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# A simulation model of development of a group of companies

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The paper presents a simple simulation model meant to reflact the basic features of behaviuor of a single enterprise or a group of enterprices in a poorly known environment. The model reflects learning and goal-seeking behaviour and its functioning is illustrated with some general results concerning behaviour in the transition process.

The characteristic feature of the contemporary economic development is the intensive restructuring of economic systems in many countries of the world. The scientific and technological revolution is making much heavier demands on the management than it had in the past periods. The importance of human resources, their creativity and skills is rising. Changes in the national economies are happening faster. Foreign markets are becoming more and more demanding.

The character of work is changing radically in the world as well. The share of the manual and physical work is decreasing as the result of automation of the production and service activities. The share of the information-related work is rising. For example, according to (Strassman, 1985) the share of information-related work in U.S.A. in 1982 represented 70% of the entire working time. This share is to increase even more. It is just the information-related work that is substantially influencing further economic development, under the assumption that there exist effective mechanisms which enable rapid transformation of new information into production or service. In this connection the importance of factors which determine productivity of men — ecologically clean environment, good health conditions, good relations at the work place, first–rate educational system etc. — is increasing. From the point of view of the development of economies, the factors, which have been considered as non–economic in the past and therefore were not paid adequate attention to, are getting more and more important.

The exploration of the social functioning of various economic, social, psychological and other factors influencing the development of economic system does not represent a simple practical or theoretical task, because individual factors can influence each other by a complicated network of direct links and feedbacks and they often have a stochastic character.

The suitable method for understanding of the functioning of the complex economic systems, although highly time–consuming, is computer simulation.

A computer simulation model enables displaying and examination of economic processes in a simplified form. Creation of a simulation model resembles the work of an artist, who is creating a piece of art, which, to a certain extent, resembles some original. Like a work of art, the simulation model is fulfilling a representation functions in relation to reality, too, but in completely different dimensions and with the help of other means. In both these cases, however, the ability of abstract thinking with generalization of concrete phenomena and considerable subjectiveness in the interpretation of the original are playing the leading role, (Kondratowicz, 1978). An important contribution of simulation methods is constituted by the possibility of modelling a significantly wider range of phenomena than with the analytic methods.

These reasons have led us to simulation modelling of the economic mechanisms in the rapidly changing society. The result was creation of the prototype series od models — FYLO and FULO [1], which simulate the behaviour of a couple of companies. The most advanced model is FULO7. This model makes it possible to imitate connections between the information–related and non–information–related dimension of labour, creativity of an economic agent,

[1] The prototype series of simulation programmes FYLO and FULO was developed within the framework of a research project of the Research Institute of Labour and Social Development (VUSRP) (see e.g. (Belica et al., 1989)). Discussions with M. Belica, L. Andrasik, J. Zapletal (1984) contributed also to the successful realization of the programme.

the mechanism of origin and the value of products. It takes into account the processes of ontogeny and phylogeny, which are typical for biological as well as for social and economic systems. The results of modelling with FULO7 have qualitative character. The model is not designed for exploring exact quantitative relations among the phenomena mentioned.

FULO7 is meant for the analysis of dynamics of behaviour of a group of companies which are producing similar products or services in manufacturing or service cycles following each other. The goal of every cycle is to sell a certain amount of products or services on the market and to receive money for that. The economic activities of companies are connected with costs. The companies can exist only if they are profitable in the long term. Their profitability depends on the relationships between their revenues and costs. Revenues depend on the prices of products, which depend on the pricing, competition, government regulations etc. Profitability is also connected with the survival of companies. If the companies are not profitable, they are liquidated. Survival of companies depends upon competition. Under its influence, only effective companies will survive. Effectiveness of companies depends on the ability to introduce innovations in terms of products and to cut the overall costs. This closely connected with their creativity. A creative company puts much of its energy into innovation, which is, however, associated with additional costs.

Modelling the behaviour of the group of enterprises via FULO7 is carried out through the use of biological ideas (phylogeny, ontogeny), geometric notions (movement of a point in two–dimensional space) and the reservoirs (material, energy and knowledge reservoirs).

