STATISTICAL MODELING OF A CERTAIN CLASS OF COMPLEX SYSTEMS

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1966

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Fig. 1

Figure 1: Fig. 1

Abstract

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UDC 519.95

CYBERNETICS AND CONTROL THEORY

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(Presented by Academician N. P. Fedorenko, November 3, 1965)

At present, statistical modeling of production processes (only processes of a discrete type, characteristic, for example, of machine building, have been considered) should be regarded as sufficiently well developed (1). However, any production process is a controlled one. In the case when the production process and the process of controlling it are so closely connected that it is necessary to study the entire system as a cybernetic whole, a model of only the production process constructed without taking account of control will not be adequate. Therefore, the development of methods for statistical modeling of cybernetic systems appears important.

Fig. 1. Schematic diagram of the production process. 1 –oil; 2 –gas; 3 –straight-run gasoline; 4 –diesel fuel (DF) from the AVT; 5 –motor fuel; 6 –straight-run fuel oil; 7 –tar; 8 –losses at the AVT; 9 –dry gas; 10 –liquid gas; 11 –cracking gasoline; 12 –kerosene; 13 –DF from the KKU; 14 –cracking residue; 15 –losses at the KKU; 16 –fuel gas; 17 –commercial gasoline; 18 –commercial DF; 19 –boiler fuel; 20 –plant losses

In this connection, the present article sets forth the results of an investigation of the operation of an enterprise–one of the country' s petroleum refineries. These results amount to the following:

1. A statistical model of a cybernetic system has been developed. The production process, the functioning of the organs controlling the process, and their interaction are imitated.
2. As a formalized scheme describing the complex system studied by us, a self-adapting automatic control system (ACS) has been proposed.*

3. A methodology has been developed for modeling production processes of the continuous type.
4. In our view, a modeling-algorithm construction principle more universal than those existing has been proposed.**

At the plant under consideration the production process is carried out in two units (Fig. 1)—an atmospheric-vacuum tube still (AVT) and a combined cracking unit (KKU). The feedstock for the units is oil delivered by tankers. The units process it into a number of products, some of which are marketable and some intermediate, subject to mixing. Each unit can operate within a continuous range of productivities. The ratio of the amount of product obtained to the amount of raw material processed, i.e., the product yield coefficient, can vary within certain limits. The operators of the units are given the values of productivities and yields, but their actual quantities differ from the specified ones. Each unit operates continuously for a long period of time (about a month), and then is stopped for scheduled preventive maintenance (SPM). Unscheduled shutdowns due to accidents or a shortage of raw material are possible.

Production-process control is hierarchical. The main control functions consist in calculating the optimal (insofar as this is possible without using mathematical methods) production program of the plant subject to a number of constraints and in recalculating it when necessary. These functions are carried out by the plant management (the director, the chief engineer, and the planning and production department (PPD)), which we regard as a single body and denote below by PPD. The execution of the program developed by the PPD under changing conditions is carried out by the heads of the units (HU) and by the operators. This control body, denoted below by HU, is charged with maintaining productivities and yields at the prescribed level.

Considering the production process and the process of controlling it jointly, i.e., considering the plant as a complex cybernetic system, we use as the scheme for formalization a self-adapting (extremal) automatic control system, in which the object of control is the production process (PP), the adaptation device is the PPD, and the regulator is the HU (Fig. 2). The main feature of the production process that is of interest from the point of view of modeling methodology is its continuous character. The proposed formalization of the continuous production process (and also of the entire cybernetic system as a whole) is based on what is,

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* Here and below, when speaking of an ACS, we adhere to the terminology of (2).

** At the Central Economic-Mathematical Institute of the Academy of Sciences of the USSR, V. I. Volkov, N. A. Kornblyum, and Kh. Sh. Margulis have developed a model of another continuous production process using the same principle for constructing the algorithm.

