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MODELS OF TECHNOLOGICAL PROCESSES MANAGEMENT UNDER CONDITIONS OF UNCERTAINTY

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ABSTRACT

The methodological aspects of applying the theory of fuzzy sets in the management of technical process of production of motor vehicle equipment, concerning the reliability, accuracy and stability of the obtained solutions, are considered. A method of formalizing fuzzy concepts based on an objective probabilistic approach is proposed, which allows increasing the reliability of modeling results.

Keywords: control model, technological process, technological object, uncertainty of conditions, simulation modeling, fuzzy classification model.

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1. INTRODUCTION

Technological processes (TP) serve as the material basis for the production of technical means of automation (TMA), and therefore one of the ways to increase the efficiency of TMA production is to develop and improve methods and means of TP management.

The constant complication of TMA, the tendency to switch to small-scale multi-nomenclature production under conditions of strict restrictions on costs and terms of TP development and re-adjustment leads to the fact that TP management is usually carried out in conditions of a priori insufficiency. Uncertainty in the control process is also introduced by errors and incompleteness of measurement information, noise, heterogeneity of materials used, and drift of process equipment parameters.

In these conditions, qualitative information in the form of intuitive knowledge and experience of the technologist is of great importance in managing TP of TMA production. The role of such information at the stage of development of TP of TMA production and in the conditions of small-scale production can hardly be overestimated. The use of qualitative information allows the management model to take into account the complex internal relationships of the technological object under study (TO). Thus, a new type of uncertainty arises in the TP management tasks of TMA production that requires formalization - fuzzy information.

The main content of the TP control algorithm is a mathematical model of the process, and therefore, under conditions of uncertainty, the issue of building adequate mathematical models is particularly acute.

The successes of the development and industrial production of microprocessor technology have created a solid foundation for the design and implementation of automated systems of technological processes control (ASTPC). However, despite the wide range of work in the field of design and automation of TP control at TMA, existing ASTPCs are mostly only able to maintain the level achieved by the technologist and are ineffective during the development of new products, as well as in small-scale, multi-nomenclature production.

The manufacture of products in small batches with a wide range of sizes and properties leads to an increase in the frequency of changing settings (parameters of technological operations, equipment operating modes), and increased requirements for the flexibility of the settings model. At the same time, the model has to be developed on the basis of a limited amount of noisy experimental data and very vague a priori information about the statistical characteristics of the added disturbances. In many cases, these difficulties are exacerbated by the presence of drift in the characteristics of the maintenance system.

Automated TP control systems, most of which are based on the use of statistical models, are ineffective during the period of development of new products. Statistical models are inherently very sensitive to changes in experimental conditions, and their adequacy can only be guaranteed under the conditions under which they were built.

As a result, the technologist is usually deprived of ASTPC support and spends considerable time selecting modes for manufacturing pilot batches and collecting statistical data at the most critical moment - the moment of mastering new processes. Thus, the task of developing models for adaptive TP control in small-scale, multi-item production is an urgent one.

2. PRESENTATION OF THE MAIN MATERIAL

The construction of models for controlling technological processes of production of automation equipment is the basis for the development of control systems, a prerequisite for the creation of automated process control systems (ASTPC), flexible production systems (FPS). A general consideration of TP management issues from the standpoint of a systematic approach reveals the need to use a wide range of mathematical models for various purposes in the analysis and synthesis of control systems. When analyzing and synthesizing TP in order to select their optimal parameters for obtaining products of the required quality and quantity, the focus is on control influences.

Usually, the control model is built on the basis of the TP functioning model, and it assumes that the TP is divided into sequentially parallel branches with spatial and temporal separation of functions of each of them and appropriate coordination in time. The purpose of such a control model is that it allows detecting emergency modes of operation of technological equipment and providing for its timely automatic shutdown if necessary.

The rapid development of computing technology, including fuzzy hardware and software, and its application in TP management stimulates the development of new classes of mathematical control models. Here it is also appropriate to mention operational models of technological facilities management (TPM). This is, first of all, a model of maintenance reliability, the analysis of which allows you to regulate the time of its operation, repair and preventive maintenance schedules, and take into account natural degradation processes.

Very often, when managing TP, we deal with uncertainty of various types and causes. In these conditions, one of the main requirements for the model is the ability to adapt to changing conditions and the ability to learn. However, there are currently no adequate analytical methods for building such models.

In the development of TP management algorithms, simulation modeling has become widespread, which, due to its flexibility, is a more adequate tool for studying complex systems and processes than analytical methods. The essence of simulation modeling is to create a special algorithm, which can be implemented on a computer to reproduce the process under study by elements (in a formalized form) while maintaining the logical structure and sequence of the process. In this case, all real operations with their physical and chemical content are replaced by abstract ones that serve as a converter of product parameters.

