Modeling and formation of environmental safety management systems of construction technologies

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Abstract. The structure of the components and control connections of the known environmental safety management systems of construction technologies (ESMSCT) have been studied; a method of ecological balance of innovative plans for the development of an object, territory, industry is proposed; the principles of the formation of construction technologies that provide ESMSCT with the necessary properties of stability have been studied: predetermination, stochasticity, globality, manufacturability, flexibility, efficiency, symmetry, harmony, organization and others; the following concepts were studied and selected for the formation of construction technologies: organization, sustainable development, environmental management, environmental marketing, environmental technical regulation, environmental standardization, environmental certification, environmental information paradigm.

1 Introduction

The well-known ESMSCT (environmental safety management system for construction technologies) are characterized by a structure of components and connections (positive and negative, direct and reverse) and are implemented at different levels of government (global, international, regional, national, local, and personal). [1-3] The structure of the components of the **well-known ESMSCT** may contain types of support: organizational, legal, personnel, financial and economic, material and technical, informational, and other types of support.

Connections in the **well-known ESMSCT** are implemented in management mechanisms: organizational, legal, economic [4-6].

Object-oriented **well-known ESMSCT** are usually tied: to the technological preparation of construction production, directly to construction, to material and technical supply, to the sale and operation of products, to the system of utilization and/or disposal of waste [7-9].

The **well-known ESMSCT** usually contain functional subsystems and components in their structure: planning, coordination, control, monitoring, economics, management, marketing, audit, expertise, environmental impact assessment, public participation and others.

The **well-known ESMSCT**, depending on the type of regulator, can be automatic,

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automated and non-automated (administrative) [10-12].

ESMSCT regulators: - cadastres of natural resources, - payment for the use of natural resources, - environmental funds, - environmental insurance, - economic incentives. Studies of regulators in the legal and economic mechanisms of ESMSCT have shown their ineffectiveness in a transitional period of the country's economy. Based on the analysis of data of the first chapter, the concept of the thesis is presented - a study of the well-known methodology for the formation of ESMSCT and the determination of the main areas of the development of scientific foundations and innovative methods for the formation of ESMSCT [13-15].

The results of the study of the methodology for the formation of ESMSCT known from literary sources are presented and a new scientific area of research is formulated: **innovative ESMSCT**, which was selected in order to solve the scientific and technical problem of ensuring the environmental safety of innovative construction. ESMSCT, as a new scientific area, integrates the methodology of environmental management standards and the theory of automatic regulation based on mathematical modeling of environmentally friendly innovative building systems "object – environment" (OE), using information support standards. [15, 16]

There are 2 conceptually opposite approaches to environmental management:

- **firstly, a marketing approach** based on voluntary environmental insurance and consensus of interests of marketing participants according to the models of international management standards of the ISO 9000; 14000; 10303 series and others;

- **secondly, technical regulation** and planning-distribution approach based on deterministic methods of environmental safety management of construction according to the model of classical administrative management.

Both approaches have the right to exist in different periods, depending on the rate of development and depletion of resources of the economic system, both one and the other can have an advantage in terms of environmental efficiency and environmental safety.

During the period of economic growth, the marketing approach turns out to be more environmentally effective, and during the period of stagnation, the planning and distribution approach turns out to be more environmentally effective. Periods of growth or stagnation alternate with duration approximately equal to 30...40 years.

2 Materials and methods

In Russia, during the current transitional period of the economy, a second approach is advisable and being implemented based on deterministic methods of environmental safety management, which will probably take place until 2020...2025, and then a transition to a marketing approach model will probably take place. [2]

The problem in construction is the creation of an innovative ESMSCT based on technical regulation of construction activities (i.e. on the basis of technical regulations, standardization, metrology and certification of products, processes and services in the field of innovations in construction, and primarily in the field of new construction technologies). [5]

ESMSCT must guarantee, with an acceptable degree of risk, the sustainability of the development of the construction complex, its safety for the life and health of citizens and the environment.

The problem of developing a methodology for the formation of innovative ESMSCT is the problem of complex integration and automation of living and machine intelligence on the basis of modern information technologies.

