Ontology and Analytic Hierarchy Process in the Information and Analytical Systems

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Abstract. In our days, problems relating to decision making support in the information and analytical systems are caused mainly by the need to handle a large volume of diverse information and the occurrence of a great number of alternatives of alternatives and multi-objective criteria when choosing them. Application of ontological descriptions in the decision making support chain ensures the dynamic formation of corresponding sets of alternatives and criteria based on the properties of concepts of the domain areas for which relevant decisions are made. Inclusion of ontological models in the information and analytical system environment allows effectively apply a method of hierarchy analysis as a systematic procedure for hierarchic representation and analysis of elements which establish the core of a problem. In this case, validity of a decision depends entirely on the correctness and relevance of ontological domain model, while the objectivity of a method is ensured by fixing the transitive consistency of expert judgment, which eliminates subjectivity and supports the principle of impartiality and justice.

Keywords: Ontology · Analytic hierarchy process · Decision make support · Information and analytical system

1 Introduction and Literature Review

Decision making support is an integral functional component of advanced information and analytical systems (IAS), applied in the administrative management field particularly at the governmental level. According to the specified requirements, a solution depends on the complexity of presentation and perception of properties and functionality of composite objects and domain area (DA) processes relating to the problems under consideration. At the same time, as long as nowadays the new data sources appear and the streaming data and distributed data storage are used, much more data can be processed in IAS than before. Therefore, such systems should contain in their operating environment not only the tools for processing and analyzing data, used in the decision making process, but also the knowledge management tools to ensure processing of certain

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opinions, propositions and statements that carry the object representations and perceptions of DA.

Usually, three stages are distinguished in the decision making process: information retrieval and task setting stage; a stage when a set of alternatives is built; and a stage of choosing the best alternative. Thus, as is known, in the most general view a decision making task is characterized a next cortege: $<\mathcal{A}, E, S, T>$, where $\mathcal{A}$ are the possible alternatives, E - decision-making environment, S – system of advantages of person that makes decision (PDM). It is needed to make some action of T with the great number of alternatives $\mathcal{A}$: to find the most acceptable alternative, arcwise to put in order the list of possible alternatives, etc.

Mathematically, such tasks are described by a set of alternatives $\mathcal{A}$ according to which the values of certain indicators (criteria) are specified for each of them. Solution of a problem is regarded an alternative with the best (in total) values of criteria, which in the general case are characterized by different importance.

At the same time in modern terms the environment of decision-making E is characterized of the joint processing of interrelated diverse information, its integration and interaction with other systems and subsystems, which are different in purpose, is associated with their representation by certain information models [1,10,13,14]. In practice, each such model reflects a certain set of knowledge, which describes the properties of objects and processes being analyzed.

Problem in solving the practical tasks relating to decision making support, id east determination of the system of advantages S and implementation of certain action T is above the great number alternatives $\mathcal{A}$, is often a numerous sets of alternatives and multi-objective criteria when choosing them. One of the recognized approaches to overcome this problem is the Analytic Hierarchy Process (AHP) [17]. It is commonly known that analysis of a problem, relating to decision making process in AHP, begins with the construction of a hierarchic structure that includes the purpose, criteria, alternatives and other factors which influence the choice.

Each element of the hierarchy can represent various aspects of DA, notably that material as well as non-material factors, measurable quantitative parameters as well as qualitative characteristics, objective data as well as subjective expert estimates can be taken into consideration at that time. It is at this stage that the effectiveness of a method is determined, since availability of an identical information model and body of knowledge attributed to DA makes it possible to clearly define a list of alternatives and restrictions as well as to minimize the lack of AHP application, which is associated with the relations of consistency as a Q-factor of expert estimates [4].

In addition, something must be done to overcome the following drawbacks of the method: (1) it is difficult to propose a universal model of quality evaluation solution; (2) existing model is difficult to reuse. As a result, many experts have to spend a lot of time updating the model.

