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SIMULATION AS A TOOL TO PROMOTE DECISION-MAKING IN THE DEVELOPMENT OF REGIONS[1]

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Abstract

The determination of the optimal strategy for the development of regions both in Europe and in the individual countries as e.g. Hungary is of great importance and has very significant economic and social consequences. This contribution outlines an overview about this problem and shows a simulation methodology intended to promote the decision-makers to choose optimal solutions.

Keywords: simulation, decision-making, intelligent agents, macroeconomy.

1. Introduction

The development of regions is a highly complex and multidisciplinary problem, where human factors as the growth of population, the rate of unemployment, ecological influences, environmental pollution as well as economic factors as the GDP, taxation, investments into industrial, agricultural and service areas have to be considered.

In this article our purpose is to give an overview about simulation possibilities in economics and to suggest a class of simulation techniques.

In Section 2 we describe some reasons why to use simulation.

Section 3 describes the Keynesian macroeconomic model and a simulation model.

In Section 4 we present an agent intended to solve the common problem in simulation to refine the initial, mainly estimated relation.

In Section 5 we describe an economic model of the development of regions, focusing on the development of the road network.

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2. Why Do We Use Simulation?

Let us describe this by solving a simple problem. How can we determine a reasonable number of required service points in a bank? We solve this problem with mathematical tools and the use of simulation.

Clients arrive randomly; clients' service time is random. Let us make some constraints:

- clients arrive according to a Poisson Process with rate λ;
- clients are served according to a Poisson Process with rate μ (service times have an exponential distribution if no idle time);
- only one service point;
- unlimited queue.

2.1. Mathematical Solution

These constraints can be satisfied by a model of an M/M/1 queue [1]. The average number of clients waiting for being served in M/M/1 queues is:

$$\overline{N} = \frac{\lambda}{\mu - \lambda} = \frac{3.5}{4.5 - 3.5} = 3.5, \tag{1}$$

i.e. if $\lambda = 3.5$, $\mu = 4.5$, the average number of clients waiting is 3.5. (Service time must be less than the average time between the arrival of clients, $\mu > \lambda$, otherwise the queue will grow infinitely).

2.2. Using Simulation Tools

Using ProModel [2] as a simulation tool, with its graphical interface, we build up a model with a generator, a queue and a server:

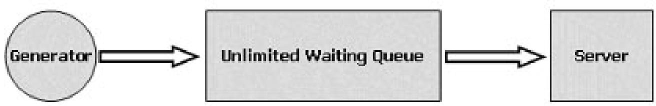

Fig. 1. Simulation model

In ProModel we established the connection between the elements. In the next step the following parameters must have been set:

- generator: Poisson Process with rate λ;
- queue: unlimited length, FCFS (First-Come, First Served);
- server: exponential service time (μ).

Results (λ, μ are in minutes):

Table 1. Simulation model results

Simulation running time [hour]	$\overline{N}$
2	0.6
10	7.09
18	4.22
24	3.32
48	3.52

2.3. Comparison of the Mathematical Solution and the Simulation Results

Simulation results converge to the mathematical results (see *Table1*). In this case we spent more time building up the simulation model than the time spent evaluating the mathematical formula above. But if we take into consideration the fact that problems are usually not so simple, then simulation may be an alternative. For example, in real life clients do not arrive according to a steady Poisson process, or we may specify that 2 independent queues are present, one for companies and one for citizens, but if one of the queues reaches 5 and the other queue is empty, the clients may use the other queue, too. In these circumstances a mathematical solution is difficult or almost impossible, while if we use simulation, the problem is only a bit harder than before.

This shows that simulation may be used in difficult and complex cases, with several problems. Mathematical analysis may serve the correct answer, but we may solve only simple problems with it.

3. Macroeconomic Models

The Keynesian economic model is a known and generally used model. It has the advantage that it is comprehensive, easy to calculate; relationships are simple and well described. This model may not be used in a simulation, because it is well solvable with other mathematical tools.

3.1. Keynesians [3] [4]

According to Keynes' General Law, the aggregate demand for goods (Y^D) is composed of consumption spending (C), investment spending (I), government expenditure (G) and the trade balance ($X - M$). Consumption spending depends on the aggregate incomes while investment is a negative function of interest rates and we treat government expenditure as an exogenous variable.

The structure of a possible model is shown in *Fig. 2*, where the continuous lines indicate a positive influence and the dashed line a negative one.

