Situational model of decision-making system based on environmental monitoring data in the conditions of urban development

I G Ivanova, A D Danilov, V L Burkovskii, K Yu Gusev and P Yu Gusev

Voronezh State Technical University, 14 Moscow ave., Voronezh, 394026, Russian Federation

E-mail: gussev_konstantin@mail.ru

Abstract. Urban population growth is a trend of industrial society. According to the annual UN reports on the rate of urbanization of countries in 2007, the urban population became equal to the rural population in the world and continues to increase. As a result, following the population growth and the growth of cities. Development planning of urban areas is a complicated and important task, requiring the solution of a number of social issues: the optimization of the location of municipal facilities, improve the quality of life of citizens, the formation of leisure and recreational areas, the formation of the urban landscape and design, the formation of zones of residential development, the transport infrastructure, street and road network with minimal impact on the environment, placement of objects of social sphere, development of suburban areas. Compaction of the development of modern Russian cities, with narrow streets and often no sidewalks, makes the task of reducing the level of environmental safety in megacities difficult, and in some cases impossible. On the other hand, urban areas are constantly increasing due to the introduction of new districts, residential areas and cottage settlements, which requires taking into account the level of environmental safety at the planning stage of their development.

1. Introduction
Modern industrial cities are the centers of acute environmental problems associated with air pollution, which is a serious obstacle to the development of urban areas. The dense construction of modern Russian cities, with narrow streets and often no sidewalks, makes it difficult or impossible to reduce the level of pollutants and harmful substances in the Central parts of megacities. But on the other hand, the urban area is constantly increasing due to the construction of new districts and micro-districts, residential areas and cottage settlements, and the regulation of concentrations of pollutants and harmful substances should be mandatory at the stage of their development. Currently, there are many sources of air pollution in urban areas: vehicles, manufacturing plants, individual boilers, unauthorized garbage dumps, etc. [1]. However, over time, most of the sources of pollution in cities are eliminated: enterprises are moved outside of residential areas, boilers are provided primarily with gas fuel to reduce emissions into the atmosphere, and vehicles are converted to gas fuel or electric traction. However, despite large-scale measures to minimize emissions into the atmosphere, one of the constantly growing sources of negative impact on the air basin of cities is the road environment.
According to the reports of the Ministry of transport of the Russian Federation, the annual increase in the number of cars in Russia is 7-10%.

This trend is directly reflected in the amount of pollutants entering the atmosphere from vehicles, which is more than 90% of the total emission of all pollutants. The amount of emissions is affected by both the technical condition of the road environment units in use and the quality of the road surface, as well as the organization of traffic on the road network. But managing the traffic situation inside existing cities is an economically costly and technically difficult task.

It is proposed to use the models obtained when analyzing the level of air pollution in existing cities, when making decisions in the conditions of urban development to improve their efficiency [2].

2. Decision making system
The proposed situational model includes three main blocks:

- state assessment block (fuzzification);
- the decision-making unit;
- unit severance effects (defuzzification).

Two linguistic variables are entered for the input and output data streams:

\[ X_i < "Concentration" , T_x , [0, P_i] > , \]
\[ Y_i < "Average pollution level" , T_y , [0, 1] > , \]

where \( T_x = \{ small , medium , high enough, high \} \), \( T_y = \{ small , medium , high enough, high \} \), \( P_i \) is the MPCx3 for each of the studied pollutants, and the semantic rule that sets the correspondence of each fuzzy variable from the set \( T_x , T_y \) is the fuzzy set \( C_{xi} \) and \( C_{yi} \) shown in figure 1 [4]. The form of the membership functions selected for the approximation of data obtained from Voronezh environmental monitoring center:

\[ \mu(a_i) = \exp \left[ - \frac{(a_i - x^k)}{s^k} \right]^2 , \]

where \( n \) – is the number of inputs of the fuzzy model, and the function parameters have an interpretation: \( x \) is the center, and \( s \) is the width of the Gaussian curve [3].

