AUTOMATON MODELING AS AN INSTRUMENT FOR THE FORECASTING OF COMPLEX ECONOMIC SYSTEMS

The study elaborates on the modern imitation methods of automaton modeling for complex economic system developed by the Institute of Cybernetic of the National Academy of Science of Ukraine / 1-3 /.

Further discussion requires a clarification of the essence of automaton modeling. Among all the published definitions of a probabilistic automaton, the Moore automaton is the most suitable for automaton modeling / 3 /. Without going into a rigorous definition, we only indicate that an automaton is an object which at every time instant has a certain internal state , is capable of receiving some input signal, and produces some output signal.

In order to define a probabilistic automaton we need to define the sets of values that may be observed for the internal state, the input signal, i.e. the internal input signals of the automaton. We should define the initial state of the automaton (some element in its internal alphabet) with which the analysis of automaton behavior starts. We should also specify the algorithm that generates output signals (output functions) and the algorithm that changes the internal states. This algorithm may be defined by a family of stochastic matrices that depend on a parameter (this parameter is equal to the number of elements in the input alphabet), by a stochastic equation, or else by a special row consisting of two subrows: the upper and the lower. The upper subrow contains logical propositions that depend on the internal state and the input signal; the lower subrow contains the state-updating functional corresponding to these propositions.

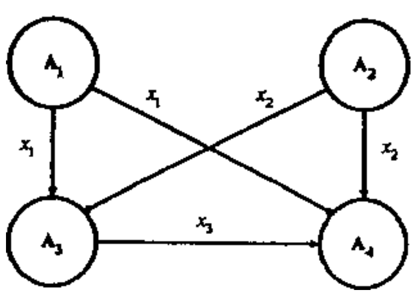

Fig 1. Automaton interconnection graph.

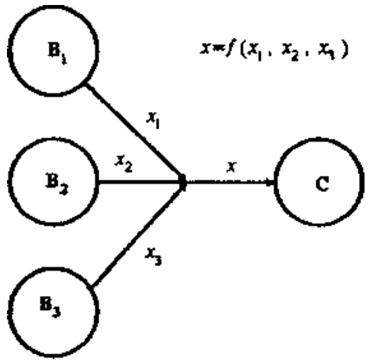

Fig. 2. Generation of a composite input signal.

A system of probabilistic automata is not a simple collection of automata, but actually an object of a new nature. The main feature here is that for each system of probabilistic automata we must define the interconnection between the automata, i.e. the alphabets of the circulating signals and the algorithms for converting the output signals of some automata into input signals of other automata. The links between automata are conveniently defined in terms of a so-called alphabet matrix. This is a square matrix in which the number of rows and columns equals the number of automata, the matrix elements are symbols representing numerical sets. The elements along the main diagonal are the symbols of the internal automata; the other matrix elements are the alphabets of the signals transmitted from the automaton corresponding to the given row to the automaton corresponding to the given column.

The links between automata are conveniently visualized by the automaton interconnection graph, in which automata are shown by circles or rectangles and their interconnections by arrows (Fig. 1).

The initial state of the system is defined as a collection of the initial states of its component automata, i.e., as a vector of initial states. The values of the vector components must be compatible with one another. The algorithm that takes the system from one state to another is defined by a special table of conditional transition functionals. This table is represented either as a collection of rows describing the transitions of individual automata or as a system of stochastic equations.

The relationships for computing the output signals of all the automata in the system form a single list of relationships - the system of output functions. In practical modeling, it is often helpful to express the input signal of some automata in terms of a functional that depends on the output signals of other automata (Fig.

2). Such functionals are usually referred to in the literature as intermediate variables / 1-3 / .

The specification of a system of probabilistic automata also includes probability distributions of random variables , which are arranger in a table of conditional transition functionals.

In the process of simulation calculations are carried out in the following order. The internal state variables, the input signals, and the intermediate variables are saved in two versions: old and new. First, the values of the initial state vector are assigned to the old state. Then new automaton states are computed using the system of output fanctions, the relationships for intermediate variables and table of conditional transition fonctionals. The table of conditional transition functionals is used after the realization of the random variables obtained from the given distributions have been substituted to the corresponding symbols. After that the clock is advanced one unit, which correspond to assignment of the new values to the old states. This system of calculations forms a so- called elementary loop. T-fold repetition of the elementary loop constitutes the main simulation loop over simulation time T; n-fold repetition of the main loop ensures the required averaging accuracy of the entire dynamic process in the simulated system over the main loop.

