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ARCHITECTURAL SOLUTION OF SYSTEM FOR SEMANTIC COMPARISON OF THE TEXTS

Vitalii Velychko

Abstract*: The paper describes the process of designing an architectural solution of semantic text comparison. The reference text is compared with the base of texts in domain ontology. Ontology data storage is organized as a growing pyramidal network. A flexible architectural solution for semantic comparison of texts based on design pattern Visitor is proposed. Advantages of implementing this architectural solution aimed at adding comparison operations are represented.*

Keywords*: Design patterns, semantic comparison of texts, visitor, fussy sets.*

Introduction

Software system for semantic text comparison can be developed in many areas, namely:

- possibility to recognize text from image files;
- defining the level of similarities considering grammar mistakes;
- processing hieroglyphs smiles and so on;
- to support visualization of comparison results;
- saving comparison history;
- visualize steps of comparison algorithms;
- recognize text in audio files;
- development of security aspects of the software system;
- to detect the same text in different languages.

The growing pyramidal network is one of the organizations of data information storage about problem domain. It allows storing facts about problem domain in trees of RDF triples. Thus, the operation of semantic comparison is based on the comparison of two trees. One of them is extracted from text other trees are stored in the repository of ontologies. Otherwise, a successful semantic comparison of texts must be grounded on an extensible number of operations that should be added or removed flexibly.

Related papers and systems

Comparative analysis of software complexes of natural language processing

Measuring the similarity between texts is an important task of searching and processing texts. Software modules aimed to solve this problem are integrated into different systems in various applications. There are many different approaches to comparing texts. Let's identify their advantages and disadvantages and consider recommendations for a number of specific cases of use.

There are several groups of metrics that allow you to measure distances between texts: The following metrics allow to determine similarities based on

- editing;
- tokens;
- analysis of sequences;
- phonetic;
- hybrid.

Similarity-based editing - the more simple operations you have to perform to convert one line of text to another, the greater the distance between them. For example, the distance between the words "ert" and "wrt" is one, and the distance between "wer" and "sef" is two. This approach applies only to words and short phrases, and is not effective for longer texts. Also, this approach cannot take into account the semantics of words, because it compares only symbols. For example, the semantic distance between "banana" and "kiwi" is less than between "banana" and "mouse". This is why editing-based distances are used in applications where semantic meaning is not as important as similarity in writing. It is also worth noting that the most well-known editing-based algorithm is the Levenstein algorithm.

The similarities based on tokens are a bit more complicated. They analyze the text as a set of tokens (words). This allows you to take into account semantics and process large texts. The semantic meaning plays an important role here, as you can use word vector representations (word2vec) to describe each word in the text and then compare the vectors. Using this approach and the TF-IDF method allows you to compare the semantic similarity between whole texts (although not between independent words). Token-based similarities are widely used in various fields. However, this approach does not apply to a number of cases.

The next group of distances is sequence-based distances. This is a bit like defining syntactic distances. The longest common subsequence is ignored if there are some letters between the characters in the subsequence. For example, consider the letter sets "aebcdnlp" and "taybcrd". The longest common subsequence between these words is "abcd", while the longest common subsequence is only "bc".

Phonetic algorithms form a separate group of methods for comparing strings. In this case, it's not even a line comparison, but rather an audio comparison. These algorithms compare words based on how they are pronounced. It is difficult to compare long texts in this way. Short sentences or phrases are the maximum threshold for these algorithms. In addition, they cannot take into account the semantic meaning.

The following several algorithms (i) compare strings based on similar prefixes or postfixes; (ii) algorithms called "length distance" and "identity similarity". The first compares the strings, counting the number of characters in each of them, and the second algorithms simply check whether these strings are exactly the same or not.

The last group is hybrid algorithms. Consider the method: Monge-Elkan. This is a combined method that takes into account syntactic distance distances and tokens. The Monge-Elcan method compares every word in one text with every word in another text, but when comparing words it uses some methods based on syntactic distances. Then the distances between the words are aggregated to get a single value of the distance between the two texts. The important thing here is that this method is not symmetrical. This means that the result of the comparison depends on which line you take as the first line and which as the second.