Among existing approaches to the representation of information models in the analytical system environment, a certain set of ontologies is considered to be the most adequate representation [3,5,6,11,12,15,18,21], and each model or combination of models can be represented and defined by distinct taxonomy.

Any ontology contains informational descriptions based on an object-oriented formalization procedure and on descriptions of interpretational functions, which (based on ontology) control the supply of information resource for its further processing. Such structure reflects the comprehension of a problem by PDM. Equally, analysis of the decision-making situation in AHP is similar to the procedures and methods of argumentation normally used by a person at the intuitive level. These distinctive features of two methods under consideration represent the factor that unites them.

The same time period has also seen marked growth in corporate structural complexity. This lack of awareness of the corporate data landscape impacts the ability to govern data, which in turn impacts overall data quality within organizations. Not surprisingly, many researchers and practitioners offer tools and methods to better manage data and processes, including the use of ontology-based related data.

At the same time, due to the complexity of business processes, the main idea in decision making is to use expert knowledge to help the user in making the best decision in terms of multicriteria. There are many researchers are considering AHP for this purpose, which is well suited for hierarchical data structures, in particular those that have been formed in terms of ontologies.

However, it should be noted that in many ontology- and AHP-based sharing research and projects mostly interconnected integration is not observed. Mainly, it is an ontology based preliminary data preparation and then separately used by AHP to obtain certain estimates. Owing to the known drawbacks of AHP, it is often the case that search for a multicriteria analysis method best suited to the problem is expanded or modified by AHP, or other methods. For example, it is proposed in [20] concerning the development of a software selection decision support system.

The study [14] presents a generic ontology-based architecture using a multi-criteria decision making technique to design a personalized route planning system. Initially, an ontology builds a general user-oriented architecture. A user-centric abstract model has a domain-specific ontology. From the built models stand out criteria that are weighted and evaluated by the AHP.

In [22] combining AHP and the scores of evaluation features obtained by ontology querying a comprehensive evaluation is realized. An ontological request is performed to obtain information on the quality of the parts. It is then proposed to quantify the degree of reuse parts by AHP.

In [2] the authors present a method for using information from WordNet ontology (general purpose ontology), and their related terms and relationships from domain ontology. The web pages ranking module uses AHP algorithm.

The purpose of paper [9] is to propose a way to ontologically represent the AHP method, which not only specifies the concepts and their relationships that are necessary for applying the AHP method, but also realizes the priority assessment and consistency evaluation mechanisms in the AHP method through corresponding reasoning rules. The result is an ontology called AHP Ontology.

As can be seen from the analysis of existing solutions, the issues of using ontologies and AHP in administrative management are very limited. Among the few examples is work [19] that offers conceptual modeling of requirements of government to citizens (G2C) service provision. An ontology model developed represents requirements of service provision in a web service environment. Hereafter, AHP is used to determine the pre-selected services for contributing to quality features.

The main conclusion is that such approaches allow us to find acceptable solutions only if the state of DA is clearly defined and its mathematical description is presented in the form of defined sets of concepts and their properties.

This part of the problem, which is still poorly understood in the field of administrative management, can be solved by combining a process of ontological model-based domain formalization and information structuring with AHP-based multicriteria analysis.

The aim of the research is the proposes a technique based on a joint use of ontology and analysis of hierarchies methods with a view to ensure the correctness and effectiveness of the decisions supported.

2 Materials and Methods

2.1 Core of Ontological Methodology in the IAS Operating Environment

Considering the core of ontological methodology, it should be noted that it is based on the object-oriented approach, in which DA is represented as a set of objects interacting with each other by means of semantic binding of propositions, statements and opinions. An object is understood as a certain entity (real or abstract) characterized by a status, behavior and identity.

A status of an object is determined by a list of all possible properties and values of each of such properties. Behavior of an object (or its functionality) characterizes how an object interacts or is exposed to interactions from the side of other objects, manifesting its identity. Behavior of an object is realized in the form of functions, which are called methods. In this case, the structure of an object is accessible only through its methods, which all together form the interface of an object. Finally, the identity of an object is characterized by its properties that distinguish this object from the other objects.

