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Situational modeling for the control of technospheric safety

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ABSTRACT: The work represents the results of formulation and actualization of a system for control of urbanized areas biotechnosphere functioning of which is based on data intellectual analysis along with use of situational modeling. There was developed a functional and a generalized structural model of the system as well as of its basic component, i.e. an ecologic situation center which ensures intellectual monitoring and intellectual support of decisions related to reduction/elimination of ecotechnogenic risks, direct transformation of ecological data into effective control actions. There was developed a method of integrated evaluation of an actual and a forecasted environmental situation based on synthesis of fuzzy logic and GIS technologies. There were generated situational models for evaluation and prediction of the state of biotechnosphere at the yard territories depending on the environmental conditions and planning structure.

Introduction

In the present-day conditions of building system densification and expansion urbanized and suburbanized territories undergo constant technogenic transformation of biosphere and fast development of biotechnosphere which is characterized by structural and functional integration of natural, technical and social factors and the state of which is determinative for formation and development of a certain environmental situation. The results of various investigations as well as data of ecological monitoring evidence show [1-8]: a considerable part of such type of territories is located in the zones with increased negative technogenic influence where the sanitary norms of air toxic and cancer-inducing substances content as well as the norms of noises and magnetic fields exposure are exceeded, where solid wastes are accumulated and vegetation suffers from suppression. Special attention should be drawn to the urban yard territories and the rural-urban areas which are characterized by specific conditions of biotechnosphere formation and environmental quality of which influences the health of the most vulnerable part of population [9-14].

Control over the territorial bitechnosphere is control of a complicated dynamic system the state of which is characterized by both quantitative and qualitative parameters, diversified and non-uniform background data; in order to take administrative decisions it is necessary to take into account weakly-formalized concepts and miscellaneous data on the state of a controlled object and of environment. Under such conditions the most reasonable way would be formation of an intellectual control system which will generate administrative decisions on the basis of intellectual data analysis, i.e. acquisition and presentation of data on a controlled object and other subsystems, procedures of their interaction between themselves and with environment; model-based evaluation of the state of biotechnosphere and the methods of its control at the level of mathematical and logical-linguistic models; use of training, generalization and classification in the course of formation of control scripts in regard of actual and forecasted environmental situations.

Due to the above development of a complex of methods, models and algorithms which would actualize functioning of intellectual systems of control over biotechnosphere of urbanized territories including with use of a situational approach and situational modeling is an urgent scientific mission nowadays.

Despite of a wide range of investigations in the sphere of generation and development of the systems implementing the functions of environmental monitoring, forecasting and environmental safety administration the task of ensuring support for decisions in the sphere of integrated control over the state of natural and technogenic systems of urbanized territories accompanied by direct transformation of the obtained environmental data into scientifically grounded effective control actions has not been yet solved.

Main part

The authors set the task of creation of a system of control over urbanized territories biotechnosphere which would function on the basis of intellectual monitoring and intellectual support of decision-making via use of situational modeling.

There was performed an analysis of formation of an environmental situation at urbanized territories of different hierarchic levels under the conditions of building system expansion and densification; an analysis of the existing approaches to implementation of decision support in the sphere of control over the territories biotechnosphere state dynamics based on actualization of the monitoring systems which use up-to-date technologies for environmental data collection and processing. There were found out the principal disadvantages of such type of systems which condition reduction of their efficiency being the basis of control information support, namely weak connection with the tasks of administrative decisions support (generally it consists in generation of reports, data bases, environmental data mapping, in some instances use of analytical methods and programs for evaluation and prediction of the level of contamination propagation); lack of an integrated evaluation of an environmental situation on the basis of cumulative state of various components of biotechnosphere.

There were stated the requirements and principles for formation of the intellectual control system for urbanized territories biotechnosphere functioning of which will favor practical improvement of an environmental situation.