Comparative analysis of approaches allowing to process texts is represented in figure 1.

Text Distance Infographics

CATEGORY	APPROACH	⊕ PROS	⊖ CONS	ALGORITHM	AREAS
Edit based Similarities	compare two strings by counting the minimum number of operations required to transform one string into the other	+ Simplicity + Good for short strings	− Inefficient for longer strings − Computationally expensive − Doesn't take into account the semantic meaning	Hamming Levenshtein Damerau-Levenshtein Jaro-Winkler Strcmp95 Needleman-Wunsch Gotoh Smith-Waterman MLIPNS	Spelling correction Duplication search DNA analysis Correction systems for OCR Measuring the linguistic distance of the languages
Token based similarities	compare two strings by looking at units (tokens) of the strings (for example, words, n-grams etc)	+ Computational efficience + Applicable for long texts + Can take into account the semantic meaning	− May be not very good for single words or short phrases from several words − Magnitude of the vectors doesn't play any role in comparison for some algorithms	Jaccard index Sørensen-Dice coefficient Tversky index Overlap coefficient Tanimoto distance Cosine similarity Bag distance	Computer science Text mining Many general NLP problems Bioinformatics Informatiion retieval
Sequence based	compare two strings by looking at different subsequences of the strings	+ Simplicity + Good for short strings	− Inefficient for longer strings − Computationally expensive − Doesn't take into account the semantic meaning	Longest common subsequence similarity Longest common substring similarity Ratcliff-Obershelp similarity	Computer science Bioinformatics Version control systems
Phonetic	compare two strings by comparing how do they sound in pronunciation	+ Allows to analyze another side of the language: pronunciation + Good for short strings	− Inefficient for longer strings − Doesn't take into account the semantic meaning − Needs special preprocessing of the strings − Applicable only for very specific tasks	MRA Soundex Metaphone NYSIIS Editex	Names retrieval Database software
Simple	compare two string by looking at some simple measurements of each string	+ The simpliest algorithms + Good for short strings + Computational efficience	− Inefficient for longer strings − Doesn't take into account the semantic meaning − Very primitive − Applicable only for very specific tasks	Prefix similarity Postfix similarity Length distance Identity similarity	Computer science
Hybrid	combines edit based approach with the token based approach	+ Can take into account the semantic meaning of the word in a text + Can be used for texts of any length + Performs better in texts with misspellings + Flexibility: you can pick any edit based similarity measure	− Can be computationally inefficient for long texts (depends on the edit similarity) − It is not symmetrical	Monge-Elkan	General NLP problems

Created by ActiveWizards

Figure 1 Comparative analysis of approaches to process texts

Figure is taken from

https // activewizards.com/blog/comparison-of-the-text-distance-metrics/

In other words, there are many cases of using text comparison methods in which symmetry is not important.

Authors of SEMILAR (Rus et al., 2013) proposed an approach to compare texts. This approach is based on a collaboration of different levels of similarities between texts. One of them is the word to word similarities. Then more complex levels of similarities are proposed, namely, sentence to sentence, text fragment to fragment. SEMILAR includes implementations of algorithms for solving the problem of defining of text-to-text semantic similarity.

Authors (Furlan et. al., 2013) proposed an approach when the comparison of texts based on their statistical analysis. Mathematical apparatus, designed by authors, aimed to calculate the differences between texts. Authors specialized in small text analysis. That’s why structural differences are more related to semantic similarities or differences. The essence of the proposed approach is represented in figure 2.

Authors (Harispe et. al., 2014) proposed open-source software solutions dedicated to measures of semantic similarities of different texts. It uses Open Biomedical Ontology (OBO) Foundry or BioPortal (Smith et al., 2007; Whetzel et al., 2011) provide access to hundreds of biomedical ontologies expressed in various formats, e.g. Resource Description Framework (RDF), OBO, Web Ontology Language (OWL). These structured vocabularies are used to characterize entities through conceptual annotations. The general structure of libraries involved to the measurement of semantic similarities of the text is represented in figure 3.

