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OPERATIONAL CONTROL OF CITY ENGINEERING NETWORKS BASED ON ARTIFICIAL INTELLIGENCE SYSTEMS

Abstract: This article proposes a situational approach to the construction of intelligent decision support systems for the operational management of city utility networks. This approach is based on the use of a directed weighted graph of fuzzy situations. The situational fuzzy control algorithm presented in the article is based on the expert method of forming and evaluating alternatives to management decisions and the structural generality of the oriented graph of the fuzzy situational network.

Keywords: city utility networks, intelligent decision support system, fuzzy situational network, structural generality of a fuzzy situational network, fuzzy situational algorithm

Introduction

From the point of view of control theory, any large city is a complex non-stationary spatial system. It is characterized by two main features: the dependence of the parameters of control objects on their spatial location and the variability of these parameters over time. The study of such objects that are sufficiently universal to obtain practically significant results, taking into account the fact that experimental influences on them for various reasons (limited time frames, danger of irreversible changes, high cost of experiments, etc.) are usually impossible or undesirable, can be performed practically only by methods of modeling possible situations.

The functioning of a modern city is based on a complex of various means of ensuring the life of citizens and the work of organizations, including city utility networks (GIS), providing a centralized supply of electricity, heat, gas, water, etc.

Today, large cities (especially megacities) contain a very complex configuration of urban utility networks (gas pipelines, water pipelines, sewerage, etc.). As a consequence, ensuring the smooth operation of city engineering networks (CEN) is an extremely difficult task. The CEN manager makes operational decisions in a complex environment characterized by the following problems [1]:

— uncertainty and inconsistency of information about the emergency situation that has arisen in the work of the CEN;

— dynamics of changes in emerging emergency situations in CEN;

— aging of information used for decision making;

— compromise between economic benefits for the city and the quality of services for residents of decisions made by the dispatcher;

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- multiple decision-making options;
- responsibility for a single decision.

Taking into account the above, decision-making requires a lot of psychophysiological tension from the dispatcher, the consequence of which may be that the dispatcher makes erroneous decisions. The real way out of this situation is to use decision support systems (DSS). It is obvious that in this case it is impossible to build a DSS based on mathematical models. Hence, the most suitable method for implementing effective operational decisions is an intelligent decision support system (IDSS) of a situational type, the general structure of which is presented in Fig. 1.

