood of the cell, it becomes developed itself (Fig. 6.b). After analyzing the neighbourhood of all cells the new structure has emerged (Fig. 6.c).

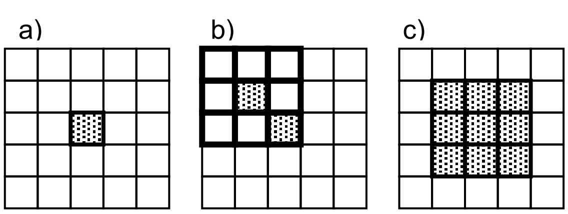


Fig. 6. The CA model. a) t = 1 b) the neighbourhood and the result of rule c) t = 2

Source: [3]

It is obvious that in the next step (t = 3) all cells will be developed.

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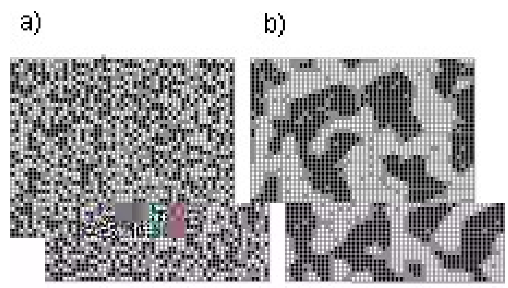
An interesting example of using this kind of tion [15]. Schelling examined the mechanism of the racial segregation in American cities.

Suppose that members of two groups are distributed randomly (white and black points) and and there is a free area to move (gray points) (fig. 7.a).

The following rule was used to change the status of the cells. Residents are satisfied with their location, if most of their neighbours belong to the same group as they do. When this condition is not met, they move on to other free space. As a result homogeneous aggregations have emerged and the new structure was built (fig. 7.b).



Fig

Source: [4]

The cellular automata model was one of elements of simulation of urban land use change for city of Calgary in Canada [9].

In order to create land use maps in 1985, 1992 and 1999 satellite images were classified. The operation of the classification, known in GIS [12], allows to determine the type of land use in the following categories: housing, services, industry, transportation, parks, vacant area and water bodies.

Then the 1985 and 1992 land use maps were compared and the transition matrix was built. This matrix contained the information how many cells have changed type of land use. By using the matrix CA model simulated the land use pattern of 1999 what can be compared with the real image. High compatibility between them was obtained (Fig. 8.)

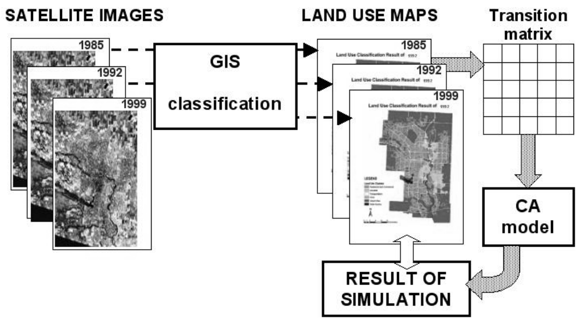


Fig. 8. The schema for the simulation of urban land use change in Calgary
Source: [9]

As you can see cellular models simulate phenomena on local scale. However, in the subsequent steps, the phenomenon is spreading more and more. Dynamics is an important feature of these models.

The most common applications of cellular automata concern issues such as modeling processes in cities and regions, the change of the land use, creating polycentric structures, simulation of urban sprawl, development of settlement systems.

These models are primarily tools for testing hypotheses and theories about cities, although it is increasingly tempting to use them in more practical issues [1, 2, 17, 18].

3. MULTI-AGENT SYSTEMS (MAS)

The multi-agent system (MAS) is composed of the cooperating agents. Agent is an enterprise that operates in a certain environment, is capable of communicating with others, can decide autonomously, but does not have full knowledge of the system.

MAS systems tend to find the best solution for

similarity here to physical phenomena, such as energy minimizing, where physical objects tend to reach the lowest energy possible, within the physical constrained world.

