THE INFORMATION TECHNOLOGIES IN THE TASKS OF PLANNING OF SMART CITY DEVELOPMENT

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ABSTRACT

The article defines the main tasks and stages of the planning of Smart City development. There was developed a sequence for solving planning tasks. Presented a mathematical formulation of the task of planning of Smart City development. Formalized the main steps for creating plans of the Smart City development. There was considered an example of decomposition in solving the task of ranking factors into a hierarchy and creating a multilayer model for assessing the Smart City development parameter. The energy efficiency of objects is considered as such a parameter and the process of ranking factors is described. It is shown that the use of the proposed methodology makes it possible to streamline, algorithmize and correct the procedure for expert assessment of dissimilar factors and to improve the quality of the results obtained for the formation of the decision-making process during the planning of Smart City development.

The use of the methodology proposed in the article will allow you to streamline, algorithmize and adjust the procedure for expert evaluation of various factors and improve the quality of the results obtained in the decision-making process for the development of Smart City.

Keywords: *Smart City Development, Planning, Energy Efficiency*

1. INTRODUCTION

In modern conditions, the most important tasks facing city leaders today is the creation of a "smart" urban infrastructure that would be able to provide:

- the most efficient use of natural resources while ensuring a high standard of living of the population;
- combining various trends of urban development aimed at modernizing infrastructure with fundamentally new opportunities for centralized management;
- a new level of services and security.

Such a "smart" city development strategy is based on technological advantages that allow centralized collection of various data, processing and displaying them in the form and quality that the administrative apparatus needs to effectively manage the city [1], [2]. With the use of such "smart" infrastructures, excess resource consumption can be reduced by 10-30%. This is very significant in the modern world. The implementation of the Smart City concept to ensure sustainable development is based on the intellectualization of their subsystems (energy, transport, buildings, water supply, public services). For its implementation, as a rule [3], there are several main components of Smart City:

1. Power supply and energy control: automatic and automated smart grids, and flexible distribution systems; intelligent systems for accounting and demand regulation; improving the energy efficiency of buildings and structures; introduction of ecologically clean and renewable energy types;

2. Water supply and water distribution: automatic and automated systems of water intake, water distribution; intelligent accounting and regulation systems;

3. Transport: systems of intelligent control of urban flows, as well as the quality of the road surface; development of the infrastructure of charging stations for electric transport; software and hardware systems for traffic and urban transport control (metro, trolleybuses, buses, trams);

4. Security: video fixation and video surveillance systems; systems that ensure the physical security of critically important urban infrastructure; intellectualized systems for operational and emergency services call, etc.;

5. Education and healthcare: introduction of distance learning systems, notification mechanisms on the progress of city programs, electronic registration to doctors, etc.;

6. City government: decision support systems, analysis and prediction of urban infrastructure development, services for the provision of municipal services in electronic form, open automatic data publication;

7. Residents: users of urban infrastructure and information services within the Smart City concept; information providers in the "feedback" mode [1], [2], [3].

In order to solve the tasks of effective planning of Smart City development and decision-making, it is necessary to analyze the external environment (analysis of the current situation) in which planning objects operate. The external environment is defined as a set of economic, social and political factors and subjects that directly or indirectly affect the possibility and ability to achieve the goals in planning [2], [3]. For orientation in the external environment in order to solve the tasks of planning of Smart City development, it is necessary to clearly define the main characteristics of the external environment (situation). The following main characteristics of the external environment can be determined [1], [2], [4], [5], [6]:

1. Complexity - the number and variety of factors that will influence the planning process of Smart City development;

2. The set of relations between factors, that is, the strength with which a change in one parameter (factor) affects the change in other parameters of the Smart City development plan;

3. Dynamism - the speed with which changes occur in the external environment (changes in the situation), and the speed of impact on the Smart City development plan, which is initially developed;

4. Uncertainty (weak structures).

Selection and processing of such information characteristics and analysis of information to describe the environment indicates that it is necessary to apply a systematic approach and to consider the external environment as a system or a set of systems that affect the developed Smart City development plan. Within the framework of this approach it is customary to represent any objects in the form of a structured system, to select the elements of the system, the relations between them and the dynamics of their development and the entire system as a whole. Therefore, the analysis and processing of information used to study the external environment and to accumulate the necessary information for further use at various stages of the planning of Smart City development should be considered as a necessary component of planning.

All of the above mentioned predetermined the relevance of the topic of this study.

2. THE GOAL AND OBJECTIVES OF THE STUDY

The goal of the study is to develop methods, models and procedures for analyzing information necessary to create c plans and relevant information systems that contribute to the implementation of Smart City development plans.

In order to achieve the research goal within the framework of the article, it is necessary to solve the following tasks:

1) to consider methods of analyzing and processing information in the tasks of planning of Smart City development;

2) to consider a multi-model and multi-criteria approach for solving the tasks of planning and decision-making for Smart City development;

3) to consider an example of developing a model and modifying the hierarchy analysis method to assess the energy efficiency level of Smart City development plans.

3. REVIEW AND ANALYSIS OF RESEARCH IN DYNAMIC PLANNING

3.1 Methods of analysis and processing of information in the tasks of planning of Smart City development

Analysis and processing of information is the initial stage of the planning process.

At this stage, there are investigated real processes of various nature that affect the process of creating a Smart City development plan. Ignoring this stage leads to the impossibility of creating a plan model for a specific process and its suitability for solving the planning tasks.

At the stage of information analysis and processing, the following tasks are solved:

- definition of goals and their hierarchy, as well as the number of target states and their parameters;
- establishing relations between the stages of Smart City development;
- determination of external influences and disturbances and their type, and establishing the possibility of their statistical description using specific types of random variables distribution;
- analysis and determination of the main types of risk and its indicators;
- identification of key uncertainties and methods to overcome them;
- defining the possibility of dividing the process into separate subprocesses - if the process has a hierarchical structure, then it is necessary to clearly delineate the level, to define the functions of each of them and to define the type of relations between them;
- finding knowledge about the process functioning features, and the patterns of its course;
- to assess and define the disadvantages and advantages of previously created models, as well as to determine the possibility of their modification;

The information obtained is used to assess the structure of the plan or several candidate models (alternatives), which are assessed using experimental data. When performing an analysis of the functioning of the process under study, it is advisable to use and compare information of different types. This is especially true for processes, the functioning of which may receive information with contradictions, omissions, errors and delay [5], [6].

Information analysis methods are divided into two groups [7], [8]: methods for analyzing qualitative information and methods for analyzing quantitative information. Qualitative information analysis techniques are used to identify the main goals of planning. In contrast to methods of analysis of quantitative information, based on statistical procedures, methods of analysis of qualitative information are a more complex procedure. They are aimed at studying a wide range of manifestations of the process and track not only its quantitative patterns, but are guided by the disclosure of cause-and-effect relations. The main methods of analysis of qualitative information are methods of expert assessment [9], [10], [11], methods of multi-criteria analysis [12], [13], SWOT analysis [14], [15], and situational analysis [16], [17].

A quantitative assessment of information in solving planning tasks is performed on the basis of the analysis of uncertainties and risks, statistical analysis, probable calculations, and methods of cognitive analysis carried out with the help of experts. In the process of analyzing qualitative and quantitative information in solving various planning tasks, there are determined criteria and quantitative indicators of a dynamic plan (DynPL).

The main groups of criteria used in solving d planning tasks are qualitative and quantitative ones [18], [19]. Expert assessments are used to form qualitative criteria. In the planning process, the Smart City object or its components, for example, energy and water supply systems and energy and water distribution systems, etc., are considered from the standpoint of decision making.