While forming a correct operating environment IAS, two types of hierarchic object relationships are in particular interest: 1) the links, denoting equitable relations between objects; an object cooperates with others through the connecting links; 2) the aggregation, describing a ratio of the whole and the parts that lead to the corresponding taxonomy (hierarchy of objects).

In the general case, the computer ontology of some DA is formally represented as an ordered triple $O = <X, R, F>$, where X, R, F – are the finite sets of correspondingly: X – concepts (notions, terms) of a domain, R – relations between them, F – interpretation functions X and/or R [3,15,18].

Then the ontology of certain DA shall be considered as a certain not empty set of objects satisfying the following requirements:

1. Objects are organized in the form of a hierarchic structure of a finite set of concepts that describe a given DA.
2. Structure can be represented by a set of bipartite graphs, where: the vertices are concepts, and the arcs are semantic relations between them.
3. Concept and relation are interpreted in accordance with the generally valid functions of interpretation from the electronic sources relating to a given DA.
4. Definition of concepts and relations shall be derived from the axioms and restrictions of their scope.
5. Interpretation functions and axioms are described in the formal theory language.

The process of formation of the IAS operating environment requires setting of a definition of thematic ontology with the most complete set of concepts and conceptual relations, and the interpretation function with the added axioms, definitions and restriction of the subject of a particular system, that is, there is: $R \neq \oslash, F \neq \oslash$.

Thematic ontology is a formal representation of conceptual knowledge about the subject domain and can be represented by a certain system of information resources. Building process of such information system can be represented as a composition of certain propositions, opinions, statements, terms (concepts) and relations between them, while its result can be represented as a foundation for building ontological knowledge base in a given DA, described in a declarative form [1,3]. In this case, description of all components is given in a formal language, which can be interpreted by some procedure (algorithm).

Formal model scheme of thematic ontology is described by a quartet [15]:

$$O = <X, R, F, A(D, R_S)>, \tag{1}$$

where X is the concepts set; $X = \{X_1, X_2, ..., X_i, X_n\}$, $i = \overline{1, n}$, a finite set of concepts (notions) defined in the IAS operating environment;

$R = \{R_1, R_2, ..., R_k, ..., R_m\}$, $R : X_1 \times X_2 \times ... \times X_n$, $k = \overline{1, m}$, $m = CardR$ - is a finite set of semantically significant properties (relations) among the DA concepts. They define a type of interaction between concepts. In the general case, relations are divided into universally significant (of which, as a rule, a partial order relation is singled out) and the specific relations of a given DA;

$F : X \times R$ - is a finite set of interpretation functions defined on concepts and/or relations. A glossary, compiled for a set of X concepts, is a particular case of a definition of a set of F interpretation functions. In the general case, definition of X_i concept includes a subset of $\{x_{i-1}\}$, concepts, through which the X_i, relations (connecting X_i and $\{x_{i-1}\}$, are determined, and a set of attributes (indicators) inherent in $X_i \mid i = \overline{1, n}$;

A – is a finite set of axioms used to record the identically true propositions (definitions and restrictions) - tautologies in the terms of DA subjects;

D – is a set of additional definitions of concepts (notions) in the terms of DA subjects; R_S – is a set of restrictions, which define certain properties of DA concepts and can be interpreted as criteria in defining the areas of conceptual structures (concepts, notions, propositions, statements) of a certain subject – $R_S : R_S \subset R$.

2.2 Properties of Ontology Objects in Multi-criterion Decision Making Tasks

When forming ontologies in the IAS operating environment, we define R_S a set of restrictions, as the one that allows selecting such subset A from a set of X concepts that it can be decomposed into subsets $\mathcal{A}_i = \{a_{i1}, ..., a_{in}\}$, which intersect and which we call a set of characteristics alternatives ($\prod_{i=1}^{n} \mathcal{A}_i \neq 0$, where 0 is an empty set) (1). All the a_{in} elements of each $\mathcal{A}_i$ set shall have the property of a certain advantage, enabling selection of the necessary tautology at the problem solving stages related to the decision making support. That is, a lot of restrictions in such tasks allow building a set of alternative concepts based on the definition of ontology taxonomic structure (Fig. 1).

