The mechanism of optimal control of the evolution of continuous technological systems

1st Boris V. Paliukh
dept. Information System
Tver State Technical University
Tver, Russia
pboris@tstu.tver.ru

2nd Irina A. Egereva
dept. Information System
Tver State Technical University
Tver, Russia
irina.egereva@gmail.com

***Abstract*—Due to competition in the conditions of continuous development of technology, enterprises have to constantly optimize production processes. There is a problem of choosing the most suitable solution to a particular situation managing the evolution of a technological system because the activities of enterprises must take into account a large number of external factors, take into account various kinds of limitations (resource, material and others).**

This paper presents the mechanisms of optimal control of continuous technological systems based on the application of the theory of active systems, the theory of fuzzy systems, artificial intelligence methodologies, multi-agent systems. A method is proposed for forming a minimum set of solutions to problems with given constraints by combining a number of control mechanisms for the functioning of the technological system.

***Keywords*—optimal control, evolution of continuous technological systems, semantic systems, theory of fuzzy systems, artificial intelligence methodologies, multi-agent systems**

I. Introduction

Achieving target production efficiency level is made possible by developing technological processes through continuous control of main production metrics and generation of management decisions for technological systems evolution. This work presents a management model for fuzzy multi-stage technological system evolution, based on algorithmic support to managing fuzzy multi-stage technological system evolution. A method is proposed for forming a minimum set of solutions to problems with given constraints by combining a number of control mechanisms for the functioning of the technological system.

II. The task of managing the technological system evolution

Managing the system functioning can be represented as a multi-stage process. Figure 1 shows a formal model of the technological system evolution in the management process.

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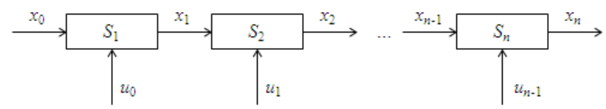

Figure 1. Example of a figure caption.

Let X be the set of states of the stages of the evolution of the system, U be the set of corresponding controls. Let $x_0 \in X$ be the state of the technological system at the input of the first stage of the system evolution process. As a result of using the control $u_0 \in U$ at the output of the first stage, a state is formed $x_1 \in X$ that is not known in advance. It is only known in advance that the variables x_0, u_0, x_1 are interconnected by a fuzzy relation S_1 with the membership function $\mu_{S_1}(x_0, u_0, x_1)$. Moreover, at the end of the functioning of the first stage, the actual state of the process x_1 is available for observation.

Similarly, if $x_{n-1} \in X$ is the state of the process at the input of stage n, $n = 1, \ldots, N$, where N is the number of evolution stages, then as a result of using the control $u_{n-1} \in U$ at the output of stage n, a state is formed $x_n \in X$. Variables x_{n-1}, u_{n-1}, x_n are interconnected by a fuzzy relation S_n with the membership function $\mu_{S_n}(x_{n-1}, u_{n-1}, x_n)$.

The task of the evolution technological system control is to find the control mechanisms $u_0, u_1, \ldots, u_{N-1}$ of the set U that maximize the goal achievement G, provided that the initial state x_0 is given.

The substantiation of this problem is considered in detail in [1].

III. Formation of the optimal control set of the technological system evolution

To manage the evolution technological system, it is necessary to process a huge amount of information to select the best option of solving various problems.

Let a finite set of solution options be the intersection of several sets, including the options obtained in the following ways:

- set $M1$ - expert information (external consulting services);

- set $M2$ - search for solutions in a distributed computing environment;
- set $M3$ - information generated in the process of applying motivational management;
- set $M4$ - the construction of a set of preferred states.

Briefly consider the methods of forming each sets.