This problem arises due to the lack of scientific foundations and optimization methods for solving problems of environmental management adapted to construction, in particular,

to construction sites, to a development area, to building technologies, to building materials and structures.[8]

This problem exists due to the lack of systematization in the theory of safety management of buildings, structures, facilities and the safe use of adjacent territories at all stages of the life cycle of a construction object

As a result, the areas of research in the ESMSC methodology were specified in order to ensure sustainable development at the levels: - organization, - territory, and - industry on a national scale.

The process and synergetic approach, as a new area of interdisciplinary study of self-organization and development processes taking place in open nonlinear and far from equilibrium systems, acts as a scientific approach to the description of environmental safety management processes in innovative construction and plays the role of a new paradigm of sustainable construction. [11]

The study of the optimization problems of environmental management showed that certain classes of environmental optimization problems are characteristic of different management functions of ESMSC, which are more expedient to solve using ecological and mathematical models.

The development of any optimization model can be roughly divided into five stages, partially overlapping each other and having no clear boundaries.

Uncertainty about the structure of the environmental data set is the reason for the lack of realistic mathematical models and methodologies for identifying and assessing the environmental impacts of construction. This is caused by the pronounced heterogeneity of environmental aspects during the construction of facilities and the ambiguity of human perception of the results of these impacts. [14]

The second reason is the presence of bifurcations in the environment, which are the determining factor in the stability of the object's development.

Figure 1 shows an illustration of the integration of the process approach and the innovative principle of the ESMSC formation

Fig. 1. Innovations “I” are being introduced into the product and information flows controlled by ESMSC in the processes of a large construction company (LCC) [15].

The hypothesis of innovative development of an object, territory, industry. A formalized interpretation of the trajectory of technological development of systems in information coordinates is proposed.

The hypothesis of innovative development of an object, territory, industry consists in interpreting changes in environmental parameters under the influence of a construction object in the form of a homogeneous differential equation describing the “trajectory of motion” of the “object – environment” system in a multiparameter information space of environmental parameters. In this case, research tools can be applied with the necessary reliability: well-known mathematical optimization models and well-known motion stability criteria in accordance with the classical theory of automatic control.

The following are proposed: - criteria for identifying the states of development of processes in the “CO-E” system, - three-dimensional graphic interpretation of the trajectory of ESMSC development in information coordinates. In its development, the technosphere is in a state of unstable disequilibrium $\{(M\uparrow);(E\uparrow);(R\uparrow)\} \neq \text{Const}; (K\uparrow) \neq \text{Const}$, since from ancient times to the present day, it uses energy resources accumulated by the biosphere over billions of years. The task of the XXI century is to transfer the state of development of the technosphere from a state of unstable disequilibrium to a state of stable disequilibrium $\{(M); (E); (R)\} = \text{Const}; (K \uparrow) \neq \text{Const}$. [15]

The hypothesis of the unity of the laws of development of the biosphere and technosphere as a condition of their mutual compatibility is postulated. Space, materials and energy must be used by the technosphere without damaging the biosphere, and the structure of the components of the technosphere must correspond to the holonic structure of the biosphere, which provides the possibility of combining the development models of the biosphere and the technosphere.

The aspects of the parameters and structure of ESMSC are considered using examples: a model for solving environmental problems by linear programming \ a model of ecological balance of innovative plans for the development of an object, territory or industry \ a graphical method for constructing an area of permissible impacts by solving linear programming problems \ a model for identifying dangerous innovative impacts by the simplex method \ a method of formation of sustainable ESMSC. [16]

3 Results

A method for solving environmental problems by linear programming. A significant part of the decision-making tasks in ESMSC is the task of allocating resources between technical and/or natural objects.

Let m types of environmental components (land, water, air, flora, fauna, people) have the corresponding amount of resources. The presence of each i -th type of resource is b_i ($i=1..m$) in the appropriate units. These resource components can be used by natural and/or technical production systems - n types of systems in total. To ensure the reference (reserved for natural systems and/or normative for technical ones) ecological state of a unit of the j -th type of systems, a_{ij} units of the i -th type of resource component are required. It is required to determine what type and how many systems should be kept in order for such a set to be the best for the accepted criterion of optimality.

