Operational Management of Distributed Socio-Economic Systems

V.V. Krasnoproshin[1], E.P. Maksimovich[2], A.N. Valvachev[1]

1) Belarusian State University, 4 Nezavisimost av., Minsk, 220030, Belarus, e-mail: krasnoproshin@bsu.by; van_955@mail.ru

2) United Institute of Informatics Problems of the National Academy of Sciences of Belarus, 6 Surganova Str., Minsk, 220012, Belarus, e-mail: elenamaksimovich@mail.ru

Abstract: *The paper deals with decision making in operational management of geographically distributed socio-economic systems. A possibility of the problem solution is investigated. The proposed solution is based on situation management, theory of active systems and pattern recognition.*

Keywords**:** decision making problem, distributed system, active systems, situation management

1. INTRODUCTION

Under world-wide globalization, information and communication technologies are being intensively implemented into all spheres of human activities. New types of complex geographically distributed socio-economic systems emerge. The efficiency of their functioning greatly depends on the solution of newly-posed problems of operational management, the development of adequate models, methods and algorithms.

The peculiarities of such problems: undefined and poorly predictable environment; flexible structure of Distributed Systems (DS); a great number of control objects and their active behavior; a variable number (and semantics) of numeric and linguistic diagnostic features; short time for making adequate management solutions [1].

An approach for solving such problems is considered. The approach is based on methods of situation management, theory of pattern recognition, artificial intelligence and theory of active systems.

2. PROBLEM STATEMENT

Let W be DS functioning in the environment S and consisting of the center *Center* and n geographically distributed control objects $P^1,\ldots, P^n$. Assume that objects have their own behavior and are related by partial ordering:

$$W = (Center, P^1,P^2,\ldots,P^n, O),\ n\neq cons. \tag{1}$$

where O determines the relation «$\succ$»: $P \succ G$ and means that object G is under control of object P. It's evident that $Center \succ P^i,\ \ \forall i = 1,\ldots,n$.

The general scheme of management in DS W can be represented as a tree (Fig.1).

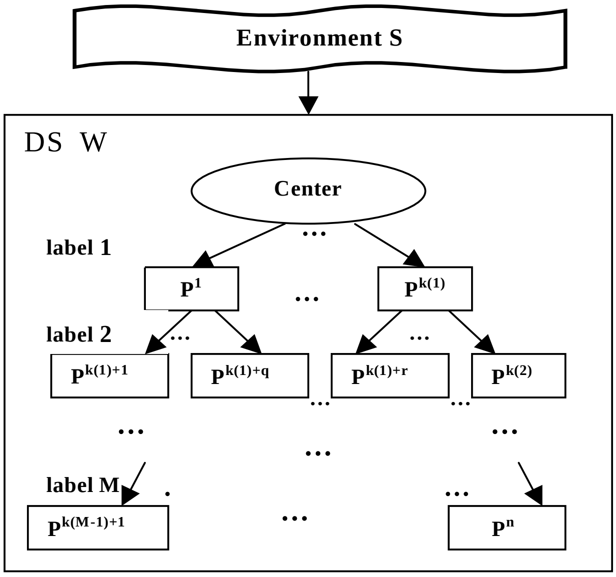

Fig. 1 Tree-like structure of DS management.

Operational management of DS W is associated with the function of goal that ensures efficiency of its functioning. The goal is represented as a set of quantitative or qualitative indices (e.g., business profits, cost effectiveness, increase of the market share, etc.) and a range of their values. The effectiveness means that the value of indices is within the predetermined boundaries. The goal is not homogeneous in time due to the change of inner and outer conditions.

Because objects $P^1,\ldots,P^n$ have their own behavior, we differentiate between effectiveness function of F-behavior of DS W as a whole (at the level of *Center*) and $F^1,\ldots,F^n$ – behavior of objects $P^1,\ldots,P^n$. The functions form a hierarchical system corresponding to DS structure. If for P^i, P^j the condition $P^i \succ P^j$ is satisfied, then $F^i = F^i(F^j)$. In particular, $F = F(F^1,\ldots,F^n)$.