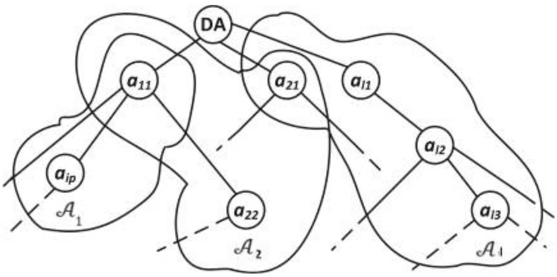

Fig. 1. General scheme allocation characteristics of alternatives on ontological data of the domain area

The properties of ontology objects can be used as criteria, according to which experts can choose alternative from a set of possible alternatives. In the ontological representation, criteria constitute a certain subset in a set of properties R. Taxonomic structure of ontology provides the selection of a certain set of alternatives that define some tasks relating to choice [8]. Each of the ontology elements used in the decision making tasks has a certain set of criteria (properties).

Some set of criteria can be represented in the form of a certain evaluation function $\mathcal{C}$, that takes values on some set of estimates $\mathcal{O}$, or in the form of a rule by which the "best" alternative is chosen. In this case, the "best" alternative corresponds to the maximum or minimum value of the evaluation function, depending on the content of the criterion. If $\mathcal{A} = \{a_i, ..., a_n\}$ is a set of alternatives or solutions, then $\mathcal{C} : \mathcal{A} \rightarrow 0$ [7].

Occurrence of several criteria turns the decision-making task into multi-criteria one. A multi-criteria task has a set of $q > 1$ criteria such that $\mathcal{C}_1, ..., \mathcal{C}_q$, $\mathcal{C}_q : \mathcal{A} \rightarrow \mathcal{O}_r$. Where $\mathcal{O}_r$ is a set of values of the function $\mathcal{C}_q$. Sometimes it may be convenient to consider several criteria in the form of a single vector criterion or vector estimate $\mathcal{C}(a) = (\mathcal{C}_1(a), ..., \mathcal{C}_q(a))$ of alternative a.

Thus, a multi-criteria decision making task is determined by a set of possible solutions $\mathcal{A}$, vector criterion $\mathcal{C}$ and a ratio of preferences in a set $\mathcal{A}$. The aim of solution is to search for "optimal" (to some extent) alternative A or a group of alternatives with consideration of the preference relations based on the vector criterion $\mathcal{C}$.

This is ensured by arranging ontology object-concepts on the basis an integrated processing of properties that characterize them. For this we use weight, ball and linguistic scales. Each such scale defines the values of the criteria characterizing the properties objects of DA thematic ontology.

2.3 Combination of Ontology and Analytic Hierarchy Process

Decision of a problem at decision-making stage is a process of gradual setting of priorities. At the first stage, the most important elements of the problem are identified; the second stage is the best way to verify observations, to test and evaluate the elements; and the next stage can possibly be evolving of a way to apply a decision and to assess its quality.

The process can be carried out over a sequence of hierarchies: in such case, the results obtained in one of them are used as inputs for study of the following one. The entire process shall be checked and re-evaluated until confidence that the process has covered all the important characteristics required for presentation and solution of the problem.

This multistage method is inherent in the AHP theory and involves systematization of a task solving process on the principles of identity and decomposition, discrimination, comparative opinion and synthesis.

When applying AHP, the first stage has provision for structuring of a problem in the form of hierarchy or network based on the principle of identity and decomposition. Typically, a hierarchy is built from the top (i.e. the targets from the management point of view), through intermediate levels (criteria and sub-criteria, on which the subsequent levels depend) to the lowest level (hierarchy leaves), which is usually a list of alternatives. Here, alternatives are understood by some objects in the subject area that are evaluated relative to the achievement of the goals specified at the top of the hierarchy.