The purpose of the resource allocation problem is established by one of the mutually exclusive statements:

1) with the given available resources, maximize the result, for example, approximate the environmental indicators, incl. biodiversity of the territory, to the value of a nature reserve or wildlife sanctuary (The reserve or wildlife sanctuary must correspond to the location of the object (territory) in geographical latitude and other habitat conditions) by reconstructing and/or reducing all or part of industrial activities;

2) for a given result, minimize the required resources, for example, in the existing state of the environment, including production technical systems on the territory, minimize the consumed resources and environmental pollution.

Let us denote by x_j the amount of the allowed number of the j -th type of systems. Then, for the i -th type of resource component, we can write

$$\sum_{j=1}^n a_{ij} x_j \leq b_i,$$

where the left side of the inequality expresses the need for a resource of the i -th type, the right side - the available amount of this resource.

Extending to m types of resources, this limitation can be written

$$\sum_{j=1}^n a_{ij} x_j \leq b_i (i = 1 \dots m), \quad (1)$$

Additional variables can be introduced into dependence (1).

$\sum_{j=1}^n a_{ij} x_j + y_i \leq b_i (i = 1 \dots m)$ If the nomenclature of types of systems is limited by the limiting number and values of their volumes, then the following boundary conditions will be written

$$\underline{N}_j \leq x_j \leq \overline{N}_j (j = 1 \dots n), \quad (2)$$

where $\underline{N}_j$ — the minimum and maximum allowable volumes and/or the number of the j -th type of systems, respectively.

Each task of linear ecological programming contains an objective function, constraints, boundary safety conditions. Constraints can include dependencies for both resource components (b_i) and environmental performance (C).

The first statement will be written down analytically:

$$\left\{ \begin{array}{l} \max L_1 = \sum_{j=1}^n c_j x_j; \\ \sum_{j=1}^n a_{ij} x_j \leq b_i (i = 1 \dots m); \\ \underline{N}_j \leq x_j \leq \overline{N}_j (j = 1 \dots n); \end{array} \right.$$

where x_j — the number of admissible number of the j -th type of systems - the desired variable ($j = 1 \dots n$); n — number of system names; c_j — a quantity that shows how much the unit system of the j -th type contributes to the result; b_i — a given amount of a component resource of the i -th type ($i = 1 \dots m$); m — number of names of resource components; a_{ij} — resource consumption rate, i.e. how much of a resource component of the i -th type is consumed by a unit of the systems of the j -th type.

The second statement of the problem will have the form:

$$\left\{ \begin{array}{l} \min L_2 = \sum_{i=1}^m y_i; \\ \sum_{j=1}^n c_j x_j \geq C; \\ \sum_{j=1}^n a_{ij} x_j \leq b_i (i=1...m); \\ \underline{N}_j \leq x_j \leq \overline{N}_j (j=1...n); \\ y_i \geq 0 (i=1...m) \end{array} \right.$$

Where C — minimum acceptable result.

The solution of the problem gives the determination of the values of x_j , ensuring the maximum result for the given resource-components. The first and second problems, in which the variables x are included in the first degree, that is, in the form of linear dependencies, will be called linear ecological programming problems.

If the linear equation of action with two variable factors $2x_1 + x_2 = 2$ can be represented by a straight line on a plane, then the inadmissibility of action in the form of a constraint $a_1 x_1 + a_2 x_2 \leq b$ is depicted as a half-plane. The admissibility of the impact in the form of a constraint on the maximum permissible impact $2x_1 + x_2 \leq 2$ is a shaded half-plane, the coordinates of all points of which, i.e. the variable factors x_1 and x_2 , satisfy the specified constraint.

The developed method for solving environmental problems by linear programming consists in the following: it is necessary to determine: - the vertices of the area of permissible impacts as points of intersection of restrictions; - the values of the objective function of exposure at the vertices; - the vertex at which the target function of exposure acquires an extreme (**max** or **min**) value is optimal; - the coordinates of the optimal vertex are the optimal values of the sought variables of influencing factors.

Studies carried out using the model of solving environmental problems by linear programming have shown its suitability for the formation of ESMSCT for objects and territories where it is necessary to solve the problem of allocating resources between technical and/or natural objects. Studies carried out by the graphical method for constructing the area of permissible impacts when solving environmental problems of linear programming have shown its effectiveness and clarity, in comparison with the results obtained by calculation.

