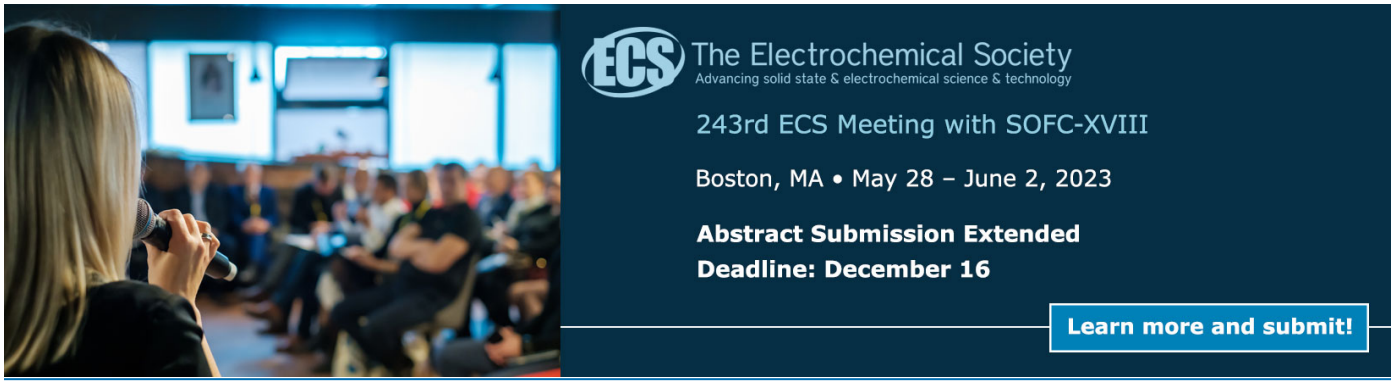
The potential of digital economy framework to tackle sustainability challenges in urban area



The potential of digital economy framework to tackle sustainability challenges in urban area

D V Polevoi and I B Mamai[1]

Federal Center of Theoretical and Applied Sociology of Russian Academy of Sciences, 24/35, Krzhizhanovsky Street, Moscow, 117218, Russia

[1]E-mail: ibmamai@mail.ru

Abstract. Natural systems and techno-systems form ecosystems of urban areas that are holistic and ordered in time and space. In the context of digitalization, the assessment of the quality of the urban environment necessitates a system analysis, which will make it possible to trace the changes in each factor of anthropogenic load, and to determine the dynamics, patterns and vectors of these changes. The existing approaches to the analysis of the urban environment have a low classification accuracy due to the a priori fuzzy partitioning of the space of anthropogenic load signs. Mathematical and software support for an intelligent system for determining anthropogenic load in the digital economy based on methods of evolutionary calculations and pattern recognition has been developed.

1. Introduction

Industrialization and urbanization are social phenomena, their factors and patterns create contradictions between the natural harmony of the biosphere and human needs. Cities are man-made results of social development, but they are mounted as subsystems in a global ecosystem - the biogeosphere, changing the structure and properties of natural ecosystems. It is necessary to systematically manage socio-economic and ecological processes in urbanized ecosystems to maintain their viability and comfort for residents in the context of digitalization. Technologies for ensuring sustainable development of large urban agglomerations have long attracted the attention of specialists. Computer technologies for determining the anthropogenic load in urban areas make it possible to increase the reliability of assessing the stability of an ecosystem and the functional efficiency of its correction [1, 2].

The known methods of geographic information systems [3, 4] are mainly of a model nature, since they do not take into account the cross section of recognition classes that characterize various states of the ecosystem and arbitrary initial conditions for the formation of images. Therefore, the main way to increase the functional efficiency of the system for determining the anthropogenic load in urban areas from images is to provide it with the adaptability property based on machine learning. One of the promising approaches to solving this problem is the use of ideas and methods of intelligent systems, which are based on maximizing the resolution of the decision support system (DSS) in the process of its training [5, 6]. In the works [7, 8], a learning algorithm for the system for determining anthropogenic load based on the image of the ecosystem was proposed within the framework of the DSS technology, but the asymptotic recognition reliability was not high enough. It is advisable to use an evolutionary approach to teaching DSS for video-computer diagnostics and correction of anthropogenic load, using fragments of the ecosystem image in urban areas.

