Situational management of urban engineering networks with intelligent support for dispatching decisions

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Abstract. To improve the efficiency of urban engineering networks management, an intelligent system for supporting dispatching decisions (IDSS UEN) proposed, based on a situational approach using fuzzy logic. The developed algorithm for situational fuzzy control is the basis of the IDSS UEN and is based on the original method of mixed estimates of alternatives and fuzzy situational network UEN

Keywords: urban engineering networks, weighted graph of situations, intelligent decision support system, fuzzy situation management algorithm.

1 Introduction.

The work of the dispatcher of urban engineering networks (UEN) (power grids, gas pipelines, water pipes, sewers, etc.) is an extremely difficult task [1, 4, 5].

Decision-making by the UEN dispatcher takes place in a complex environment characterized by the following difficulties [2]:

-impossibility to get reliable, complete and accurate information about an emergency;

-the transience of changes in emerging situations in UEN;

-obsolescence of information used for decision making;

-the presence of a large number of factors;

-a multivariate approach to decision-making;

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

-responsibility for the sole decision;

It is known [1-4], when a large amount of initial information used for decision-making, the quality of decisions significantly reduced. Research shows that decision-makers without additional analytical support tend to use simplified and contradictory decision-making rules. In this sense, effective decisions of the dispatcher in the work of UEN largely depend on the capabilities of technology and software tools that implement methods and methods of intellectual support for decisions. The use of the intellectualization tools, which based on the experience of experts in this subject area, can significantly improve the efficiency of UEN operation.

The most appropriate method for implementing effective solutions is an intelligent decision support system in urban engineering networks (IDSS UEN), built on a situational approach using fuzzy logic [4, 6].

2 Problem statement

It knew [7] that the decision-making task (DMT) can represent as:

$$DMT = \langle T, A, Q, Y, F, G, D \rangle, \tag{1}$$

where: $\boldsymbol{T}$ – problem statement; $\boldsymbol{A}$ – the set of alternatives; $\boldsymbol{Q}$ – a set of selection criteria (evaluating the effectiveness of solution options); $\boldsymbol{Y}$ – multiple methods for measuring relationships between options; $\boldsymbol{F}$ – mapping a set of valid options to a set of ratings; $\boldsymbol{G}$ – the system preferences of experts; $\boldsymbol{D}$ – a decision rule that reflects the preference system.

Assume that the current situation that has developed in the process of UEN operation described as a fuzzy situation of the following type [9]:

$$S_{TEK} = \{ M_{S_i}(x_i) / x_i \}, x_i \in X, \tag{2}$$

$M_{S_i}(x_i)$ – the function of belonging to a linguistic variable x_i , that characterizes the current situation S_{TEK} .

Also, assume that for each linguistic variable x_i corresponds to the j-th term of the set of terms in the knowledge base. Then the formula (2) can be written as:

$$S_i = \{ M_{M_{S_i}(x_i)}(T_j^i) / T_j^i \}, j = \overline{1, M}; i = \overline{1, N}; x_i \in X, \tag{3}$$

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

To determine the current state of urban engineering networks it is necessary to compare this fuzzy situation with each fuzzy situation from a certain set of existing situations in the knowledge base of this subject area $S = (S_i, \ldots S_K)$ The result of the comparison should be a dispatcher's decision on the strategy for further UEN management with the involvement of IDSS. If the current situation is "regular", the control implemented automatically according to the existing algorithm for this situation. If occurs in an "emergency" situation, the IDSS will help you choose a management strategy that is close to this situation, or, if one is not found, form a new management strategy.

3 Literature review

Decision-making in most cases consists of generating possible alternative solutions, evaluating them, and selecting the best option. In most cases, the choice of the optimal solution made under conditions of information uncertainty and conflicting factors. Uncertainties in a particular subject area can be divided into uncertainties associated with incomplete knowledge of the problem solved and uncertainties associated with the inability to fully account for the state of the environment [4, 5]. Inconsistency occurs due to ambiguity in the assessment of situations, errors in the choice of priorities, which greatly complicates decision-making. Research shows that decision-makers without additional analytical support tend to use simplified and sometimes contradictory decision-making rules. In this case, the most effective tool for making a potentially better decision is decision support systems (DSS). DSS provides assistance decisions make in the analysis of initial information (assessment of the current situation and restrictions imposed by the external environment). DSS provides identification and ranking of priorities, take into account the uncertainty in the estimates of the decision-maker and forming preferences, generation of possible solutions (forming a list of alternatives); evaluation of possible alternatives; analysis of the possible consequences of the decisions taken; selection of the potentially best solution [6,21].