Such a library can be used for computations and analyses of semantic similarities between terms/concepts defined in terminologies and ontologies. The comparison of entities (e.g. genes) annotated by concepts is also supported. A large collection of measures is available. The software project is based on JAVA library, as well as a command-line tool that can be used on personal computers or computer clusters.

The advantage of the proposed software solution is using of open source and open architecture approaches to modify the software to support a new combination of measurements.

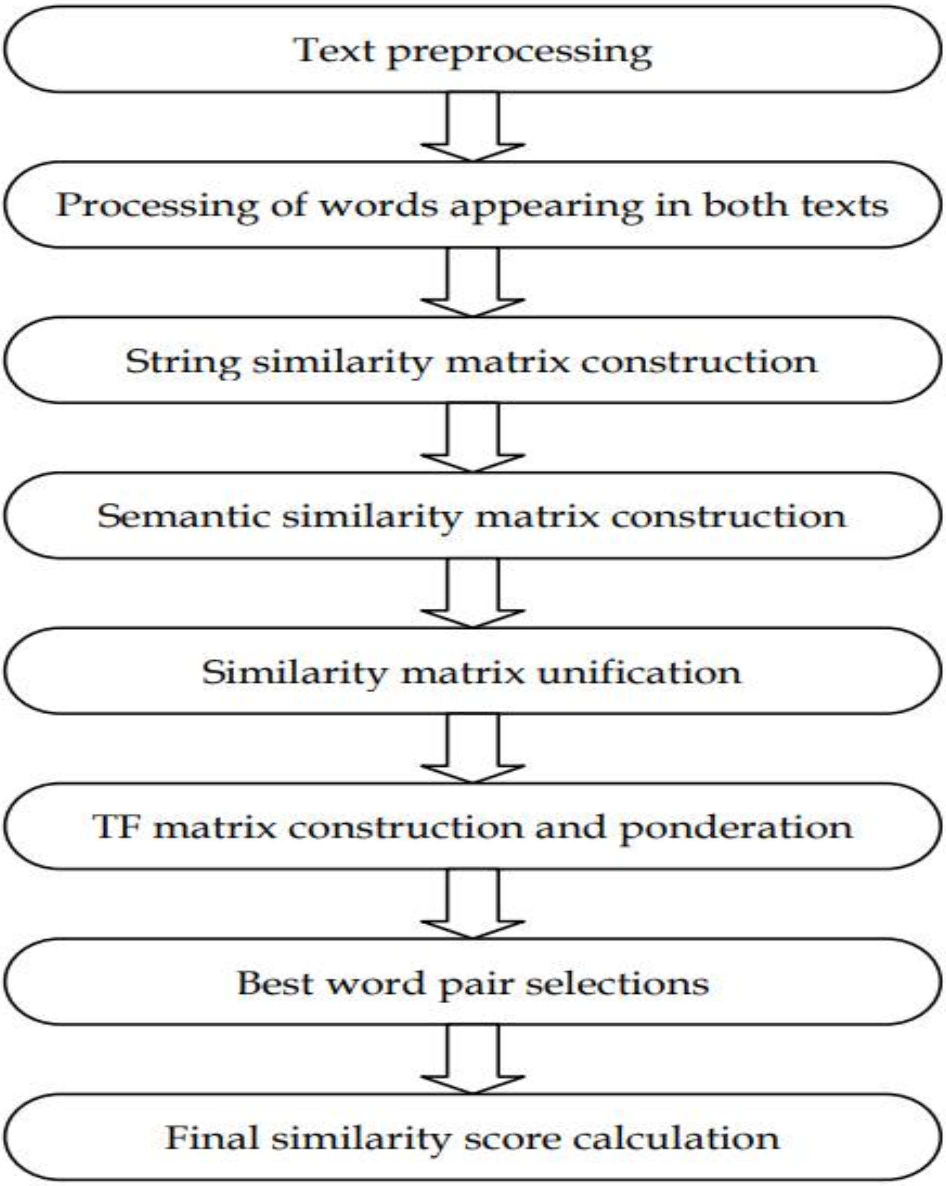

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Figure 2. Workflow of the process of semantic texts comparison based on statistical text analysis