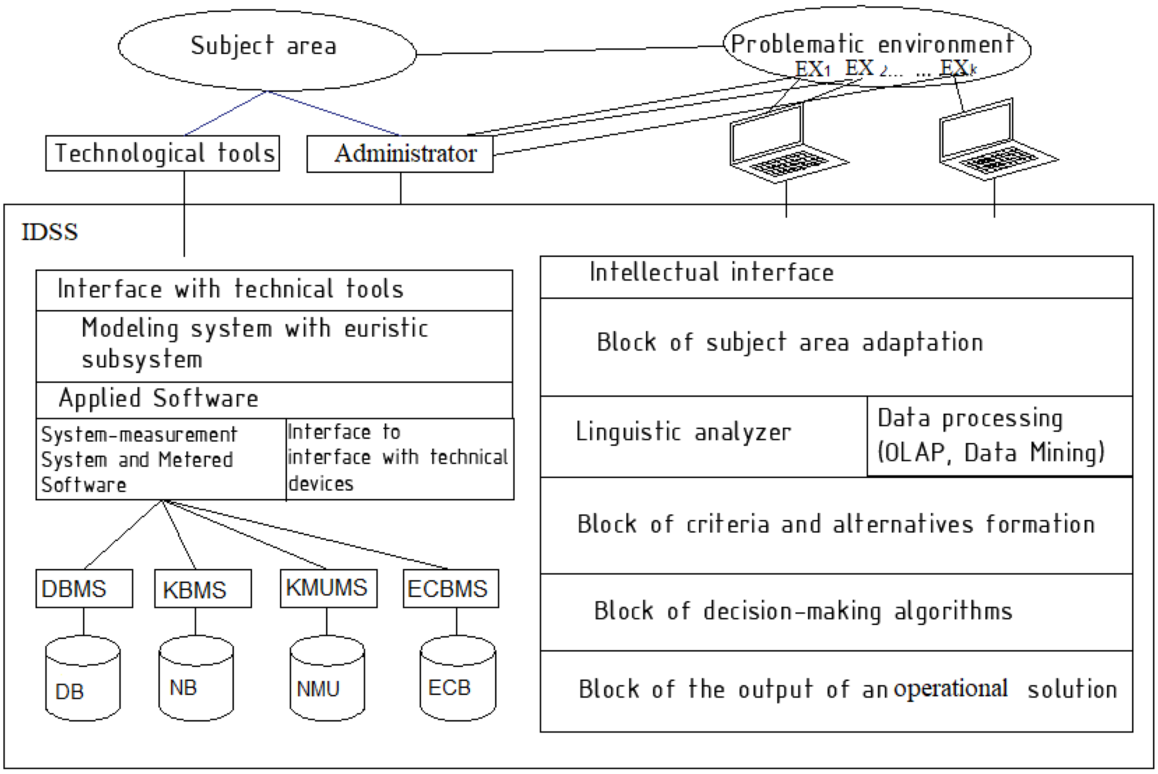

Fig. 1. Generalized structure of IDSS (DBMS, KBMS, KMUMS, ECBMS - management systems of database, knowledge base, knowledge model update, evaluation criteria base, respectively; EX_1, EX_2 ,…, EX_K – experts of problematic environment)

Statement of the problem

Let the current situation that has arisen in the CEN be described as a fuzzy situation of the following form:

$$S_k = \{M_{S_k}(x_i)/x_i\}, \;\; x_i \in X, \tag{1}$$

where $M_{S_k}(x_i)$ – membership function of the linguistic variable x_i, characterizing the current situation S_k.

Since each linguistic variable corresponds to the j-th term from the set of terms in the knowledge base, formula (1) can be written as:

$$S_k = \left\{ M_{M_{S_k}}(T_j^i)/T_j^i \right\}, \ \ x_i \in X, j = 1, M, \ \ i = 1, N. \qquad (2)$$

T_j^i – j-th term of the i-th linguistic variable.

The task of operational control of the CEN dispatcher is to identify the emergency situation that has arisen and optimally transfer it to a given normal situation.

Review of existing desizions

Uncertainty and a large number of contradictory factors are an integral part of the decision-making processes for most urban entities, including CEN [4]. Uncertainty is associated with the impossibility of fully taking into account the influence of the external environment on the current situation in CEN. The inconsistency is associated with an ambiguous assessment of the current situation in CEN and errors in choosing the priorities of the right management decisions for it.

It is extremely difficult and practically impossible to reduce the tasks of operational CEN management associated with a large volume of uncertain and contradictory information to precisely set goals. One of the common ways to remove uncertainties and inconsistencies in current information is the subjective assessment of a specialist (expert, manager) in the subject area, which determines his preferences. Subjective assessment has now turned out to be the only possible basis for combining heterogeneous physical parameters of the problem being solved into a single model that allows one to evaluate solution options. Taking into account the factor of subjectivity of the decision maker (DM) in making a decision violates the fundamental principle of operations research methodology: the search for an objectively optimal solution. Recognition of the decision maker's right to subjectivity of decision is a sign of the emergence of a new paradigm, characteristic of another scientific direction - decision-making under many criteria. On the other hand, when making decisions based on many criteria, there is also an objective component. Typically, this component includes restrictions imposed by the external environment on possible solutions (availability of resources, time constraints, environmental requirements, social situation, etc.) [1,2,8,9].

Hence, the use of IDSS is an effective tool for making operational management decisions using specialized information warehouses (Data Warehouse) and OLAP (On-Line Analytical Processing) technologies for operational data analysis (Data Mining), as well as the ability to model and forecast various situations in GIS [5- 7]. In addition, the use of IDSS makes it possible to solve the problem of multicriteria, taking into account the restrictions imposed by the external environment on possible operational management decisions (availability of limited resources, time constraints, environmental requirements, social

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situation, etc.) [8-10]. Of particular interest in this subject area are IDSS based on distributed artificial intelligence. Research in this direction is currently following the path of intensive theoretical research and applied development aimed at creating integrated intelligent systems based on the concept of multi-agent systems (MAS) of distributed artificial intelligence [11-13]. Among the existing IDSS, situational type IDSS should be especially highlighted, built on the basis of fuzzy logic [14-16], which work effectively in the above-mentioned conditions of a given subject area. Below we propose IDSS CEN, built on a fuzzy situational network (FSN), as the basis of a situational algorithm for the operational management of a CEN.