Formalization of methods for analysis and generation of solutions, their evaluation and coordination is quite a difficult task. Its solution made possible due to the widespread use of computer technology and largely depends on the capabilities of technical software tools that implement methods and methods of intellectual support [8].

The decision-making process can proceed according to two main schemes: intuitive-empirical (based on comparing the problem situation with similar situations that have previously occurred) and formal-heuristic (based on building and researching a model of the problem situation for this particular subject area).

Under building a model of a problem situation, we examine the structure of the DSS, which determined by such elements as the state of the initial data of the problem, the model of the decision-making situation, restrictions, decision options, and their consequences, and external factors of an objective and subjective nature. The combination of these elements forms a specific environment (system). In other words, a DSS is a system that provides the decision-maker with the data, knowledge, conclusions, and/or recommendations necessary for making a decision [10].

Considering the existing conceptual models of the DSS, the authors identify approaches based on the use of the ideology of information systems, artificial intelligence, and the instrumental approach.

Within the framework of the ideology of the information approach, DSS classified as a class of automated information systems whose main purpose is to improve the activity of knowledge workers in organizations by using information technology.

Within the framework of the ideology of intelligent decision support systems (IDSS), knowledge-based systems differ significantly from similar systems, primarily expert systems (ES), in their target orientation [3, 19]. IDSS designed to help decision-makers solve problems, and ES designed to replace people in solving specific problems [3, 18].

The tool approach, depending on the specifics of the tasks to be solved and the technological tools used, we take into account applied DSS, which serve to support decision-making for individual applied tasks in specific situations. Application DSS are packages of software tools for searching and issuing data, modeling, etc., which used by developers to create specialized systems and objects.

Modern IDSS based on the use of specialized information storage (Data Warehouse) and OLAP (On-Line Analytical Processing) technologies - operational data analysis. The main purpose of OLAP technologies is dynamic multidimensional data analysis using an effective data-mining tool, modeling, and forecasting [2.20].

4 Building an IDSS based on a fuzzy situational network

The degree of proximity of a fuzzy situation S_{TEK} and situation $S_k\left(k=\overline{1,K}\right)$ from the knowledge model determine as:

- degree of fuzzy enabling a fuzzy situation S_{TEK} in a fuzzy situation S_k;
- the degree of fuzzy equality S_{TEK} and S_k;
- degree of the fuzzy community S_{TEK} and S_k;

Setting one of the chosen proximity measures, we can set some fuzzy relationships between situations, not only about the current one STEK but also between existing ones in the knowledge base of this subject area.

From this subject area, the most convenient measure of proximity can be considered the degree of fuzzy inclusion of the situation, which characterized by a certain threshold of inclusion determined by the expert, based on the conditions in which the work of urban engineering networks takes place. The inclusion threshold is defined, as well as the membership functions, in the normalized range [0, 1] as follows:

$$t_{on} \in \left[\alpha_{\min}, 1\right] \tag{4}$$

$\alpha_{\min}$ - the lower limit of the range of the degree of inclusion, usually $\alpha_{\min} = 0.6/0.7$. In this case, we can talk about how fuzzy signs of the current situation S_{TEK} are included in the fuzzy values of the corresponding signs of the situation $S_k(k=1,K)$ [4, 15].

Further, for the existing knowledge base of this subject area and the conditions of GIS operation in different operating modes, we form typical "regular" situations for which control actions on the UEN are developed in detail on the expert methods. In this case, the possible transition from one "regular" situation S_k to another S_i carried out using some R_{ki} solution. In this case, each possible solution determined by the degree of preference for this solution $\gamma_{kl}(S_k, R_{kl})$ In this way, you can build a fuzzy situational network (Fig. 1), which clearly shows possible transitions from one "regular" situation to another and the degree of preference for these transitions [10, 15].