Fig. 2. Representation of the plant in the form of a self-adapting automatic control system. I —production process; II —unit management; III —plant management; 1 —planned assignments and information about tankers; 2 —production program; 3 —productivities and yields; 4 —disturbing influences (accidents, random fluctuations of productivities and yields); 5 —information on the functioning of the plant

Figure 2: Fig. 2. Representation of the plant in the form of a self-adapting automatic control system. I —production process; II —unit management; III —plant management; 1 —planned assignments and information about tankers; 2 —production program; 3 —productivities and yields; 4 —disturbing influences (accidents, random fluctuations of productivities and yields); 5 —information on the functioning of the plant

in our view, a successful combination of principles known from modeling practice, which reduce to considering the system: 1) at the moments of its transitions from one state to another; 2) through sufficiently small time intervals Δt. In our opinion, the proposed principle of formalization can—by virtue of its universality —also be successfully applied in modeling discrete processes, and if the system is sufficiently complex, it is the only practically acceptable principle.

Fig. 2. Representation of the plant in the form of a self-adapting ACS.
I —production process; *II* —unit management; *III* —plant management; 1 —planned assignments and information about tankers; 2 —production program; 3 —productivities and yields; 4 —disturbing influences (accidents, random fluctuations of productivities and yields); 5 —information on the functioning of the plant.

For discrete processes, usually formalized in the form of a queuing system, the states of the system are introduced in the usual way. Using the ideas and concepts of queuing theory, we introduce the so-called essential changes of the system, understood in this model as the facts of: the arrival of new planned assignments; the arrival of tankers; the start-up or shutdown of some unit. Essential changes are classified as transitions of the system from state to state.

The application of the second modeling principle is due to the continuity of the production process. Namely, if the time interval between two neighboring essential changes is large, the continuous-

nature of the process may lead to significant deviations in operation even without the occurrence of a substantial change.

The functioning of the adaptation device can be modeled in different ways. For example, to compute the optimal production program one may use one of the methods of mathematical programming (convex, dynamic, etc.). In the present model the process of developing and recalculating the production program that takes place in existing practice is imitated.

The adaptation device is switched on at moments of certain substantial changes and in the presence of so-called substantial deviations from the intended plan. The regulating actions of the CU are generated at the beginning of each shift if, in the operation of any of the installations, there are deviations exceeding the established level. The PP—CU loop represents a closed tracking control system with negative feedback. The control system, like the entire ACS, is relay-pulse and nonstationary.

In the formalized scheme it is assumed that the moments of arrival of tankers and their tonnage, the moments of changes in the plan and the values of the new planned indices, the moments of occurrence of accidents and their durations are independent random variables with distribution laws determined from factual data. Continuous random functions of productivities and withdrawal coefficients are approximated by piecewise-constant random functions.

The constructed formalized scheme can, obviously, be investigated only by the method of statistical modeling. We give an enlarged scheme of the modeling algorithm; its structure in block form corresponds to the structure of the system under study. In generally accepted notation (see, for example, (1)) the scheme has the form:

$$\Pi_1\ {}^{22}\Pi_2\Phi_3\ {}^{20}\Pi_4\ {}^{14,17}A_5\ {}^{14,18}A_6\ {}^{9,13}A_7\ {}^{19}A_8\ P_{9\downarrow 7}\ P_{10}^{\uparrow 15}\ K_{11}\ P_{12}^{\uparrow 20}\ P_{13\downarrow 7}\ P_{14\downarrow 6}^{\uparrow 5};$$

$${}^{10}P_{15\downarrow 19}\ P_{16\downarrow 18}\ A_{17}^{\uparrow 5,\ 16};\quad A_{18}^{\uparrow 6,\ 15};\quad A_{19}^{\uparrow 8,\ 12};\quad P_{20\downarrow 4}\ K_{21}\ P_{22}^{\uparrow 2}\ {}_{23}.$$

Here each operator represents a subalgorithm that realizes, in the modeling process, a sufficiently complex operation.