Phylogeny is the development or evolution of a particular group of organisms. The number of organisms in population is varying depending on the living condition of the species. The number of organisms in population can be modelled as the changing level of the material reservoir. In the process of evolution the organisms change their shapes and their genetic information and that is the prerequisite of their survival and development in changing conditions. The genetic information is the contents of phylogenetic memory which is transferred from the ancestors to the new organisms. In such a way lower species have evolved to higher species. Similar processes can be observed in the economy. New companies are not beginning to work with obsolete methods which were typical for the old times, but they are using the methods of work typical for the new period. These methods are transferred by education and organisational culture of the society and their use is necessary for the survival of the company.

Ontogeny is the development of individual organism. During its life, an organism acquires experience, which helps to survive and adapt to changing conditions. A similar situation is typical for an individual company, which looks for better operation and management methods, develops its organisational culture etc. The process of acquiring knowledge can be modelled as the process of changing the contents of the knowledge reservoir, which is the representation of the ontogenetic memory.

Survival of the individual species or a company depends on the possibility of acquiring food and sustaining the functions of the bodily organs. In order to generalize this idea, it may be useful to introduce rather abstract idea of energy reservoir. From the energy reservoir, the organism takes the energy needed for the survival. If the energy level in the energy reservoir falls to zero, the organism dies. The prerequisite of life is therefore periodic replenishment of this container. The similar idea is true for a company. In order to survive a company needs a positive cash flow. If the cash flow is in long term negative, a company cannot perform its activities, since there is lack of money for paying workforce, buying materials, machines etc. Activity and life of an organism or company depends on energy or financial resources and their effective utilization.

The geometric idea of movement of a point in two–dimensional space is being used in the model for modelling the costs of economic activities of companies during the consecutive operations cycles. Behaviour of every company is described by the movement of the point from the origin of the two–dimensional space to a target. This target represents the goal of an operation cycle — selling of a certain quantity of products on the market. When the target is hit by all the points, the operation cycle is finished. Points representing different companies have different trajectories. From the characteristic features of these trajectories (lengths, number of steps in trajectories, coefficient of penalization) the cost of company operation can be derived.

## Behaviour of companies

There is a set of companies $K_1, K_2, \dots, K_n$. The number of companies, $n$, may vary in every operation cycle. Every company $K_i$, $i = 1, 2, \dots, n$;
$2 \leq n \leq n_0$; has the goal–seeking behaviour which displays a certain degree of creativity $p_i$.

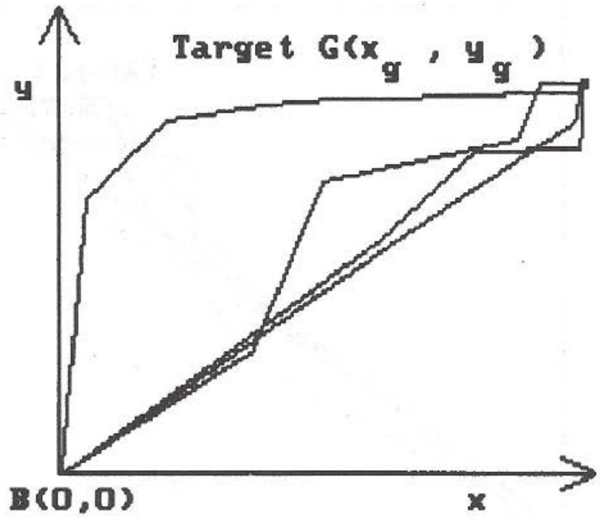


Figure 1. Movement of the points in the 10-th operations cycle in the two dimensional space

The goal–seeking behaviour is expressed geometrically in Figs. 1 and 2 as the movement of points representing the activity of companies in the two dimensional space with a target. Both figures represent the results of computer simulation. The first one represents a 10-th operation cycle, and the second — the 33-rd operation cycle. Note that in the second case the trajectories are shorter, as the result of creativity of companies expressed in a more effective search for the shorter trajectories towards the target. The target is the square object defined by its centre — point $G(x_g, y_g)$, and the length of its side $a$.