It notes that both the knowledge base of this subject area and the situation network are evolutionary and are periodically updated both when a new "regular" situation appears (in fact, this is a variant of the "non-standard" situation developed by experts) and new requirements for the UEN operation.

As a result, based on the knowledge base of this subject area and conditions robots UEN fuzzy situational network is a fuzzy directed graph, whose vertices correspond to existing "regular" fuzzy situations, arc-weighted possible solutions required to transition situations, and degrees of preference of these decisions (fig.1).

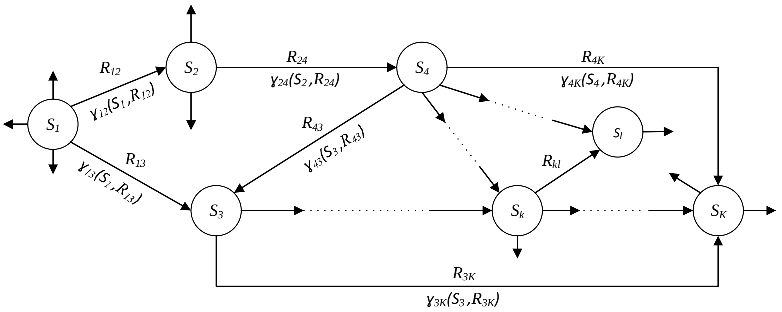

Fig. 1. Fuzzy situational network

The degrees of preference for solutions in each situation either unchanged and determined by an expert survey, or depended in some way on the situation and determined by the preferred solution in this situation. The control solution corresponding to the current state is a sequence of decisions necessary for the transition from the current situation to a given target situation along the "optimal route" in a fuzzy situation network. The criteria for minimizing time and/or energy costs can be used as a preference for solutions in the case of UEN. Then the "optimal route" corresponds to the minimization of the total time and/or energy costs when moving along this route. In this case, you can use the dynamic programming method.

Thus, the output of the solution is divided into setting a goal (target situation) and building a management strategy that corresponds to the optimal translation of the UEN to the target state. This conclusion of the decision is valid if the current situation can be included in one of the "regular" situations.

Otherwise, if the current situation has a degree of fuzzy inclusion less than αmin in the formula (4), then this "non-regular" situation presented to the experts to bring it to the rank of "regular" and form variants of transition situations. Thus, the existing fuzzy situational network corrected, which ensures its evolution. In fig.2 shown a block- scheme of the IDSS UEN containing the main blocks (modules) of the software: a knowledge base (KB), a block for generating control solutions, a block of hints, a knowledge acquisition block and an intelligent interface presented.

The intelligent interface combines linguistic, information, and software tools for interaction between the dispatcher, knowledge engineer (analyst), and UEN experts with the corresponding components of the Toolkit. The hint block is intended to show, if necessary, in a form that is understandable to the dispatcher, the progress of the" reasoning" (working scenario) of the output mechanism to justify the management decision made by it.

Before the main work, IDSS UEN creates a knowledge base (KB). KB UEN includes two components: long-term knowledge about UEN, which can be represented as a set of rules of logical inference, hierarchical frame structures, semantic networks, or other information structures that combine the above; operational knowledge (operational data) that describes the current situation.

Note once again that the UEN database is evolutionary and is periodically updated either with new information in this subject area or with the emergence of new situations in the management of UEN.

The formation KB of the UEN is as follows. In the knowledge acquisition block, goals (sub-goals), criteria, requirements, and working conditions of the GIS formed. Next, the term sets of the domain formed based on the descriptors of this domain, i.e. UEN, which defined according to the work [11].

