Indian Journal of Science and Technology, *Vol 9(46), DOI: 10.17485/ijst/2016/v9i46/107500, December 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Ontology and Multi-Agent Technology Application for Intellectual Property Knowledge Management

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Abstract

Objectives: Every rocket and space enterprise possesses unsystematized knowledge describing intellectual property objects (IPO). One of the system's aims is to make knowledge easily reusable and boost up the innovative development. **Method:** To increase efficiency of rocket and space enterprises, development of the system for management of intellectual property knowledge is suggested. The novelty consists in using domain ontology (Semantic Web) and "multi-agent internet" as an intellectual base for knowledge management of rocket and space enterprises and the whole industry. **Findings:** The article provides an analysis of software tools that ensure total domain-independent support for ontological analysis. The article also gives advantages and disadvantages of existing tools. The paper describes an approach based on use of multi-agent technology and ontologies and an example of its implementation. **Improvements:** Applications of the reviewed methodology will make it possible to systematize the available volumes of information, thereby enabling effective use of knowledge. Implementation of these plans is capable of realizing the main corporate priority - creating competitive advantage.

Keywords: Increasing Economic Efficiency of Intellectual Property Objects, Intellectual Property Objects Management, Knowledge Systematization, Multi-Agent Technology, Ontology

1. Introduction

Increasing complexity of the tasks to be solved at modern industrial enterprises, highly dynamic changes of complex projects as well as constantly increasing requirements of customers in the sphere of Research and Development (R&D) to project implementation period and confirmation of value indicators of contracts force top managers search for new approaches to increasing efficiency of work execution.

Under severe competition, only unique intellectual property can ensure a strong position of an enterprise in the market, which enables it to receive regular income in the long-time period. Technologies for assessment of IPO make it possible not only to define resource value for proprietor but to present its market value and market relevance degree and, consequently, further strategy of proprietor's actions aimed at implementation of IPO.

Taking into account the above-mentioned demands of industrial enterprises, we have created a system for intellectual property management (SIPM), implementation of which can increase the efficiency of enterprise activity.

The aim of the project is development of the SIPM for the rocket and space industry (RSI). It is based on innovative means and methods of support of design and implementation of advanced engineering solutions in development of rocket and space products (RSP). These solutions are based on designing corporate network of knowledge management, which is contained in technical documentation of developers, patents, publications and other results of intellectual activity (RIA).

For this purpose the project presupposes:

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- Designing ontology of the RSI, industry knowledge base and modern technology of classification and big data mining;
- Developing special interfaces of accessing heterogeneous data circulating in the networks which contain information about objects of invention, rationalization and intellectual property of space enterprises and Russian Federal Space Agency "Roskosmos" as a customer;
- Developing organizational algorithms of interaction between networks of rationalization, invention and innovation based on multi-agent technology and standards of Semantic Web as a base of the SIPM.

The developed components are aimed at increasing productivity and efficiency of performance of the RSI specialists due to semantization of RIA (national and international publications, patents and inventions, 3D-models of products, results of calculations, simulation and full-scale tests, etc.) as well as due to semantic support of communication and interaction processes between developers. It gives an opportunity to overcome barriers between enterprises due to formation of a unified industry knowledge base and an active expert community, which is open for all enterprises.

In the course of the project implementation, the first stage presupposes development of ontology prototype of the RSI, industry knowledge base and multi-agent SIPM and support of interactions between developers of rocket and space enterprises. Domain ontology will allow for design of formalized descriptions based on ontology fragments (semantic descriptors) for objects of invention, rationalization, innovation and intellectual property of enterprises. Besides, it gives the opportunity to structure and accumulate information about results of executed works as well as personal data about experience, qualification and competence of leading experts of the industry.

For example, for the product assigned one can describe: what basic components it consists of, which enterprises make these components, who is the chief designer of each part, what are competences and experience of each designer, which patents the product is based on, where can publications with results of product tests be found, who conducted the tests, which improvements were made, and a range of other parameters, which provide exact positioning of the given RSP in the industry ontology.

Search for information which is annotated with the help of semantic descriptors, unlike keyword search, provides extraction and logical derivation of bits of knowledge, presented as models of interconnected concepts and relations of high relevance by the formulated query[1].

The developed descriptors are input data and results of works of intelligent agents. The agents represent demand and resource network (DRN), where information is considered as resource, and information users – as orders (demands).