2. Structuring of anthropogenic load elements and their classification

Natural systems and techno-systems form the ecosystems of megalopolises, which are spatially-ordered aggregates of natural and man-made elements that function as unified systems. The ecosystem of a megalopolis is a set of forms and states of interaction of the components of the natural environment with engineering objects and systems at all stages of their functioning. Assessment of the state of the urban environment implies the following tasks:

- analysis of the current state (analytical stage);
- forecast of the future state (forecasting stage);
- an interpretation that synthesizes the first two stages (synthesis stage).

Ecosystems have a greater or lesser, positive or negative impact on the environment, landscape, people, despite all the forecasts in the phase of their design. However, it is equally important to take into account the possible impact of ecosystems, especially their biotic component. Retrospective analysis is necessary to assess the state and quality of the urban environment, which will allow tracing changes in each factor and their components in the process of city development, as well as determining the dynamics, patterns and vectors of these changes. A systems approach to the analysis of urbanized ecosystems, as highly complex artificial formations, allows us to investigate the most general properties of regularities, and to identify chains of causes and effects of individual phenomena.

Determination of anthropogenic load on the ecosystem was initially considered as a purely ecological problem [9, 10]. The practical value of these works lies in the structuring of the load elements and their classification depending on the load level. This allows you to form an input mathematical description of computer diagnostic systems.

In [11, 12], decision support systems were developed that establish the correspondence of fragments of ecosystem images to various load states. At the same time, methods such as the Bayesian classifier, artificial neural networks, and fuzzy methods of knowledge representation and output are used to recognize the load. The main disadvantage of the considered methods for recognizing the state of the ecosystem is that they do not take into account the initial conditions for the formation of images and the influence of uncontrollable factors. In addition, the relationship between the ecological and socio-economic states of the ecosystem of urban agglomerations is not taken into account. The common main disadvantage of the methods is the use of structural or distance measures of similarity, which reduces the reliability of the classification in conditions of a priori fuzzy partitioning of the feature space into recognition classes.

In [13, 14], the application of the information-theoretic approach to the recognition and tracking of the state of the ecosystem and its structural elements is considered. In this case, the information measure is used as a criterion for the diversity of objects. At the same time, the problem of information synthesis of the system for recognizing the state of the ecosystem by the combination of factors of digitalization of the economy of urban agglomerations was not considered.

Thus, in order to eliminate certain shortcomings, it is promising to create, within the framework of the information-theoretic approach, intelligent systems for determining the anthropogenic load in the digital economy based on the ideas of machine learning and pattern recognition. This will make it possible to provide the property of adaptability in conditions of a priori uncertainty.

3. Information synthesis algorithm for solving sustainability problems in urban areas

The task of information synthesis for determining the state of the ecosystem of urban areas can be formulated as follows. Let there be an alphabet of recognition classes characterizing various states of the ecosystem and a training matrix of images of individual urban areas for different stages of digitalization. A structured vector of DSS training parameters is known. It is necessary at the stage of training DSS to optimize the coordinates of the vector by searching for the global maximum of the alphabetically averaged recognition classes of the principle of optimality. At the diagnostic stage, it is necessary to make a decision on whether the instance belongs to one of the classes of the given alphabet. The main task of the basic algorithm for information synthesis of the DSS is to optimize the geometric parameters of the partition for a given system of control tolerances for the signs of recognition of

anthropogenic load. For the analysis of the stability of urban areas, it is proposed to restore hyperspherical containers of classes of anthropogenic load recognition in the space of signs. In this case, the optimal radius of the container of the recognition class is determined as the maximum combination of the optimality principles.

The input information for training DSS is a multidimensional matrix $\| x_{ij} \|$ of brightness of the pixels of the receptor field of the ecosystem image, as well as a system of control tolerance fields α_i for recognition signs and the level of selection β_j of coordinates of reference binary vectors-implementations of recognition classes. In addition, the structure of the coordinates of the vertices of rectangular fragments of the ecosystem image is set.