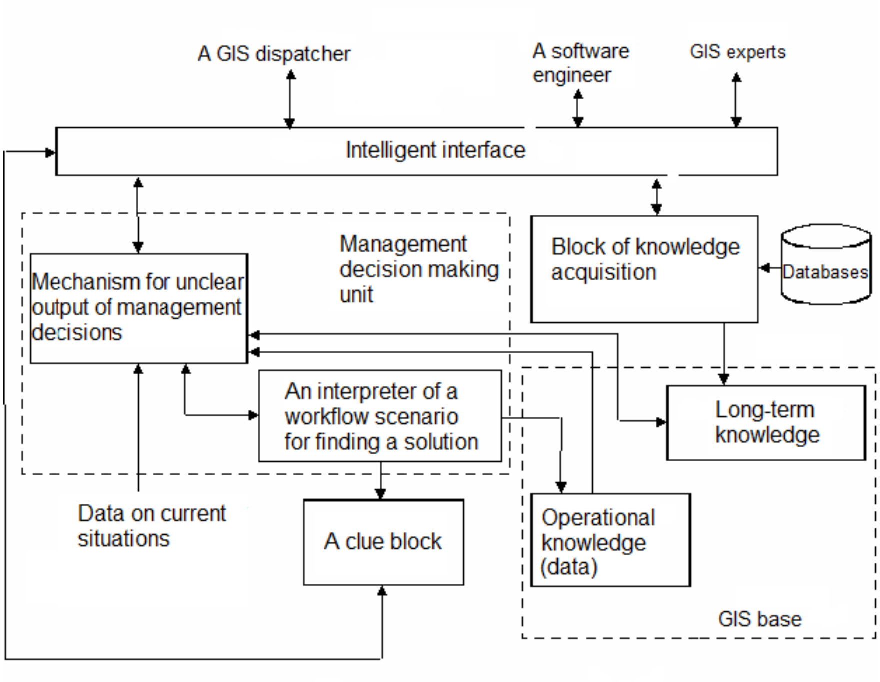

Fig. 2. Block-scheme IDSS UEN

From the selected set of descriptors, the most significant ones are selected, which are used in the software module according to the work [12] for the intelligent multi-agent subsystem (IMS) for searching information on the Internet, which one of the main components of the database (DB), for accumulating the UEN knowledge base. In this IMS synthesizes a generalized model of data collection and analysis based on a genetic approach and a multi-agent method for synthesizing decision trees and a neural network [13] that uses the decision-making specificity index. The decrease in search time in IMS is due to an algorithm for selecting control solutions that use estimates of sets of types of situations and specifics of logics, rather than the sets themselves. Improving the quality of information achieved at each iteration by selecting behaviors with a high frequency of use and cutting off the area of superposition estimates by the logic specificity index and the situation index, which increases the level of ontological representation of information.

Information obtained from the Internet and other sources based on latent semantic analysis form the most significant content of the UEN KB [11] following the purpose and conditions of the UEN operation.

Next, a fuzzy situational network of this subject area, i.e. UEN, built in the interpreter of working scenarios for finding solutions in the block for generating control solutions. To do this, we extract a set of "regular" fuzzy situations from the UEN database, for which possible transitions between situations are determined based on information about the goals/sub-goals of GIS work, criteria for work, and requirements for UEN work. The result is a fuzzy situational network that is a fuzzy oriented weighted graph. The fuzzy situational network, as the KB UEN periodically updated with new information, clarifying objectives, criteria and the emergence of "nonstandard" situations missing BRS in GIS, i.e. in effect, the training of IDSS UEN.

The mechanism for fuzzy inference of management decisions based on operational data about the current situation, based on long-term knowledge, predicts the actions required by the current situation, planning a step-by-step working scenario for finding a solution. The block for forming management decisions implements the fuzzy situational management algorithm shown below (Fig.3) [15].

5 The algorithm of fuzzy situational control

In fig.3 shows a block-scheme of the UEN fuzzy situational management algorithm, which, if an "emergency" situation occurs, will help you choose a management strategy that is close to this situation, or, if one is not found, form a new management strategy.