![Figure 1. Membership functions of a fuzzy set \( C_{xi} \) and membership functions of a fuzzy set \( C_{yi} \).](image-url)
The input data vector $C_{(12\times1)}$ uses the concentrations of six main components of atmospheric air pollution in the center of the intersection and six near residential buildings, i.e. signs that describe the state of the object under study: nitrogen dioxide, suspended solids, sulfur dioxide, carbon oxide, phenol and formaldehyde [5].

The analysis of the state of atmospheric air in the selected areas was carried out according to the maximum single concentration in the center of the intersection and at the nearest residential development of priority pollutants. A regression equation is obtained for the dependence of the concentration of pollutants in the center of the intersection and the concentration near residential buildings:

$$C_1 = 0.031 + 0.7651 \cdot C_2 - 0.0878 \cdot C_2^2$$

where $C_1$ – concentration of pollutants in the center of the intersection, $C_2$ – concentration of pollutants near residential buildings [6].

The resulting regression model is used in cases of incomplete certainty of the input vector and to improve the accuracy of the fuzzy situational model.

The concentration of pollutants $C$ is described by the linguistic variable $X_i <C, T, D_i>, i=1, \ldots, n$, and the fuzzy variables $<T_i, D_i, C_i>$ are used to describe the terms $T$ corresponding to the concentrations of pollutants $C$. Thus, the resulting fuzzy situation is a second-level fuzzy set $s = \{\mu_i(C)/C\}$, where

$$\mu_i(C) = \mu_{\mu_i(C)}(T_i)/T_i$$

When the situation model of the input vector $C_{(12\times1)}$ is fed to the input of the fuzzification block, the vector $S_0_{(12\times4)}$ will be obtained, consisting of the functions of the input concentrations belonging to the linguistic variable "Concentration". The resulting situation $s$ is fed to the input of the next decision block.

In the case of situational models, the knowledge base is a key block in making an adequate decision. The thesis uses a static knowledge base that stores pairs of matrices of the type:

$$<\text{Fuzzy situation (the current values of the concentrations)>}$$

$$<\text{Generalized assessment of the level of pollution (forecast)>}.$$.

The fuzzy situation is a matrix identical to the matrix $S_i_{(12\times4)}$, $i=1, \ldots, k$ obtained in the fuzzification block. The matrix $S$ is constructed in the same way using the block and membership functions described above. The second element of the pair is a vector $R_i_{(1\times4)}$, $i=1, \ldots, k$, obtained using the linguistic variable $Y$ and the corresponding membership functions (figure 2). Thus, the knowledge base has an explicit form and is a record with dimension $(k \times 2)$ [7].

Two main approaches were used in the formation of the knowledge base:

- creating pairs in the knowledge base based on retrospective data, using the membership functions of the linguistic variables $X$ and $y$, at this stage, reference situations are formed (by expert means), which are used in the future when making a forecast;
- adding pairs to the knowledge base based on expert assessments of the current state of pollution. At this stage, the vector $R_i_{(1\times4)}$, $i=1$, is formed explicitly from expert estimates $R_{(1\times4)}$, $j=1, \ldots, k$.

At this stage of the simulation, possible relationships are implemented in fuzzy situations. The thesis uses the degree of equality as a criterion for choosing the closest situation from the knowledge base, and, consequently, the corresponding output vector $R$:

$$\mu(S) = \mu(S_o, S_j) \cap \nu(S_j, S_o).$$
where \( j=1,\ldots,k \), \( \mu \) is the degree of equality of fuzzy situations, \( \nu \) is the degree of inclusion of fuzzy situations. In other words, this block compares the situation obtained from the input data with the reference situations in the knowledge base. The thesis does not pay attention to ways to optimize the search for the maximum degree of equality and uses the method of direct search of all possible options.