A place of the prototype system in the hierarchy of the common intellectual control network of urban functions was determined on the basis of analysis of the approaches to a “smart” city (settlement, territory) control and detailed elaboration of the corresponding control system. The offered functional model of the system of such type in shown on Figure 1: $\mathbf{I}_0$ – data on a biotechnosphere state; $\mathbf{I}_{01}$ – processed data; $\mathbf{I}_1$ ($\mathbf{I}_1$={$\mathbf{I}_{11}$,$\mathbf{I}_{12}$}) – results of initial evaluations ($\mathbf{I}_{11}$) and forecasts ($\mathbf{I}_{12}$); $\mathbf{I}_2$ – forecasting results, control scripts evaluation; $\mathbf{I}_3$ ($\mathbf{I}_3$={$\mathbf{I}_{31}$,$\mathbf{I}_{32}$}) – models; $\mathbf{I}_C$ – control scripts selected for implementation.

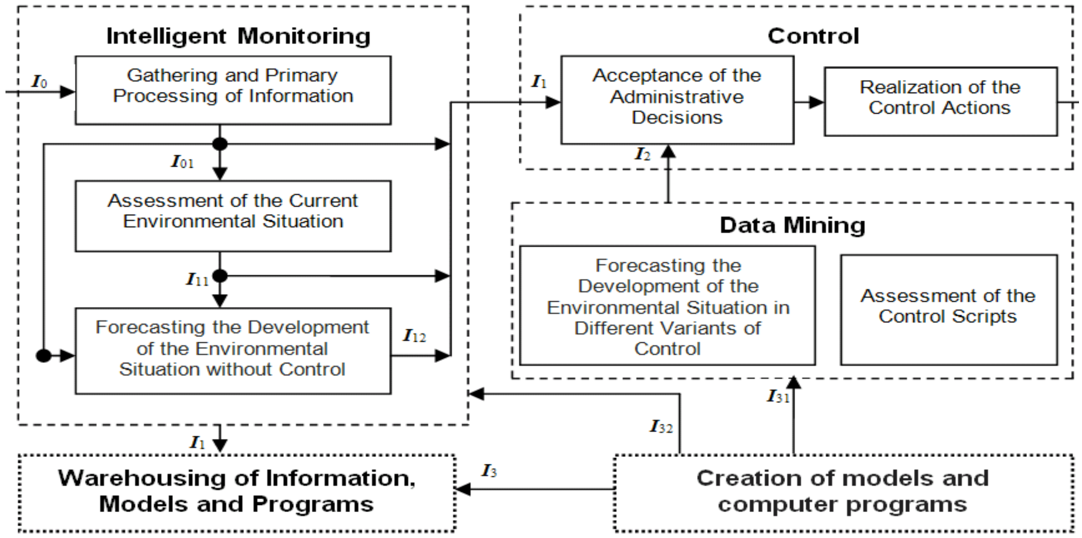

Figure 1. Functional model of intellectual biotechnosphere control system.

The carried-out analysis and the determined functiones allowed to form a structural model of the system (Figure 2) with use of a methodology of composition and a generalized model of an automated system of environmental safety control of territories which had been developed by the authors earlier [15]. The system undergone fundamental changes connected with integrated realization of intellectual monitoring and decision support based on an ecological situation center (ESC) introduced into the system. Thus the principal components are as follows: a controlled object (state of biotechnosphere); a control system forming administrative decisions ***Υ*** and implementing control actions ***U***; the ESC which joins intellectual subsystems of monitoring and decision support; ***X*** – controlled object state variables; ***Y*** – a set of the control system input parameters ensuring decision support (***Y′*** – processed data of intellectual monitoring, ***Y″*** – results of intellectual data analysis, ***Y‴*** – models); ***Υ′*** – selected control actions, changes in territory parameters etc.; ***C*** – system feedback parameters; ***Q*** – environmental effect parameters.