The method of ecological balance of innovative plans for the development of an object, territory, industry. Studies carried out using the model of ecological balance of innovative plans for the development of the territory have shown its suitability for the formation of plans and programs for the development of objects and territories, as well as for monitoring their implementation using ESMSCT. Conducted theoretical studies by the method of forming sustainable ESMSCT based on solutions to the optimization environmental problem showed the theoretical possibility of forming sustainable construction systems.

The most environmentally efficient is the development of ESMSCT related to sources, definitions and categories of waste, as well as the composition and treatment of waste streams, with the aim of promoting waste prevention and the creation and implementation of mechanisms for the prevention and minimization of waste, as well as systems for recovery and recycling of waste from construction industry.

Results of the study of the methodology for the formation of local, territorial or sectoral ESMSCT include: the initial conditions for the formation of ESMSCT \ identification of processes and requirements in ESMSCT of an object, territory, industry \ a mathematical description of the innovative ESMSCT “object – environment” \ the concept of innovative sustainability of ESMSCT of an object, territory, industries \ mathematical criteria for assessing the innovative sustainability of ESMSCT.

Identification of processes and requirements in ESMSCT of an object, territory, industry. Let us denote: IR^m is a multidimensional space formed by a set of points X , in which, by means of operator transformations T of information I about the initial state of a large construction company, we obtain variants of trajectories of movement of the area of points X in the direction of the selected long-term environmental goals of the construction company. [15,16]

Then we can write:

$$T:\{I, G, u, t_n\} \Rightarrow I_n; \quad (3)$$

where G - a set of long-term environmental strategic goals of a large construction company,

$$G = \{G_g\}; g = 1, g^*; \quad (4)$$

g^* - the number of goals the achievement of which guarantees a stable position of the construction company; u - control vector characterized by changes in the constituent components; t_n - lead time period for making a managerial decision.

The multidimensional space in which the search for structural solutions of ESMSCT is carried out is determined by the structure of the innovative marketing S_{LCC} .

Components of marketing component S_{LCC} :

People (P_1); $P_1 = F_1\{P_k; P_m; P_r\}$; where $= F_1$ - sign of the functional dependence component P_1 ; P_k - construction company personnel; P_m - personnel of realtors; P_r - consumers.

Construction product (P_2); $P_2 = F_2\{P_p; P_a; P_s; P_{tm}; P_c; P_{pos}\}$; where $= F_2$ - sign of the functional dependence component P_2 ; P_p - “packaging” (architecture, design); P_a - advantages (properties) of products; P_s - style (matching the consumer tastes); P_{tm} - trade mark (image); P_c - competition in maintenance and operation; P_{pos} - positioning.

Price (P_3); $P_3 = F_3\{P_{cp}; P_{al}; P_{cr}; P_{com}\}$; where $= F_3$ - sign of the functional dependence component P_3 ; P_{cp} - cost price; P_{al} - allowance; P_{cr} - credit; P_{com} - competitiveness.

Place (P_4); $P_4 = F_4\{P_e; P_{soc}; P_{den}; P_{dis}; P_{st}; P_{sec}\}$; where $= F_4$ sign of the functional dependence component P_4 ; P_e - ecological situation of the location; P_{soc} - social environment of the location; P_{den} - building density; P_{dis} - ecological market distribution; P_{st} - storage (warehousing); P_{sec} - ecological market sector.

Promotion of innovation (P_5). $P_5 = F_5\{P_{adv}; P_{sti}; P_{pr}\}$; where $= F_5$ - sign of the functional dependence component P_5 ; P_{adv} - innovation advertising; P_{sti} - stimulating innovation, realtors and advertising agents; P_{pr} - public relations;

In a generalized form P_S - the marketing position of a large construction company, controlled by the function F_S of the five constituent components: $P_S = F_S\{P_1; P_2; P_3; P_4; P_5\}$; (5);

where $= F_S$ - sign of functional dependence of the marketing position of a large construction company - P_S ;

P_1 - component “People”; P_2 - component “Product”; P_3 - component “Price”;

P_4 - component “Place”; P_5 - component “Promotion of innovation”.