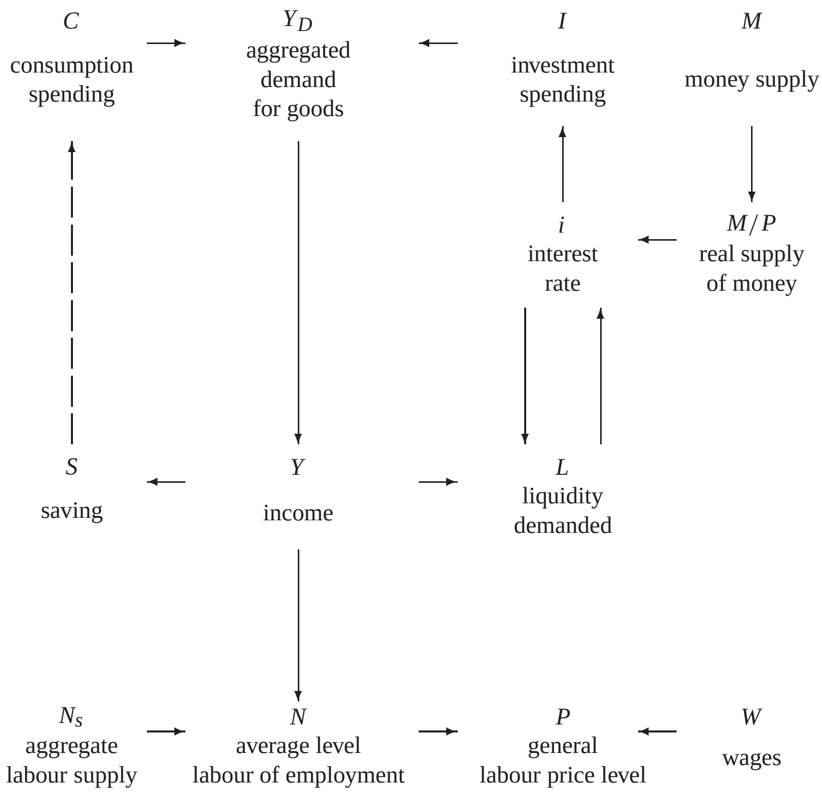

Fig. 2. Relationship between variables in a Keynesian model

3.2. Simulation

Simulation models can handle more complex models than pure mathematical ones. One example can be seen in the following figure (suggested use for strategic planning):

In the figure positive and negative relationship are indicated by small + and − signs at the ends of the arrows. Most variables are in negative or positive feedback loops that may cause unexpected and not trivial results, e.g. if the number of jobs is increasing, then the aggregate wages will grow, causing the growth of household incomes and demand. On the other hand, the increasing number of working people

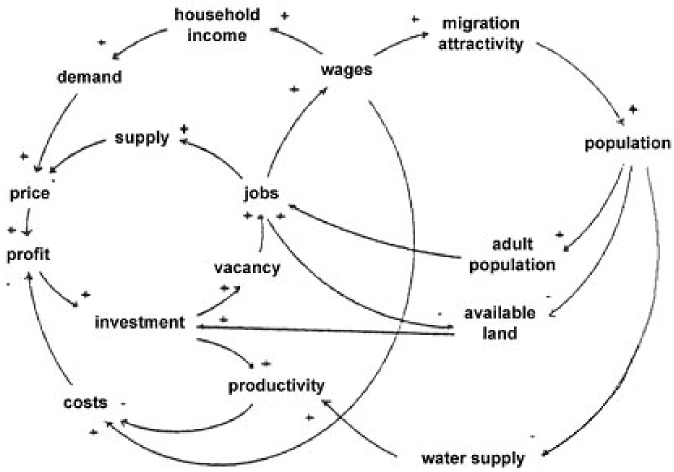

Fig. 3. Relationship between variables [5]

boosts the amount of goods produced. We know that the increasing demand also increases the price level, but increasing supplies decrease the price level. This way the increasing number of jobs increases and also decreases the price level, and usually we do not know, which trend is stronger.

4. Agents

One major problem in complex simulation is the difficulty to define the relationship between variant factors. In a complex economic problem the interrelation between variables usually cannot be defined exactly. In our research, we have developed agents (based on the demons [6]) to refine the initial relation between two variables based on historical data.

5. Road Traffic Simulation

One of the major factors in the economics of regions is the road infrastructure. In this section a simulation methodology is outlined that is intended to promote the decision-makers to choose optimal road building solutions (more information about this research is available in [8]). This is a tool to simulate the interaction between road building and the growth of economy.

In our research we use the CASSANDRA simulation system and our model is based on previous simulation results [7].