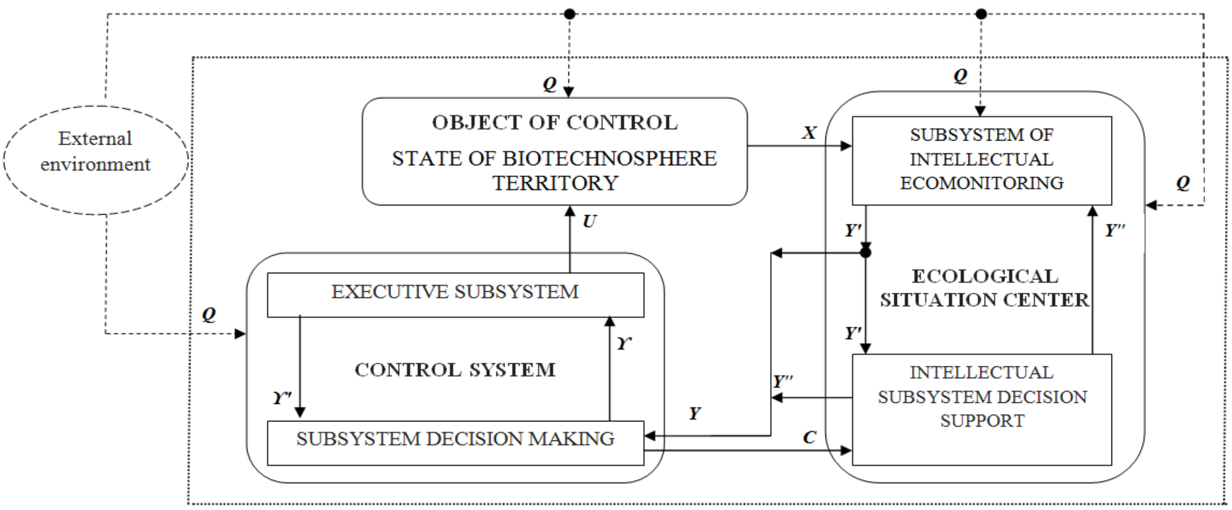

Figure 2 . The structural model of intellectual control system of the biotechnosphere territory.

The ESC should be characterized by flexibility ensuring the possibility of modernization with account of new conditions of formation of the state of biotechnosphere, change of building system conditions, of control mechanisms etc. The ESC as a system may be represented via the following set-theoretical formula:

SitCent= <SS, X,Y,R,EI, F, O>, (1)

where SS is a set of principal components; X, Y, R – sets of inputs, outputs and states of SS components; EI – external actions, EI= {C, Q}; F– mapping onto X, R, Y and EI, F: (X,R,EI) → Y; O– relations; O: (X^i, R^j, Y^k, EI^l)*. There was found out the correspondence between the principal ESC functions and the subsystems for their implementation; Figure 3 shows its structural model. The constituents of R set:* R_{11} *describes the state of a subsystem of data collection and processing;* R_{12} *and* R_{13} *– of subsystems of preliminary evaluation and preliminary forecasting;* R_{21} *– knowledge database;* R_{22} *– models, electronic maps, programs;* R_{23} *–results of operation of a subsystem of intellectual* analysis and control scripts formation. Therefore observation data are transformed directly into control scripts along with evaluation of efficiency of the latter.