Let $(c_1,\ldots,c_k)$, $(c_{11},\ldots,c_{1k(1)}),\ldots,(c_{n1},\ldots,c_{nk(n)})$ be sets of effectiveness indices for *Center*, and $P^1, P^2,\ldots,P^n$ correspondingly, $(<c_1>,\ldots,<c_k>)$, $(<c_{11}>,\ldots,<c_{1k(1)}>),\ldots,(<c_{n1}>,\ldots,<c_{nk(n)}>)$ be their values and $C^* = \{\Delta_1^*,\ldots,\Delta_k^*\}$, $C_1^* = \{\Delta_{11}^*,\ldots,\Delta_{1k(1)}^*\}$, …, $C_n^* = \{\Delta_{n1}^*,\ldots, \Delta_{nk(n)}^*\}$ be sets of their required values. Both numeric and linguistic indices are allowed. Then,

$$F := (<c_1> \in \Delta_1^*) \wedge \ldots \wedge (<c_k> \in \Delta_k^*), \tag{2}$$

$$F^j := (<c_{j1}> \in \Delta_{j1}^*) \wedge \ldots \wedge (<c_{jk(j)}> \in \Delta_{jk(j)}^*),\ 1\le j\le n. \tag{3}$$

The problem of operational management Z can be formulated in the following manner.

Let W be DS of type (1) and F, $F^1,\ldots,F^n$ be the corresponding effectiveness functions. It is required to develop a management technology ensuring the fulfillment of the criterion (2) during the DS lifetime under conditions of possible changes of:

– environment S and structure of W (objects $P^1,\ldots, P^n$, their number, position and the relation of partial order);

– indices $(c_1,\ldots c_k)$, $(c_{11},\ldots c_{1k(1)}),\ldots,(c_{n1},\ldots c_{nk(n)})$, $k\neq const$, $k(1)\neq const,\ldots, k(n)\neq const$ and the set $C^*, C_1^*, \ldots, C_n^*$.

In this connection, time interval $\tau(u)$, necessary for decision making u, should satisfy the condition:

$$\tau(u) \le \tau^*, \tag{4}$$

where τ^* is a threshold, which can also be changed during the DS lifetime.

Changes of environment S and DS W can result in unfulfillment of criteria (2)-(3). Due to unpredictability of these changes, we propose to use the methodology of situation management (making management decisions as problem situations arise). In this case the development of control actions is based on the analysis of the current state and the selection of the corresponding solution from a set of permissible alternatives.

The activity of objects $P^1,\ldots, P^n$ assumes their own decision making. This motivates decomposition of problem Z into a hierarchical system of sub-problems $Z^C, Z^1,\ldots, Z^n$. Problem Z^C is solved at the level of *Center*, and problems Z^i, $1\le i\le n$ are solved at the level of object P^i. If $P^i \succ P^j$, then the results of the solution of problem Z^j are taking into consideration when choosing a control action for problem Z^i. In particular, the solution of Z^C is based on the results of the solution of problems $Z^1,\ldots, Z^n$ [2].

At the current time t, fulfillment of conditions (2)-(3) depends on states v, $v_1,\ldots, v_n$, of *Center*, $P^1,\ldots, P^n$. If $P^i \succ P^j$, then $v_i = v_i(v_j)$. In particular, $v = v(v_1,\ldots,v_n)$. Let $V, V^1,\ldots, V^n$ be sets of permissible states for *Center*, and $P^1,\ldots, P^n$ correspondingly. The state of *Center* is identified with the state of the system as a whole.

States of *Center* or P^i, $1\le i\le n$ depend on outer (related to environment S) and inner (related to DS W) conditions, formed at the current time and influencing the fulfillment of (2)-(3). The set of the conditions (situations) is characterized by a set of measurable parameters (diagnostic indices).

Let $x=\{x_1,\ldots,x_m\}$ and $x^i=\{x_1^i,\ldots,x_{m(i)}^i\}$ be sets of diagnostic indices for *Center* and P^i, $1\le i\le n$ correspondingly,

$$X = \{x \mid x = (x_1,\ldots,x_m), x\in X_1,\ldots, x\in X_m\},$$

$$X^i = \{x^i \mid x^i = (x_1^i,\ldots,x_{m(i)}^i),\ \ x_1^i\in X_1^i,\ldots, x_{m(i)}^i \in X_{m(i)}^i\},$$

$1\le i\le n$ be sets of their permissible values, and $\langle x\rangle = (\langle x_1\rangle,\ldots,\langle x_m\rangle) \in X$ and $\langle x^i\rangle = (\langle x_1^i\rangle,\ldots,\langle x_{m(i)}^i\rangle) \in X^i$ be current values. Numeric and linguistic variables can be used as diagnostic indices. The number and semantics of indices can be changed.

On the basis of $V, V^1,\ldots, V^n$ analysis with regard to (2)-(3) we determine sets of permissible control actions:

$$U = \{u \mid u = (u_1,\ldots,u_m),\ \ u\in U_1,\ldots, u\in U_m\},$$

$$U^i = \{u^i \mid u^i = (u_1^i,\ldots,u_{m(i)}^i),\ \ u_1^i\in U_1^i,\ldots, u_{m(i)}^i \in U_{m(i)}^i\}$$

for *Center* and P^i, $1\le i\le n$, correspondingly. Each quality index has its own control action. It is clear, $U = U(V)$, $U^i = U^i(V^i)$ and if $P^i \succ P^j$, then $U^i = U^i(U^j)$. In particular, $U = U(U^1,\ldots,U^n)$. Sets V, U, V^i, U^i, $i=1,\ldots,n$ can be changed.

