External environment modelling in the control system of the regional socio-economic system

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Abstract. The concept and methods of describing the external environment of a regional socio-economic system from the perspective of control theory are considered. The position and relations of the external environment with other elements of the control system of the regional socio-economic system are also determined. It is shown that the external environment is set by factors that determine the linguistic composition of external influence on the object of management; the main disturbances that determine the dynamic nature of the influence; interferences. A structural-functional and mathematical model of the external environment of a regional socio-economic system is proposed which is characterized by the author's classification of environmental factors, formalization of its main components and information flows. It is also shown that for describing disturbances of the external environment and their interferences fuzzy logic is applicable; the description of fuzzy dynamic characteristics of the external environment is provided. The general model of using measuring devices for determining the influence of the external environment on the object of control – the regional socio-economic system - is presented.

1. Introduction
Analysis of the external environment influence on the regional socio-economic system is associated with the assessment of the dynamism level of its changes. The study of the external environment influence on the subjects of state regulation has been studied in the works of many Russian scientists including the members of Institute for Systems Analysis of Russian Academy of Sciences such as Klimanov V.V., Kuznetsova O.V. [1, 2], Leksin V.N. [3], Moskvitina N.A., Naumov A.I. [4,5], Pazyuk Yu.V., Petrovskaya I.A. [4,5], Porfiriev B.N [3, 7-9], Semechkin A.E., Shvetsov A.N. [10]. The theory of self-development of regional economy is also contributed by Sukharev O.S. [11] and Tatarkin A.I. [10]. At the same time, the effective regional development from the standpoint of control theory was evaluated by the scientists of the Institute of Control Sciences Burkov V.N., Gilev S.E., Zalozhnev A.Yu., Korgin N.A. Leontyev S.V., Novikov D.A., Chernyshev R.A. [13-17]. Their works are devoted to the tasks of regional development management based on the definition of metacenters - regional governments - which determine the rules of interaction within the regional system, form the decision-making procedure for managing a variety of regional development projects. Thus, there is a need to determine the external environment of influence on the regional system, including from the point of view of assessing its regulatory and legal influence, to determine its directed transformation. So, we
formulate the aim of this paper as the formalization of the external environment influence on the regional socio-economic system from the standpoint of control theory.

2. Problem Statement

The definition of the external environment position in the control of the regional socio-economic system (RSES) and the main relations presented in the context of the author's studies [18-22] is visually depicted in (figure 1). The main principle in the developed RSES control system is a combined principle, which includes a negative feedback loop, circuits of error compensation and environmental disturbances.

![Figure 1. The regional socio-economic system control system.](image)

Setting action $g(t)$ is realised by the goals of the Russian national projects. It goes to the control device – a system of decision support (DSS "DATA" [15]), then the output parameters $y(t)$ using the functionality of the system negative feedback are corrected by error $\varepsilon(t)$. The external environment produces disturbance $f(t)$, that are registered by the controlling device of the system implemented in the form of DSS "DATA". The control action $u(t)$ is formed by the control device and affects the object of control – RSES. In the developed RSES control system, the actuator is an abstract civil servant, for example, a head of the low or middle level, who refers to DSS "DATA" in the process of making managerial decisions to form the control actions $u(t)$.

3. Definition and Description Methods of RSES External Environment

The external environment in RSES control system in this paper is understood as the external environment of RSES, which is determined by the complex and versatile influence of political, economic, demographic, technological, and other disturbances. The proposed methods of describing RSES external environment will allow to provide for dynamic and objective assessment of changes occurring in RSES under the influence of the external environment, in other words, special conditions will be created for rapid decision-making at different levels of power based on the assessment of the impact of the external environment. For the subsequent formalization of the external environment in the context of RSES control system, the following methods of its description are proposed below (table 1).

| №  | Methods Contents                                      | Methods Applied                          |
|----|-------------------------------------------------------|------------------------------------------|
| 1  | Formalized representation of the main elements models of RSES external environment (factors, main disturbances, interferences) | - set-theoretic method; - methods of fuzzy logic; |
| 2  | Construction of a structural and functional model for forming the flow of disturbances of RSES external environment | - method of correlation and regression analysis; - method of hierarchical classification; - methods of control theory; |
| 3  | Construction of a dynamic model of the main disturbances of RSES external environment | - methods of mathematical analysis |
The proposed methods are based on the consideration that the external environment is defined by:

- $F_{ij}$ factors that determine the linguistic composition of the defining influence on the object of control (RSES). For example, $F_{41} =$ "Consumer culture of the region's population". $F_{ij}$ factors are neutral in regard to the object of management.