Figure is taken from [Rus et al., 2013]

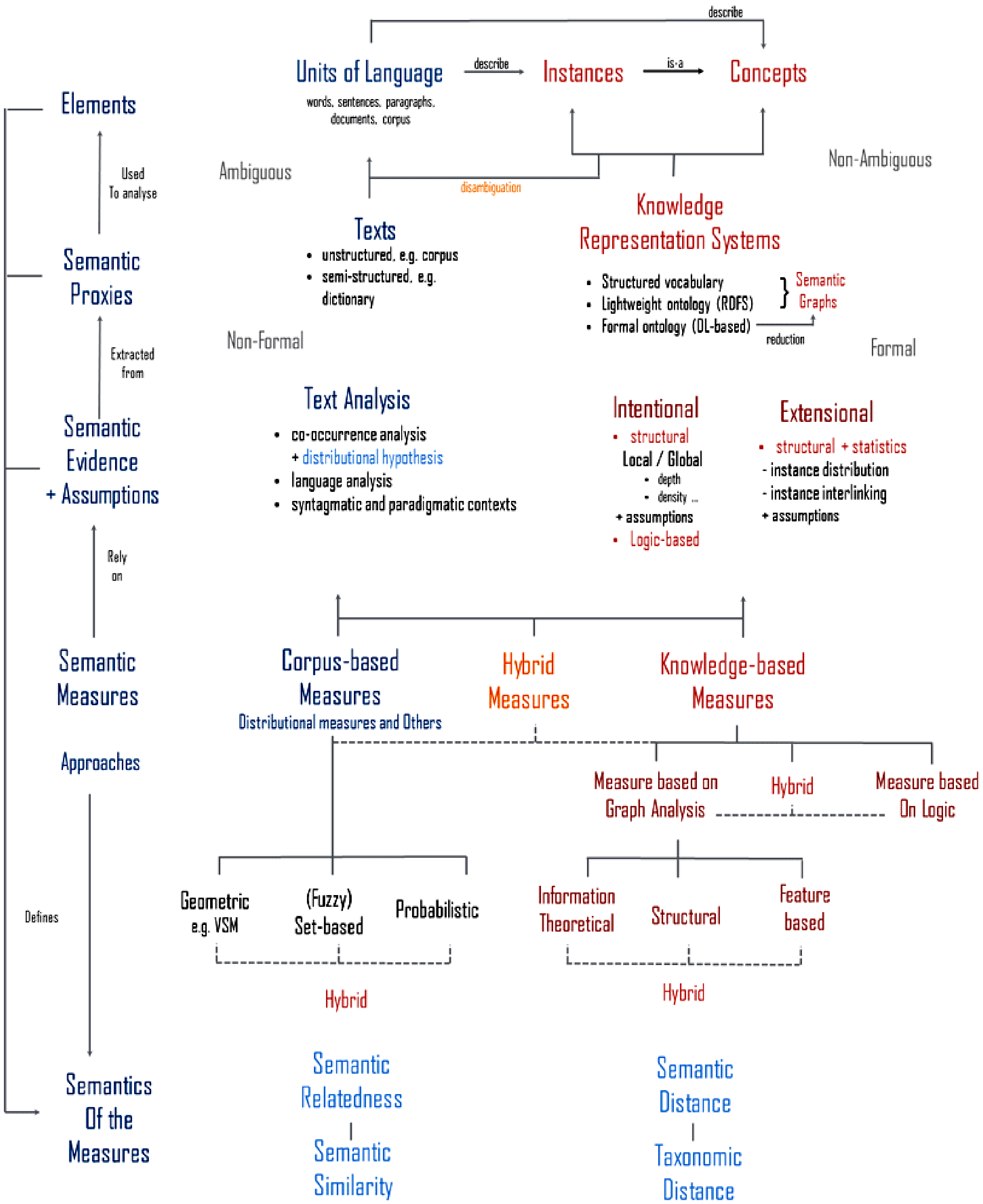

Figure 3. Overview of the types of semantic measures which can be used to compare various types of texts' elements (Harispe et al., 2013b)

Task and research questions

To design an architectural solution for flexible semantic comparison based on possibilities of adding operations and supporting principally new operations for semantic comparison of texts.

RQ1: Propose a requirement specification of a system for semantic comparison of texts.

RQ2: Choose a design pattern for designing such an architectural solution.

RQ3: Design an architectural solution, represented as UML class diagram, implementing composed requirement specification.

Requirement specifications of a system for semantic comparison of texts

Table 1 contains the requirement specification for a software system aimed to perform a semantic comparison of texts.

Table 1. Requirement specification of a software system for semantic texts comparison

RQ code	RQ textual description
F1	Design a problem domain tree Such a tree contains concepts (other words entities, represented by nouns or combination of nouns and adjectives (noun chunk example “operating system”)) and RDF triples to store relationships between entities.
F1.1	Download problem domain tree from ontology storage (In order to do this the Growing pyramidal networks are transformed into an ontology of problem domain)
F1.2	Modify problem domain tree by means of adding or changing new brunch, facts, and entities.

RQ code	RQ textual description
F1.2.1	Remove keywords and corresponding processes
F1.2.2	Add keywords and corresponding processes
F 1.3	Save tree to ontology repository
F1.4	Represent problem domain tree graphically
F2	Select text and define whether its topic of matches with topics (name of the processes) of the problem domain tree.
F2.1	Design a tree from the text
F2.1.1	All entities related to the topic should be found.
F2.1.2	All facts related to the topic should be found.
F 2.2	Show text tree
F3	Compare problem domain tree and text tree
F3.1	Propose a criterion how to define whether trees are equal based on equality of the branches Think how brunch should look like to define preliminary equality Propose criterions precision equality of sub-brunches