The proposed in the thesis model of the ESMSCT structure allows considering the phenomena contained in the fixed provisions P_S on the area of the marketing structure S_{LCC} . This consideration indicates the interaction and relationship between the five constituent

components P_i forming causal series that do not lie in parallel. The trajectories of the positions of the individual constituent components P_i intersect, intertwine, merge in separate sections of the area of the marketing structure S_{LCC} so that the links of one P_i become links of another, then diverging again in the form of independent ramifications. [15, 16]

Environmental functions of a large construction company: M_{o-1} - managing the interaction of partners; M_{o-2} - partner needs management; M_{o-3} - management of communication between partners; M_{o-4} - managing the independence of partners; M_{o-5} - partner preference management.

Subgroups of ESMSCT methods: $M_{o/P-T}$ - production management; $M_{o/B}$ - business management; $M_{o/F}$ - financial management; $M_{o/Pr}$ - protection management; $M_{o/FA}$ - funds accounting management; $M_{o/A}$ - administration management; $M_{o/I}$ - innovation management.

Matrix-positional structuring of the content of environmental marketing makes it possible to identify the processes and safety requirements in the formation of ESMSCT by imposing the conditions of the environmental exchange M_o on the activities of a large construction company.

4 Main Results

1. The mathematical descriptions of ESMSCT of objects have been developed, including: a model of the “construction object – environment” (“CO-E”) system, a model of the stability of an innovative ESMSCT, the areas of possible change in the values of the parameters of the innovation system are determined, at which the stability of its operation is not disturbed.
2. The principles of formation of management systems for environmental safety of construction have been developed, including: principle of systemic unity; development principle; principle of prevention; principle of responsibility; principle of openness. Also, information methods have been developed for the formation of territorial and sectoral management systems for environmental safety of construction, including: method for modeling a logistics innovation system; method of forecasting innovative critical technologies; method of modeling the life cycle of an innovative object; functional modeling methods; method for modeling cluster solutions.
3. Information models for the formation of ESMSCT have been developed, including: - information model for the approval of new technical construction regulations; at the same time, environmental safety management of innovative building systems “object – environment” should be carried out on the basis of optimization methods of modeling and management, in particular, methods of technical regulation of environmental safety requirements, metrology and environmental certification of innovations and critical (breakthrough) technologies of construction production.
4. A functional and informational model of ESMSCT has been developed, which reflects the object of research in the broadest sense: as a subsystem of the State Urban Cadastre (SUC), as a subsystem of the RF unified state ecological monitoring system; as part of the State System of Scientific and Technical Information (SSSTI); as an integrated information system of industrial property, technical regulation, standardization, metrology and environmental certification of construction production; as a system uniting federal, sectoral and territorial information resources in the field of accreditation; as a system of end-to-end technology for the development and implementation of interactive electronic environmental guidelines (IEEG) for construction objects.
5. A model of the territorial software complex for collecting and processing data on environmental forecasting and monitoring of innovative construction has been developed, which is an integral part of the federal system for environmental monitoring of

construction, which provides accounting of construction sites and structures and territorial environmental monitoring of construction at the level of the constituent entities of the Russian Federation. This system will provide reliable data for making timely innovative decisions.

5 Discussion

The new scientific area was chosen in order to solve the scientific and technical problem of ensuring the environmental safety of construction technologies, which integrates the methodology of environmental management standards and the theory of automatic regulation based on mathematical modeling of environmentally friendly innovative building systems “object – environment”, using information support standards. The synergetic approach, as a new area of interdisciplinary research of self-organization and development processes occurring in open nonlinear and far from equilibrium systems acts as a scientific approach to describing the processes of ESMSC.

The problem was the complex integration and automation of living and machine intelligence in environmental management systems for construction. This problem arose due to the lack of methods for interpreting the optimization problems of mathematical modeling to solve problems of environmental management adapted to the construction of facilities on the territory, construction technologies, materials and structures. This problem is solved on the basis of its systematization in the theory of environmental safety management of buildings, structures, facilities and the safe use of adjacent territories at all stages of the life cycle of a construction object.