In block 1, enter information about the current situation in the GIS, which characterized by many factors. In this case, some factors entered into the system automatically based on the readings of the corresponding measuring instruments, and some are targeted monitoring information. In General, information about the current situation will be characterized by both quantitative and qualitative values of factors. In block 2, the situation compared with a set of "regular" situations that are in the knowledge base (KB) and characterized by the same set of factors as the current one. Thus, this block allows you to limit the number of possible situations for which you need to calculate the degree of proximity to the current situation. This will significantly reduce the running time of the algorithm. In block 3, the degree of proximity $\nu = t_{on}$ of the current situation is calculated and the "regular" situations from block 2 that are close to it are determined. Determining the degree of proximity of fuzzy situations necessary to provide the required data for the algorithm for selecting control solutions that operate on the control decision matrices stored in the database of "regular" fuzzy situations. In block 4 compares the calculated degree of proximity $\nu = t_{on}$ (the degree of belonging) to the specified normalized inclusion interval according to the formula (4), where $t_{on} = \xi$. This makes it possible to select the "regular" situations that are closest to the current one.

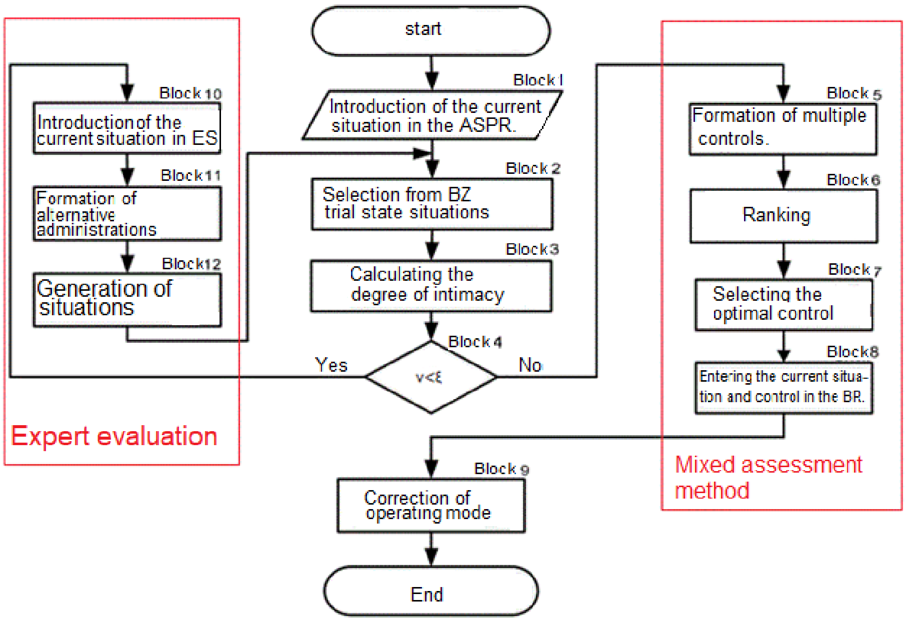

Fig. 3. Block-scheme of the fuzzy situational control algorithm

In block 5, management decisions generated that correspond to the "regular" situations selected in block 4. In blocks 6.7, the effectiveness of control actions ranked in descending order within a subset of selected "regular" situations and the optimal one is determined among them. In block 8 the optimal control and the corresponding situation are entered as "regular" in the knowledge base about the functioning of the UEN. In block 9 the operation mode is adjusted to take into account the current situation and the criteria for the effectiveness of the UEN.

In block, 10 the current situation is placed in the expert environment (ES) and the knowledge base of the subject area. In block 11, possible control actions are requested from experts in this subject area placed in the knowledge base. In block 12, possible situations and relevant management decisions generated and entered into the knowledge base. On the method of mixed assessments developed by the authors, new "regular" situations are formed and entered into the knowledge base about the functioning of UEN.

6 Mixed assessment method

The proposed method differs from the known methods PARK, ZAPROS, ORCLASS, and SHNUR [14] in that the entire set of alternatives evaluated for each criterion at once. The main stages of the method include:

Stage1. Construction of a set of hypotheses-bases $\{Z_i\}$ corresponding to a set of criteria $\{K_i\}$and a set of hypotheses-consequences $\{z_{ij}\}$ corresponding to a set of criteria values.

Stage2. Formation of quantitative and linguistic scales of criteria for evaluating alternatives.

Stage3. Drawing up a block structure of the questionnaire and filling it out on the hypotheses-bases and hypotheses-consequences.