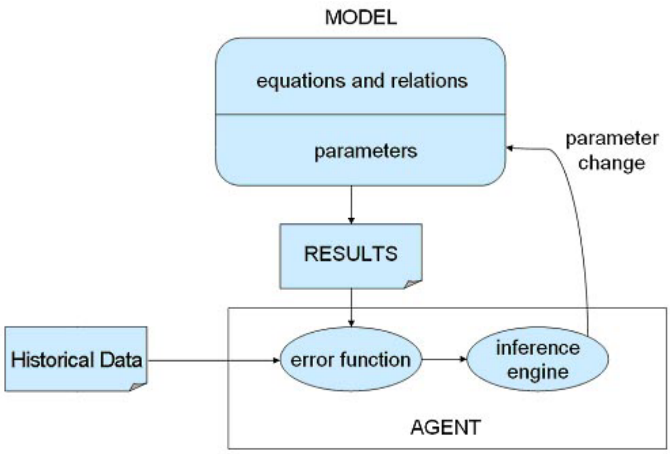

Fig. 4. Relationship between variables

5.1. Model

In our model we have used the following statements as axioms:

- employees want to spend only a limited time to get to work, better road conditions may increase the number of cities they can work in;
- for enterprises, better road conditions mean that they can reach their market quicker than before.

This model is based on these statements. The model contains cities, roads, employees and trucks. City means not only the city itself, but the agglomeration as well, also called microregion in this paper.

The model is based on these microregions and the interconnecting roads. These microregions have home employees, most of them working locally. Employees may work at other microregions or are unemployed. This means that the total number of employees working in a microregion is the sum of the number of employees living in the microregion and working in the microregion, and the number of employees coming from other microregions.

To simulate the wide range of professionals to maintain production, we introduced a limit. This is a simple approximation of the fact that the available working power with given expertise in the region is limited. This limit shows the minimum rate of the employees coming from other microregions, that means if the current rate of the employees coming from other locations and the employees working in this microregion are above this limit, then nobody from the microregion can be hired as far as somebody comes from another microregion modifying this rate.

Enterprises treat cities as markets, the size of the market is the function of the population of the city. A microregion produces goods according to the number of the employees working there.

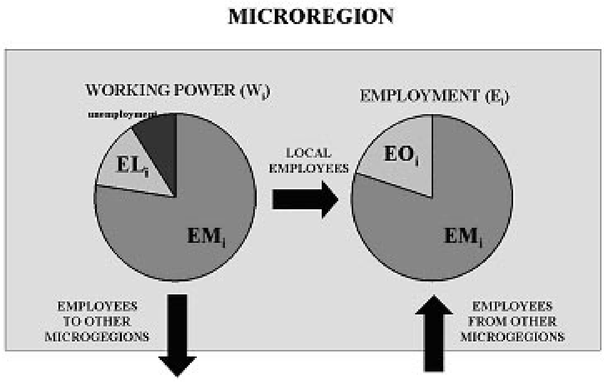

Fig. 5. Structure of microregions (employment)

The goods produced may be sold locally or transported to other microregions. Selling goods locally has a fixed profit, while the profit of goods transported to other microregions is decreasing due to transportation costs (in our model profit is decreased according to the transportation time).

A profit-maximizing demon tries to maximize profit, acting as a CEO. This means that if the demon thinks that hiring unemployed people may increase profit, then the demon tries to hire new employees, and if the demon thinks that the number of employees working locally is higher than required, then the demon will fire some of them.

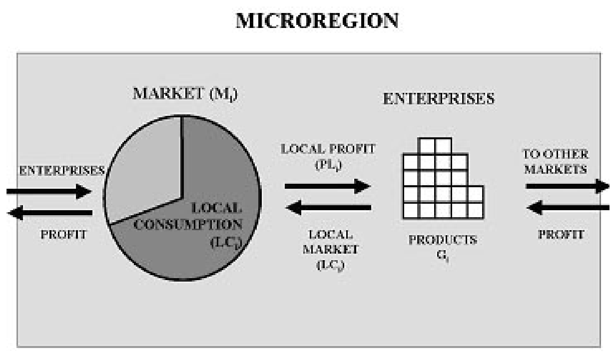

Fig. 6. Structure of microregions (market)

Employees also act as intelligent individuals. Unemployed people seek jobs regularly in the surrounding microregions (the travel time may not exceed a limit, as shown in our first statement).

Road traffic is generated by employees (not working in the same city), vehicles of enterprises transporting goods and unemployed people seeking jobs.

5.2. Variables and Constants

A microregion homes a number of people (P_i), forming the available working power (W_i, $W_i, < P_i$), constant for each city.

The size of the market depends on the population size:

$$M_i = c_m \cdot P_i. \tag{2}$$

Employees living in the microregion may work at the microregion (EM_i), or work at other locations (EL_i – total number of local employees working at other microregions).

Unemployment is calculated using the above variables:

$$U_i = \frac{W_i - EM_i - EL_i}{W_i}. \tag{3}$$

Employees may come from other microregions (EO_i – the total number of employees coming from other microregions).