As can be seen from both figures, the trajectory of movement $t_i$ is composed of the series of lines (partial movements or steps) linking the points $A_j(x_j, y_j)$ and $A_{j+1}(x_{j+1}, y_{j+1})$, where $j = 0, 1, \ldots, r-1$, $r$ being the number of lines constituting the trajectory. Since a trajectory begins at the origin of the coordinate system, we have $x_0 = 0, y_0 = 0$.

At the beginning of the simulation — in the first operation cycle — the forms of partial movements are not known and therefore all the lines are generated by the formulas:

$$x_j + 1 = x_j + \Delta x_j \tag{1}$$

$$y_j + 1 = y_j + \Delta y_j \tag{2}$$

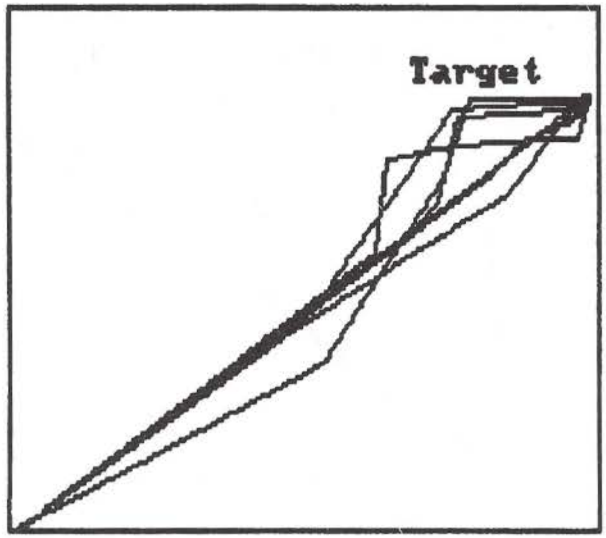


Figure 2. Movement of the points in the 33-rd operations cycle

where

$$\Delta x = (x_g - x_j) \cdot \mu \tag{3}$$

$$\Delta y = (y_g - y_j) \cdot \mu \tag{4}$$

are increments of $A_j(x_j, y_j)$, and $\mu$ is a random number from the interval (0,1). The length of the trajectory $t_i$ is calculated by the formula:

$$t_i = \sum_{j=0}^{r-1} \overline{A_j A_{j+1}} \tag{5}$$

The values generated are then stored in the knowledge reservoir. The knowledge reservoir is the three dimensional matrix $M[s, n_0, 3]$, where $s$ is number of sectors, which are defined by concentric circular lines with the centre in target and radial lines which intersect in the target, over the square defined by the points B(0,0) — left lower corner and target $G(x_g, y_g)$ — right upper corner (see Fig. 3), $n_0$ is the maximum number of companies, the third dimension allows to store three values: $\Delta x$, $\Delta y$ and $U$, for each sector and company $K_i$.

$U$ is the utility function. It evaluates the efficiency of movement by the following formula:

$$U = \frac{V_1 - V_2}{V_3} \cdot 100 \tag{6}$$

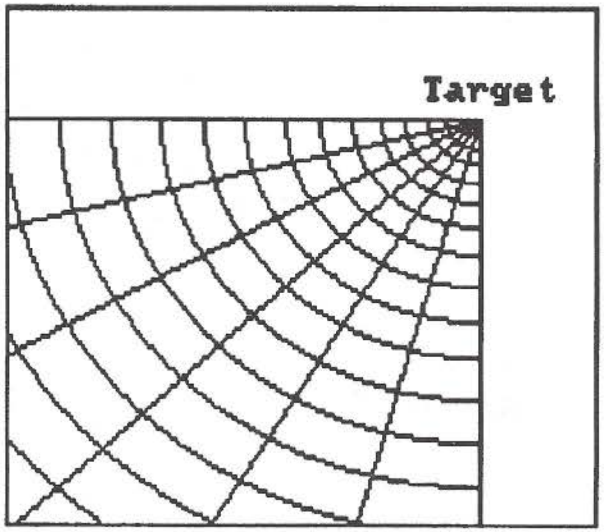


Figure 3. Sectors of the knowledge container

where $V_1$ is distance from point $A_j(x_j, y_j)$ to $G(x_g, y_g)$, $V_2$ is distance from point $A_{j+1}(x_{j+1}, y_{j+1})$ to $G(x_g, y_g)$, $V_3$ is distance from point $A_j(x_j, y_j)$ to $A_{j+1}(x_{j+1}, y_{j+1})$. See details in Fig. 4.