This method was used for forecasting of the development of a region.

We examine the development of automaton-modeling multipurpose simulation systems. Such systems constitute a single problem-oriented package of applications based on a general simulation model, which is equipped with a task source language, interaction tools, file management tools, and an output document editor. The simulation models are described by the method of probabilistic-automaton modeling [4-7], which ensures standard representation of models and standardization of the modeling algorithm. Examples of such systems include the demographic forecasting system DEPROG, the VOKON system for assessing the quality of consumer services in terms of free time, and the SONET system for servicing partially accessible customers .

Multipurpose simulation systems are based on a single simulation model, constructed and programmed in advance and adapted to solving a whole range of optimization and forecasting problems. Each multipurpose system, as distinct from a "global" system, is specialized for a certain class of problems. We can pass from solving one problem to another problem without programming a new model. This transition is anticipated in the system and is usually done interactively. Different problems are solved using input data from a single database. Each problem is supplied on-line with the necessary data by a special file management system, which is incorporated in multipurpose simulation systems. Model description in simulation systems should preferably be based on automaton modeling [1-3], which ensures sufficiently standard representation of models and standardization of the simulation

algorithm. Experience with this form of simulation is fully consistent with theoretical predictions.

Different multipurpose simulation systems have widely differing software requirements. Yet some software tools are necessary for almost all simulation systems. It is therefore helpful to subdivide the application software into typical and special. Typical software, unlike special, includes the tools used in many systems. Typical and special software are as if merged when the system is generated, forming a single software complex.

DEPROG

The proposed technology has been applied to design several automaton-modeling multipurpose simulation systems on a town level. One of these systems is DEPROG .

The dynamics of demographic characteristics (migration flows, birth and death rates, marriage and divorce rates) has been studied in considerable detail. However, there are virtually no demographic forecasting models that utilize all the available scientific information and the relevant interconnections among data. Such models are particularly necessary for the analysis of small regions, for which exact forecasting results are difficult to obtain.

Automaton models are capable of representing dynamically the simultaneous effect of various interconnected factors while ensuring compact description and using standard simulation algorithms. Automaton modeling therefore appears suitable as a working method for modeling the demographic processes in a region.

The multipurpose simulation system DEPROG exploits to the maximum extent the capabilities of the automaton modeling method. The automaton model of the system allows for the first time in forecasting practice for a variety of important factors: the marriage structure of the population, the balance of ages of the married partners, the birth rate depending on the mother's age, and also separately for married and single mothers, the death rate for males and females depending on age, the dynamics of marriages and divorces, in- and out-migration. Allowance for these factors, including interactions, ensures forecasting accuracy which has previously been unattainable in long-term demographic forecasts [4-6] .

DEPROG constructs the automaton model using the following variables as the internal automaton states:

b_{xy} (t) is the number of married couples in the region for women of age x and men of age y at the end of year t (t = 0,1,...,T);

$a_x(t)$ (x = 0,1,2, … 100) is the number of unmarried women of age x in the region at the end of year t ;

$c_y(t)$ (y = 0, 1,2 ,… 100) is the number of unmarried men of age y in the region at the end of year t ;

$g_x(t)$ (x = 16, 17,… 100) is the actual ratio of the number of marriages with women of age x during the current year to the total number of unmarried women of age x ;

$d_x(t)$ and $d'_x(t)$ (x = 16, 17, … 50) is the number of births in the region by married and single women of age x respectively during the year (t +1);

$e_x(t)$ (x = 1,2, … 100) is the number of deaths of women of age x in the region during the year (t + 1);

$f_y(t)$ (y = 1,2, …100) is the number of deaths of men of age y in the region during the year (t + 1);

$h_x(t)$ (x = 16, 17, . .. 100) is the number of divorces of women of age x in the region during the year (t + 1);

$m_i(t)$ (i =1,2,… I)- is the current annual in-migration flow of type i (total number of immigrants of type I entering the region during the year(t+1) ;

$n_j(t)$ (j = 1,2,… J) is the current annual out-migration flow of type j (total number of emigrants of type j leaving the region during the years (t +1);

DEPROG allows calculating forecasts of any age intervals, for different groups of the population, and for arbitrary forecasting years. External control is implemented by the system source language, which fully encompasses the entire range of tasks handled by the system. The overall system operation algorithm executes the sequence of actions corresponding to each task and determines the internal control in the system.DEPROG has been applied to calculate demographic forecasts for the Moscow District in Kiev and for the entire city .