- The main disturbances $f_{ij}(t)$, which determine the dynamic nature of the defining influence $F_{ij}$ on the object of management. It is determined that each $F_{ij}$ corresponds to $f_{ij}(t)$, specified by the linguistic variable. For example, the external environment factor $F_{41} =$ "Consumer culture of the region's population" corresponds to disturbance $f_{41}(t)$, which can affect the object under control (RSES) weakly, moderately, or strongly.

- Interferences (noises) $\delta_\omega$, which are of a statistical nature and change $u(t)$ within acceptable limits; it is determined that $\sum_{\omega=1}^{3} \delta_\omega \rightarrow 0$.

4. Formalized Representation of the Main Elements Models of RSES External Environment (factors, main disturbances, interferences)

The external environment of influencing RSPP can be described as the following model (1):

$$F = \left\| F_{ij} \right\|_{i=1,j=1}^{9 \times 21},$$

where $F_{ij}$ is factor of $j$-subgroup in $i$-group of environmental factors; $1 \leq i \leq 5$; $1 \leq j \leq 21$; $i, j \in N$.

The number of non-zero environmental factors is 67.

Environmental factors $F_{ij}$ determine the linguistic composition of the defining influence on the object of control (RSES). For example, $F_{41} =$ "Consumer culture of the region's population". It was previously shown [14] that the external environment can be represented as 5 groups of factors, each of which consists of a different number of subgroups, and these, in turn, are defined by a set of finite factors. Thus, the dimensions of the proposed matrix of environmental factors $F$ is determined by the classification [21]. Its structure defines 9 vectors set by the total number of $j$-subgroups and the maximum number of $j$-factors $\theta_{(j_{max}=21)}$. The main difference of the classification is the combination of regional, country (all-Russian) and global factors of influence of the external environment on RSES. The main disturbances of the external environment $f_{ij}(t)$ are also determined by the matrix of dimensions $9 \times 21$, because its elements are the dynamic equivalent of the linguistic interpretation of environmental factors:

$$f(t) = \left\| f_{ij}(t) \right\|_{i=1,j=1}^{9 \times 21},$$

where $f_{ij}$ is disturbance of $j$-subgroup of $i$-group of main environmental disturbances are defined as $f = \{(f_{ij}; i, j \in N, 1 \leq i \leq 5), V\}; V$ is the relation of main environmental disturbances $f_{ij}(t)$ between each other.

For example, the first order disturbances (linguistic interpretation: "Socio-demographic") can be represented as the following expression: $f_1(t) = (f_{41}(t), f_{42}(t))$. Accordingly, the second order disturbances (linguistic interpretation: "Social") may be specified by the following formula $f_{ii}(t) = (f_{411}(t), f_{412}(t), ..., f_{416}(t))$, which elements are finite (particular) disturbances of the external environment, which impact on RSES is set as " high", "medium", "weak" (e.g., the current status of the disturbance influence $f_{411}(t)$= «Level of region population education» for RSES is estimated as "high").

Let us define $L_{f_{ij}}(t_z)$, which sets a certain level of the state of $ij$- disturbance of $f_{ij}$ external environment in the relation to RSES at $t_z$ time as follows:

$$L_{f_{ij}}(t_z) = \langle \lambda_{ij}, P_{ij}, X_{ij}, J_{ij}, V_{ij}, t_z \rangle.$$
where \( \lambda_{ij} \) is the name of \( ij \) - external environment disturbance; \( P_{ij} \) is the set of values \( L_{f_{ij}}(t_z) \), which represents terms: \( P_{ij} = \{ «weak impact», «medium impact», «strong impact» \} \); \( X_{ij} \) – definition domain of \( ij \) - external environment disturbance, set by experts; \( J_{ij} \) is a syntax rule; \( V_{ij} \) is a semantic rule of defining fuzzy subsets of the set \( X_{ij} \), \( t_z \) which is the year reference number.

Interferences (noises) of measurements \( \delta(t) = (\delta_1(t), \delta_2(t), \delta_3(t)) \) determine indicators deviations of information (signals) coming from the external environment influencing measuring devices of RSES control system. Let us determine that \( \delta(t) \) forms the tolerance level of the variable values of the control action \( u(t) \).