Experts describe the problematic situation, its clarification using possible alternative situations, the definition of a set of planning goals and a variety of plan variants. The advantages of experts on a variety of plans, goals and situations can determine different aspects of assessing the quality of plans: the degree of achievement of planning goals, deadlines, and the consumption of various resources.

In defining goals, experts can assess their relative importance and define relations between them.

For quantitative criteria, there is a division into two groups: absolute and relative criteria.

The group of absolute criteria includes goal criteria X_g, time criteria $X(t)$, cost criteria and quality criteria. The group of relative criteria consists of criteria for comparing plans and criteria for comparing alternatives when solving selection problems, as well as quality criteria for assessing plans as a whole. The general scheme of information transformation stages in the development of plans using various groups of criteria is shown on Fig. 1.

For a more efficient solution of the tasks of dynamic planning and decision-making during Smart City development and for the systematic use of a set of information technologies: IT analysis and information assessment; IT construction and analysis of plans; IT prediction and IT decision support, etc., there is proposed a method for the synthesis of information technologies.

Each information technology is based on the systematic use of instrumental methods that solve individual tasks of planning and decision-making for the development of Smart City. Groups of instrumental methods are used depending on the type and mechanism of selection and on the specific task of planning of Smart City development.

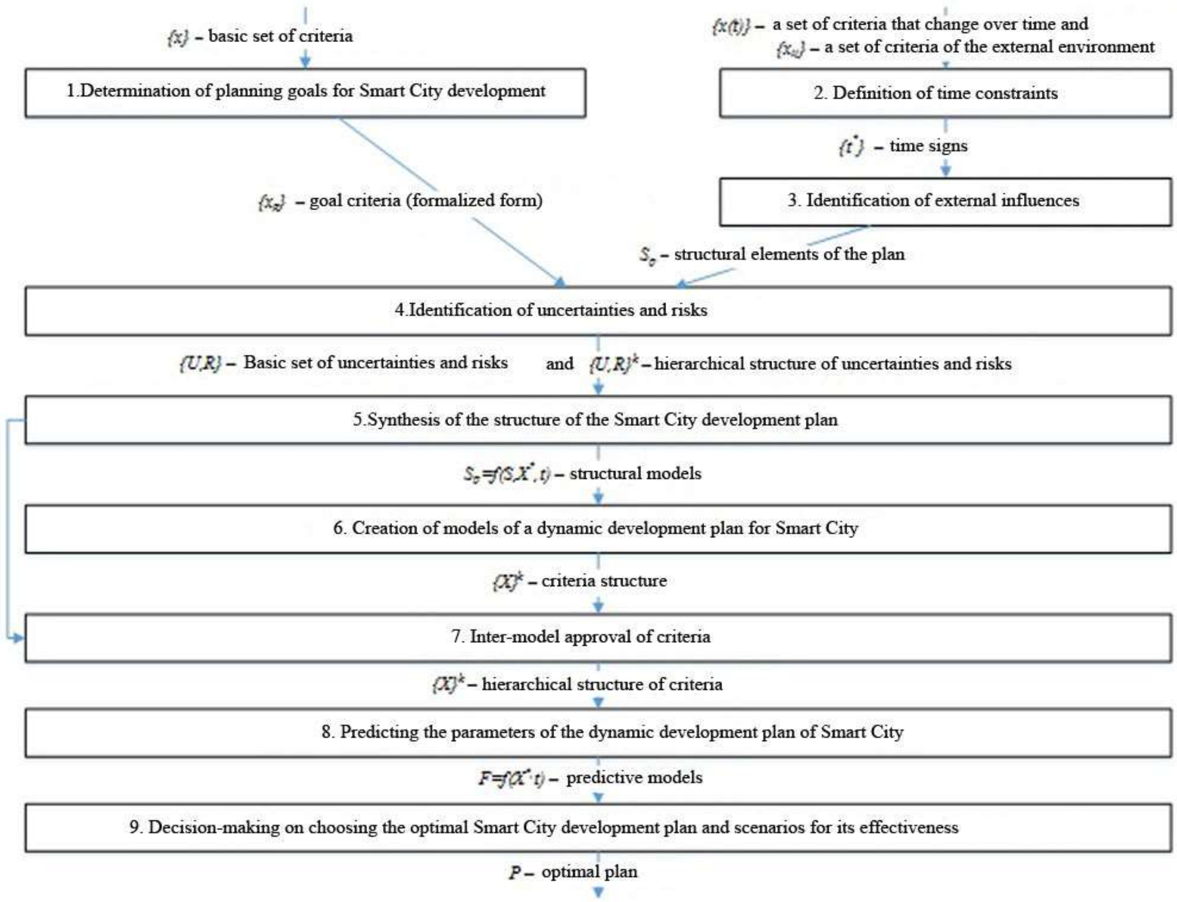

Figure 1. Information Transformation Stages Scheme In The Development Of Plans, Using Various Groups Of Criteria

Information technology for analyzing and assessing information is used for information processing tasks. At the same time, there are used methods of analysis and processing of expert information, methods of cognitive modeling, etc. The architecture of IT and software for assessing and analyzing information in the course of planning of Smart City development is shown on Fig. 2.

Information technology for modeling and creating plans for the development of Smart City is used to construct a c plan structure. At the same time, there are used graph-theoretical models, methods of analysis and calculation of

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risks, search algorithms in the space of states, modeling based on fuzzy situational nets, Petri nets (temporary and color) [3], [6], [8], [9], [11], [13], [14], [17]. In general view, the method of synthesis of information technologies for solving tasks of planning of Smart City development is shown on Fig. 3.

Information prediction technology is used for the tasks of constructing forecasts of the development of situations and predicting indicators of the plan of Smart City development.

Information decision support technology - for making decisions at different stages of planning and for choosing the optimal development plan for Smart City.

All methods can be used both separately - to solve individual tasks, and systematically to solve the tasks of planning.