The solution of the task

This article proposes to build a IDSS CEN based on a fuzzy situational fuzzy network (SFN) [2,3]. In this case, decisions are formed by logical-analytical processing of data about the situation that has arisen with its subsequent translation into a given standard situation based on the fuzzy situational algorithm proposed in the article. IDSS CEN provides, in dialogue with an expert, automated configuration for a specific GIS by entering into the system basic concepts, attributes, their possible values, connections between them, as well as types of possible situations. The model of the functioning process of a city infrastructure subject is specified in the form of a set of “standard” situations, which represent a fuzzy situational network (FSN), a fragment of which is shown in Fig. 2.

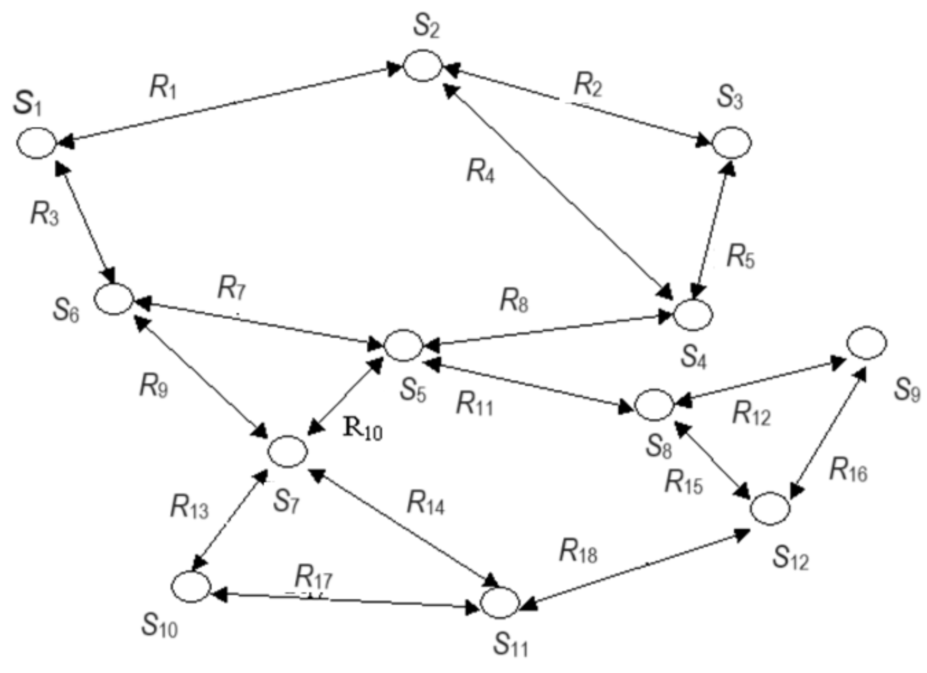

Fig. 2. SFN IDSS CEN of situational type

Taking into account the specifics IDSS CEN of the situational type, in the subsystem of accumulation, storage and updating of information, appropriate requirements must be formulated for the main structural unit of this subsystem - the knowledge base (KB). This concerns the system of concepts, the adequacy of the content and compliance of the formulated knowledge with the processes being studied and suitability for performing the required actions. A holistic description of the situation by experts of a specific management object in CEN is ensured if there is a complete set of indicators characterizing this situation.

We believe that in the knowledge base of the IDSS CEN there is a certain set of standard fuzzy situations $s_q = (s_1, s_2, \dots, s_Q)$. By specifying one of the selected proximity measures, we can define some fuzzy relationships between situations, not only in relation to the current s_k but also between those existing in the knowledge base of a given subject area.