Thus, the solution of problem $Z = \{Z^C, Z^1,\ldots, Z^n\}$ reduces to monitoring of the fulfillment of the criteria (2)-(3), and in case of their violation (threat of violation) to the development of control actions $u\in U$, $u\in U^1,\ldots, u\in U^n$ at the level of *Center*, $P^1,\ldots, P^n$. In this connection, the total time from violation discovery (2)-(3) till correcting actions should satisfy the condition in (4).

3. PROBLEM IDENTIFICATION AND ANALYSIS

Realization of situation management reduces to the solution of the following problems [1]:

– monitoring of the state of DS and its participants;

– integrated assessment of the state of DS or its participants;

– development of control actions.

1. Monitoring problem is related to modelling, acquisition and integration of values of indices characterizing the operating benefits of DS or its participants.

1.1 Modelling of a dynamic knowledge domain.

1.1.1 The model is built in accordance with the current state of S and W. It should be adequate to the current state of S и W, satisfy the condition of completeness and contain all the details sufficient for the solution of the stated problem.

The modelling problem is considered under fuzziness due to dynamism and a great number of distant objects, multiaspect nature and poor formalization of factors. The main stages of modelling are: construction of an unenriched model performed by the center, delivery of the model to objects, enrichment of the model by including additional information, delivery of the enriched model to the *Center* [1].

Unenriched model of DS should reflect the general structure of DS, its outer and inner communication, and should also include a set of permissible states of *Center* V; diagnostic indices X and sets of controls U.

Objects $P^1, P^2,\ldots,P^n$ can act as black boxes or can be partially described (in accordance with the information that *Center* has).

Enrichment of DS model is made by constructing models of objects. After the enrichment the model is sent to the *Center*.

The main advantages of the model are: separability (decomposition of the model at the level of *Center* and objects P^1, $P^2,\ldots,P^n$), adjustability, complexity and adaptability.

1.1.2. Determination and current actualization of the used criteria (2)-(3) include:

– determination of effectiveness indices $(c_1,\ldots c_k)$, $(c_{11},\ldots c_{1k(1)}),\ldots,(c_{n1},\ldots c_{nk(n)})$ and a set of their values $C^*, C_1^*, \ldots, C_n^*$;

– formation of effectiveness functions F, $F^1,\ldots,F^n$.

The criteria should satisfy the conditions of adequacy to the current state of S and W, completeness and irredundancy (in sets of effectiveness indices for *Center*, $P^1, P^2,\ldots,P^n$).

The problem is solved by analyzing the current state of environment S (needs of the market, profits, productive efficiency, etc.) and functionality of DS model W. Determination of values of indices depends on particular characteristics of DS and the current state of W and DS. The evaluation method depends on DS characteristics.

1.1.3. Determination of permissible states $V, V^1,\ldots, V^n$

The main requirements to their determination are adequacy to the state of S and W and completeness. The problem is poorly formalized and is solved by taking into consideration particular characteristics of S and W on the basis of the analysis of the constructed DS model.

The main stages of the problem solution are: determination of a set V performed by the center and delivery of the set to objects; construction of a set V^i (with regard to V and particular characteristics of P^i) performed by each object P^i, $i=1,\ldots,n$ and delivery of the sets to the center; adjustment of the set V by the center with provision for the constructed $V^1,\ldots, V^n$.

1.1.4. Determination of diagnostic indices.

The space of diagnostic indices should meet the requirements of adequacy of W model and completeness of state description ensuring a possibility for the development of effective management on the basis of the current values of indices.

The number of factors affecting the state of W is great, the factors are poorly formalized and are changed during DS functioning. There arises a nontrivial poorly formalized problem of construction and adjustment of diagnostic indices and their permissible values.

The main stages of the problem solution are: determination of outer and inner diagnostic indices $\{x_1,\ldots,x_m\}$, X and their permissible values performed by the center; delivery of $\{x_1,\ldots,x_m\}$ and X to objects; construction of sets $\{x_1^i,\ldots,x_{m(i)}^i\}$ and X^i by objects P^i, $i=1,\ldots,n$; the delivery of sets to the center; adjustment of sets $\{x_1,\ldots,x_m\}$ and X by the center with provision for $\{x_1^i,\ldots,x_{m(i)}^i\}$, X^i, $i=1,\ldots,n$.