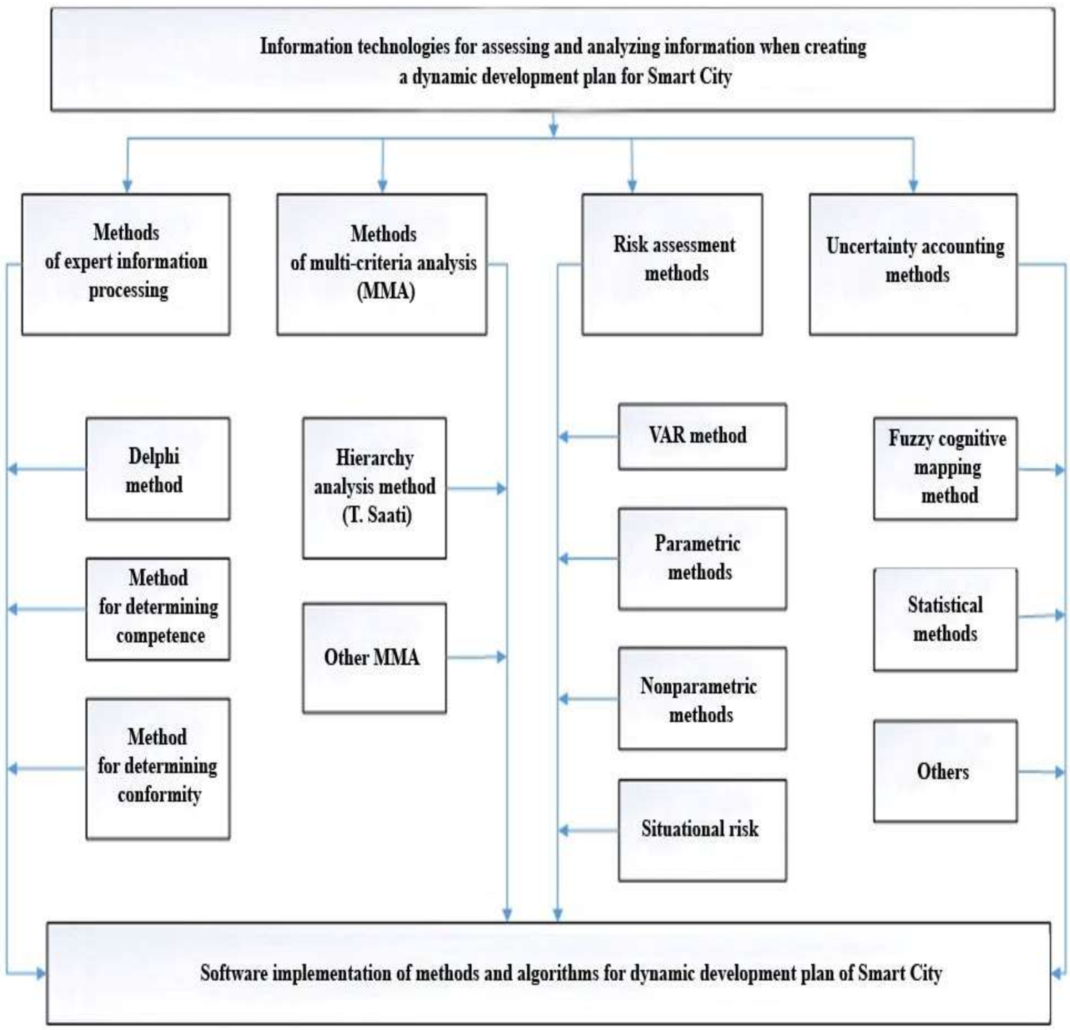

Figure 2. IT and software architecture for assessing and analyzing information during the planning of Smart City development

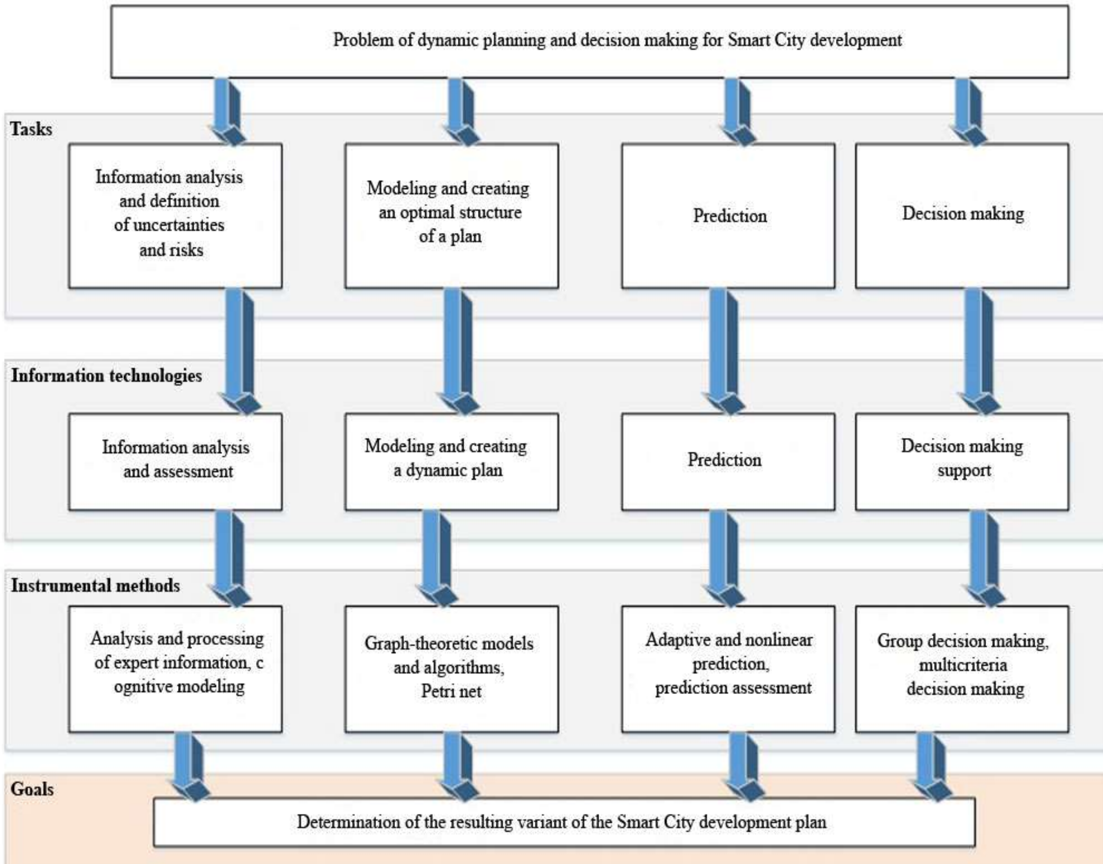

Figure 3. Information technology synthesis method for solving the tasks of planning of Smart City development

Depending on the type of tasks to be solved, the system methodology can be applied in various types of planning of Smart City development. Moreover, the proposed information technologies can be used in various sequences.

The sequence of using information technologies for various types of planning is presented in Table 1.

The Fig. 4 shows the methodology of using information technologies in solving the tasks of planning of Smart City development. The proposed method of using information technology and information technology for solving the tasks of various types of planning [3], [5], [7], [9], [18], [19] will be in the next publications.

Table 1 - The sequence of using information technology for various types of planning of Smart City development

Planning types	The sequence of creating a development plan for Smart City	The sequence of IT application
Strategic planning	Determination of the main goals and criteria for creating a plan. Forecasting development based on the main criteria. Construction of plan structures variants. Decision making to determine the best variant of strategic plan.	1. IT of analysis and assessment of information (**ITAAI**). 2. IT of prediction (**ITP**). 3. IT of modeling and creating DynPL (**ITMCDP**). 4. IT of decision making (**ITDM**). (**ITAAI** + **ITP** + **ITMCDP** + **ITDM**)

Scenario planning	Determination of the main goals, factors and parameters for creating a scenario. Construction of scenario variants. Forecasting development based on the main criteria. Decision making to determine the best scenario variant.	1. IT of analysis and assessment of information (**ITAAI**). 2. IT of modeling and creating DynPL (**ITMCDP**). 3. IT of prediction (**ITP**). 4. IT of decision making (**ITDM**). (**ITAAI** + **ITMCDP** + **ITP** + **ITDM**)
Intelligent planning	Analysis of incoming information, creating a system of planning criteria. Construction of variants for resource distribution models. Assessment of plan model variants. Decision making to determine the best variant of the resource distribution plan.	1. IT of analysis and assessment of information (**ITAAI**). 2. IT of modeling and creating DynPL (**ITMCDP**). 3. IT of decision making (**ITDM**). (**ITAAI** + **ITMCDP** + **ITDM**)