A. *Expert information (external consulting services)*

Today consulting services of third-party organizations are quite common. The demand for services for the development of management systems, the introduction of new financial technologies, business valuation, and marketing research has increased. However, the results of the analysis, for example, in [2], showed a number of problems in the consulting services market, such as the lack of a clear pricing policy in consulting services; uniformity of consulting programs associated with an underdeveloped scientific and methodological base for the provision of services; the presence of a large number of non-adapted translation programs; the high cost of consulting services for small and medium enterprises. Of course, the enterprise management should recur to the use of external consulting services, however, this method cannot be used as the only one for solving complex problems of managing the technological system.

B. *Search for solutions in a distributed computing*

Distributed environments are focused on supporting research in domains united by thematic areas. To provide users with access to services and packages contained in distributed environments thematic information catalogs have been developed. In order to avoid restricting access to the full amount of information contained in the catalogs of scientific and computing services of distributed environments, it is advisable to submit a request to the system in a qualitative form (see [3]).

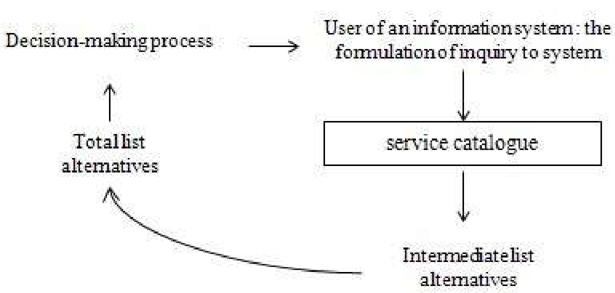

Figure 2. Multistep decision making, general view.

Briefly give a mechanism for the formation of many decisions in managing the technological system evolution (figure.2).

Let the set $X = \{x\}$ be the service catalog containing the services $\{x_1, x_2, \ldots, x_n\}$. The author, who includes information in the catalog, registers the service using a catalog card. Each $x_n \in X$ corresponds to a set of characterizing attributes:

$$x_j\left(a_1(x_j), a_2(x_j), \ldots, a_k(x_j)\right),$$

where x - services, $j = 1 \ldots n$, a - attributes, $k = 1 \ldots n$.

Each corresponds to the semantic service description, characterized by semantic units:

$$x_j\left((s_1(x_j), s_2(x_j), \ldots, s_k(x_j)\right),$$

where x - services, $j = 1 \ldots n$, s - semantic units, $k = 1 \ldots n$.

A user request to the system formulated in an informal form can be represented as follows:

$$L = L_1 \cup L_2 \cup L_3 \cup L_4$$

where L_1 is the set of terms from the search string, L_2 is the additional set of synonyms that are similar in meaning and words that are close in meaning; L_3 - an additional set of associative words and phrases; L_4 - a lot of translated keywords, depending on the settings for connecting dictionaries (dictionaries of automatic word processing are used when forming sets).

Denote the set of semantic descriptions generated on the basis of a user inquiry as

$$L = \{l_1(s_j), l_s(s_j), l_q(s_j), j = 1 \ldots m\}$$

When choosing the most suitable service for solving the problem, it is necessary to use a given set of parameters $p_j \in P$ evaluating the content of services and their functionality.

User sets priority service requirements

$$P = \{p_1(a_j), p_2(a_j), \ldots, p_r(a_j), j = 1 \ldots k\}$$

where p - parameters, a - attributes.

For simplicity, we denote the intersection of the fuzzy sets A (set of attributes) and P (set of parameters) as $Y = A \cap P$ the intersection of the sets S (set of semantic units) and L (set of users semantic units) as $H = S \cap L$.

To construct the membership function μ_Y of the set Y, we associate each $y_i(x_i)$ with a number $\mu_{y_i}(x_j)$ where $i = 1, \ldots k, j = 1, \ldots n$, $0 \leq \mu_{y_i}(x_j) \leq 1$

Similarly, to construct the membership function μ_X of the set X, we associate each $h_i(x_i)$ with a number $\mu_{h_i}(x_j)$ where $i = 1, ..., l, j = 1, \ldots, n$, $0 \leq \mu_{h_i}(x_j) \leq 1$

For $\mu_{y_i}(x_j)$ and $\mu_{h_i}(x_j) = 0$ - according to this description, the service does not fit exactly, with $\mu_{y_i}(x_j) = 1$ and $\mu_{h_i}(x_j) = 1$ - the service fits exactly, with $0 < \mu_{y_i}(x_j) < 1$ and $0 < \mu_{h_i}(x_j) < 1$ are intermediate variants.