As a measure for determining the degree of proximity of fuzzy situations, we will use the degree of fuzzy inclusion of the fuzzy situation s_k in the standard fuzzy situation s_q . The inclusion threshold is determined, like the membership functions, in the normalized range [0,1] as follows:

$$t_{in} \in [\alpha_{min}, 1],$$

where α_{min} – the lower limit of the range of inclusion degree, usually $\alpha_{min} = 0.6 – 0.7$.

In this case, we can talk about how fuzzy the features of the current situation s_k are fuzzyly included in the fuzzy values of the corresponding features of the standard situation s_q .

For the knowledge base of the IDSS CEN and the operating conditions of the CEN in various operating modes, we form standard situations for which control actions are developed in detail. The connection between typical standard situations in IDSS CEN clearly presented in the form of an FSN (Fig.2). In this case, a possible transition from one standard situation s_q to another s_l is carried out using a certain solution $R_i = R_{ql}$, characterizing the degree of costs normalized in the range [0,1] during a mutual transition from s_q to s_l and vice versa [2,3].

The general structure of the situational type IDSS can be interpreted for our case in the following form (Fig. 3), where the solid line shows the information exchange between the modules of the IDSS CEN.

The work of the IDSS CEN is as follows. The current situation that has arisen is compared in the knowledge base with existing standard situations for maximum approximation to some of them. If such a standard situation is found, then a potentially best alternative (PBA) is selected from the set of alternative control solutions for it and implemented for the current situation [17]. If such proximity is not detected, then the current situation that has arisen is processed accordingly in the “Generation and expert assessment of alternatives” subsystem. After this, the PBA is determined and its dynamic assessment is carried out in the subsystem “Modeling and forecasting the development of the situation.” If the assessment is positive, the corresponding control decision is formed in the “Synthesis of Control Actions” subsystem, after which this situation is transferred to the standard category.

The algorithm for implementing a fuzzy situational control decision in the ISSS is shown in Fig.4 and is shown as a dotted line in Fig. 3. The implementation of a fuzzy situational algorithm for taking control action is as follows 6:

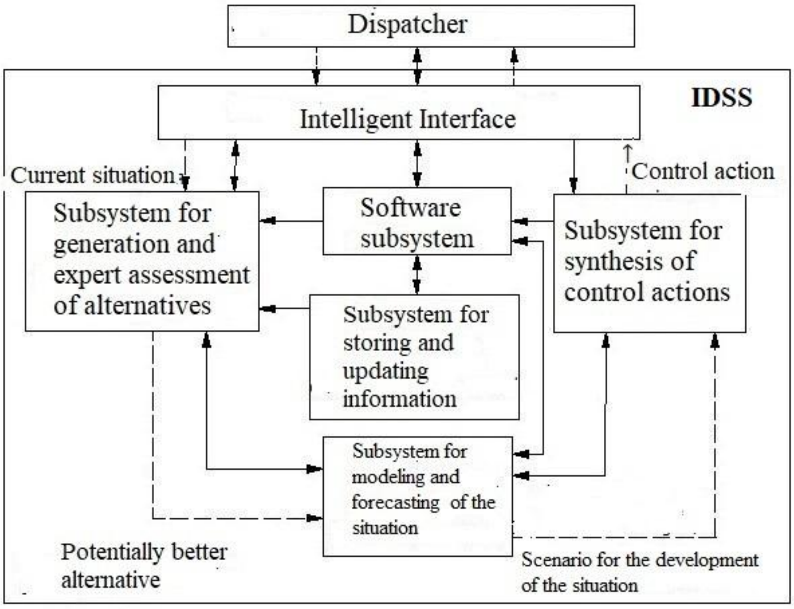

Fig. 3. Information connection between modules of the IDSS CEN

Block 1 contains information about the current situation in the CEN. In the most general case, information about the current situation is characterized by both quantitative and qualitative parameter values. In block 2, the current situation is compared with a set of standard situations located in the knowledge base (KB) and characterized by the same set of parameters as the current one. Thus, this block contains a certain set of possible situations for which the degree of proximity to the current situation can be calculated. In block 3, the degree of similarity between the current situation and similar standard situations from block 2 is calculated. Block 4 determines the standard situation closest to the current one. In block 5, control decisions are generated that correspond to the standard situations selected in block 4. In blocks 6 and 7, the effectiveness of control actions is ranked in descending order in a subset of selected standard situations and the optimal one is determined among them. In block 8, the optimal control solution and the corresponding situation are entered as standard into the knowledge base about the functioning of the corresponding GIS object. It should be noted that blocks 5-8 are implemented using the method of mixed assessments of alternatives proposed by the authors in [12]. In block 9, the driving mode is adjusted taking into account the current situation. Block 10 contains the current situation in the expert environment (ES) and the knowledge base of this subject area. In block 11, possible control actions are requested from experts in a given subject area, which are also placed in the knowledge base. In block 12, specialists in this subject area are asked questions about possible situations that could lead to the choice of control action, which is generated by them, and is also entered into the database.