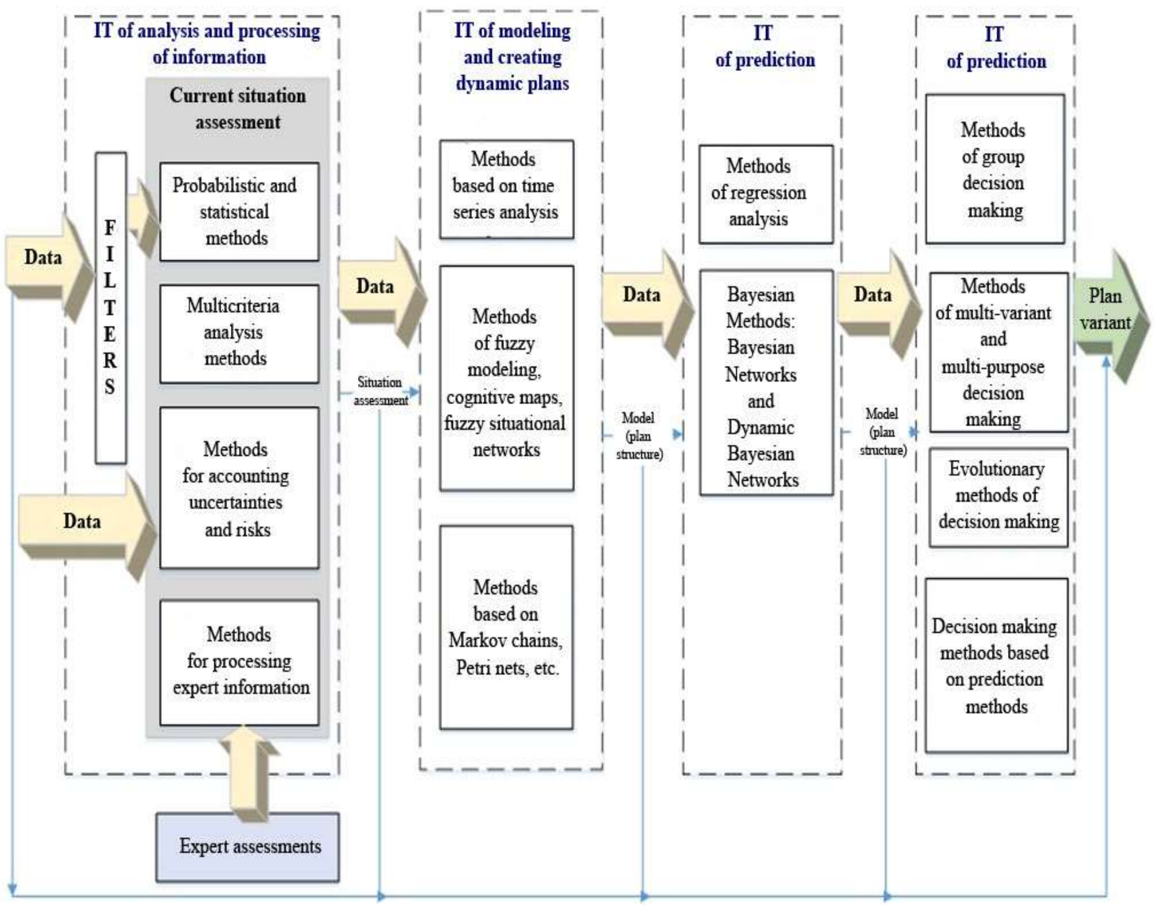

Figure 4. Methodology for using information technologies in solving the tasks of planning of Smart City development

The creation of synthesis methods based on various methods for solving complex information tasks is based on a system analysis of the applied field and on a clear definition of goals and methods for solving the tasks [18], [20], [21]. And also on the principles of multi-model and multi-criteria approach and integration of different types of information [3], [6], [9], [18], [22], [23].

The mathematical structure of the task of dynamic planning and decision-making of Smart City development has the form:

$$\begin{pmatrix} Q(S_t), S_D, P_D, \{R_i, i \in N\}, \\ \{f_j, i \in M\} \end{pmatrix} \rightarrow opt, \quad (1)$$

where $Q(S_t)-$ selection model; $S_t -$ type of structure (models in the form of a graph, differential equations for dynamic systems, predictive models, etc.); $S_D -$ space of alternative solutions. Depending on the type of models, this is a finite space of vectors or a space of vector functions that characterize the solution to the Smart City development planning task; $P_D -$ dynamic development plan for Smart City, $R_i -$ a set of relations that limit the choice in the task of Smart City development planning. They reflect the main spatio-temporal, technical and other constraints in tasks planning; $f_i -$ a set of relations of advantages that are set in space S_D and reflect the requirements for the best choice.

The formalization of the task of dynamic planning and decision-making for Smart City development is defined in terms of the theory of dynamical systems and the theory of solving problems of choice in order to determine the effective variant of the plan.

For a detailed description of the structure of the DynPL, there is used a set-theoretic model of the dynamic development plan of Smart City, which has the form:

$$P_D = \begin{Bmatrix} Gp_D, Fp_D, Xp, Cp_D, Sp_D, \\ Ep_D, Rp_D, Up_D, RSp_D, \tau \end{Bmatrix}, \quad (2)$$

where $Fp_D = \{f_1, f_2, ..., f_n\}-$ a set of functions that are implemented in a dynamic plan (DynPL) ; $Gp_D -$ a set of goals to be achieved with the help of a DynPL; $Xp -$ a set of DynPL parameters; $Cp_D -$ a set of restrictions on the input and output parameters of the DynPL; $Sp_D -$ a set of DynPL states; $Ep_D -$ a set of DynPL events; $Rp_D -$ a set of connections between events of a DynPL; $Up_D -$ a set of uncertainties when creating a DynPL; $RSp_D -$ a set of risks when creating a DynPL; $\tau -$ time parameters of a DynPL.

In order to reflect the goal presentation of the DynPL Dp, it is necessary to define two groups of indicators: Gp_D goal indicators and criteria indicators for decision making Xp.

In turn, it is extremely difficult to solve such a task in modern conditions without information and computer support, and in many situations it is simply impossible.

3.2. Multi-model and multi-criteria approach to solving planning and decision-making tasks of Smart City development

The presentation of all the main aspects in the problems of choosing effective solutions to the tasks of planning of Smart City development can be achieved using a multi-model approach, when the choice of solutions is carried out using a system of heterogeneous mathematical models. The set of different requirements for solutions leads to a multi-criteria formulation of the problem of choosing effective solutions.

Therefore, planning problems are defined and solved as tasks of multi-model and multi-criteria selection of effective solutions on a variety of mathematical models. In this case, it is necessary to highlight the following tasks [3], [6], [9], [18], [22-25]:

- selection of a set of solutions (alternatives) that are most effective for solving problems of creating development plans of Smart City under given external conditions;
- substantiation and definition of criteria for assessing effective solutions when creating DynPL and their elements and their distribution according to models;
- combining solutions (models) into a single complex for solving the tasks of dynamic planning of Smart City development, for example, for the problem of multi-criteria choice of the plan structure;
- intra-model and inter-model criteria streamlining (ordering).

In these models, the main aspects are taken into account when solving problems related to the creation of effective plans and to the selection of mathematical models, namely: determining the set of plans and determining the structure of the plan, it is also possible to optimize target functions, accounting the dynamics of changes in the state space, accounting the main uncertainties when creating the structure of the plan, as well as accounting the influence of risks - it is possible in some models completely, and in others only partially. The developed IT and software architecture for assessing and analyzing information during the d planning of Smart City development (Fig. 2) and the methodology for IT use in solving the tasks of the dynamic planning of Smart City development (Fig. 4) make it possible to describe the plan and to use these approaches in the process of creating a plan for saving data on the integral structure of the development plan of Smart City.

A multi-model and multi-criteria approach to solving the tasks of planning and decision-making for Smart City development consists of the following stages:

Stage 1. A preliminary definition of a solution Sx, which is put in accordance with the set of feasible variants of solutions SO, a mathematical model M_v, within which optimal solutions x are found.