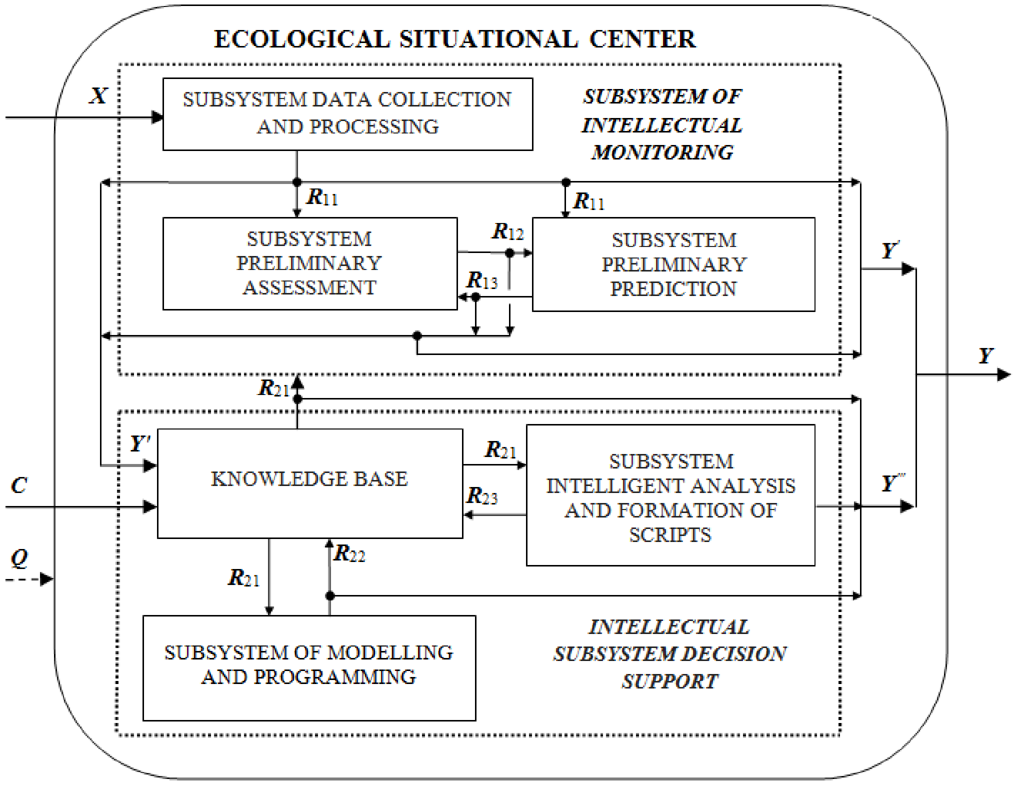

Figure 3. The structural model of ESC.

As it was specified above implementation of control over biotechnosphere as a complex natural, social and techogenic system the state of which is characterized both by qualitative and quantitative parameters, diversified and non-uniform background data and in relation to which a classical optimization problem is no way reasonable should be based on the artificial intelligence technologies, situational approach and situational modeling. A key object is an environmental situation which from the point of view of classical situational approach in the sphere of control is determined as a spatiotemporal evaluation (analysis, generalization) of a set of characteristics of the objects of a territory biotechnosphere and of relationships between them. Proceeding from the common principles of situational modeling let's introduce a concept of the actual environmental situation ($EcSit^{act}$) estimated at a time and full environmental situation ($EcSit^{full}$) as an aggregate consisting of $EcSit^{act}$, knowledge of the state of control system at a time, knowledge of control mechanisms and technologies. An elementary control act may be represented by the following logical-transformation rule:

$$EcSit_i^{full} : EcSit_j^{act} \underset{U_k}{\rightarrow} EcSit_i^{act}, \qquad (2)$$

Where *Uk* is *k*-number control action, $k = \overline{1,K}$ (*K* - number of control variants). Let's differentiate the possible administrative decisions and the corresponding actions by the terms of their realization and the resources involved: long-term (strategic) decisions; medium-term (tactical) decisions; short-term decisions aimed at implementation of real-time control actions.

Traditionally evaluation of ecological situation is made on the basis of evaluation of negative consequences for natural landscapes and health of population. This work offers to use different approach, i.e. an integrated evaluation of environmental situation both from the point of view of the possibility of environmentally fragile zones occurrence and from the point of view of the necessity to implement administrative decisions belonging to different levels. Let's use a linguistic variable for description of an environmental situation:

{EcSit,T,ES,G,H}, (3)

where T is a basic term-set; ES is a set of quantitative characteristics for determining membership of EcSit in T; G is a set of syntax statements for forming names of new values of EcSit; H–mathematical rules.