VOKON

A second automaton-modeling multipurpose specialized simulation system is VOKON, a system for evaluating service quality in terms of free time.

Although the time budget of the population has been studied in detail by many sociologists, various important questions remain unanswered. In particular, the problem of modeling the population time budget has not been solved. The available modeling results suggest the need for further development of a system of objective comparative estimates of regional development alternatives on the basis of change in free time. This fruitful idea is difficult to implement, however, because of the complexity of the modeled system and the need for allowing simultaneously for a large number of interdependent factors

The automaton modeling method, which permits simulating processes with branched interdependences, has demonstrated its power also for time budget modeling

in a region. The automaton modeling method has been applied to develop the VOKON simulation system, which is the first system capable of modeling the time budget of the population in a region

Time budget modeling requires a single classification of the various components of the time budget. A number of such classifications are available in the literature, reflecting the specific needs of the user. In the stage of pre-model formalization in the VOKON system, we had to develop a special classification of time uses, which although not quite general and universal is nevertheless suitable for modeling the relevant process. The main feature of our classification is the clear distinction between different time budget components, so that the time used to satisfy each particular need can be uniquely assigned to a certain budget item.

Efficiency comparison of regional development alternatives can be based on the ratio of the cost associated with a particular alternative to the weighted-average free time gained by the population when this alternative is implemented. This ratio is the "price" of an additional unit of free time under the particular alternative. Alternatives with the lowest ratio are preferred in all cases.

The VOKON system is intended for comparison and choice of efficient decisions in the area of urban development planning and development of various regional units. The system can be used as a standard software for general planning of urban development and regional socio-economic development, and also for making more particular decisions concerning the organization of services and location of specific service facilities. The tools for internal manipulation of data flows available in the system can be used to generate recommendations for any regional development decision. The system is commonly used to solve the following problems:

- **comparative evaluation of the quality of service across regions;**
- **efficient location of service facilities and determination of their required capacity;**
- **allocation of funds to different service facilities in the region and between regions;**
- **determination of efficient development alternatives for the regional transportation network;**
- **theoretical studies intended to elucidate the optimal regional structure and the organization of services in the region;**
- **determination of the optimal sequencing of service projects in the region subject to resource constraints.**
- **The VOKON system has been applied to solve a number of problems concerning changes in local services for the Moscow District in Kiev.**

SONET

The third automaton-modeling multipurpose specialized simulation system is SONET (service networks for partially accessible customers) . The main purpose of this system is to simulate a new class of queuing networks, with a systematic property of partial accessibility. Let us describe this class of problems and list some of its properties.

1. Given is a certain number of customers, servers, and a set of service operations.

2. For each customer we know the list of operations that have to be completed while the customer is in the network; the volume of service corresponding to these operations (in conventional units); and the arrival time of the customer in the network.

3. For each server we know the list of operations that it can perform in providing service to customers; the beginning time of service; and the rate of service by all the listed operations, expressed in conventional units per unit of time,

4. For each operation, we know the list of other operations that must be completed before the given operation can start.

5. At any time, each customer may be served by several servers performing the same operation or different operations. If the customer is served simultaneously by several servers performing the same operation, the service rates of the different servers are summed.

6. At any time each server may serve only one customer performing only one operation.

7. Customers and servers are indexed separately; customers and servers with a lower index have higher priority.

8. All operations are indexed; if a customer requires service at a particular instant and can be served by several operations on a server capable of performing these operations, then service starts with the operation having the lowest index.

9. A customer is completely served when all the prescribed service operations have been completed.

10. When a customer is already in the network but has not been completely served, the customer may be in a waiting state if none of the available servers at that instant is capable of performing the operations by which the customer must and may be served at that instant.

11. A server may be in an idle state if at the given instant there are no customers that require service and can be served at least by one operation that the server is capable of performing.

12. The network is without prespecified paths for the motion of customers from one server to the next. Customers reach servers instantaneously according to need and to the availability of particular service operations, and also according to the availability of suitable servers.

13. The set of customer arrival times in the network (the set of server starting times) and the set of service completion times by some operation constitute the set of so-called nodal points. At each nodal point servers are reallocated to customers so as to reduce server idle time to a minimum and to accelerate the service process to a maximum, especially for customers with the highest priority.

The SONET system has applications for long-range planning of housing construction, integrated maintenance of technical equipment, and development of new technological processes.

The methodology of multipurpose simulation systems is currently being applied for the solution of economic problems of environmental improvement in a city [5- 7].

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