F3.3	Represent result of comparison by the following way Text matches to “root process” on xx% Text matches to “process1” on xx% ……………………….. Text matches to “process_n” on xx%

RQ code	RQ textual description
F6	Ability to see the most popular topic at all or specific groups of people.
NF1	web-application
NF2	Satisfy to WCAG requirements
NF2.1	Avoid malicious code attacks from client web page to server
NF2.2	Avoid fishing sites and SQL injections
NF2.3	Provide correct user input and avoid using UI components and frameworks with vulnerabilities
NF2.4	Set up the updated policy (to check for critical updates of the libraries and modules)
NF2.5	Forbid to the attacker can run malicious code through the server's API

The requirement specification for the software module “processing of ontological output by means of fuzzy sets as well as multiset” is represented in Table 2.

Table 2. Requirement specification of a software module of taking decision about different texts

RQ code	RQ textual description
F0	Implementation of common operations on multisets and fuzzy sets Functional representation of multisets and fuzzy sets Coefficient and category. For fuzzy sets the coefficient {0, 1}

RQ code	RQ textual description
	For multisets coefficient {0, + max int } value coefficient only positive The category must be a unique value
F1	Adding two types of sets
F1.1	The operation of combining sets is performed
F1.2	If the sets have the same categories then their coefficients are added
F2	Multiplying sets by a number
F 2.1	All coefficients of categories are multiplied by a certain number
F3	Subtraction of sets
F3.1	All types of categories in different sets are considered in pairs. For common categories, their coefficients are subtracted. If the coefficient is less than zero, then the category is removed from the set
F4	Determining the power of sets as the sum of all their coefficients
F5	Determination of the maximum coefficient for all categories in the set
F6	Checking the coefficients when performing arithmetic operations and set initialization operations and within the range.
F7	Division of sets by coefficient When dividing multisets, keep in mind that the division operation is possible if all the coefficients result in integers. If the result is