The main feature which is achieved when developing multi-agent systems, if they work, is flexibility, since a multi-agent system can be added, modified and reconstructed, without the need for detailed rewriting of the application.

Very often agents are introduced into CA model, what allows to simulate long distance relationships. Agents may also move.

In the applications concerning spatial planning CA represents the environment, while agents take decisions, which have changed the land.

MAS can be used to simulate spatial scenarios based on modelling multi-actor decision-making within a spatial planning process. Agents represent organizations and interest groups involved in an urban allocation problem during a land use planning process [10].

Since the end of the 1990s., these types of models have been applied for a wide range of problems.

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Batty and Torrens [5] simulated the development of Chicago Region for over 200 years (1800-2000) (Fig. 9). They assumed the Neumann neibourhood ago, Madison, Milwaukee, Gary, South Bend, Lansing and Grand Rapids.

Each cell in the region can be occupied by any number of agents its population. Cells have five attributes: developed or not, developable or not, and a measure based on the number of agents located there. Agents locate in cells according to seven rules:

- Cells are developed if there are no constrains.
- Growth is compact, agents locate around existing poles of the development.
- Local centers might attract development to maximize agglomeration economies.
- Agents locate along roads to maximize their accessibility.
- It is possible to develop in a completely new places (scattered growth).
- Agents develop new cells which connect and compete with the existing cells (bifurcated growth).
- Cells can lose their attraction.

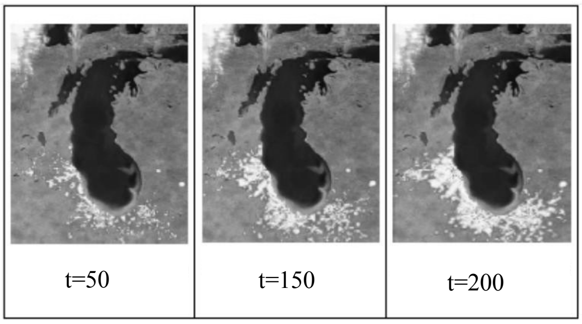

Fig. 9. The development of Chicago Region
Source: [5]

The modelled urban sprawl shown was greater than in reality, while the degree of fragmentation of urban land use was smaller than the real one.

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Torrens and Nara presented model for testing urban gentrification dynamics that uses cellular and agent-automata [19]. Gentrification, a term that was first coined in 1960s, means a process when there is the transition of property markets from relatively low value to higher value under the influence of redevelopment.

The usefullness of the model was presented through application to a real-world example: the Gateway district, a part of the downtown of Salt Lake Cty in Utah that is undergoing recent transformation.

4. GIS

A great potential of Geographic Information Systems (GIS) must be mentioned. According to definition of ESRI (Environmental Systems Research Institute) ction of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced informa

Such system allows not only to collect spatial and descriptive data, but also to conduct various spatial analyses, which helps explaining and forecasting many phenomena. In addition, the spatial objects can be easily visualized.

CA have a natural affinity with raster data. Raster data and remotely sensed information seem well suited to GIS because both CA and GIS organize space into discreate units. CA can use satellite images as source of information and may easily cooperate with some modules of GIS, which are adapted to the processing of raster data.

It should be added that many Geographic Information Systems contain transportation-allocation modules allowing to simulate transport and location problems.

5. CONCLUSIONS

A model is a simplified picture of real phenomenon. Each type of presented models highlights other aspect of phenomena related to cities and regions.

Conducting simulations we realize the dichotomy. On the one hand we focus on the individual units, households, which are independent objects and on the other hand, we have to deal with groups, sets, populations, regions. There is a confrontation between local and macro scale.

The transport-allocation models represent general description of phenomena occurring in the towns or regions (top-down) and apply vector data. For cellular automata models another approach (bottom-up) is characteristic. A small number of rules applied to many objects at the local level often leads to ordered structures. These models work with raster data.

Because in reality there are two situations so it seems that hybrid models should be the best solution.

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