5. Construction of a Structural and Functional Model for Forming the Disturbance Flow in RSES External Environment

Using the concepts of control theory, we can imagine the origin of the disturbing effects of the external environment \( f(t) \) (figure 2). Thus, each structural element of the external environment \( F_i \) gives the disturbing effect \( f_i(t) \) (figure 3). It is assumed that group disturbances give independent effect directions.

It should be noted that environmental factors \( F_{ij} \) themselves are evaluated as neutral, for example, such an environmental factor as \( F_{42} \) "level of health of the regional population" does not have specific value regarding a single subject of the Russian Federation, but the disturbances generated by it \( f_{42}(t_z) \) according to RSES can take different values (for example, "low, medium, high" influence of "level of health of the regional population " on RSES).

External environment produces a varied effect, but given the main aim of RSES control system – to bring RSES control system into the desired state in accordance with a set impact \( g(t) \) - must be limited to collecting and recording only the information that will be relevant to the aims of RSES control system. To do this, RSES control system has three measuring devices (MD) for recording the necessary information:

- MD 1 analyzes the nature of the influence of environmental disturbances on RSES (described by the concepts and techniques of expert assessments and fuzzy logic);
- MD 2 monitors the state of the external environment based on regularly repeated aggregating and analytical actions to collect and process relevant regional socio-economic information;

![Figure 2. Model of forming general disturbance flow \( f_i(t) \) of RSES external environment.](image-url)
- MD 3 analyzes the dynamics of RSES socio-economic development indicators (polynomial dependencies are formed based on open statistical information).

Thus, features of the external environment impact on the object of control (RSES) can be determined by means of MD 1, 2, and 3, this will determine the nature of the relationship of the external environment and RSES and prioritize them. Passing through MD, the disturbing effect \( f(t) \) is transmitted to the control device, which acts as DSS "DATA".

6. Construction of a Dynamic Model of the Main Disturbances of RSES External Environment

The first paragraph after a heading is not indented (Bodytext style). Dynamic characteristics of flows of the main external environment disturbances and their interferences can be represented in the form of a corresponding model in (figure 3).

![Diagram](image)

**Figure 3.** Model of dynamic flow and main disturbances in RSES control system.

Measuring device 1 are expert estimations of external environment influence on RSES, measuring device 2 is monitoring of RSES external environment, measuring device 3 are dynamics of parameters of RSES socio-economic development.

The main focus is on the presence of MD 1, 2, and 3 and the division of the main flow of disturbances into three small flows, respectively. Interferences are also considered as separate flows that pass through MD 1, 2, and 3.

Let’s define \( \Theta \) as a set of environmental influences on the object of control through the control device (DSS "DATA"):

\[
\Theta = \{\|f_{ij}(t)\|_{i=1, j=1}^{9 \times 21}, \{f_{wy\theta}(t)|\theta = 1,2,3\}, \{\delta_{\omega}(t)|\omega = 1,2,3\}\}.
\] (5)

We determine that the dynamism of the main disturbances of RSES external environment is estimated by changing the states of its disturbances and can be represented using the following model:

\[
f_{ij}(t) = f_{ij}(t_z) + \Delta f_{ij},
\] (6)

where \( f_{ij}(t_z) \) is \( ij \)-disturbance of the external environment, defined by the linguistic variable \( L_{f_{ij}}(t_z) \) at \( t_z \) time; \( \Delta f_{ij} \) is the change of \( ij \)-disturbance of the external environment under the influence of \( y(t) \); \( t_z \) is a year serial number; \( t_{z-1} \) is the previous period to the years serial number.

In this paper, we propose to evaluate \( \Delta f_{ijk} \) as a measure of environmental disturbances dynamics, which can also be described using fuzzy logic.
7. Conclusion
The proposed approach to the description of the external environment impact on RSES from the positions of control allowed us to formalize the elements of the external environment, the main disturbances and their measurement errors. The external environment is considered in the paper in the context of RSES control system as a "disturbing" element, which influence must be taken into account when describing the object of control – RSES. The presented methods of describing the external environment can be used in the future when creating a general model of RSES control system and its control methodology. This will allow to provide a directed transformation of RSES within the framework of the regulatory and legal impact of National projects under the influence of the external environment.

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