Minimum evaluation accuracy: T_1= "favorable", T' = "unfavorable"; accuracy is improved through specification: T = {T_1, T'}= {T_1, T_2, T_3, T_4, T_5}, T_2 = "relatively tense", T_3 = "tense", T_4 = "conflict", T_5 = "crisis" (the expert evaluation method was used).

The analysis of the control object, i.e. a territorial biotechnosphere shows that EcSit is a complex variable: EcSit= ($EcSit_{NS}$, $EcSit_{TS}$), where $EcSit_{NS}$ characterizes the state of a natural subsystem; $EcSit_{TS}$ characterizes the state of a technogenic subsystem. Moreover further specification is needed: $EcSit_{NS}$ = ($EcSit_{NS1}$, $EcSit_{NS2}$, …, $EcSit_{NSi}$,…, $EcSit_{NSI}$), $i = \overline{1,I}$; $EcSit_{TS}$ = ($EcSit_{TS1}$, $EcSit_{TS2}$, …, $EcSit_{TSi}$,…, $EcSit_{TSJ}$), $j = \overline{1,J}$, which complies with specification of the studied control object subsystems. Similarly to (3) let's introduce the linguistic variables $EcSit_{NS}$ and $EcSit_{TS}$:

{$EcSit_{NS}$,T_{NS},ES_{NS},G_{NS},H_{NS}}, {$EcSit_{TS}$,T_{TS},ES_{TS},G_{TS},H_{TS}}, (4)

Minimum evaluation accuracy for the state of the natural and the technogenic biotechnosphere subsystems T_{NS1} = T_{TS1} = "satisfactory", T'_{NS}= T'_{TS}= "unsatisfactory".

Thus the process of EcSit classification is split into the analysis of interaction of a range of components which will allow synthesizing a result. At that $EcSit_{NS}$ and $EcSit_{TS}$ are also evaluated as aggregates. It is necessary to form sets of conventional derivative rules, for example for EcSit:

if ($EcSit_{NS}$ *is* T_{NS1}) *and* ($EcSit_{TS}$ *is* T_{TS1})
or ($EcSit_{NS}$ *is* T_{NSn}) *and* ($EcSit_{TS}$ *is* T_{TSm})
… (5)
than EcSit is T_l,

where T_{NSn} ($n = \overline{1,N}$) and T_{TSm} ($n = \overline{1,M}$) are fuzzy terms used for evaluation of $EcSit_{NS}$ and $EcSit_{TS}$, $T_{TSm} \in T_{TS}$; $l = \overline{1,L}$. Each numerical value of sets ES_{NS}, ES_{TS} (experimentally measured of forecasted with use of models) is assigned with the degree of membership in T_{NSn} or T_{TSm} according to the prescribed membership functions $\mu_{T_{NSn}}$ and $\mu_{T_{TSm}}$. Conclusion of rules of membership of the actual (forecasted) environmental situation in T_l is also performed according to μ_{T_1}, μ_{T_2}, …,μ_{T_L}. The resulting estimate is represented by the degree of membership in a definite level of a point scale {1,2,3,4,5} (the smallest point corresponds to the worst state).

The GIS tools were used for visualization and spatial data analysis.

Here were developed the following algorythms: for realization of integral evaluation both for the actual and forecasted environmental situations at the urbanized territory under consideration, for forming of control actions implementation of which would not result in a contradictory effect consisting in change of quality of individual biotechnosphere components.

The established method was used as a basis for generation situational models of the state of biotechnosphere at yard territories of multi-storey building complexes. A yard territory is a territory adjacent to a residential building and is in common use of the persons residing in such building, this territory is bounded along its perimeter by residential buildings, constructions, facilities or fencing. Design, creation and development of yard territories are implemented by means of realization of a definite set of architectural and design decisions.