System performance is based on constant matching between demands and resources in order to form groups (clusters) of interconnected resources in the ontology.

In the result, the suggested system will represent a self-organizing DRN, where a dynamic balance of agents' interests is built depending on satisfaction of users.

The main distinctive feature of multi-agent system is self-organization[2]. Each agent has to make a decision and create new links or destroy the existing ones if they are ineffective. However, they do it in accordance with those agents, with whom links are already built. Some agents can gain points and go "up" in the self-organizing environment, participate in more complex structures of links and improve their rating due to their relevance for users. Others lose their rating and gradually "quit the stage". After that, they are finally removed from the system or placed in the archive and model the performance of dissipative systems with non-linear thermodynamics. Structural scheme of interaction between heterogeneous applications of the SIPM is presented in Figure 1.

Performance of SIPM will allow for introduction of new events at any time (new document, new expert, etc.) for adaptive rearrangement of the network without stop or reset of the whole system. In the result of the system performance, it will be possible to see the rating of all materials and the level of their use in different projects.

The results can be used for assessment of relevance and efficiency of knowledge which is generated by various enterprises and organizations of the industry.

The main result of SIPM development will be an increase in the efficiency of using IPOs in execution of R&D projects in industrial enterprises and decision-making over resource management in innovative projects. The developed solution will allow for considering resource allocation and assessing risks of R&D execution.

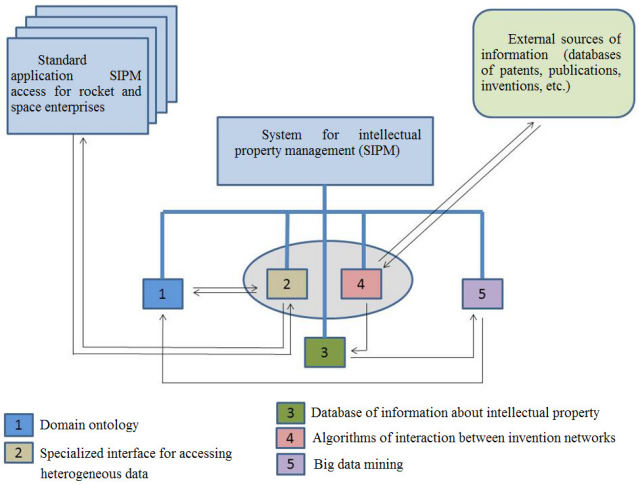

Figure 1. Scheme of interaction between heterogeneous applications in SIPM.

2. Comparison with Existing Solutions

It is worth noting that one of the advantages of using ontologies is the availability of software tools, which provide general domain-independent support of ontological analysis. There are a number of tools for ontological analysis, which support editing, visualization, documenting, import and export of ontologies in various formats, their presentation, merging, and comparison. The most popular tools are the following:

- Protege;
- DOE;
- OntoEdit;
- OilEd;
- WebOnto;
- Fluent editor;
- Palantir Gotham.

Let us consider them in more detail:

Protege is a local Java program designed for constructing (as well as editing and viewing) ontology models of application domains. Protege includes ontology editor that allows users to design ontologies, breaking down the hierarchical structure of abstract or concrete classes and slots. Ontology structure is similar to the hierarchical structure of a catalogue. Protege is based on a frame model of knowledge representation (Open Knowledge Base Connectivity). On the basis of the formed ontologies Protege can generate forms of knowledge acquisition for introduction of instances of classes and subclasses. The tool supports use of OWL language and can generate html-documents showing the ontology structure. Because it uses frame-based model of knowledge representation (OKBC), it allows users to adapt it for editing domain models not necessarily in OWL, but in other formats as well (UML, XML, SHOE, DAML+OIL, RDF, RDFS, etc.).

Protege-OWL editor allows users to build ontologies for semantic web, in particular using OWL. OWL-ontology can include descriptions of classes, properties and their instances. By giving such ontology, the formal semantics of OWL defines how to obtain the logical consequences, i.e., facts that are not present in the ontology itself, but can be withdrawn through the existing ones using semantics. These findings can be based on a single document or on multiple distributed documents that have been combined using specific OWL mechanisms[3].