Let us assume that a solution is a set of D services formed during the operation of a multi-step alternative search system that meets the conditions set in the request as much as possible. Let

$$\mu_y(x_n) = min\{\mu_{y_k}(x_n), \ldots, \mu_{y_k}(x_k)\}$$

and

$$\mu_h(x_n) = min\{\mu_{h_k}(x_n), \ldots, \mu_{h_k}(x_l)\}.$$

Following the Bellman-Zade formula [4], we will present the solution as a fusion of goals and limitations. Then the result of solving the problem is the set goal $D = Y \cap H$ coincides with the solution. Thus, to find a suitable scientific computing service from the set D, one selects the service for which the membership function will be the largest

$$\mu_D(X) = min\{\mu_Y(x), \mu_H(x)\}$$

Then the optimal solution comes down to finding

$$x^* = \arg\max_x \mu_D(x).$$

The software implementation of the proposed mechanism for the formation of many options for solving problems is presented in [5]

C. Information generated in the process of applying motivational management

Using the terminology of the theory of active systems [6], the procedure for the interaction of a center (enterprise manager) with agents (employees) as follows: first, the center learns from agents only an approximate description of their technological sets and finds a solution to the problem; the center asks the agents for evaluating the plan, clarifies their interests in the vicinity of the decision in exchange for incentives for awareness; Having received new information, the center carries out a review of the solution and poses new questions to the agents until an exact or close solution is received.

D. The construction of a set of preferred states

The analysis by the Z center of the efficiency of production functioning shows that the volume and quality of finished products directly depends not only on the level of modernization of technological equipment, the quality of raw materials, etc., but also on the degree of coordination of interests of the managing and controlled systems, the agent's target functions f and the center F. Competitive production requires high qualifications and training of employees, as well as motivation, interest and intellectualizing [7]. Specialists involved in projects to improve existing technological processes need to be aware of the significance and importance of the tasks assigned to them.

Since the specific form of the objective function of agent f and the composition of the sets P and X are not completely known, it is advisable to solve the problem of constructing preferred states by the center Z using "reducible" algorithms, that is, to solve the problem on the basis of solved locally optimal problems by agents a_k and obtaining from them for more information.

The formation of counter information with this approach is to implement a set of sequential procedures designed to search for intermediate solutions, on the basis of which the agent clarifies its capabilities and forms the final decision. The agent's full cycle of generating information about its capabilities consists of the following steps:

- step 1 - Agent a_k at the $r-th$ step receives from the center a version of the plan $v(r)$ and a control action $u_k(r)$. Based on this, the agent forms many P_k of its potential capabilities and x_k marginal technological capabilities. Here is the formation of a point

  $$y^{\omega *} = y(x), x^t(x_k(p)), p \in P_k$$

  determining the point of assessing the reliability of the result $\omega(y^{\omega *})$.
- step 2 - At this stage, the task of finding a potentially preferred set of actions is being solved

  $$x^* = x(p)$$

  Wherein $x^* \in C(p)$. If there is no such solution, you should try to find a compromise solution corresponding to the initial sets P_k and X_k and go to step 3; otherwise, go to step 5.
- step 3 - Here we analyze the directions of the possible expansion of the set P. By studying the properties of the situation and organizing the search for new information (knowledge) for

  $$P_k(r + 1) \supseteq P_k(r)$$
- step 4 - If the extension of the set $P_k(r)$ is possible and there exists $P_k(r + 1)$ such that inclusion (1) holds, then we go to step 1.
- step 5 - Based on the procedure for constructing the sets $P_k + 1$ and $X_k + 1$, the procedure for searching for the minimum-preferred point in the space of evaluating the value of the situation of a purposeful state is carried out.
- step 6 - The possibility of expanding the sets P and X is determined, the procedure is based on the search for additional information. In the case of a positive result, the go to step 1.