Stage4. Normalization of scales of criteria for evaluating alternatives.

Attributes that form alternatives to A_i contain both numeric (quantitative) and linguistic (qualitative) variables. The membership function μ:x→[0,1] quantitatively grades the membership of elements of the set of alternatives A to the fuzzy set $\overline{A}$, with normalized variables, i.e. $\widetilde{A} = \{(x, \mu_A(x)) | x \in X\}$.

A value of 0 means that the element not included in the fuzzy set, and 1 means that the element is fully described by the given set. Among the most well-known and used auxiliary functions, the most convenient and universal for the variables under consideration is a triangular function of the form [7,18]:

a) for the max-min preference scale of the A_i alternative

$$\mu(x_{ij}) = \begin{cases} 0, if \ \ x \le a_{ij}; \\ \dfrac{x_{ij} - a_{ij}}{b_{ij} - a_{ij}}, \ if \ \ a_{ij} \langle x \langle b_{ij}; \\ 1, \ if \ \ x \ge b_{ij}, \end{cases} \tag{5}$$

where $a_{ij} = x_{\min\ ij}; b_{ij} = x_{\max\ ij}$

б) for the min-max preference scale of the A_i alternative

$$\mu(x_{ij}) = \begin{cases} 1, if \ \ x_{ij} \le a_{ij}; \\ \dfrac{b_{ij} - x_{ij}}{a_{ij} - b_{ij}}, \ if \ \ a_{ij} \langle x_{ij} \langle b_{ij}; \\ 0, \ if \ \ x_{ij} \ge b_{ij}, \end{cases} \tag{6}$$

where $a_{ij} = x_{\min\ ij}; b_{ij} = x_{\max\ ij}$

Rationing of estimates of the compared alternatives carried out on the formulas (5) and (6). For this:

- for all quantitative estimates the maximum and minimum values of the variable under consideration determined;
- for all linguistic (qualitative) assessments, the maximum and minimum verbal value of the variable determined;
- the values of the criteria are determined following formulas (5) and (6).

Stage5. Identifying a potentially better alternative

The values of ratings on the normalized scale according to the formulas (5) and (6) are formed as follows:

$$vij' = \mu(ij), \tag{7}$$

where i – alternative number, j –index of the value of a quantitative or linguistic scale.

Then the sum of s-th alternative can be calculated by adding the sum of scores for each j-th question, which is summed across all issues of the i-th block and all blocks of the questionnaire:

$$r_S = \sum_{S=1}^{n} \sum_{i=1}^{m} \sum_{j=1}^{k} v_{ij}^{'} \tag{8}$$

As a result, can formulate for the initial set of alternatives As an ordered set of their ranks $R = \{r_1, r_2, ..., r_n\}$. If it is necessary to take into account the importance of a particular criterion (question), it is necessary to enter weight coefficients in formula (8), which can be determined on the known methods of expert assessments [18].

7 Modeling optimal transitions in a fuzzy situational network

Let be a weighted oriented graph (Fig.4) is a fragment of a fuzzy situational network (Fig.1). Necessary to transfer the UEN from the" regular "situation S_1 to the "regular" situation S_{10} with the minimum total value of the preference functions $\gamma_{ij}\left(S_i, R_{ij}\right), i = 1,...,10; j = 1,...,10$, which reflect the time and material costs of the transition from S_i to S_j. Numerical values of preference functions indicated on the arcs of the graph in conventional units.