Determination of diagnostic indices and their permissible values is based on discovery and analysis of bottlenecks in model W.

1.1.5 Determination of permissible control actions.

The main requirements to sets U and $U^1,\ldots, U^n$ are their adequacy to the current state of S and W and completeness (availability of an effective solution for any v from V or V^i in U, U^i, $i=1,\ldots,n$).

The problem is also poorly formalized and is solved by analyzing sets $V, V^1,\ldots, V^n$. Its aim is to form alternatives ensuring the fulfillment of criteria (2)-(3) at any time of DS functioning.

The main stages of the problem solution are: determination of a set U by the center on the basis of the analysis of V ; delivery of U to objects; construction of a set U^i by objects P^i, $i=1,\ldots,n$; delivery of the set to the center; adjustment of the set U by the center.

1.2. Monitoring of fulfillment of criteria (2)-(3).

Monitoring is carried out both at the level of *Center* and at the level of objects $P^1,\ldots, P^n$. Violations (threat of violation) are promptly discovered: violation of criterion (2) is recognized by the center and violation of criteria F^i, $i=1,\ldots,n$ is recognized by objects P^i. Algorithms $A, A^1,\ldots, A^n$, ensuring a check of criteria $F^C, F^1,\ldots,F^n$, are constructed.

The check is carried out by enumerating conditions $<c_i>\in\Delta_1^*$, $i=1,\ldots,k$ or $<c_{ij}>\in\Delta_{ji}^*$, $j=1,\ldots,n$, $i=1,\ldots,k(j)$, or with the help of heuristics based on particular characteristics of DS, or by fuzzy formalization. In particular, an approach can be used consisting in partition construction of the following type

$$X = X_+ \cup X_- \quad (\text{or } X = X_+ \cup X_- \cup X_0),$$
$$X^i = X^i_+ \cup X^i_- \quad (\text{or } X_i = X^i_+ \cup X^i_- \cup X^i_0),\ i=1,\ldots,n \qquad (5)$$

where X^i_+ is a class of normal states, X^i_- is a class of malfunction states requiring the corresponding control actions and X^i_0 is a class of borderline states requiring preventive actions. The known methods of clusterization with the predefined number of classes can be used for the partition construction. As a result, the problem of discovering the malfunction situation reduces to the classification of the current state of *Center* or P^i with regard to (5). The nearest neighbor methods can be used as a decision rule.

The current monitoring consists in the following. Fulfillment of criterion F is checked. In case of its violation (threat of violation), the corresponding message is sent to sub-objects of the first level of DS. Then, criteria of objects are checked. If they are fulfilled, the corresponding message is sent to the center; if they are unfulfilled, the corresponding message is sent to sub-objects of the second level, etc. As a result, a set of malfunctioned objects is determined.

Besides, objects P^i initiate a check of criteria F^i and the corresponding sequence of hierarchical checks for sub-objects. The checks can be carried out periodically or when malfunctioning of DS or objects is observed. Type of criteria depends on particular characteristics of DS. In particular, a possible criterion can be a check of fulfillment of the following conditions $<c_i>\in\Delta_1^*$, $i=1,\ldots,k$ or $<c_{ij}>\in\Delta_{ji}^*$, $j=1,\ldots,n$, $i=1,\ldots,k(j)$.

2. Evaluating the state of DS or its participants

The problem can be solved by partitioning a set of permissible states of DS W and objects P^i, $1\le i\le n$ into classes of one-type situations with similar management. Partition construction is solved within the clusterization problem with an external goal and without a tutor [3].

The nearest neighbor methods can be used for the classification. State evaluation of *Center* (P^i) is made in case of violation (threat of violation) of criterion F (F^i). The evaluation is a set of partially ordered sub-object state values that led to criterion violation. Due to the tree-like structure of DS, state evaluation is carried out “from the bottom to the top” with the transfer of evaluation results from sub-objects to parent objects through feedback links.

3. Selection of a control action.

A control action is selected at the level of *Center* and objects P^i. In accordance with the results of evaluation of the current state a decision is made. The decision corresponds to the identified class of states. With regard to *Center* (P^i), the decision is the development of a set of hierarchical solutions of objects that caused violation of F (F^i) and are identified during monitoring. In regard to the tree-like structure of DS, the decision making is carried out from “from the bottom to the top” with the transfer of the decisions from sub-objects to parent objects through feedback links. Control actions are selected with regard to decisions made at the level of sub-objects.

4. CONCLUSION

The paper considers main problems arising during operational management of dynamic distributed systems with a great number of active objects. The obtained results can be used when developing a comprehensive approach to the solution of operational management of modern socio-economic systems.

5. REFERENCES

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