Thus, this hierarchical structure is a graphical representation of the problem in form inverted tree, where each element, with the exception of the uppermost one, depends on one or more elements located above. Using information available in the database, built on the ontological model considered above, such a hierarchy can be formed on the basis of the R_S and $\mathcal{A}$.

After the hierarchical reproduction of the problem the issue of setting criteria priorities and evaluating each of the alternatives by criteria is identified, identifying the most important of them.

In AHP it is necessary to find out important elements of a problem (objects) in terms of their influence w_i (weight) on a common characteristic (criterion). For this purpose experts perform pairwise comparisons y_{ij}, which lead to a square table - a matrix form with the property of inverse symmetry, i.e. $y_{ij} = 1/y_{ij}$, where i and j indices refer to a row and to a column, respectively. Then "solutions" of such square inversely symmetric matrices are carried out. The meaning of such calculations is that they determine the way for quantitative estimation of relative importance of the factors in a problem being analyzed (sets of local priorities). Further on, while solving a problem, attention shall be focused on factors with the largest values of importance.

It is important to understand that the values $w_1, w_2, ..., w_n$ are not known in advance, and they are formed based on the subjective opinions made by the experts who evaluate their number using a special scale of relative importance (value); its structure is proposed by the author of the AHP ideology.

Starting with the left element in the matrix, an expert has a question: at what extent is this element more important than an element at the top? If the first element is more important than the second, then an integer from the scale of relative importance is used, and otherwise an inverse value is used. (When an element is compared with itself, the ratio is equal to one). The relations, that are reverse to each other, are recorded in the symmetric positions of matrix. Therefore, experts normally deal with positive inverse symmetric matrices, and only $n(n-1)/2$ opinions are necessary, where n is the total number of compared elements. It is not assumed that opinions are fully coordinated and they are not subject for coordination, except for the requirements of inverse symmetry.

A very useful indicator in the AHP theory is the so-called consistency index (CI), which provides degree of violation made by experts in relation to numerous and transitive (ordinal) consistency. That is, this quantitative assessment of the inconsistency of the results of comparisons arising from subjective views (and errors) of experts. In every matrix and for the whole hierarchy CI can be obtained by certain calculations. The CI value is positive, and the less contradiction exists in comparisons, the less is the CI value.

When CI is divided by a number corresponding to the random consistency of a matrix of the same order, the compatibility relation (CR) will be obtained. CR value shall be not more than 10% in order to be acceptable. In some cases, this value can be tolerated up to maximum 20%. If the CR goes beyond these limits, the expert participants should investigate the task again and check their opinions.

To prevent inconsistencies of matrices due to the influence of various factors and properties of evaluated alternatives on expert opinions, the extreme subjectivity shall be avoided. Within such frames the DA ontology shall be built; and it shall clearly define all the DA factors and make the basis for expert estimates.

It is the ontological model that enables a group of experts interacting among themselves in order to solving a task, modifying their opinions and, as a result, forming their own opinion in a rational way.

Thus, the acceptable consistency relations are provided by iteratively repeating the AHP stages and using the knowledge about DA, formed on the basis of ontological model, and giving more attention to certain stages comparing to others in some situations.

3 Experiment, Results and Discussion

Let's consider an example of a decision related to choice (ranking) standard (industrial) software of the class ERP.

The algorithm for performing the actions in the conditions of using the proposed integrated method is shown in Fig. 2.

First of all, there is a list well-known and widely used standard industrial software solutions of the class ERP (hereinafter - ERP-systems). Given the large number of such solutions on the market, it is advisable to select only a few. This choice is made by the manager on the analysis of ontological data domain based. Their groups (short list) formation is carried out on the basis of the ontology of the domain "Software quality", built in accordance with the standards ISO/IEC 12119 and ISO/IEC 9126 [16].