Stage 2. Presentation of the tasks of multi-model and multi-criteria choice of effective solutions. Formalization is carried out in the form of the following mathematical structure:

$$ST^M = \left\langle \begin{matrix} B(M), \{r_i^{M(\alpha)}\}_{i\in N_1^M}, \\ \{r_i^{M(\beta)}\}_{i\in N_2^M} \end{matrix} \right\rangle, \quad (3)$$

where $M -$ a set of models within which solutions are determined when developing a development plan of Smart City; $B(M)-$ the set of all subsets (boolean) of the set M; $r_i^{M(\alpha)} -$ binary relations defined on a set that reflects the preferences for choosing a set of models (solutions) such as simplicity of models, the degree of adequacy to external conditions, etc.;

$r_i^{M(\beta)} -$ relations that set the restrictions imposed on the choice of a family of models (presentation of all the main aspects of the problems of creating effective plans, the completeness of the functions of model research, the impossibility of using one or another class of models, etc.).

The result of a choice in a mathematical structure ST^M is the element M^* of the boolean $B(M)$. That is, a subset of M: $M^* = \{m_v\}_{v\in J^*} \in M,$ where $J^* -$ set of indices of elements of the set M^*.

Stage 3. Distribution of criteria for assessing the quality and effectiveness of solutions. Distribution by models is represented as a mathematical structure of choice:

$$St^X = \left\langle \begin{matrix} [B(X)]^{M^*}, \{r_i^{X(\alpha)}\}_{i\in N^{X_1}}, \\ \{r_i^{X(\beta)}\}_{i\in N^{X_{2_1}}} \end{matrix} \right\rangle, \quad (4)$$

where $X = (x_i)_{i\in j} -$ a set of criteria by which quality indicators are assessed; $[B(X)]^{M^*} -$ a set of all presentations; $M^* \rightarrow B(x)-$ presentation that matches each model M^* with the subset of criteria; $r_i^{X(\alpha)} -$ relations reflecting the choice in the distribution of criteria by models, for example, the minimum number of criteria for each model, duplication of criteria in different models; $r_i^{X(\beta)} -$ relations that set constraints in the specified distribution (completeness of accounting all criteria in a complex of models, impossibility of representing certain criteria in one model or another, impossibility of optimizing a certain model, etc.)

The result of a choice in the structure St^X is a set of tuples of the form $\langle m^*, X_{m^*}\rangle$ which assigns a set of criteria to each model (solution) $X_{m^*} : \{\langle m^*, X_{m^*}\rangle\}_{m^*\in M^*} \in [B(X)]^{M^*}$. Combining sets of criteria X_{m^*} by all models m^* from M^* forms a coverage of the resulting set of criteria X (completeness of accounting all criteria).

Stage 4. Consistency of criteria within individual models is presented in the form of a selection of mathematical structures:

$$ST^{m^*} = \left\langle \begin{matrix} \langle m^*, X_{m^*}\rangle, PS^{m^*}, \\ \{r_i^{m^*(\alpha)}\}_{i\in N_1^{m^*}}, \{r_i^{m^*(\beta)}\}_{i\in N_1^{m^*}} \end{matrix} \right\rangle, \quad (5)$$

where $PS^{m^*} -$ set of possible rules for consistency of a group of criteria in a model $m^* \in M^*$ (rules for transition from a set of criteria X_{m^*} to the resulting preference relation); $r_i^{m^*(\alpha)}, r_i^{m^*(\beta)} -$ relations that set, respectively, advantages and limitations when choosing a rule for model consistency of criteria. The result of a choosing in the structure St^{m^*} will be rules for constructing the resulting relations of advantages $PS^{m^*}, m^* \in M^*$.

Stage 5. Consistency between models.

Stage 6. Creation of an effective solution.

Over the past decades, technological foresight has become an indispensable tool for the developed countries of the world in solving the problems of short-term and long-term planning and making strategic solutions regarding industrial and economic development. Moreover, this is typical both at the national and regional levels (in particular when planning urban infrastructure) and at the level of large organizations and companies.

Today, there is a problem of insufficiently developed mathematical apparatus for solving technological foresight problems for the development of constituent components and technologies of Smart City development. And although there are both quantitative and qualitative methods that can be used at certain stages of the foresight process, the advantages and disadvantages of each of the methods used are often not taken into account, as well as the peculiarities of the behavior of complex systems with a human factor. Note that such tasks should be solved on the basis of the system analysis methodology, which allows taking into account the entire set of necessary properties and characteristics of the objects under study. Therefore, the issue of developing methodological and mathematical support for obtaining reliable solutions to technological foresight problems is relevant. In this regard, in the next paragraph of the work, there is presented a methodological and mathematical apparatus to ensure the formalization of a qualitative method of expert assessment of such an important direction of Smart City development as energy conservation. This is necessary to obtain reliable variants of alternatives in the tasks of dynamic planning of Smart City development and the subsequent stage of implementation of the corresponding information systems based on the modernized method of hierarchy analysis.

In the past two decades, energy conservation has become a major concern for the entire world. The international community is concerned that human activities are destroying the environment, changing the climate and leading to the depletion of non-renewable natural energy resources [1]. Therefore, the relevance of energy conservation on a national scale, at the level of individual states and cities, is associated both with the need to improve the environment, and with ensuring energy security and competitiveness of national economies. Therefore, most developed countries have identified the latest technologies in the field of energy conservation and the transition to renewable energy sources not only at the country level, but also at the level of a single city as a priority of their policy, which fits into the Smart City concept. Indeed, today cities have become the main vector of economic development and have taken a central place in production, consumption network, defining social and economic relations and now provide a significant share of the gross domestic product of many countries. As for 2020, there were 30 megacities in the world with a population of 450 million. With 54% of the world's population currently living in urban areas, cities face a variety of different challenges. The total share of the world's urban population by 2050 will grow to 66% [2]. As a result, pressure will increase on available natural resources such as water, land and fossil fuels. Understanding the problem of the key importance of cities in national, regional and global development, it is necessary to impose special energy-efficient requirements on them, such as: saving resources and funds for their use, environmental friendliness and the development of renewable energy sources for urban infrastructures. Modern science has a large number of proven and justified energy conservation technologies for urban infrastructure, but in conditions of limited funding, economic instability, uncertainty of external influences, the process of choosing economically justified solutions is not easy. The city authorities are faced with the problem of choosing a set of priority energy conservation solutions, taking into account economic, technical and operational requirements. The choice of priority energy conservation tools while increasing energy efficiency is a complex multivariate task that requires effective assessment criteria as part of the dynamic planning of Smart City development.

4. AN EXAMPLE OF MODEL DEVELOPMENT AND HIERARCHY ANALYSIS METHOD MODIFICATION FOR ASSESSING THE ENERGY EFFICIENCY LEVEL OF SMART CITY DEVELOPMENT PLANS

4.1 Problem statement.

The feasibility of making effective management decisions in the context of plans for the development of energy efficiency of Smart City depends on the reasonable choice of criteria that form the factors of energy efficiency, their "weight" and significance in the set, etc. Therefore, there is occurred the question of determining the indicators of such an assessment and ranking the array of factors according to their degree of importance in decision-making models for the energy efficiency of Smart City objects. It should be noted that the system of indicators, which is formed on the basis of a set of factors, criteria and their indicators, contains a significant degree of uncertainty, which is characteristic for such systems. In addition, the choice of factors for the assessment largely depends on both the external environment (objective reasons) and the qualities and tasks that the decision maker sets (subjective reasons). Therefore, therefore there is the problem of developing an algorithm for ordering and determining the weight of individual factors based on an analysis of their internal content (a criterion set of an array of indicators), taking into account both external factors and the decision maker's requests, and the development of a global criterion for the relative values of factors.

The problem of reducing the subjectivity of the managerial decision-making process can be implemented by formalizing individual stages of the processes by taking into account and assessing quality criteria. But at the same time, the decision maker may face several problems.

First, the assessment of the situation may require the use of qualitative criteria that are difficult to formalize, so it will either be necessary to apply formalization procedures or reject such criteria.