The paper proposes to use the procedure for generating the output vector \( R \) depending on the calculated degrees of equality as follows in Table 1.

| \( \mu_{\text{max}} \) | Accept \( R \) with the highest degree of equality | Select situations with the three highest degrees of equality and get the resulting set \( R \) by intersecting the selected ones \( R = R_{\text{max}} \cap R_{\text{max-1}}, i = 1,\ldots,3 \) | Select situations with the five highest degrees of equality and get the resulting set \( R \) by intersecting the selected ones \( R = R_{\text{max}} \cap R_{\text{max-1}}, i = 1,\ldots,5 \) |
|-----------------|-------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------------|
| \( > 0.9 \)     | \( 0.5 < \mu_{\text{max}} < 0.9 \)             | \( 0.5 < \mu_{\text{max}} < 0.9 \)                               | \( 0.5 < \mu_{\text{max}} < 0.9 \)                               |
| \( \leq 0.5 \)  | \( \mu_{\text{max}} \leq 0.5 \)                | \( \mu_{\text{max}} \leq 0.5 \)                                 | \( \mu_{\text{max}} \leq 0.5 \)                                 |

As a rule, this block implements defuzzification algorithms and generates a solution at the output. To improve the quality of functioning of the system for monitoring the composition of atmospheric air, the dissertation paper proposes to expand the block by including real instantaneous data on the level of pollution of the studied atmospheric air in the decision-making process [8]. To do this, it is proposed to use the block for assessing the current state of atmospheric air. In the proposed block, the input concentrations of harmful and dangerous substances are converted into a fuzzy set using the linguistic variable \( Y \) "Average pollution level", \( T_y, [0, 1] \) by calculating the average pollution level \( R_c \):

\[
R_{cp} = \frac{\sum_{i=1}^{n} C_i}{n}
\]

As a result, the decision block receives two fuzzy sets \( R_i \) and \( R_0 \) from the forecast generation block and the current air condition assessment block, respectively [9]. At this stage a set of fuzzy rules is implemented to form recommendations for improving the quality of atmospheric air:

\[
IF R_0 = A \text{ AND } R_i = B \text{ THEN } Z = N_j.
\]

The base of rules for implementing the decision-making process is formed on the basis of a simulation model that simulates a major road intersection in a city. To obtain the necessary data, a number of studies were conducted on the effects and possible consequences of certain management recommendations to improve the quality of air polluted from the road environment [10]. To do this, we compared the values of the average level of pollution in the current situation and after the introduction of measures that affect the level of pollution (for example, changing the algorithm of traffic lights).

Figure 2 shows a structure of the decision-making system for planning the development of urban territories. In the absence of complete information about the ecological state of a city or a certain territory, the method of direct assessment was used to determine the groups of control impacts and their comparative effectiveness, and measures were ranked according to their effectiveness. Based on the obtained efficiency values, using the direct assessment method (taking into account the expected reduction in the concentration of pollutants, minimizing the amount of resources needed to perform a specific action and implemented in the shortest possible time), groups of control effects are formed and recommendations for air quality management are presented. The obtained estimates of the
effectiveness of measures to improve the environmental safety of developing urban areas were tested in a simulation environment.

3. Algorithm of the decision-making system
The initial data are concentrations of air pollutants measured at monitoring points. After determining the linguistic variables and generating undefined input data, pairs of fuzzy situations are formed using the RG analysis: first, based on the available retrospective data and, second, based on the obtained expert data. As a result, all pairs are combined into a single knowledge base.

The structure of the decision-making system consists of two fuzzy models:

- fuzzy situational system is a fuzzy "situation-action" management model. After forming the rule base and knowledge base, a fuzzy input set (fuzzification) is formed, denoted by the source or current situation. After that, the current situation is compared with the situations from the knowledge base and the greatest degree of equality of situations is determined. After determining the maximum degree of equality, the second value from the knowledge base is selected (the fuzzy set "pollution level"), which is the input data for the non-clear system [11].
- fuzzy system implements the classic Mamdani algorithm with the exception of the fuzzification block, since the input is already a fuzzy set.

The task of making decisions on air quality management can be reduced to determining the most effective alternatives (control solutions) when the i-th environmental situation arises and develops on the j-th territory. Let's assume that there is a certain set of environmental measures, from which one event is selected to implement the task of air quality management, the purpose of which is to reduce the concentration of pollutants to an acceptable level.