Next, you need to define a set of characteristics of ERP-systems for use as criteria for ranking ERP-systems from the list of alternatives. Characteristics are desirable to be grouped together in such a way that the presence of each group characteristics is a prerequisite for choosing an ERP-system. At the same time, an inadequate level or even lack of any characteristic in the middle of the group may not be critical in the final selection of the best ERP-system. (2). The set characteristics and their groups formation is carried out on the basis of the ontology. This is done by distinguishing from the ontology sets characteristics $\mathcal{A}$, which are formed taking into account the constraints R_S, which are the peculiarities of ERP-system business solutions.

As a result, in this example 6 groups of characteristics were selected: positioning ERP- system on the world market, positioning ERP-As a result, in this example 6 groups of characteristics were selected: positioning ERP- system on the world market, positioning ERP-system in the domestic market, technological characteristics, supplier's infrastructure in the local market, functional characteristics, and others. (3). Attributable descriptions (properties) of criteria can be presented in the ontological database in form of frames, in slots containing the corresponding numerical or linguistic data. Further, according to the AHP algorithm, to accomplish this task, you must:

(i) build a dominant hierarchy of criteria - those properties of alternatives that have a significant impact on the task;
(ii) make expert comparisons of alternatives with an assessment of the superiority of one alternative over the other on each criterion on a Saati scale;
(iii) summarize the estimates obtained using a scalar (linear) convolution, taking into account the importance (weight) of the criteria and, possibly, the competence (weight) of the experts.

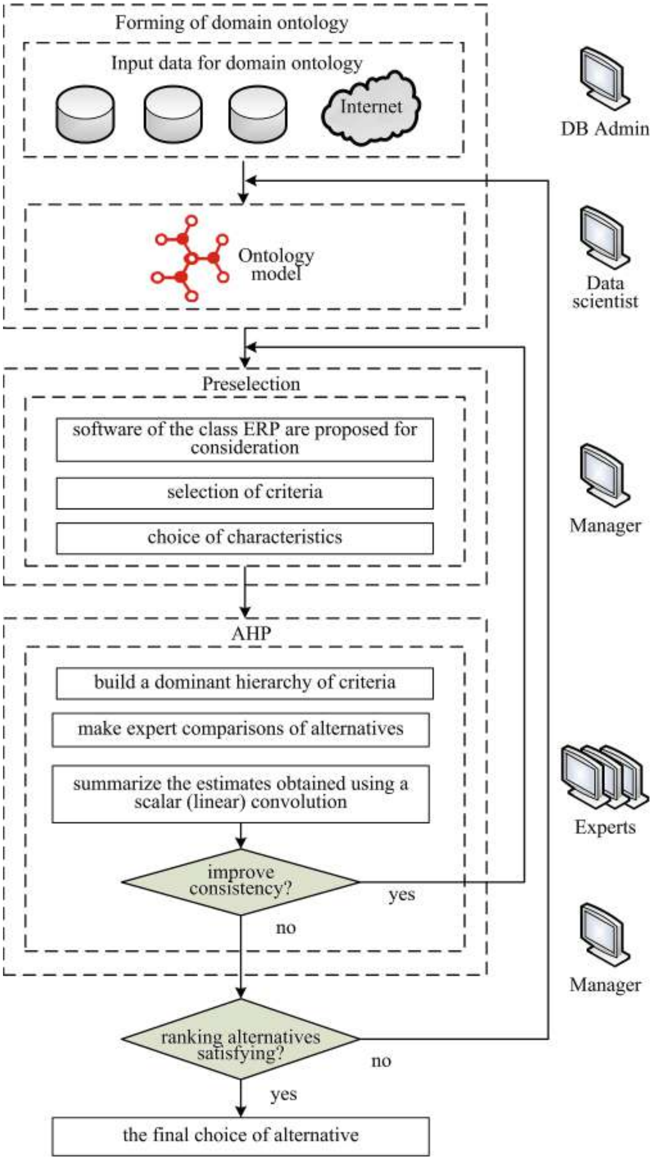

Fig. 2. A structural block chart of the algorithm to performing the actions in the conditions of using the proposed integrated method

In the end, this will allow you to get a total rating (rating) for each alternative and thus rank them.