Secondly, due to the significant formalization of the managerial decision-making process, it is necessary to have additional knowledge, skills and abilities to correctly interpret the results obtained in the calculation process. And it should be borne in mind that the complexity of the object of research puts the decision maker in front of the need to make a multi-criteria choice and to use certain software, which is not always available to the decision maker.

In addition, it can be noted that in order to simplify the decision-making procedure, it is possible to use not just individual criteria, but their groups. This will facilitate the decision-maker not only the selection process, but also the procedure for establishing interdependencies between individual criteria, because when formulating the criteria, it is necessary to take into account the fact that the achievement of optimality according to one criterion can lead to deterioration in other parameters, which are no less important.

At the same time, it is necessary to understand that it is impossible to take into account all the criteria, and not all of the formulated criteria are equivalent, taking into account the specific situation, therefore, it is necessary firstly to analyze the purpose of the assessment, the criteria by which the assessment can be carried out, and the experts involved in the decision-making process.

4.2. Modifications of the hierarchy analysis method for assessing the energy efficiency of Smart City development plans

The module for analyzing the state of energy efficiency of municipal facilities in the context of creating a development plan of Smart City at the system level involves operating with a set of assessment factors. The peculiarity is that the factors selected for the analysis include at the second level of decomposition a set of indicators (criteria), which largely determine their significance. Thus, the general description of the system at the level of the energy efficiency assessment system also includes the vectors of criteria for each individual alternative (from the space of alternatives):

$$St = \left\{F, R_{(F)}, I, R_{(I)}\right\}, \quad (6)$$

where $F = \left\{f^1,...,f^m\right\}$– a set of elements, alternatives, criteria for assessing system states (energy efficiency factors); $f^i = \left\{I^1,...,I^k\right\}$– the internal structure of a separate alternative, which is formed using a set of indicators $I^k \in I$ for each individual factor (alternatives).

The task of ranking factors for assessing their level of significance in the information system (IS) and for assessing energy efficiency should be carried out using the hierarchy analysis technique, taking into account the peculiarities of the formation of factors by their indicators [26, 27, 28].

The use of expert assessments to construct a generalized matrix of pairwise comparisons should also take into account the internal structure of factors. Thus, there will be achieved the implementation of the basic principles of the theory of systems-hierarchies, preservation and cause-and-effect restrictions.

The initial conditions for using the technique are:

1) array of factors $F = \left\{f^1,...,f^m\right\}$;

2) certain arrays of indicators for each of the factors: $f^i : I^i = \{i_1^i, \ldots, i_k^i\}$.

The task is to determine the weight of factors, taking into account the peculiarities of their formation using indicators. Thus, the ranking of the importance of factors in creating a system for assessing the energy efficiency of Smart City development will be determined by its global relative value ω_{gl}^i.

At the first stage, we will decompose and present the problem in a hierarchical form (Fig. 5).

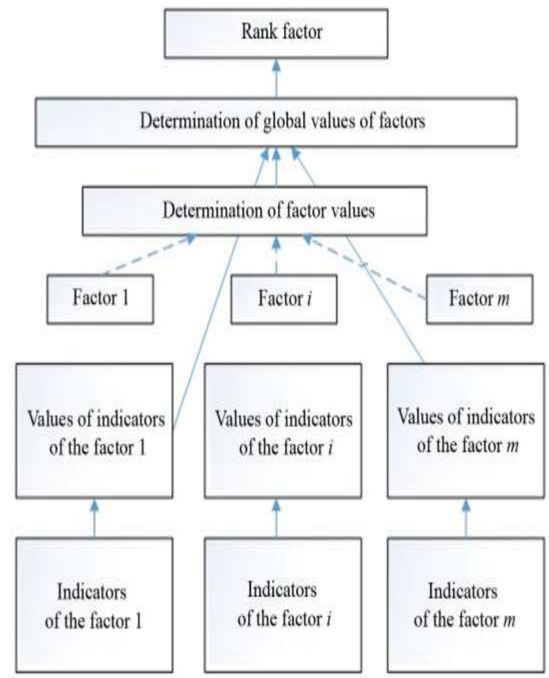

Figure 5. Decomposition of solving the task of ranking factors into a hierarchy

Based on certain factors, criteria, indicators and their relations, we will create a hierarchical form of the system for ranking factors and assessing the energy efficiency of the Smart City development plan, see Fig. 6.

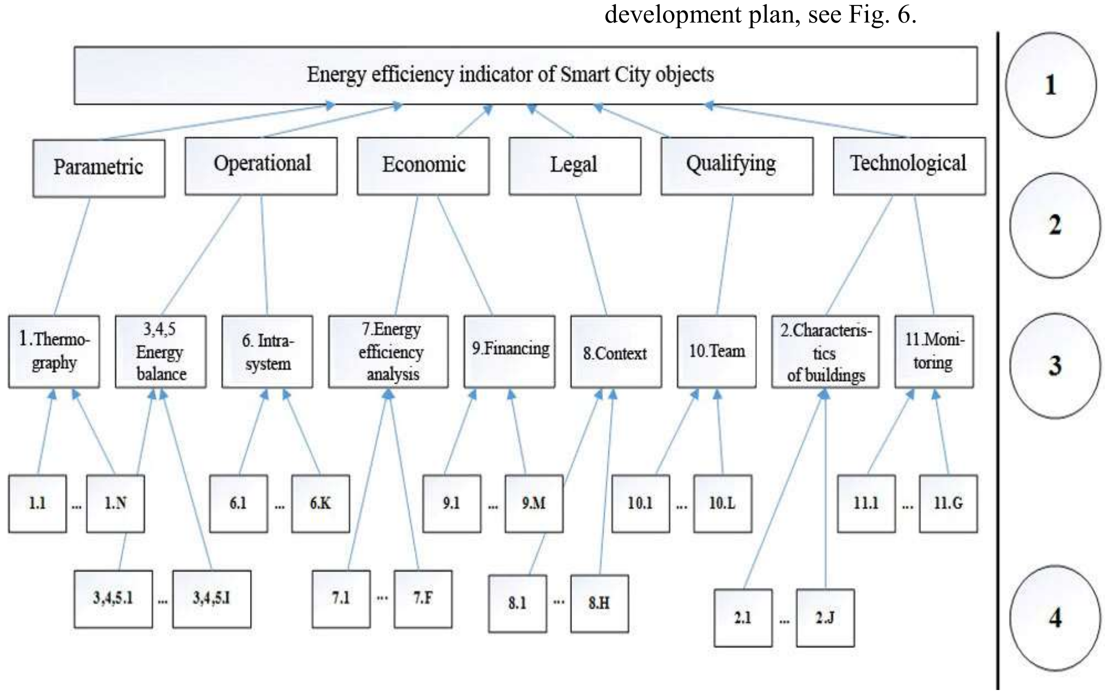

Figure 6. Hierarchical form of a system for assessing energy efficiency of an individual object or Smart City as a whole

In the given hierarchy, the following levels can be distinguished:

Level 1 - "integral assessment" - the level at which a complex indicator of energy efficiency of an individual object or Smart City as a whole is determined.

Level 2 - "the formation of groups of factors" - the level of determining the weight coefficients of the contribution of factors to the integral complex indicator of energy efficiency.

Level 3 - determination of the array of factors influencing the level of energy efficiency - determination of global indicators of the influence of factors, ranking of factors.

Level 4 - formation of an array of indicators and determination of their relative values in the formation of factors (level 3).

A hierarchical 4-step energy efficiency assessment model can be represented as 2 subsystems, each of which has its own separate functions, namely:

- subsystem 1 - ranking of factors (level 4, level 3);
- subsystem 2 - determination of a complex indicator of energy efficiency (level 2, level 1).