<table>
<tr><th>RQ code</th><th>RQ textual description</th></tr>
<tr><td></td><td>not an integer number coefficient is rounding</td></tr>
<tr><td>F 8</td><td>Convert a multiset to a list of sets (fuzzy set)
<pre><code>
  public sets(object[] keys, T[] vals)
        {
            List<object> tempobj = new
List<object>();
            List<T> tempval = new List<T>();
            if (!defineThesameLen(keys.Length,
vals.Length))
                return;
            for (int i = 0; i < keys.Length; i++)
            {
                tempobj.Add(keys[i]);
                tempval.Add(vals[i]);
            }
            ConvertListsToSet(tempobj, tempval);
        }
public sets(List<object> keys, int val)
        {
            List<T> templ = new List<T>();
            T x = (T)Convert.ChangeType(val,
typeof(T));
            for (int i = 0; i < keys.Count; i++) {
                templ.Add(x);
            }
            ConvertListsToSet(keys, templ);

        }

  void ConvertListsToSet(List<object> keys, List<T>
vals)
        {
            // before form a set check the next
conditions:
            // 1. number of keys and values should
be the same
            if (!defineThesameLen(keys.Count,
vals.Count))
                return;
            // 2 all values should be the specific
type and inside of the allowed range
            cht = new checkType();
</code></pre></td></tr>
</table>

RQ code	RQ textual description

	`if (!defineTypeForVals(vals))`
	`    return;`
	`a = new Dictionary<object, T>();`
	
	`for (int i = 0; i < keys.Count; i++)`
	`{`
	`    try`
	`    {`
	`        a.Add(keys[i], vals[i]);`
	`    }`
	`    catch (Exception ex)`
	`    {`
	`        sayError(ex.Message);`
	`    }`
	`}`
	`}`

NF 1	Sets are stored in the Dictionary data structure

Implementation of the multiset and fuzzy set arithmetical processing

The first operation is to check the type of coefficient before performing arithmetical operations. It is realized by means of polymorphism.

```
class checkType
    {
```

Virtual method in base class id designed to verify different types of objects.

```
public virtual void CheckRange(object a, string error, string
ErrorEnd) {
     }}
    class checkInt : checkType
    {
```

```
        public override void CheckRange(object a, string error,
string ErrorEnd)
        {
            int temp = (int)a;
            if (temp <= 0 || temp > int.MaxValue)
            {
                throw new Exception(error + temp + ErrorEnd);
            }
        }
    }
    class checkdouble : checkType
    {
        public override void CheckRange(object a, string error,
string ErrorEnd)
        {
            double temp = (double)a;
            if (temp <= 0 || temp > 1)
            {
                throw new Exception(error + temp + ErrorEnd);
            }
            temp = Math.Round(temp, 5);
        }
    }
```

Example of code to perform additional operations with different types of coefficients.

Static T Add<T>(T a, T b) the realization is based on expression trees. Expression tree is compiled on predicate Func<T,T,T>.

```
   public static T Add<T>(T a, T b)
        {
            GetParam<T>();
            // add the parameters together
```

```
            BinaryExpression body = Expression.Add(paramA, paramB);
            // compile it
Func<T, T, T> add = Expression.Lambda<Func<T, T, T>>(body, paramA,
paramB).Compile();
            // call it
            return add(a, b);

        }

  public static T Sub<T>(T a, T b)
        {
            GetParam<T>();
            // add the parameters together
            BinaryExpression body = Expression.Subtract(paramA, paramB);
            // compile it
            Func<T, T, T> sub = Expression.Lambda<Func<T, T, T>>(body,
paramA, paramB).Compile();
            // call it
            return sub(a, b);
        }

        public static T Mul<T>(T a, T b)
        {
            GetParam<T>();
            // add the parameters together
            BinaryExpression body = Expression.Multiply(paramA, paramB);

            // compile it
            Func<T, T, T> mul = Expression.Lambda<Func<T, T, T>>(body,
paramA, paramB).Compile();
            // call it
            return mul(a, b);
        }

        public static T Div<T>(T a, T b)
        {
            GetParam<T>();
            // add the parameters together
            BinaryExpression body = Expression.Divide(paramA, paramB);

            // compile it
            Func<T, T, T> div = Expression.Lambda<Func<T, T, T>>(body,
paramA, paramB).Compile();
            // call it
            return div(a, b);

        }
```