DOE is a simple editor that allows users to build ontologies. The process of ontology specification consists of three stages. During the first stage, user builds taxonomy of concepts and relations, explicitly outlining the position of each element (concept) in the hierarchy. Then user indicates what is the specificity of the concept with respect to its "parent" and how this concept is similar to or different from its "brothers". The user can also add synonyms and an encyclopedic definition in multiple languages for all concepts. During the second stage, two taxonomies are considered from different points of view. The user can expand them with new objects or add restrictions on the domain of relations. During the third stage, the ontology can be translated into knowledge representation language[4].

OntoEdit is a stand-alone Java application that performs screening, reviewing, coding and modification of ontologies. Among the advantages of this tool one can name usability (ease of use), development of ontology under the guidance of methodology using the inference process, development of axioms, expandable (via plug-ins) structure, representation language support (Flogic, including inference engine, OIL, RDFS extension and inner (based on XML) serialization of ontology models for OXML usage), as well as high-quality documentation.

Oiled is a stand-alone graphic ontology editor. The tool is based on the OIL language (OSEK Implementation Language) (adaptation for OWL (Web Ontology Language) is planned in the future), which combines a

frame-based structure and expression of descriptive logic with services of reasoning. This combination ensures clear and intuitive user interface style, as well as advantages of reasoning support (detection of logical contradictions in classes and hidden relationships within a subclass). Among the disadvantages, one can identify lack of support for copies.

WebOnto is an ontology editor developed for Tadzebao - a tool for ontology research - and designed to support shared viewing, creating and editing of ontologies. For modeling ontologies WebOnto uses the OCML language (Operational Conceptual Modeling Language). In WebOnto users can graphically create structures, including classes with multiple inheritance. The tool checks the newly entered data using code integrity control. The tool has a number of useful features: preservation of structural diagrams, separate viewing of relations, classes and rules, joint work of several users on ontology, use of charts, transmit and receive functions, etc.

Fluent Editor is a comprehensive tool for editing and processing of complex ontologies based on the Controlled Natural Language (CNL). This editor provides user-friendly interface for users who are not familiar with XML principles, thus providing comfortable conditions for creation of ontologies, which significantly distinguishes it from other editors[5].

Key capabilities of *Fluent Editor*:

- Building ontologies by recording statements in natural language (English is used, but Russian language support is also possible);
- Import/export of ontologies into OWL format;
- Support of references to external ontologies;
- Support of modal expressions (restrictions on model elements);
- Built-in calculator of logical expressions (reasoner);
- Support of semantic structures, complying with ISO 15926 standard;
- Ability to work as part of the semantic framework Ontorion.

But its main advantage lies in the fact that in order to create the data model users do not need to know the syntax of OWL - modeling is carried out in natural language.

Cognitum company also presents a solution of a higher level - semantic framework Ontorion. It is a cloud-based, scalable solution for storing and managing large ontologies. The main capabilities of this framework are the following:

- Full support of OWL2/SWRL;
- Support of logic OWL-DL and OWL-EL;
- Compatibility with OWL API, which makes it possible to be used in cooperation with other tools;
- Support of controlled natural language (CNL);
- Built-in calculator of logical expressions (reasoner);
- Cloud-based (Windows Azure/Cassandra; Linux platform is also possible);
- Support of joint work on ontologies according to the algorithm of version control systems (update/commit);
- Setting up access rights, security audits;
- Scalability, high performance and safety;
- Compatibility with Linked Data;
- Compatibility with Solr/Lucene;
- Built-in ontology mapping[6].

Palantir Gotham is a flexible, object-oriented data model, including a dynamic ontology, which helps to transform data from several sources from their original storage formats into data objects and associated properties that represent real-world objects – people, places, things, events, and relationships between them[7].

Due to the subjective view and a high rate of changes in objects and events in the real world, there is the need for a dynamic ontology, which can meet these requirements.

Ontology Palantir is an intermediate link between generalized (no semantic) and highly specialized (over-defined semantic) ontologies, which basically has 3 types of strictly fixed concepts: object, entity and event. Objects are also strictly divided into documents, entities and events[8]. The remaining objects are not strictly fixed: ontology elements can be added/deleted/edited during adaptation to the specific task. The resulting unified data model can considerably simplify and reduce the data integration process.