If the knowledge reservoir contains the information needed for defining the partial movements of points, this information can be used for the definition of the form of the step. However, even in such a case the partial movement may be generated again from scratch and the knowledge stored may not be used. In every step the simulation algorithm analyzes the position of the point $A_j(x_j, y_j)$ and finds the corresponding element of knowledge reservoir. If this element is empty, the algorithm generates a new movement. If it is not empty, the algorithm decides whether to generate a new movement or use the increments from the knowledge reservoir. The frequency of generation depends on the value of the parameter of creativity of a company. The parameter of creativity $p_i$ is the probability of generating the new movements for a company $K_i$. The initial values of the parameters of creativity are set up before the start of the simulation for the initial number of companies.

The generated values of increments are used for movement of points only if the value of their utility is better than the corresponding utility stored in the knowledge reservoir. In that case the content of the corresponding elements in

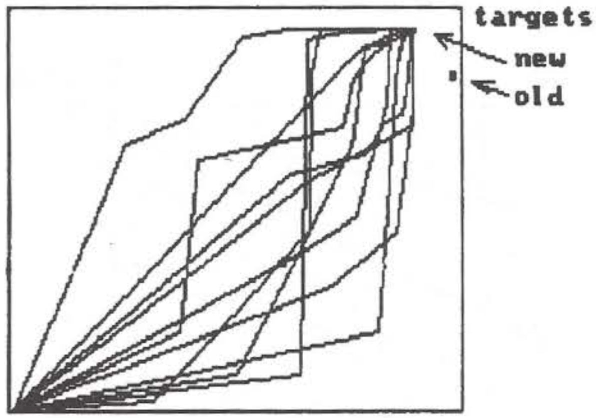


Figure 4. Change of target during the simulation

the knowledge reservoir is replaced by the generated values. This is the basis for trajectory improvement.

## Costs of companies in the operation cycles

The costs $c_i$ of a company $K_i$ in operation cycle $m$; $m = 1, \ldots, m_0$; is derived from its behaviour as the sum:

$$c_i = (g_i + h_i) \cdot P_i \tag{7}$$

where $P_i$ is number of products produced by $K_i$ (at the beginning of the simulation, each company produces the same amount of products i.e. 1) and $g_i$ are information–related costs, which can be interpreted as the general management costs and the costs of research&development; $h_i$ are non–information–related costs and can be interpreted as the cost of the routine operations in the company. We have:

$$g_i = (\Omega_i + \Phi_i) \cdot G_i \tag{8}$$

$$h_i = [\overline{BG} + (L_i - \overline{BG})^b] \cdot H \tag{9}$$

$\Omega_i$ is number of times the knowledge reservoir was used during the movement of company $K_i$ in the operation cycle $m$, $\Phi_i$ is number of times the movement was generated in the trajectory of $K_i$ in the operation cycle $m$, $G$ and $H$ are the unit costs of the information–related and non–information–related work, $L_i$ is the length of trajectory $t_i$ from the beginning of the coordinate system to the target; $\overline{BG}$ is the minimal distance from beginning of the coordinate system to the target square and $b$ is the coefficient of penalization, which penalizes inefficient trajectories.

## Energy reservoir

Financial reserves of the companies are stored in the energy reservoir $E_1$, $E_2, \ldots, E_{n_0}$. Before the start of a simulation the reserves are set up by the user for the existing companies. For each subsequent operation cycle we have (the operation cycle index being made explicit here):

$$E_i^{m+1} = E_i^m - c_i^m + r_i^m \tag{10}$$

and

$$r_i^m = R_i^m \cdot P_i^m \tag{11}$$

where $R_i$ is the revenue of company after reaching the target, per one unit of product.

A company $K_i$ can exist only if $E_i > 0$, otherwise it becomes bankrupt and is liquidated. Liquidation of companies is, though, one of the prerequisites of phylogeny and of the rise of new companies.