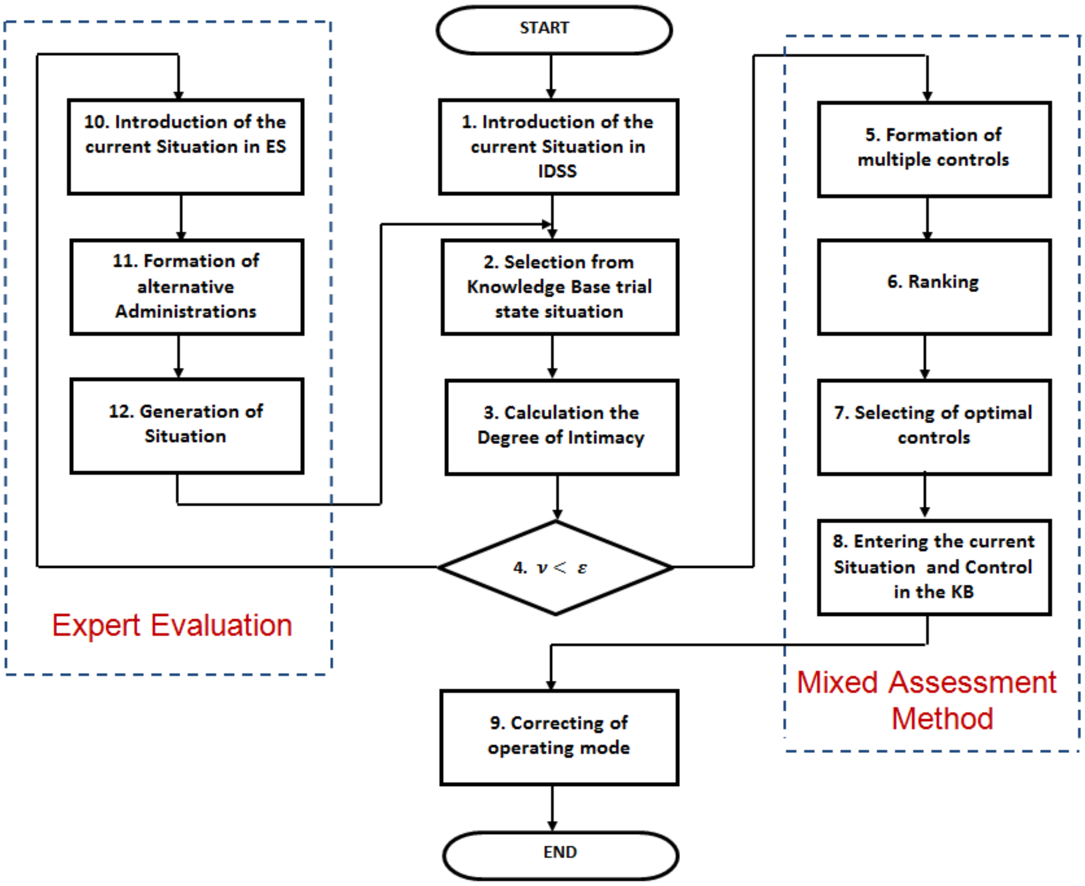

Fig. 4. Scheme of implementation of a fuzzy situational algorithm

In addition, when the external operating conditions of a certain CEN subject change, it may be necessary to move from one standard situation to another. The strategy of such a transition is described by the optimal route along the FSN from the initial situation s_q to the target situation s_l. Transitions are determined by decisions R_i, which correspond to a certain degree of cost. Since the total number of situations and transitions between them in the GIS, and accordingly in the FSN, can be very large, to simplify the task of finding the optimal strategy for the optimal transition in the FSN, it is proposed to use the FSN compression method based on the definition of “community structures”. Structures of the community Q_i that have non-empty intersections with each other are called neighboring, and the set of vertices of the area of intersection of two neighboring structures is called the transition region of the community structures [15]. We use the minimum total costs as an optimality criterion. The path that has minimal costs is considered optimal. We will show the essence of the proposed approach based on the FSN compression method for the given FSN fragment using the following example.

An example of determining the optimal path in an NSS network using the structural commonality method

Let us assume that for a fragment of the NSS (Fig. 2) the structures of the generality of situations with the costs of mutual transitions have the form shown in Fig. 4. Determine the optimal transition from situation s_2 to situation s_9. Since $O_2 \cap O_9 = \emptyset$ (empty set), it is impossible to go from s_2 to s_9 using one local control solution. Since there are not a single pair of vertices adjacent to each other from among those belonging to O_2 and O_9, we proceed to searching for the shortest of all possible paths between all pairs of vertices of the sets O_2 and O_9. Hence the shortest path is $L_{min} = (O_2, O_3, O_6, O_7)$. Moving on to the transition points of neighboring structures of the common path L_{min}, we obtain the optimal transition strategy: $C_{opt}(s_2, s_9) = (s_2, s_4, s_5, s_8, s_9)$. The desired path in Fig. 5 is highlighted with a double line.

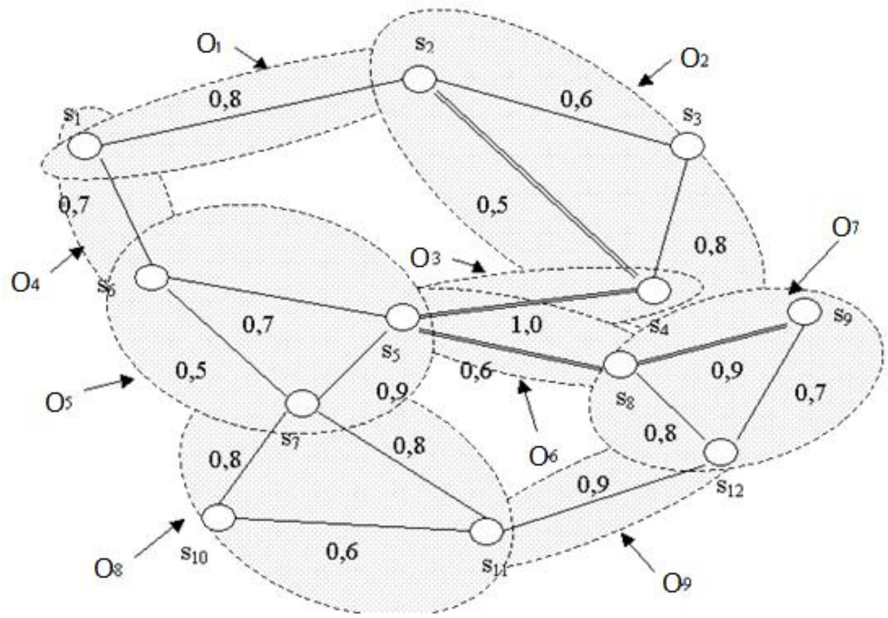

Fig. 5. Community structures of the FSN IDSS

Conclusion

The approach proposed in this article to constructing a situational type GIS IDSS based on a fuzzy situational network is universal and can serve as a powerful incentive for the creation of intelligent information technologies and the development of effective management systems for various types of infrastructure entities on the territory of a municipality [18]. The situational fuzzy control algorithm presented in the article is based on the expert method of forming and evaluating alternatives to management decisions and the structural generality of the oriented graph of a fuzzy situational network.

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