Despite the numerous advantages of existing software tools for working with ontologies, they all have a number of drawbacks:

- Absence of an ontological basis, which would simplify description of the domain;

- Absence of full-text search tools for information presented in the ontology;
- Absence of a proactive model, which offers the user potentially interesting for him information;
- Absence of tools for describing business processes;
- Limited functionality in visualization of the ontology.
- The proposed system gives the opportunity to solve the following functional tasks:
- Forming the core classes of concepts and relations within the domain ontology;
- Generating semantic descriptors of domain objects for expansion of the knowledge base;
- Specifying the general user requirements for the desired information;
- Specifying semantic user queries in the knowledge base;
- Matching semantic descriptors with each other and between user profiles within the internal virtual market of the system;
- Rebuilding the relations between information bits dynamically (adaptively, depending on events);
- Modeling and supporting cooperation of experts in the flow of events, connected to appearance of new information bits;
- Saving and keeping versions of the emerging network in a special data storage;
- Visualizing and analyzing the knowledge network in order to identify the "bottlenecks" and the TOP areas.

3. The Proposed Approach

The proposed approach is based on the use of multi-agent technology and ontologies. For construction of ontology it is proposed to use the "Aristotle's model" meta-ontology as the basis. This model provides the following basic concepts to describe the domain: "object", "attribute", "relation", "property", "action", "process"[9]. "Aristotle's model" is proposed as the most adequate one for describing complex heterogeneous domains. The developed ontology will contain the basic classes of concepts and relations of the RSI domain for specification of organizations, products, technology processes and competencies of specialists involved in the design, production and operation processes.

Having the domain ontology will allow users to create semantic descriptors for any particular objects of invention, rationalization, innovation, and intellectual property of enterprises, as well as to create descriptions of the obtained results, experience, qualifications and competencies of experts. Each such descriptor, which, in contrast to the conventional keywords (tags), is a semantic network based on the domain ontology, can describe (annotate) the content of any bit of knowledge (in fact - a model of the situation), including texts of articles or patents, 3D-models, photos or videos, tables with data from experiments, simulation or full-scale tests, etc.

The developed descriptors become input data and results of work for software agents, which are a simple DRN, in which, for example, documents are seen as resources and information users - as demands. The system performance is based on constant matching (finding correspondences) between demands and resources, as well as among themselves, in order to form groups (coalitions) which acquire great importance and significance for the system. As a result, the proposed system will be a self-organizing DRN, which is building a dynamic balance of the agents' interests in satisfying the users.

To explain these principles of self-organization and the "dynamic character" of the emerging balance of "stable nonequilibriums (or unstable equilibriums)", according to I. Prigogine, one should note that once the user chooses any document, it should immediately increase the rating of its "popularity" and allow this document to earn some points in the virtual market of the system. Such points will help it in the future to occupy a more favorable position in the search results.

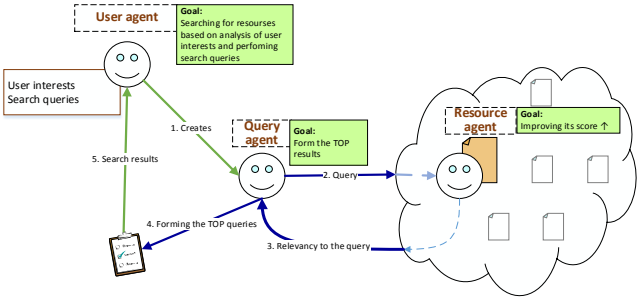

Figure 2. Interaction between agents.

Using the multi-agent technology means that each user and resource is assigned a smart agent, acting in their best interests[10]. To perform a search query the user agent creates a query agent, the purpose of which is finding all

the resources that match the search query and returning the most appropriate N-resources as a search result. The query agent, basing on the analysis of semantic descriptors of resources and the search query, finds the most relevant resources. Then a queue for viewing these results is formed, taking into account a given search strategy Figure 2.

Next, the query agent takes the first N-resources from the queue and returns them to the user agent. While viewing a resource, the user can evaluate it in the light of resource utility and how consistent it is with his expectations. Based on the user's assessment, resource rating is formed, which in the future, depending on the selected search strategy, may influence its position in the view queue Figure 3.