A model of the control object, i.e. of the state of biotechnosphere of a yard territory was made more specific. There was introduced a complex linguistic variable "Ecological situation at a yard territory" *EcSit*= ($EcSit_{NS}$,$EcSit_{TS}$), where $EcSit_{NS}$= "The state of natural environment of a yard territory"; $EcSit_{TS}$= "The state of layout structure of a yard territory from the point of view of environmental safety"; T_{NS} = {T_{NS1}, T'_{NS}}= {T_{NS1}, T_{NS2}, T_{NS3}, T_{NS4}, T_{NS5}}, T_{TS} = {T_{TS1}, T'_{TS}}= {T_{TS1}, T_{TS2}, T_{TS3}, T_{TS4}, T_{TS5}}, where T_{NS1}, T_{TS1} = "satisfactory". There was introduced differentiation for the characteristics $EcSit_{NS}$ and $EcSit_{TS}$ "unsatisfactory": T_{NS2}= "disturbing", T_{NS3} = "relatively hazardous", T_{NS4} = "hazardous", T_{NS5} = "extremely hazardous"; T_{TS2} = "requiring short-term single-purpose architectural and design decisions", T_{TS3} = "requiring short-term multipurpose architectural and design decisions", T_{TS4} = "requiring medium-term tactical architectural and design decisions", T_{TS5} = "requiring long-term strategic architectural and design decisions".

The content of $EcSit_{NS}$ was made more specific: $EcSit_{NS}$= {$EcSit_{NS1}$, $EcSit_{NS2}$, $EcSit_{NS3}$, $EcSit_{NS4}$}, where $EcSit_{NS1}$ = "atmospheric air contamination level", $EcSit_{NS2}$ = "negative noise exposure level", $EcSit_{NS3}$ = " level of negative infrasound effect", $EcSit_{NS4}$ = "negative magnetic field effect level". The following terms were introduced for description of variable data:

$EcSit_{NS1}$:T^{NS}_{11}= "lowered", T^{NS}_{12}= "increased", T^{NS}_{13}= "high",

$EcSit_{NS2}$: T^{NS}_{21} = “lowered”, T^{NS}_{22} = “increased”, T^{NS}_{23} = “high”,

$EcSit_{NS3}$: T^{NS}_{31} = “lowered”, T^{NS}_{32} = “increased”,

$EcSit_{NS4}$: T^{NS}_{41} = “lowered”, T^{NS}_{42} = “increased”.

For implementation of integrated evaluation of the state of layout structure:

$EcSit_{TS}$= {$EcSit_{TS1}$, $EcSit_{TS2}$,$EcSit_{TS3}$}, where $EcSit_{TS1}$ = “level of vegetation of a yard territory”, $EcSit_{TS2}$ = “level of insolation of a yard territory”, $EcSit_{TS3}$ = “state of automobile parking conditions at a yard territory”. The following terms were introduced for description of variable data:

$EcSit_{TS1}$: T^{TS}_{11}= “low”, T^{TS}_{12}= “lowered”, T^{TS}_{13}= “satisfactory”,

$EcSit_{TS2}$: T^{TS}_{21}= “lowered”, T^{TS}_{22}= “satisfactory”,

$EcSit_{TS3}$: T^{TS}_{31}= “unsatisfactory”, T^{TS}_{32}= “satisfactory”.

There were formed sets of the corresponding membership functions and developed derivation rules for integrated evaluation of the state of natural environment, planning structure and environmental situation as a whole.

There was developed a software implementation ensuring evaluation of individual biotechnosphere components; integrated evaluation of the actual (Figure 6) and the forecasted environmental situation (Figure 7); efficiency of control actions (Figure 8).

The intellectual biotechnosphere control system functioning was shown by the example of the cities of regional subordinance Orel and Belgorod where 241 yards were investigated and environmental situation was integrally assessed as well as the corresponding recommendations were elaborated.