The simulation process includes the following steps:

- compiling a meaningful description of TP. This is based on a thorough study of the TP. In the absence of a real object or the impossibility of conducting experiments at an existing object, the accumulated experience and results of observations of processes of similar purpose are used. A meaningful description allows you to: to form a clear idea of the physical nature and quantitative characteristics of TP; to dismember TP into maintenance and simplest elements, determine their indicators and parameters; to draw up a diagram of the interaction of elements in an operation, and operations in TP; to determine the patterns of change in TP indicators when its parameters change; to formulate the problem statement, initial and boundary conditions;
- build a formalized scheme. At this stage, the quantitative characteristics of the TP are specified and a strict mathematical definition of all dependencies between the indicators and parameters of the TP and its individual elements is given. The experimental data obtained at the previous stage are systematized, taking into account the random nature of their receipt. Finally, the exact mathematical formulation of the research problem is established;
- the development of a modeling algorithm is based on the construction of a mathematical model. Modeling algorithms are most often presented in the form of a diagram, where each block represents a sufficiently large group of TP elements, and the links between the blocks reflect the logical structure of the TP;
- “running” the model and analyzing the modeling results. The number of realizations of the modeling process is calculated based on the specified accuracy of the results. The results are valid for fixed values of process parameters, input information, and initial conditions. If the input data changes, at least new model runs or changes to the modeling algorithm are required. All of this requires certain costs, especially time.

Thus, due to their specifics, simulation models, although they can adapt to changing conditions within certain limits, the process of adaptation and the output of the simulation result, except in trivial cases, cannot be performed in real time.

In conditions of uncertainty, when the model does not have to operate in real time, and the accumulated experience and results of observations of processes of similar purpose can be used to obtain the missing information, simulation modeling can be used to create models of both individual technological operations and TP as a whole in order to find or verify control laws, as well as to assess the variables of the maintenance process that cannot be measured or to predict its states in relation to real control.

Compared to simulation models, fuzzy models are more adaptable to changes in maintenance parameters and operating conditions. Their use makes it possible to organize the decision-making process in the management of TP in real time.

Two types of fuzzy models are most often used to automate the solution of poorly formalized management tasks in TMA production: fuzzy classification models of the “situation-action” type [1, 2] and fuzzy models based on composite inference schemes [3-5].

Fuzzy classification models are used in TP management of TMA production, where the set of control decisions is limited and small (3-5 controls). Such tasks, for example, are often encountered in product inspection. In this case, 2-3 types of decisions are used (suitable product, final defect, correctable defect, etc.). In some tasks of operational dispatch control, the set of possible controls is also often limited and relatively small (send the product for revision along one of several technological routes, start one of several batches of workpieces, select one of the TP control modes).

A fuzzy classification model is a triple (*W*, *P*, *U)* in which $W = X \times Y \times \dots \times Z$ - is a multidimensional space of features of factors that most significantly affect the choice of management decisions; $P = \{P_1, P_2, \dots, P_q\}$ - partitioning W into fuzzy reference classes P_s, $s = 1,2,\dots,q$; $U = \{u_1, u_2, \dots, u_q\}$ - a set of control decisions $u_s$corresponding to the classes P_s.

To build fuzzy classification models by interviewing experts or based on a substantive analysis of the problem, a set of features-factors *X*, *Y*,..., *Z* is selected, which, in the opinion of expert specialists, most significantly affect the choice of solutions $u_s \in U$, $s = 1,2,\dots,q$and the space $W = X \times Y \times \dots \times Z$. This stage is informal and depends on the subject area, management criteria, and the qualifications of the experts. However, in most cases, finding the signs is not particularly difficult, as they are immediately identified when comprehending the problem, formalizing it, and identifying goals and criteria. For example, in inventory management tasks, such features can be *X* - inventory volume, *Y* - accuracy class of the manufactured product, *Z* - planned output.

For each of the selected features, the expert specialist (master or technologist) associates a certain linguistic change *A*, *B*,...,*C* with its meanings $\{a_i\}, i = 1,\dots,m; \{b_j\}, j = 1,\dots,n; \{c_k\}, k = 1,\dots l.$ For these linguistic values, membership functions are built $\mu_i(x), \mu_j(y), \mu_k(z)$ on the corresponding basic scales *X*, *Y*,..., *Z are constructed.*

The qualitative structure of the management model is built in the form of a decision table. The rows of the table correspond to different sets of $(a_i, b_j, \dots, c_k)$. of linguistic values of variables *A*, *B*,...,*C*. The columns of the table are labeled with the symbols of the linguistic variables *A*, *B*,...,*C*. The last column is labeled with the symbol *U*. Columns *A*, *B*,..., *C* contain different sets of $(a_i, b_j, \dots, c_k)$ of linguistic values. For each such set, in column *U, the* expert puts one of the possible management decisions $u_s \in U$that the expert would make in the situation verbally described by the corresponding set. This step is informal and depends on both the specifics of the task and the qualifications of the experts.

At the final stage, a fuzzy classification model (*W*,*P*,*U*), is built in which $W = X \times Y \times \dots \times Z$, $P = \{P_1, P_2, \dots, P_q\}$, $U = \{u_1, u_2, \dots, u_q\}$. Each fuzzy class *P*$_s$ *of the partition P is* characterized by a FP $\mu_s(x,y,z)$defined by a fuzzy logical formula:

$$\mu_s(x,y,\dots,z) = \vee_{(a_i,b_j,\dots,c_k)\in L_s} \ \mu_i(x) \wedge \mu_j(y) \wedge \dots \qquad \dots \wedge \mu_k(z), \qquad 1$$

where L_s - is the set of sets $(a_i, b_j, \dots, c_k)$that correspond to the solution in the solving table u_s, $s = 1,\dots,q$;

V is the sign of the math operation.