Next, a group of experts who have knowledge and experience in implementation, support (maintenance) and operation of ERP-systems, select the best ERP-system in steps AHP algorithm (Fig. 3).

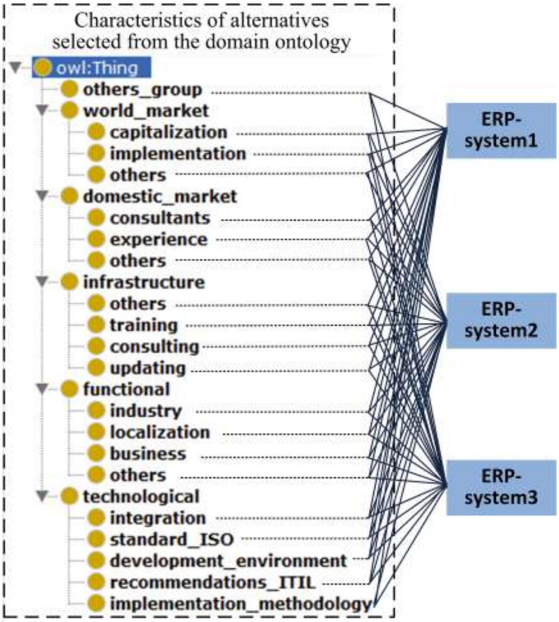

Fig. 3. Hierarchical reproduction of the task selecting an ERP-system using the domain area ontology

The presence of an attribute component in an ontological basis for each concept provides an adequate evaluation by experts in pair comparisons, making it impossible to make unreasonable marks. Thus, the necessary informational support for the experts to solve the problem of comparing alternatives may consist in the application of an ontological model of DA based on interpretive selection functions constructed by means of hyperrelationships over the concepts of the ontological taxonomic structure and their properties. It is an ontological model that provides a group of experts to interact with each other when solving a task, to modify their judgments and, as a result, to form their own opinion in a rational way.

In order to improve consistency, the search for additional information and viewing of the data, used for building the scale, can be recommended. A set of additional definitions of concept (notions) in the terms of DA subjects can be viewed as a source.

An important component of the proposed algorithm is to help experts immediately support the transitivity of their judgments, which will ensure consistency in the estimates of the various alternatives at the overall preference level.

On the other hand, according to the results of various decision-making tasks, certain corrections to the ontological model shall be made in the given DA aiming to bring it (in terms of adequacy) as close to the domain area as possible, as

AHP allows acquire new knowledge relating to DA, verifying the validity and consistency of the expert opinions, which also are the basis for ontological model.

4 Conclusions

Thus, it can be concluded that the use of ontological descriptions in decision making support process ensures the dynamic formation of corresponding sets of criteria for information and analytical systems based on the properties of concepts of those domain areas for which the relevant decisions are made. Ontological modeling ensures the decomposition of opinion-problem into simpler constituent parts – tautologies, as well as further processing of opinion sequence by experts on the basis of a certain preference property. As a result, the numerical expression for the relative degree (intensity) of interaction of elements in the hierarchy can be found.

Integrating the use of ontologies and AHP to support expert decision-making allows the same technology to be applied at different stages of the process: to determine the priority (weight) of criteria, the competence (weight) of experts, and to evaluate alternatives in-house. The proposed algorithm significantly simplifies expert activities by unifying the process of evaluating alternatives, provides information support to the transitional consistency of expert opinions, and promotes cardinal consistency.

Proceeding from the foregoing, it can be noted that the inclusion of ontological models in the IAS environment makes it possible to apply the hierarchical analysis method quite effectively as a systematic procedure for hierarchical representation and analysis of the elements, which determine the essence of a problem. At the same time, the supportability of a decision depends entirely on the correctness and adequacy of domain area ontological model, and the objectivity of method is ensured by fixing the transitive coherence of expert opinions that excludes the subjectivism and supports the principle of their impartiality and correctness.

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