![Figure 2. Structure of the decision-making system for planning the development of urban territories.](image-url)
4. Simulation results
The developed software package calculates carcinogenic and non-carcinogenic risks from air pollution with harmful and dangerous substances. The software package includes a graphical module for generating forecast values for the user, as well as the ability to save them to a database for further processing.

The obtained estimates of the effectiveness of measures to increase the level of environmental safety in the decision-making process when planning the development of urban areas were tested in the environment of simulation of air pollution from the road environment.

Figure 3 shows the working window of the simulation environment in which traffic flow and associated air pollution are realized. The model was developed for a section of the transport network at the intersection of Dimitrov street and Leninsky Prospekt in Voronezh. This model was implemented to test the control actions generated by the decision-making system. Thus, before forming final recommendations, testing is conducted to calculate the effectiveness of the proposed impact. For example, figure 3 shows a graph of changes in the concentration of CO$_2$ before the introduction of the control action and after-control occurs by changing the interval of the green traffic light on the main highway. Note that the lower the main traffic flow at the intersection, the lower the concentration of CO$_2$ in the atmospheric air.

![Figure 3. Simulation environment for traffic flow simulation.]

The system of decision-making in the conditions of urban development is formed in the form of an interactive environmental Atlas (figure 4), created on the basis of web-technologies, and implements the following indicators:

- results of statistical processing of data from laboratory studies of the state of atmospheric air;
- results of visualization of environmental statistics;
- assessment of the state and dynamics of atmospheric air pollution related to health risks;
- predictive models of the state of the air environment in a geographically distributed system of the region;
- assessment of the trend and rate of change in the levels of General morbidity among the population;
- classification of monitoring air sampling points based on cluster analysis.

The system of social and hygienic monitoring should provide the solution of three main tasks: analysis of the existing situation; formation of options for solving the problem; reasonable choice of programs to improve environmental well-being.
The interactive Atlas includes two modules: a first-level module and a second-level module. The first-level module is intended for a specialist who enters data for processing in formation for subsequent presentation of the result of environmental analysis. The second-level module, intended for users, displays ready-made data in the form of map information.

References

[1] Larionov N, Larionov M, Siraeva I, Gromova T, Ermolenko A and Zavidovskaya T 2018 The meaning of the phytotoxicity of the soils of transformational landscapes in the southeast of Russia Proceedings of the International Conference on Contemporary Education, Social Sciences and Ecological Studies (CESSES 2018) 18.2018.204

[2] Information and statistical Bulletin "Transport of Russia" 2019 01-09

[3] Feng S and Xu L D 1999 Decision support for fuzzy comprehensive evaluation of urban development Fuzzy Sets and Systems 105(1) 1-12

[4] Loyko A O, Gusev S A 2019 Decision making system for industrial companies IOP Conference Series: Materials Science and Engineering (IOP Publishing) 665 012-007

[5] Rutkovskaya D, Pilinsky M, Rutkovsky L 2013 Neural networks, genetic algorithms and fuzzy systems (Hotline-Telecom) 351

[6] Yarushkina N G 2004 Fundamentals of the theory of fuzzy and hybrid systems (Moscow, Finance and statistics) 214

[7] Balli S, Korukoglu S 2009 Operating System Selection Using Fuzzy AHP and TOPSIS Methods Mathematical and Computational Applications 14(2) 119-30

[8] Weng Q nad Yang S 2006 Urban air pollution patterns, land use, and thermal landscape: an examination of the linkage using GIS Environmental monitoring and assessment 117(1-3) 463-89

[9] Lin H Y, Hsu P Y Sheen G J 2007 Fuzzy-Based Decision Making Procedure for Data Warehouse System Selection Expert Systems with Applications 32(3) 939-53

[10] Ivashchuk O A and Ivashchuk O D 2013 Automation and intellectualization to control the ecological situation in the urbanized territories IEEE 7th Int. Conf. on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS) 2 814-9

[11] Verzilin D N, Mamonov S A and Corbunova I R 2013 Modelling coherent and self-organization behaviour of social and economic system XVI Int. Conf. “Dynamical System Modeling and Stability Investigations” (Kiev, Ukraine) pp 29-31