Subsystem 2 is designed to determine a complex energy efficiency indicator based on information from subsystem 1, in which a cognitive map is constructed (cognitive modeling module).

Sets of assessment factors and their internal structure - criteria and indicators - are largely influenced on the construction of a cognitive map for assessing the influence of factors, their ranking and the formation on their basis of a complex indicator of the energy efficiency of an object and on the process of forming decision-making in the developed information system.

A feature of data sets for analysis and decision-making is that the entire array of factors is qualitatively heterogeneous in content. And also the fact that the set of criteria and corresponding indicators is not structured both in terms of the level of influence and in terms of qualitative characteristics, which can represent various kinds of parametric technical assessments, economic indicators, qualitative characteristics, etc.

There is a problem of a generalized assessment of indicators and their relative values in order to discuss on their basis an array of factors in terms of the degree of importance (weight, significance) in the complex indicator of energy efficiency of Smart City development and the decision-making model based on it.

The process of ranking factors is advisable to carry out according to the model shown on Fig. 7.

The multilayer model is a decomposition of the problem of determining the weight of factors taking into account their internal structure - sets of indicators.

At the first level of the model, there are formed arrays of factors $F = \{f^1, ..., f^m\}$ and arrays of indicators characteristic for the research object $I^i\,\{\mathrm{I}^1, ..., \mathrm{I}^k\}$. The formation of arrays and indicators is carried out by two groups of users - a knowledge engineer (expert, experts) and a decision maker.

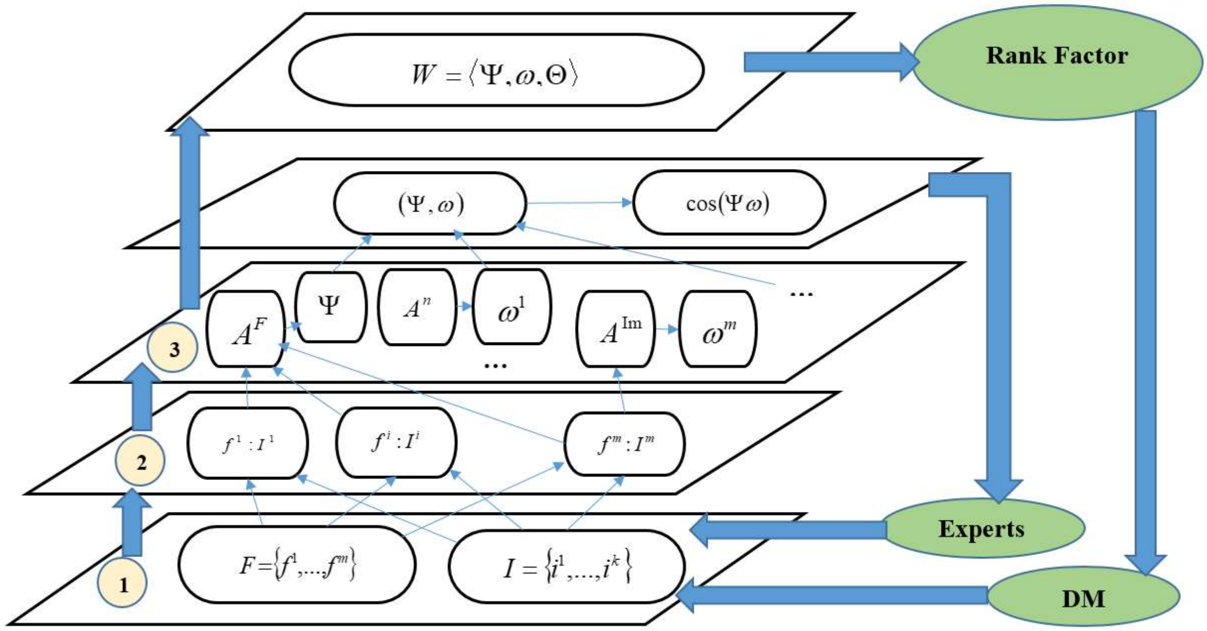

Figure 7. Multilayer model of ranking factors for assessing energy efficiency of Smart City objects

At the second level, there are determined criteria sets that characterize individual factors with their corresponding indicators $f^i : I^i = \{i_1^i, \ldots, i_k^i\}$. At the same time, within each individual factor, the set of indicators has qualitatively homogeneous indicators that are formed on the basis of groups of factors (Fig. 7).

Depending on the characteristics of the group, a factor can be characterized by sets of indicators, which are obtained on the basis of measurement results, and by indicators determined on the basis of expert assessments. Within each factorial set: $f^i : I^i = \{i_1^i, \ldots, i_k^i\}$ the task is to determine the relative values of the indicators that form it.

The purpose of this procedure is to determine the weights of influence $\{\omega_1^i, \omega_2^i, \ldots, \omega_k^i\}$ on the elements of the next levels of the hierarchy. It is advisable to implement by the method of T. Saaty [25, 28, 29] by pairwise comparison of indicators on the appropriate scale. Thus, for each individual factor f^i from the set $F = \{f^1, \ldots, f^m\}$, there will be formed a matrix of pairwise comparisons $A^i = (a_{ij}^i)$ of indicators $f^i : I^i = \{i_1^i, \ldots, i_k^i\}$, on the basis of which their vector of relative values is determined.

At the third level of the hierarchical system for assessing the integral indicator of energy efficiency, the factors $F = \{f^1, \ldots, f^m\}$ are compared and their weights $\{\Psi^1, \Psi^2, \ldots, \Psi^m\}$ are determined. The procedure for constructing a matrix of pairwise comparisons is characterized by the fact that the factorial set $F = \{f^1, \ldots, f^m\}$ includes qualitatively heterogeneous factors, the parameters of which depend on the object of study. Therefore, at this stage, it is advisable to involve qualified experts or a knowledge engineer who has the appropriate qualifications to form the matrix $A^F = (a_{ij}^F)$.

Thus, after the implementation of the third level of the system, we get a vector of indicators $W = (\Psi, \omega)$, which includes assessments of factors based on determining their weights $\{\Psi^1, \Psi^2, \ldots, \Psi^m\}$ and indicators assessments that form $\{\omega_1^i, \omega_2^i, \ldots, \omega_k^i\}$ [25, 28]:

$$W = \begin{bmatrix} \Psi^1 \begin{bmatrix} \omega_1^1 \\ \omega_2^1 \\ \ldots \\ \omega_k^1 \end{bmatrix} \\ \ldots\ldots \\ \Psi^2 \begin{bmatrix} \omega_1^m \\ \omega_2^m \\ \ldots \\ \omega_z^m \end{bmatrix} \end{bmatrix}, \quad (7)$$

where $k, l, \ldots, z-$ number of indicators which form the corresponding factor, wherein $k \neq l \neq \ldots \neq z$.

At the last level of the hierarchy, the integral (global) indicators of the weights of factors are determined taking into account their internal structure on the basis of determining the weights of the corresponding indicators $W = (\Psi, \omega)$.

The determination of global criteria based on the refinement of the weights of their internal structure is carried out using an additive convolution of the form [26-28]:

$$W_{(x_j)} = \sum_{i=1}^{m} \Psi^i \cdot \omega_{i(x_j)}^j, \quad j = \overline{1,n}, \quad (8)$$

where $x_i \in X -$ array of choice alternatives: $\omega_{i(x_j)}^j -$ weights of criteria forming alternatives;

$\Psi^i -$ the weights of alternatives estimated by the method of T. Saaty.

The method for assessing the global criterion, as a rule, is carried out in multi-criteria optimization tasks, provided that the objects of research are described by standardized criteria of the same name.