The implementation of the proposed mechanism for controlling the evolution of the system was considered in [8].

As a result of the formation of sets $M1$, $M2$, $M3$, $M4$, a single set M is formed, containing possible solutions to the problem when managing the evolution of the technological system (figure 3).

Then, by analogy with the formation of the set $M2$, we take into account the existing limitations and goals of the decision maker. As a result of the intersection of the set M, the set of goals and the set of restrictions, we get

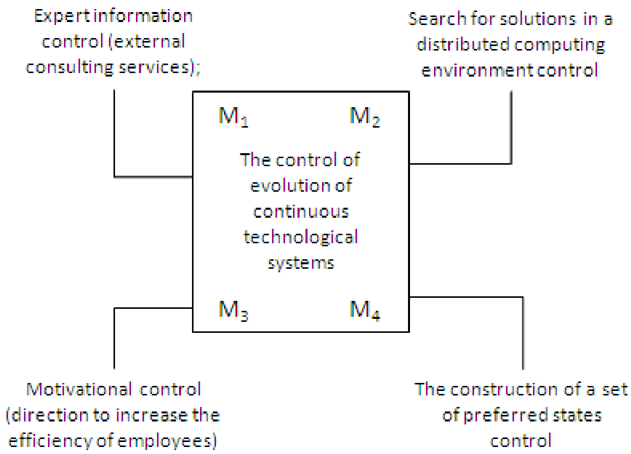

Figure 3. Optimal control set of the technological system evolution

the minimum possible set of solutions to the problems. This work was supported by the Russian Federal Property Fund (project 20-07-00199)

Conclusions

The paper proposes and considers the main ways of forming a multitude of options for solving problems arising in the process of functioning of a technological system. As a result of the application of the proposed mechanisms, management is carried out at various levels of the system, the proposed solutions of both enterprise managers and external consultants, employees of the enterprise, as well as information obtained in specialized thematic distributed systems and catalogs are taken into account. Most of the proposed mechanisms are implemented.

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Механизм оптимального управления эволюцией непрерывных технологических систем

Палюх Б.В., Егерева И.А.

В связи с постоянно растущей конкуренцией в условиях непрерывного развития технологий промышленные предприятия вынуждены постоянно оптимизировать технологические процессы на производстве. Так как деятельность предприятий должна учитывать большое количество внешних факторов, учитывать различного рода ограничения (ресурсные, материальные и другие) при управлении эволюцией технологической системы возникает проблема выбора наиболее подходящего для конкретной ситуации варианта решения задачи. В данной работе приводятся механизмы оптимального управления непрерывными технологическими системами на основе применения теории активных систем, теории нечетких системы, методологий искусственного интеллекта, многоагентных систем. Предлагается способ формирования минимального множества вариантов решений задач с заданными ограничениями путем объединения ряда механизмов управления функционированием технологической системы.

Множества решений формируются на основе информации, получаемой путем привлечения на предприятие внешних консультантов, разносторонне исследующих функционирование системы и предлагающих различные варианты решений по оптимизации организационного управления. Другое множество представляет собой знания, получаемые в процессе взаимодействия руководителей предприятия непосредственно с сотрудниками. Следующее множество формируется на основе применения информации, полученной из тематических распределенных систем путем поиска и выбора оптимального решения задачи с последующей адаптацией.

Приведенные механизмы управления эволюцией непрерывных технологических систем более подробно рассмотрены в [1], [5], [8]. Предложенные алгоритмы использованы при разработке экспертных систем и информационных систем управления предприятием.

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