Let the situation characterizing the state of the vehicle be represented by a point $w_0 = (x_0, y_0, \dots, z_0)$ in space *W*. Then the algorithm for developing a control decision based on a fuzzy classification model is reduced to the following formal procedure:

- substitute the point $w_0 = (x_0, y_0, \dots, z_0)$ in the FP of the reference classes $\mu_s(x,y,z)$ and calculate the values $\mu_s(x_0, y_0, \dots, z_0)$, $s = 1,\dots,q$;
- find $s = s_0$, such that $\mu_{s_0}(x_0, y_0, \dots, z_0) = \max_{s} \ \mu_s(x_0, y_0, \dots, z_0)$;
- make a decision u_{s_0}corresponding to the reference class P_{s_0}.

It should be noted that a fuzzy classification model allows you to choose a control decision without building a TP model.

Fuzzy models based on composite inference schemes are used in problems in which the set of control decisions is quite large (more than 5). In this case, the control model is described by a fuzzy input-output relation that connects possible states of the maintenance system with control decisions.

A fuzzy composite model is a triple (*W*, *R*, *U*), in which $W = X \times Y \times \dots \times Z$ - is a multidimensional space of features that most significantly affect the choice of control decisions, *R is* a fuzzy input-output relation on $W \times U$and *U is* a set of control decisions (in general, it can be either a finite or an infinite set).

The set of features *W is identified in the same way* as for fuzzy classification models, namely, the most significant features are determined by experts when formalizing the management problem. Determining the set of control influences *U* is also an informal stage, however, in most cases it does not pose a big problem, since control decisions are identified immediately when setting the problem and defining the control goals.

The most crucial stage in the development of a fuzzy composite model is the construction of a fuzzy input-output relation *R that connects* all possible states of the vehicle (set *W)* with control decisions (set *U)*. The relation *R* is usually built on the basis of verbal, qualitative information provided by an expert as follows. The expert describes the peculiarities of the maintenance facility functioning and its management algorithm, using inference rules of the form

P:= if *x* is A_1 , *y* is A_2 , *z* is A_3 then *u* is *B*,

or more generally

P:= if x is A_1 , y is A_2 , z is A_3 then u is B, otherwise u is C,

where x is an input variable (maintenance condition), u is an output variable (management decision), A, B, C are vague statements characterized by some linguistic meanings.

In general, the model is described by experts as a system of statements $\{\Pi_i\}$. A formalized representation of such a model is a fuzzy relation R on $W \times U$characterized by a FP:

$$\mu_R(w,v) = \mu_R(x,y,\dots,z,u) = \wedge_i \mu_i(x,y,\dots,z,u), \qquad 2$$

where. $\mu_i(x,y,\dots,z)$ - is the FP of the fuzzy relationship defined according to the statement Π_i.

Let the state of the process be characterized by the point w_0 at W. The control algorithm is reduced to the following steps:

- substitute the point w_0 into the function $\mu_R(w,u)$. As a result, we obtain the fitness function $\mu_R(w_0,u)$ of a fuzzy decision that depends on only one variable;
- among all $u \in U$ we search for a u_0, that maximizes the function $\mu_R(w_0,u)$;
- the value of u_0 the value of is chosen as the desired control decision.

Thus, the control algorithm is reduced to a composition of fuzzy relations, one of which describes the current state of the process, and the other is the control model.

Fuzzy compositional models are used to solve various tasks of operational planning of product production, for example, the task of selecting the size of batches of blanks that are launched at the input of the production line. The solution to this problem significantly affects such important technical and economic indicators as the volume of work in progress, the total percentage of suitable products, and the total cost of production.

The considered types of fuzzy models formalize human experience in TP management. In fact, based on such models, software and hardware should be created that imitate the behavior of a technologist. The use of the integrated experience of the most qualified specialists opens up wide opportunities for the introduction of computing in the management of “difficult” TPs in terms of automation. It is promising to use the considered models in the creation of FPS control systems, where they can be used for a general assessment of the situation and the development of a rational control strategy.

An important direction in modeling complex processes is the combination of fuzzy set theory with currently existing mathematical models of processes. To do this, the coefficients and parameters in the equations are represented as fuzzy sets. Thus, fuzzy analogues of mathematical statistics methods are used in industry [6,7,8], in the field of economics and business [9] and can be used to solve management problems in TMA production technology.

3. CONCLUSIONS

It has been found that the main types of models designed to solve the problems of TP management of TMA production under conditions of uncertainty are: simulation models, fuzzy classification models, fuzzy models based on composite inference schemes, fuzzy relations, fuzzy functional dependencies. The specifics and conditions of applicability of each type of model are outlined. The classes of management tasks that can be solved within the framework of the proposed approaches are defined.

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