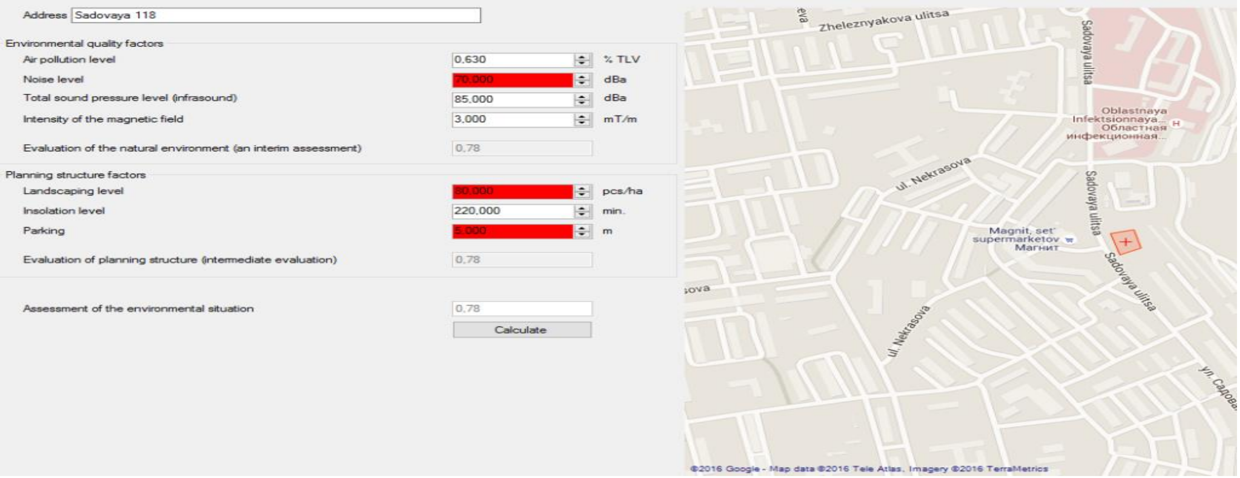

Figure 6. An example of integrated evaluation of an environmental situation.

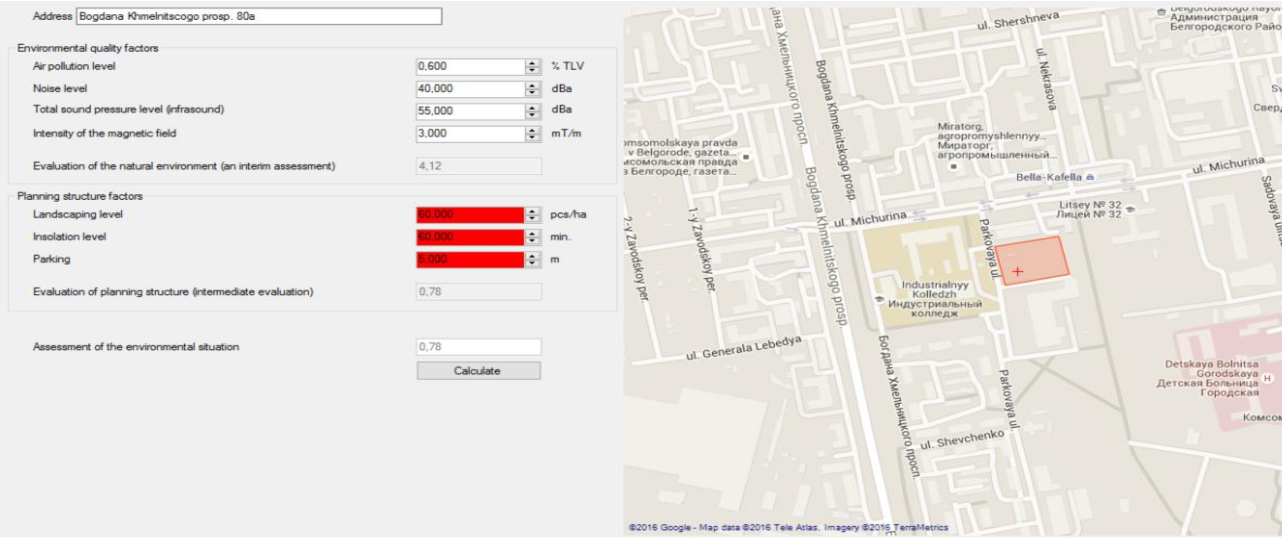

Figure 7 . An example of evaluation of a forecasted environmental situation at the territory of actual infill development.