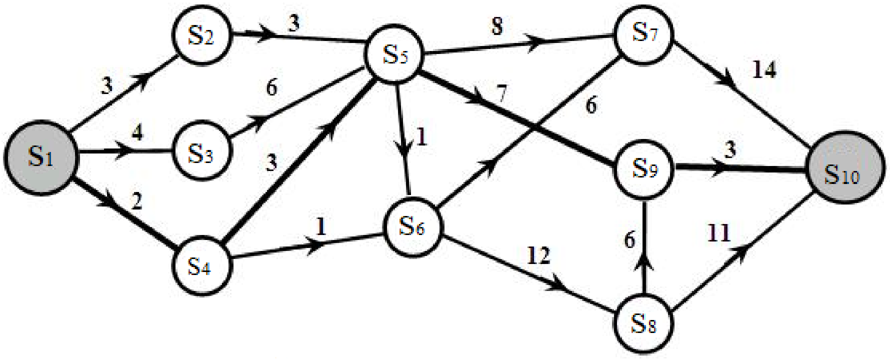

Fig.4. Fragment of a fuzzy situational network

To simplify and systematize the compilation of Bellman functions will number the vertices of Si so that the arc leaves the vertex with a smaller number. In this case, we consistently find the fi functions for each vertex of the oriented graph from the Bellman functional equation

$$f_1 = \min\{S_4 + f_1\}$$

$$f_1 = 0,\ f_2 = \min\{S_{21} + f_1\} = \min\{3 + 0\} = 3,$$

$$f_3 = \min\{S_{31} + f_1\} = \min\{4 + 0\} = 4$$

$$f_4 = \min\{S_{41} + f_1\} = \min\{2 + 0\} = 2,$$

$$f_1 = \min\left\{\begin{matrix} S_{54} + f_4 \\ S_{53} + f_3 \\ S_{52} + f_2 \end{matrix}\right\} = \min\left\{\begin{matrix} 3 + 2 \\ 6 + 4 \\ 3 + 3 \end{matrix}\right\} = 5$$

$$f_6 = \min\left\{\begin{matrix} S_{64} + f_4 \\ S_{65} + f_5 \end{matrix}\right\} = \min\left\{\begin{matrix} \underline{1+2} \\ 1+5 \end{matrix}\right\} = 3,$$

$$f_7 = \min\left\{\begin{matrix} S_{76} + f_5 \\ S_{75} + f_5 \end{matrix}\right\} = \min\left\{\begin{matrix} \underline{6+3} \\ 8+5 \end{matrix}\right\} = 9$$

$$f_8 = \min\{S_{36} + f_6\} = \min\{12 + 3\} = 15,$$

$$f_9 = \min\left\{\begin{matrix} S_{75} + f_5 \\ S_{98} + f_6 \end{matrix}\right\} = \min\left\{\begin{matrix} \underline{7+5} \\ 6+15 \end{matrix}\right\} = 12$$

$$f_{10} = \min\left\{\begin{matrix} S_{10,7} + f_? \\ S_{10,9} + f_? \\ S_{10,8} + f_8 \end{matrix}\right\} = \min\left\{\begin{matrix} 14+9 \\ \underline{3+12} \\ 11+5 \end{matrix}\right\} = 15$$

The sum of costs for the optimal trajectory is 15 conventional units. To determine it, the fi functions viewed in reverse order. In this instance

$$f_{10} = \min\left\{\begin{matrix} S_{10,7} + f_? \\ S_{10,9} + f_? \\ S_{10,8} + f_8 \end{matrix}\right\} = \min\left\{\begin{matrix} 14+9 \\ \underline{3+12} \\ 11+5 \end{matrix}\right\} = 15$$

The minimum selected amount of 3+12=15 corresponds to the vertex S_9.

$$f_9 = \min\left\{\begin{matrix} S_{75} + f_5 \\ S_{98} + f_6 \end{matrix}\right\} = \min\left\{\begin{matrix} \underline{7+5} \\ 6+15 \end{matrix}\right\} = 12$$

When calculating f_9, the vertex S_5 selected. Continuing in the same way, we get the shortest path from a vertex S_1 to vertex $S_{10} (S_1, S_4, S_5, S_9, S_{10})$. In fig.6 arcs of the optimal trajectory shown in bold lines.

8 Conclusion

The principle of building IDSS, similar to the UEN IDSS developed in this article, is universal for other subject areas and can serve as a powerful incentive for creating intelligent information technologies and developing innovative systems for managing urban development in the territory of a municipality [14-16]. The situational algorithm of fuzzy control given in the article is the basis of the ISPR and based on the automated method of mixed assessments and the expert method of generating and evaluating alternatives to management decisions [17]. Optimal trajectories of transitions from one situation to another, taking into account the preference functions, implemented on the dynamic programming method.

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