The main tasks of the study were solved, which were: the problem of identifying the components of ESMSC and the problem of interpreting mathematical models of ecological optimization of innovative environmental impacts. The research tasks were solved, which included the analysis of the well-known methodology and the development of a new methodology for the formation of innovative ESMSC, including the creation of sustainability models of ESMSC and the formulation of the concept of the trajectory of the technological development of an object, as well as the development of mathematical criteria for the sustainability of environmental safety management systems for construction at the facility, on the territory, in the country's industry. The problem of development of information technology for the implementation of the proposed methodology for the formation of ESMSC has been solved.

6 Conclusions

1. The environmental safety management system for construction (ESMSC) is characterized by a structure of components and relationships (positive and negative, direct and reverse) and is implemented at different levels of management (global, international, regional, national, local, and personal). ESMSC, depending on the type of regulator, can be automatic, automated and manual (administrative). The structure of the ESMSC components can contain types of support: organizational, legal, personnel, financial and economic, material and technical, informational and other types of support. Connections in ESMSC are implemented in management mechanisms: organizational, legal, economic. Object-oriented ESMSC are usually tied: to the technological preparation of construction production, directly to construction, to material and technical supply, to the sale and operation of products, to the waste disposal and/or burial system. ESMSC usually contain functional subsystems in their structure: planning, coordination, control, monitoring, economics and others.

2. The purpose and objectives of creating ESMSCT are to continuously maintain a stable disequilibrium (SD) state of self-development of the system “construction object – environment” (“CO-E”), i.e. the state of “CO-E”, which can be maintained for an infinitely long time by innovative influences at the level of compliance with the minimum necessary safety requirements. This is the essence and meaning of sustainable development of any social and production structures (enterprises, companies, firms, etc.), including the sustainable development of the construction industry and the country as a whole.
3. The strategic task of ensuring the environmental safety of construction is multifactorial and requires the use of system analysis in order to prevent unfavorable and emergency situations precisely at the level of innovative decision-making with effective consideration of situations and trends according to environmental monitoring data. At the same time, according to the criteria for achieving the main goals and, in fact, construction activities, the adoption of any innovative solution is an information and analytical task with direct communication and feedback.
4. Innovative sustainable construction technologies are a key element of environmental protection because they are less polluting, use resources in a more sustainable manner, and allow recycling their byproducts and residues more than their predecessors. The integration of environmental protection into the cycle of innovative construction production should be aimed at preventing pollution and introducing “clean (waste-free)” and reclaiming technological processes in construction production.
5. The main task of ESMSCT is to fully cover all links of the innovative logistics chain, including inventors, innovators and other suppliers of new ideas, product engineers, designers and other manufacturers of design products, and its consumers - builders, installers, operators of buildings and structures, in order to increase the objectivity of the reflection of modern business processes in construction.
6. The study of the optimization problems of environmental management has shown that certain classes of environmental optimization problems are inherent for different management functions of ESMSCT, which are more expedient to solve using certain methods on ecological and mathematical models. In this case, the solution of these problems will be effective if using programming methods (discrete, linear, dynamic, nonlinear).
7. The graphic interpretation of the development of systems at the level of a construction object, a development area, or an industry in information coordinates allows the most effective use of a deterministic method of describing the impacts and characterizing a trajectory section local in time and space for which the parameters are set. The probabilistic statistical method does not give an accurate description for any fragment, but approximately characterizes significant volumes of data. However, thanks to the generalization achieved, it allows finding out the general patterns of impacts and using them to analyze the genesis of impacts and substantiate the research methodology.
8. Studies carried out using the model of solving environmental problems by linear programming have shown its suitability for the formation of ESMSCT for objects, territories, and an industry where it is necessary to solve the problem of allocating resources between technical and/or natural objects. Studies carried out by the graphical method for constructing the area of permissible impacts when solving environmental problems of linear programming have shown its effectiveness and clarity, in comparison with the results obtained by calculation.
9. Studies carried out on the model of ecological balance of innovative plans for the development of objects and territories have shown its suitability for the formation of plans and programs, as well as for monitoring their implementation using ESMSCT.
10. The most environmentally efficient development seems to be the development of ESMSCT in terms of waste sources, the definition and categorization of the composition

and treatment of waste flows in order to facilitate waste prevention and the creation and implementation of mechanisms for the prevention and minimization of waste, as well as systems for recovery and recycling of waste from construction industry.

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