The revenue intensity $R_i$ is calculated by two alternative ways, which correspond to two alternative economic mechanisms:

$$R_i = \frac{D}{\sum_{i=1}^{n} P_i} \tag{12}$$

$$R_i = \frac{c_i D}{P_i \cdot \sum_{i=1}^{n} c_i} \tag{13}$$

$D$ represents here total amount of financial means which can be paid for reaching the target by all the companies. In FULO7 demand is steadily growing from one iteration to another.

Formula (12) and (13) make a clear distinction between the revenue generation in the market and in the centrally planned economic systems.

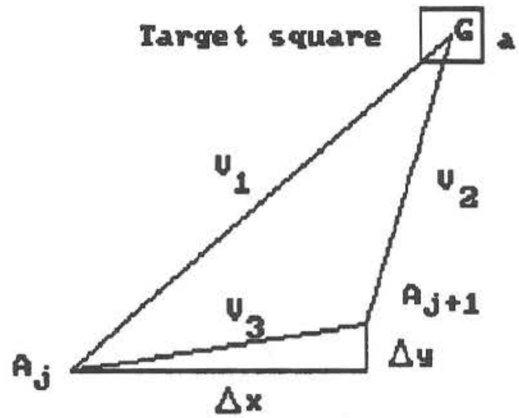


Figure 5. Partial movement of the point $(A_j, A_{j+1})$ and the variables needed for the calculation of the utility function

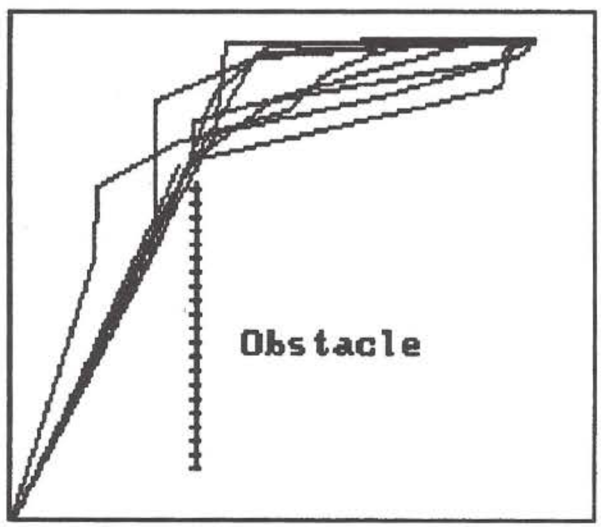


Figure 6. Movement of the points in the.space with the obstacle

# Tools for simulating the turbulent economic environment

It is quite an important question how the economic system will behave in the difficult, demanding and turbulent environment. FULO7 has three tools for modelling of such an environment:

1. Coefficient of penalization. High values of this coefficient put enormous pressure on the efficiency of companies (see the use of the coefficient in formula (9))
2. Change of position of the target. It is possible to change randomly the position of target in time. The shift of the target means simultaneously, a change of optimal trajectories, restructurization of the knowledge reservoir, so that the default values representing the experience gained from the previous movements lose a part of their relevance in the new conditions. After the change of target the trajectories usually scatter, as can be seen from the Fig. 5 illustrating a change of the target.
3. Obstacles to the movement. User can set up or liquidate an obstacle to the movement of the point representing the activity of a company (see Fig. 6). The movement of the company–point cannot cut across the obstacle, it can only circumvent it. Bypassing of the obstacle increases the costs of operations. Setting of the obstacles makes it possible to simulate critical phenomena in economics, such as for example energy and ecological problems which also increase the costs of operations.

# Expansion of companies and of production

If the economic activities are very profitable, because, say, of low costs and high demand, the economic system described starts to grow. Existing companies expand their production and new competitors emerge. Such situation is also simulated by FULO7. The model has the special decision module, which analyzes if there is a potential for growth. If the answer is positive new companies will emerge or the best of existing companies will expand their production $P_i$. The outcome of expansion — growth of production or growth of the number of companies is subject to a random process. The reverse process can also take place in the model. If the economic conditions are not very good, production of the worst companies may drop or the companies be liquidated.