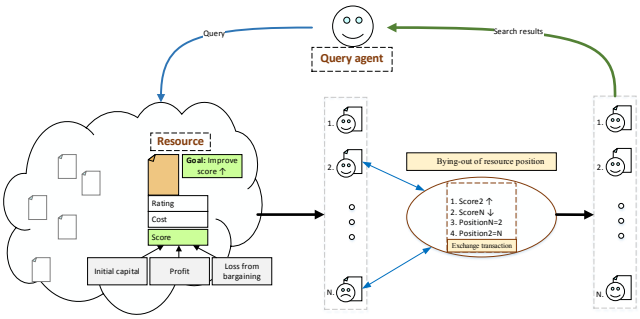

Figure 3. Algorithm of forming the resource rating.

When using commercial strategy each resource is assigned an account (virtual wallet). The goal of resource agent is to increase its account, and this rating is then converted into its cost. When the queue of resources is formed by assessing the relevance to the search query, each resource agent tries to improve its position in the queue in order to ultimately increase the resource account. To do that, one resource agent tries to buy out a position in the queue from the agent of another resource which has a better position in the queue. If the amount of compensation that the resource agent is ready to offer satisfies the agent of another resource, the exchange transaction is performed. By improving its position, the resource agent increases the probability of being viewed by the user. If the resource is viewed by the user, its account is increased by an amount equal to its cost.

4. Example of Application of the Suggested Approach

Let us consider the basic principles of application of the suggested approach by example. For systematization of domain knowledge, we single out the following composition of the ontology:

- Space infrastructure contains description of spacecraft types and ground-based space infrastructure (Space Vehicle, Transport Manned Space Vehicle, Transport Cargo Space Vehicle, Launch Vehicle, Space Tug, Rocket Carrier, etc.);
- Enterprise structure contains classes for description of organizational structure (Rocket and Space Enterprise, Head Enterprise, Branch Enterprise, Factory, Department, Construction Office etc.);
- Composition of posts and professions. It contains the basic list of classes of posts, professions and competences (General Director, Chief Engineer, Director of Pilot Factory, etc.);
- Specialists: contains classes of specialists (Engineering Technologist, Quality Assurance Engineer, Lathe Turner, etc.);
- Types of documents: contains the main classes of documents (Normative Document, Federal Standard, Draft Design, Certificate, Requirements Specification, etc.);
- IT Landscape: contains classes and objects of IT structure and software being used;
- Business processes: contains description of general business processes (for example, description of standard works on product development);
- Types of contracts: contains description of basic types of contracts (Fixed-Price Contract, Time and Material Contract, etc.);
- Patent ontology: contains classes of patent documents (Patent Description, Description of Utility Model, etc.).

It is worth mentioning that concepts from one ontology can refer to concepts from another one. Division of concepts between different ontologies is rather formal and is used for simplification of work with a large domain area. For example, extension of one or another ontology can be divided between specialists according to their expert area and specific character of work.

To systematize a bulk of documentation we suggest using document classifier. Classification of documents is made according to their functions and industry and has strict allocation rules depending on a range of criteria. However, in spite of this mechanism, selection of relevant

data out of all the information is still a time-consuming task. Hence, the best way of ensuring efficient work with documentation is interaction with the system which is able to provide data on the subject satisfying user's interests. To provide such an interaction of a user with the system it is necessary to design a semantic descriptor of the document defined with the help of domain ontology.

Semantic descriptor gives information about the content of IPO and is formed out of its abstract or review. The main benefit of designing semantic descriptor is using it while processing semantic search query. Thus, the more precise and detailed the semantic descriptor is, the more the probability of its relevance to search query.

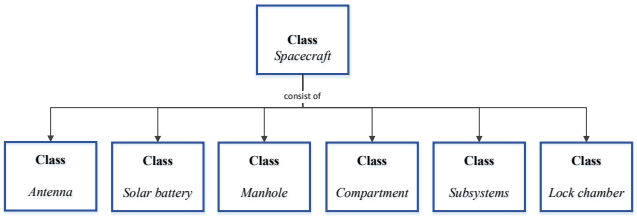

Figure 4. The physical structure of the spacecraft.