The basic information synthesis algorithm consists of the following stages:

- A binary training matrix $\| y_{ij} \|$ is formed from a fragment of the image, the elements of which are equal to one if $y_{ij} \in \alpha_i$, $i = 1,..., N$, $j = 1,..., M$.
- An array of reference binary vectors y_i is formed, the elements of which are equal to one if $\overline{y_i} \in \beta_i$, $i = 1,..., N$.
- The nearest neighbor is searched for each class Y_i.
- Optimizing the code distance $f(y_i \oplus y_k)$, $k = 1,..., N$ using the Hamming metric.
- The procedure ends when the maximum combination of the principle of optimality is found in the working area of determining its function.

$$D_l = \left(\frac{\sum_{i=1}^{S} \left(f_{il} - f_l^+ \right)^2}{\sum_{i=1}^{S} \left(f_{il} - f_l^- \right)^2} \right)^{\frac{1}{2}}, \quad (1)$$

where f_{il} is the set of radii of concentrated hyperspheres, the center of which is determined by the vertex of the reference vector f_l^+ and f_l^-. In this case, the set f_{il} is also the set of training steps for the recognition system.

Thus, the main function of the basic learning algorithm in the framework of the DSS is to calculate the optimality principle (1) at each training step and to organize the search for its global maximum in the working area to determine the optimal geometric parameters of the containers of the recognition classes. To solve the global optimization problem, it is proposed to use genetic algorithms [15, 16].

The analysis of test samples of characteristics of the ecological and socio-economic load on the ecosystems of megalopolises is carried out. As shown by the study, the first and second reliability exceed the errors of the first and second kind, respectively. Learning outcomes for ecosystems with a stable development of the level of digitalization show the possibility of forming relevant decision rules. This indicates a high degree of similarity between ecological and socio-economic factors of anthropogenic load on ecosystems. Thus, the proposed learning algorithm makes it possible to build decision rules that are able to determine the diversity between the ecological and socio-economic characteristics of the load on the ecosystem.

Analysis of the load factors on the ecosystems of urban areas, obtained at various stages of digital transformation, makes it possible to track the dynamics of changes in the value of the objective function during the formation of decision rules throughout the entire period. A conceptual scheme for correcting sustainability problems in urban areas has been developed. The scheme consists of four areas corresponding to the objective typology of the state of ecosystems of urban agglomerations: socio-

economically unstable; environmentally unstable; socio-economically stable; environmentally stable. The use of this method of displaying anthropogenic load makes it possible to observe the correctness of the decisions made, the effectiveness of individual stages of solving the problems of sustainability in urban areas.

Software has been developed that implements a conceptual scheme for correcting sustainability problems in urban areas. Using the developed software, an analysis of the anthropogenic load on the ecosystem of the city of Moscow over the past 20 years of digitalization was carried out.

During the first five-year period, the indicators of anthropogenic load worsened. This is indicated by an increase in the value of the objective function during the formation of decision rules. After that, the objective function, and hence the difference between socio-economic and environmental indicators, gradually decreased. At the second five-year stage, there was no deterioration of the anthropogenic load, but at the third stage, there was a certain inhibition of the load process. This is indicated by insignificant changes in the value of the objective function during the formation of decision rules at the third stage relative to the second stage. At the fourth stage, there was a decrease in anthropogenic load.

4. Conclusion

Scientific and methodological approaches to the diagnosis and correction of anthropogenic load have been developed to solve the problems of sustainability in urban areas. A training matrix was formed based on the factors of environmental and socio-economic load on the ecosystem of the city of Moscow. An algorithm is proposed for calculating the information measure between these characteristics in order to determine their significance. A comparison is made of the maximum values of information measures obtained when optimizing the training parameters of the decision support system, depending on the stages of digitalization of the economy of the city of Moscow. The use of the environmental characteristics of the load is more effective, since the socio-economic characteristics in the digital economy have an unstable resolution.

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