The model supposes that the emergence of new companies is connected with the transfer of experience from companies which have the best chances for survival in a current economic environment. This environment may be turbulent (high coefficients of penalization, obstacles in movements, changing targets) or relatively non–demanding subsidized revenue mechanism, movement without obstacles, stable targets.

The new emerging company will receive financial reserves from the richest companies together with their knowledge reservoir, and its creativity will be also derived from two best companies. These assumptions, built into the model, are founded on the observation that new companies try to copy the experience of the most successful companies. It is clear that the mechanism of emergence of new companies is in the real world more complicated, but it is not very well known. In spite of simplicity of the above mentioned assumptions, quite interesting results can be obtained.

## Experiments with FULO7

For carrying out of the simulation experiments special software has been developed. It ensures the control of the integrity of input data, realization of simulation experiments, storage of all the results in a database and graphical display of data on the monitor with 18 different graphs for maximum of 200 operation cycles. Graphical interpretation of results helps to understand the dynamics of the process modelled.

Fig. 7 presents graphically the results of two simulation experiments. The goal of the experiments was to study the relationship between the turbulence of the economic environment and the creativity of the companies. In both experiments the same values of variables are used at the beginning of simulations. At the beginning of simulation only three companies exist and their number can grow to 15. Their average creativity is .45. Coefficient $b$ equals 2 and the position of target changes once for 50 operation cycles. Demand $D$ rises slowly linearly from one operation cycle to the next one. The experiments use the same series of random numbers for generating stochastic variables. Untill the 97th operation cycle the graphs are identical. The same companies are liquidated and the same ones are created in both experiments. Later, the situation changes. From 97th until 180th operation cycle various obstacles are introduced and they restrict the movements of the points. The companies are additionally penalized. The

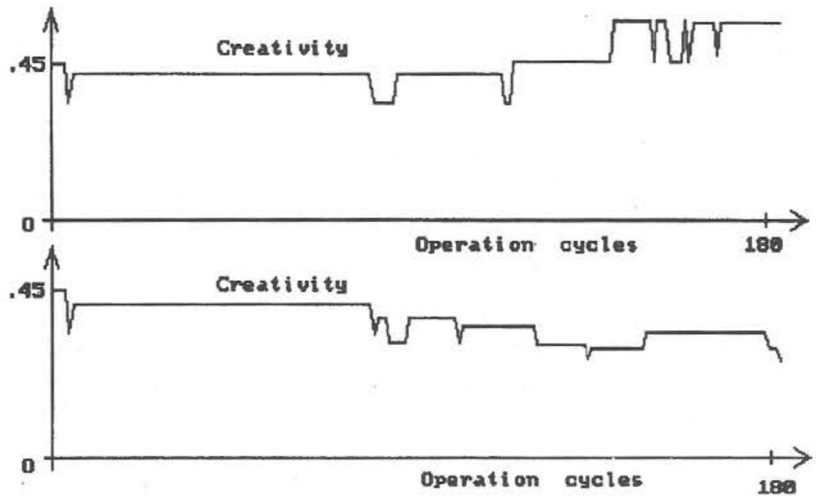


Figure 7. Influence of the turbulent economic environment on the creativity of companies. Two graphs show two experiments. On the first graph the environment is more turbulent than in the second graph.

process of phylogeny is therefore faster. This situation is shown on the upper graph. The average creativity fluctuates in time but has the tendency to rise. In the lower graph the environment is less turbulent and therefore creativity has the tendency to decrease.

There are other problems which can be studied with the support of FULO7:

1. The influence of redistribution of the total revenue (revenue produced by all companies) among the individual companies. Two experiments can be planned on the basis of formulae (12) and (13). The experiments can help to understand better which type of redistribution policy (subsidies, taxes etc.) is more effective.
2. The impact of the rising information–related costs on the effectiveness of the operations of companies.
3. Various ways of structuring the knowledge reservoir and their impact on the learning process of the companies.
4. Optimization of conditions for economic development of companies.

The main ideas of the model are suitable for the study of the problems connected with the transition to market economy, such as for instance alternative ways of privatization, demonopolization, governmental involvement in the economy and support for the competition.

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