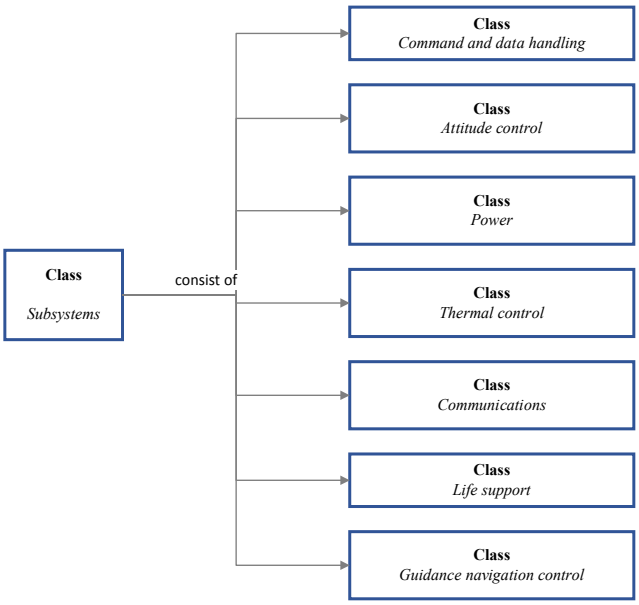

Figure 5. The functional structure of the spacecraft.

Let us consider designing of semantic descriptor by example of design and operational documentation of spacecraft. Design documentation usually contains description of physical structure of a product, description of functional modules. Hence, to design semantic descriptor of the document it is proposed to build the product ontology and connect its concepts with this document. Figure 4 "The physical structure of the spacecraft" and Figure 5 "The functional structure of the spacecraft" present the ontology fragment.

The following can be used as description of IPOs: classes of physical objects as well as description of processes, for instance, processes of product functioning and manufacturing. Let us consider the following patent document as an example: "procedure to test tightness of spacecraft compartment, gear for its implementation and process testing gear for implementation of procedure to test tightness of spacecraft compartment"[11].

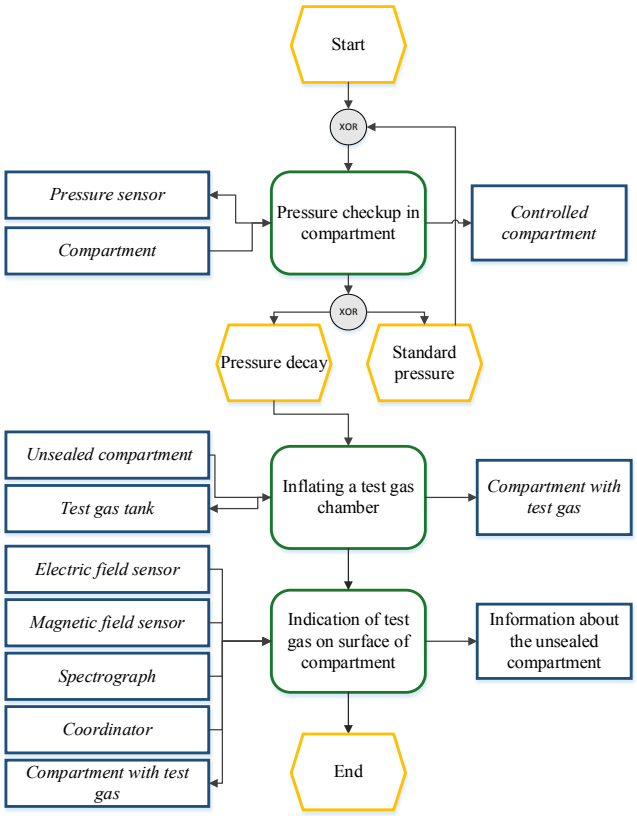

Figure 6. Example of the process.

To describe the content of the patent document the process description is created in the ontology Figure 6. The previously described class of product can be indicated as a participant of the process. Thus, one can describe different aspects of the same technical products. At that various relations can be used: functional, inheritance, "part-whole", etc. If knowledge is formalized and systematized, its value will greatly increase since it will be used repeatedly and extended by experts of various domains. Figure 7 reflects the result semantization patent document.