The total number of employees working at the microregion is the sum of employees living at the microregion and working at the microregion and the employees coming from other microregions:

$$E_i = EM_i + EO_i. \tag{4}$$

The limit showing the minimum rate of the employees coming from other microregions is a function of the population size (the bigger the city, the fewer workers are required for coming from other locations):

$$L_i = \max\left(0.1 - \frac{c_L}{P_i}\right), \tag{5}$$

this function represents the approximation of available expertise as mentioned above.

Roads are described by their length (RL_n), number of lanes (RN_n) and speed limit (RS_n).

The constant c_e is the speed limit for the vehicles of employees.

The constant c_t is the speed limit for the vehicles used by enterprises (trucks).

All c variables mean global constants.

5.3. Employment Dynamics

A profit-maximizing demon in each city is responsible for maximizing the profit. The demon may change the number of employees in order to find the maximum possible profit.

The demon will hire local unemployed people, if the demon intends to do so and the limit is not reached:

$$L_i > \frac{EM_i}{LE_i}. \tag{6}$$

Unemployed people start seeking jobs at regular intervals. It this case, each unemployed person is simulated as an individual entity. They move randomly on the network of roads, while the specified time limit has not been reached. If the person arrives at a city where the demon wants to hire unemployed people, then the person will be employed.

If the demon wants to lower the number of working employees, it fires the employees coming from other microregions first, to the limit described above, then local employees.

People not employed locally go to work at each day, causing traffic. If traffic conditions get worse, and the time spent to go to work is above a specified limit, then the person will cease to work, and will become an unemployed person again.

5.4. *Profit Dynamics*

The goods produced at a microregion (G_i) is depending on the number of employees working locally:

$$G_i = c_G \cdot E_i. \tag{7}$$

Most of the products are consumed locally, but only to a limit depending on the population size:

maximum local consumption:

$$C_i = c_C \cdot P_i. \tag{8}$$

If the amount of goods produced locally is less than the maximum local consumption, then the local consumption equals G_i, else C_i:

local consumption:

$$LC_i = \min(G_i, C_i). \tag{9}$$

Products sold locally have a fixed profit:

$$PL_i = c_P \cdot LC_i. \tag{10}$$

If products are transferred to other microregions, then the profit is a function of the quantity of products transferred to other microregions ($GT_{i,n}$), and the travel time to the microregions ($TT_{i,n}$):

$$PO_i = c_P \sum_{\substack{n \\ i \neq n}} GT_{i,n} \cdot (1 - c_{TT} \cdot TT_{i,n}). \tag{11}$$

The total profit (P_i) is the sum of the profits above:

$$P_i = PL_i + PO_i. \tag{12}$$

5.5. *Profit-Maximizing Demons*

In each microregion a demon is responsible for maximizing the profit, in this case the demon uses the hill-climbing algorithm to find the maximum. The function of the profit is according to the number of employees. The general shape of the function is shown in *Fig. 7*.

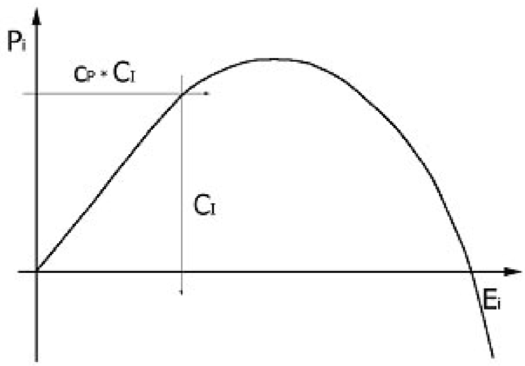

Fig. 7. Connection between P_i and E_i

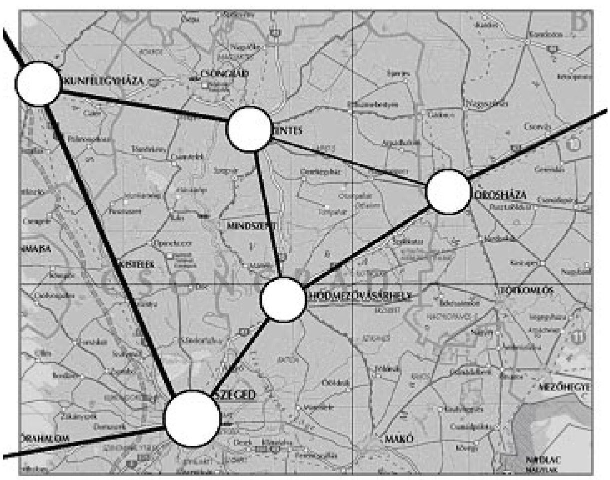

Fig. 8. Microregions connected with roads

6. Conclusions

In this paper it was intended to elaborate an approach to determine optimal solutions to influence the economic development of regions interconnected by traffic road systems. The factors taken into consideration in this initial model have been the allocation of working power, and its interaction with the growth of economy in the regions.

Further investigations of this approach are in progress.

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