A characteristic feature of the study is precisely the diversity of criteria. That is, the assessment of factors is carried out by their own sets of indicators, which are formed within each factor separately – $f^i : I^i = \{i_1^i, \ldots, i_k^i\}$. Therefore, in order to determine the global criterion, there is proposed a new approach to using the MAI with the given case of global criterion assessment.

The main idea of constructing a modified MAI method is based on three stages:

1) the formation of consistent matrices of paired comparisons of indicators in individual factors $A^F = (a_{ij}^F)$;

2) creating a consistent matrix of factor comparisons $A(F) = (a_{ij}^F)$;

3) definition of a global criterion based on factor and indicator assessments.

The use of paired comparisons in the MAI makes it possible to correctly determine the weights of indicators and perform their ranking only if the consistency index (CI) does not exceed 10% [28]. In case of the analysis of indicators and factors that have numerical characteristics (technical parameters, experimental data, monetary values, etc.), the problem of consistency of comparisons is somewhat reduced and largely depends on expert estimates when comparing nonparametric factors. In such cases, it may happen that the obtained vectors of relative values of alternatives or vectors of weights (both indicators in the factors and the factors themselves) may have a significant degree of inconsistency in comparison with an ideal experiment.

In the context of the development of the models proposed in [26-30], we will assess the measure of inconsistency / consistency by comparing an absolutely consistent matrix and a matrix obtained by expert methods. At the same time, perfectly consistent matrix has rigidly connected elements, and for such a matrix the condition $(a_{ij})/(a_{kj}) = const$ is met for all j. Let us consider the matrix of pairwise comparisons $A^F = (a_{ij}^F)$.

The elements of the consistency matrix lie within $0 \leq uc_{ij} \leq 1$ and show the degree of consistency of each pairwise comparison to the others. An intermediate result of assessing the elements of matrix (6) is the ability to determine the minimum and maximum consistencies, their ranking, the establishment of monotonic sequences, etc.

Thus, the implementation of the proposed methodology allows, despite the sufficiently large dimension of the array of indicators within a given factor, to carry out correct pairwise comparisons with the achievement of a given consistency index (IS≤10%) and the determination of the relative values of indicators $\{\omega_1^i, \omega_2^i, \ldots, \omega_k^i\}$ that can be trusted.

It is advisable to use a similar methodology to form a consistent matrix of pairwise comparisons of factors $A(F) = (a_{ij}^F)$, based on the assessment of the degree of consistency of which

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the relative estimates of the values of factors on the factor set $\{\omega^1, \omega^2, ..., \omega^m\}$ are determined. Thus, as a result, a generalized vector of weights of the $W = (\Psi, \omega)$ form (7) is formed.

The vectors of relative values of indicators $\{\omega_1^i, \omega_2^i, ..., \omega_k^i\}$ estimate the weights of indicators that form the factors corresponding to them. In turn, the assessment of the relative values of factors $\{\Psi^1, \Psi^2, ..., \Psi^m\}$ is carried out taking into account their indicator structure. Thus, the formation of a global criterion for assessing the factorial set and its ranking should be carried out taking into account the vectors of the indicator weights. As a corrective indicator for determining global weights in accordance with (9), it is proposed to introduce the following functional [28]:

$$\Theta(\cos\alpha) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}}{n^2}, \qquad (9)$$

which will allow a numerical assessment of the degree of similarity of the relative values of factors and indicators.

Then, the global criterion of the relative values of factors based on the analysis and determination of the weights of the indicators that form them will have the form:

$$W_{(F/I)} = \sum_{i=1}^{m} \Psi^i \cdot \omega^j_{i(F/I)} \cdot \Theta(\cos\alpha)_{F/I}.$$

(10)

The model is implemented in the algorithmic language C#, fig. 8.

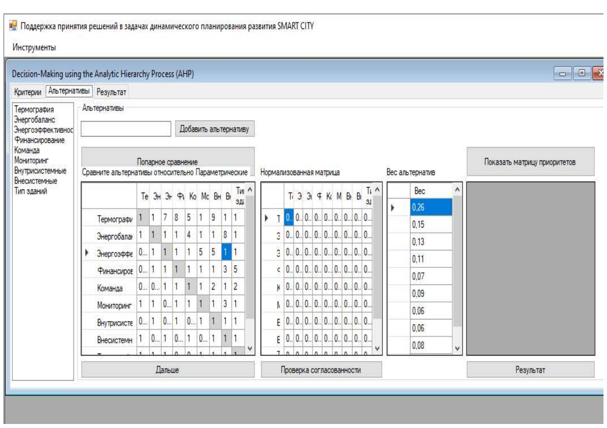

Figure 8. Modifications of the hierarchy analysis method for assessing the energy efficiency of Smart City development plans

The factors weighted in this way will more correctly reflect their relative values (weights), taking into account their internal structure. In addition, the use of the proposed methodology allows to streamline, algorithmize and correct the procedure for expert assessment of dissimilar factors and to improve the quality of the results obtained in the decision-making process. The data obtained during the modification of the hierarchy analysis method for assessing the energy efficiency of Smart City objects, as well as scaling this approach to expert opinions on other areas of the dynamic development plan of Smart City based on a system of criteria and indicators, allow to assert the following:

- there were investigated the components of information technology in order to harmonize the opinions of experts in course of planning of Smart City development;
- there was developed a model and modified a method for analyzing hierarchies for an example of assessing the level of energy efficiency of buildings.

A feature of the study is the multi-criteria assessment of factors by using their own sets of indicators, which are formed within each factor separately.

Of particular interest and at the same time a positive influence in the course of constructing dynamic plans for Smart City development is the implementation of the proposed methodology, which allows, despite the sufficiently large dimension of the array of indicators within a given factor, to carry out correct pairwise comparisons with the achievement of a given level of consistency (≤10%) and determining relative values of indicators that can be trusted.

5. CONCLUSIONS

1. The main tasks and stages of the planning of Smart City development have been determined. A sequence for solving planning tasks were developed.
2. The mathematical statement of the problem of planning of Smart City development is presented. The main steps for creating plans of Smart City development were formalized.
3. There was proposed classification of the types of multi-criteria choice tasks and multi-criteria choice mechanisms. There was developed a methodology and procedure for selection in the tasks of planning and decision-making for the development of Smart City.

4. It is shown that in order to ensure an effective solution to the problems of planning of Smart City development, it is necessary to develop and use the following types of information technologies: analysis and assessment of information; modeling plans; forecasting; decision support.

5. Based on the systematic use of methods: data analysis; modeling; prediction; decision making method for the synthesis of information technologies were developed to solve the problems of planning of Smart City development

6. There was proposed a methodology for using information technology for various types of Smart City development planning tasks.

7. There is considered an example of decomposition of solving the problem of ranking factors into a hierarchy and creating a multilayer model for assessing the development parameter of Smart City. The energy efficiency of objects is considered as such a parameter and the process of ranking factors is described.

8. The method for analyzing hierarchies has been modified by forming consistent matrices of paired comparisons of indicators in individual factors $A^F = \left(a_{ij}^F\right)$, creation of an agreed matrix of comparisons of factors (and defining a global criterion based on factor-indicator assessments. It is shown that the use $A^F = \left(a_{ij}^F\right)$ of the proposed methodology makes it possible to streamline, algorithmize and correct the factors and to improve the quality of the results obtained for the formation of the decision-making process during the planning of Smart City development.

The data obtained during the modification of the hierarchy analysis method for assessing the level of energy efficiency of Smart City objects, as well as the scaling of this approach to the coordination of expert opinions in other areas of the Smart City development plan based on a system of criteria and indicators, suggest that despite the sufficiently large dimension of the array of indicators within a given factor, it is possible to effectively conduct correct pairwise comparisons with the achievement of a given level of consistency (≤10%) with the determination of the relative values of indicators, people you can trust.

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