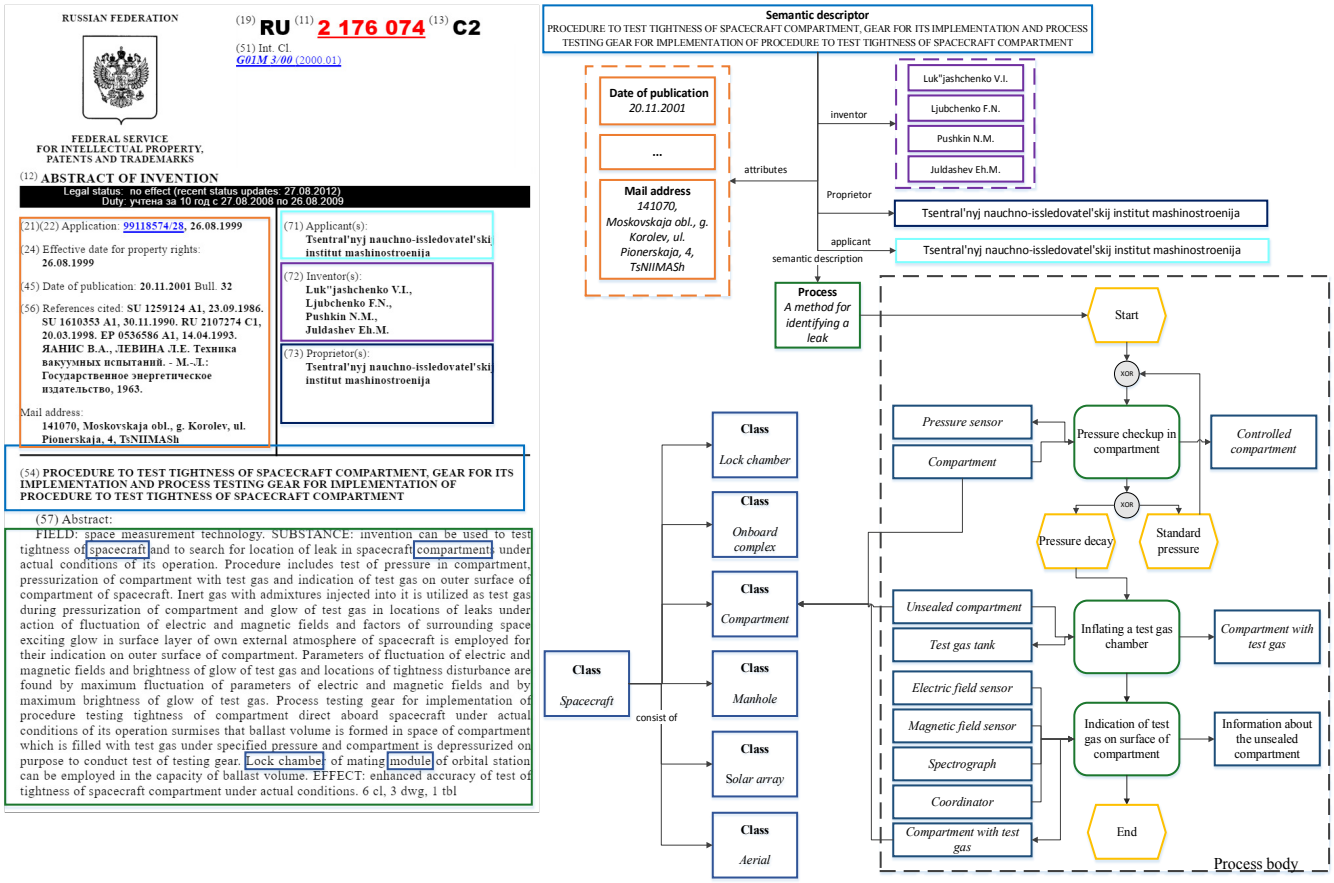

Figure 7. Result semantization patent document.

5. Conclusions

Expected results from using the methodology:

- Forming a unified knowledge base of the RSI as a basis of knowledge management system for accumulation, formalization, systematization and use of knowledge;
- Forming the base for semantization of social network of domain specialists in development of aerospace products;
- Improving the efficiency of knowledge use;
- Return on investment for enterprises from technological advances;
- Monitoring and identification of the most relevant knowledge areas, as well as problematic areas (there is a need – but there is no knowledge);
- Encouraging and motivating young specialists and supporting knowledge and technology transfer.

Applications of the reviewed methodology will make it possible to systematize the available volumes of information, thereby enabling effective use of knowledge. Implementation of these plans is capable of realizing the main corporate priority - creating competitive advantage.

6. Acknowledgement

The study was supported by the Ministry of Education and Science of the Russian Federation (the agreement No. 14.578.21.0137, unique identification number RFMEFI57815X0137).

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