Let us explain the above scheme. Π_1 carries out the transfer of information into the computer memory. The chain $\Pi_2\Phi_3 \ldots P_{20}$ models the operation of the plant during a quarter. Π_2 transfers data on the quarter into standard cells, Φ_3 forms random moments of plan changes and new values of its indices, and Π_4 prepares the information for the current month.

A_5 and A_6 model the operation of the adaptation device. A_5, whenever new planned indices enter it, in the event of an accident at any of the installations, and when there are substantial deviations in fulfillment of the plan, develops a new production program to the end of the current month, i.e., the set-point (for the regulator) values of productivities and withdrawal coefficients and the starting times of the PPR.

A_6 corrects the decision adopted by A_5 for the entire period in accordance with the actual state of the plant. Thus, if A_5 imitates long-range planning, the operation of A_6 corresponds to operative management.

A_7 reproduces regulation of the operation of the installations. It is connected to operation at the end of each shift. In the presence of certain deviations from the set-points, the regulator changes the productivities and withdrawals.

A_8 models the functioning of the production process under conditions of random disturbances, as a result of which the actual productivities and withdrawals differ from those specified by the regulator.

It has already been noted that, in constructing the algorithm, a principle was used that combines the modeling of transitions from state to state with regular viewing of the system through time intervals Δt, equal to

in the model of shift duration. P_9 checks whether the shift or another interval of time has ended (a day or a period ending with the occurrence of a new significant change). If the shift has ended, the regulator A_7 is addressed. Otherwise, P_{10} determines precisely which moment has occurred—the end of the day or the moment of a new significant change.

Consider the case in which the end of the next day has occurred. K_{11} counts the number of days elapsed; P_{12} checks whether the current month has ended. If not, we determine (P_{13}) whether there will be enough oil until the expected arrival of the tanker. If the answer is negative, no new decisions are made, i.e., the process proceeds with the same settings, but with regulation. If there is enough oil until the arrival of the tanker, we determine how large the deviations from the plan are (P_{14}). If there are significant deviations, we proceed to A_5; otherwise, to A_6.

Now let P_{10} indicate the occurrence of a new significant change. P_{15} determines whether it is necessary to address the adaptation device. If it is necessary, P_{16} determines which of the possible significant changes has occurred. In the case of changes in the plan and accidents, A_{17} takes the necessary measures (transfers the new planned data into the standard cells or determines the duration of emergency repair) and transfers control to A_5. If, however, a tanker has arrived, we proceed to A_{18}, which counts the oil reserves, after which A_6 operates. Finally, if a negative answer is obtained at P_{15} (completion of repair, shutdown of one of the units in the absence of oil, beginning of PPR), A_{19} calculates the necessary quantities (for example, the time of the next accident, the end of PPR, etc.), and operation continues (A_8).

If the current month has ended (P_{12}), but the condition checked by P_{20} (end of the quarter) does not occur, P_4 selects the necessary data for the following month.

The realization counters K_{21} and P_{22} (comparison of the number of the current realization with their preassigned number) are connected with the nonergodicity of the process. A_{23} processes the results obtained.

The statistical model constructed makes it possible to compute the values of any functional of the system parameters, provided only that these parameters are included in the model. Usually the greatest interest lies in studying the throughput capacity of the system in a broad sense, characterized by a whole series of functionals, such as: the quantity of raw material processed, the quantity and quality of output, the achieved economic indicators (profit, cost, expenditures), the idle time and operating time of individual parts of the system, etc.

In modeling, the indicated characteristics of the system can be investigated as functions of various conditions of its operation, for example, with a different stochastic pattern of raw-material arrivals, with different plan assignments, with another structure of the plant-management bodies or another method for developing control actions, with changes in the parameters of the equipment or its reconstruction, etc.

Naturally, the range of possible investigations is formed by combining the functionals under consideration and the specified conditions of system operation that interest us.

The authors express their gratitude to Prof. N. P. Buslenko for his attention and valuable advice, which contributed to the improvement of this work.

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Received
2 XI 1965

CITED LITERATURE

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