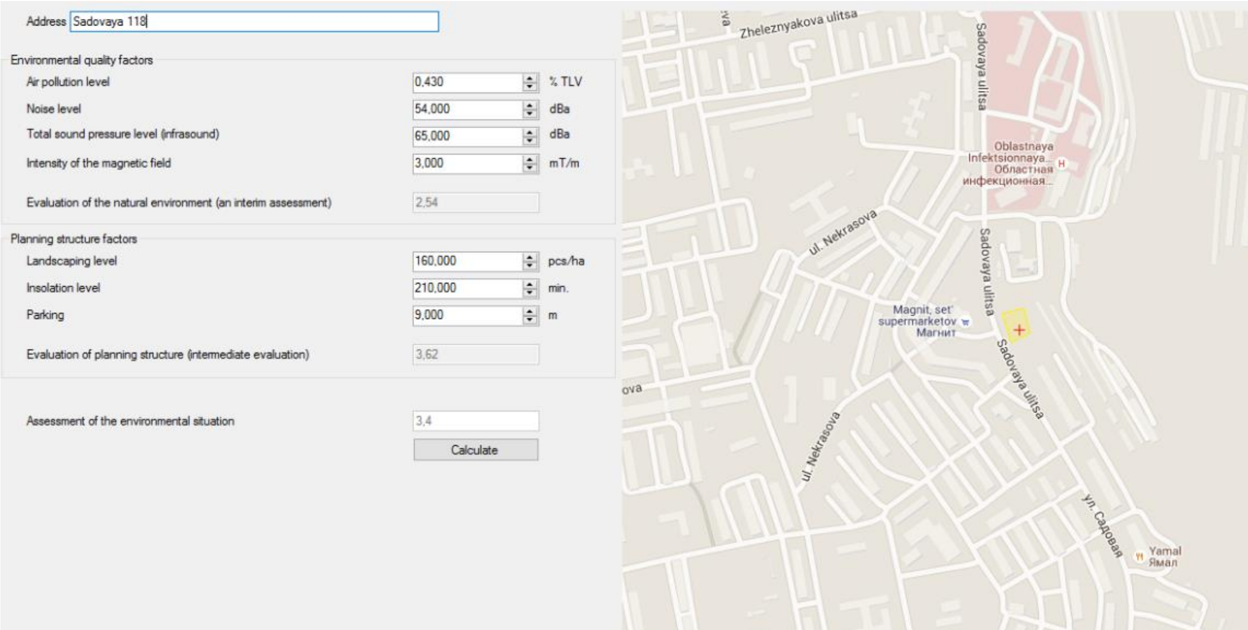

Figure 8 . An example of evaluation of control actions efficiency.

Conclusion

The result of implementation of the intellectual control system for biotechnosphere of local urbanized territories has a social and an economical effect, i.e. enhancement of regulatory bodies performance efficiency at time of a territory building development regulation, infrastructure development planning; maintenance and improvement of an environmental situation at built-up territories; upgrade of the level of control both at the stage of planning and at the stage of development, repair and reconstruction of an urbanized territory; improvement of programs efficiency, speeding up of expert examinations, reduction of costs connected with environmental assessment, rectification of the consequences of negative technogenic effect.

There were developed methods, models and their software implementation, the corresponding recommendations may be efficiently used for integrated evaluation and prediction of environmental and technical state of built-up territories; for development of control scripts and evaluation of individual actions aimed at change of parameters of utility networks and infrastructure of urbanized territories in order to achieve the required level technospheric safety; for preparing predictive evaluation at time of implementation of new technogenic objects along with assessment of ecotechnogenic risk and determination of allowable technological parameters; for forecasting environmental safety of a territory at time of construction and reconstruction of residential building complexes and other social facilities, determination of the required parameters of a territory infrastructure.

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