In order to archive the flexible and extensible software architecture the design pattern Visitor is considered (Antoniol et. al., 2001).

Table 3 explaining the correspondence of some visitor parts and fragments of the class diagram (Gamma et al, 1993).

Table 3. Adoption of Visitor design pattern to the task of text semantic comparison.

Visitor design pattern constituent	**Part of the class diagram (figure 3)**
The **Visitor** interface declares a set of visiting methods that can take concrete elements of an object structure as arguments. These methods may have the same names if the program is written in a language that supports overloading, but the type of their parameters must be different.	Interface compare defines methods for different compare approaches One of them is based on sets, another one based on ontologies comparison

Each **Concrete Visitor** implements several versions of the same behaviors, tailored for different concrete element classes.	Concrete visitors – are classes operators and packages, implementing methods for semantic comparison based on ontology comparison.
	Example of concretevisitors realization
	`public static sets<T> operator`
	`+(sets<T> one, sets<T> two)`
	`{`
	`// to define data type int`
	`or double to check`
	`sets<T> ins = new`
	`sets<T>();`
	`List<T> vals = new`
	`List<T>(one.a.Values);`
	`string errorend =`
	`ins.DefineT(vals[0]);`
	
	`foreach`
	`(KeyValuePair<object, T> kvp in two.a)`
	`{`
	`// when sets are`
	`intersects`
	`if`

<table>
<tr><th>Visitor design pattern constituent</th><th>Part of the class diagram (figure 3)</th></tr>
<tr><td></td><td><pre>
(one.a.ContainsKey(kvp.Key))
                {
                    // add koefficients
on categories
                    try
                    {
                        var rez =
oper<T>.Add(kvp.Value, one.a[kvp.Key]);

ins.cht.CheckRange(rez, ins.errors[1],
errorend);

ins.a.Add(kvp.Key, rez);
                    }
                    catch (Exception
ex)
                    {

ins.sayError(ex.Message);
                    }
                }
                else
                {
                    ins.a.Add(kvp.Key,
kvp.Value);
                }
            }
            // add those values that
are unique for a set
            foreach
(KeyValuePair<object, T> kvp in one.a)
            {
                if
(!ins.a.ContainsKey(kvp.Key))
                {
                    ins.a.Add(kvp.Key,
kvp.Value);
                }
            }
            return ins;

        }
</pre></td></tr>
<tr><td>The Element interface declares a method for "accepting" visitors. This method should have one parameter declared with the type of the visitor interface.</td><td>Elements that accept new operations are Add, Sub, Mul, and Div</td></tr>
</table>

Visitor design pattern constituent	**Part of the class diagram (figure 3)**
Each **Concrete Element** must implement the acceptance method. The purpose of this method is to redirect the call to the proper visitor’s method corresponding to the current element class. Be aware that even if a base element class implements this method, all subclasses must still override this method in their own classes and call the appropriate method on the visitor object.	Class expression plays the role of the concrete element
The **Client** usually represents a collection or some other complex object (for example, a Composite tree). Usually, clients aren’t aware of all the concrete element classes because they work with objects from that collection via some abstract interface.	Client is a Program class that calls these methods.
An explanation was taken from https://refactoring.guru/design-patterns/visitor	

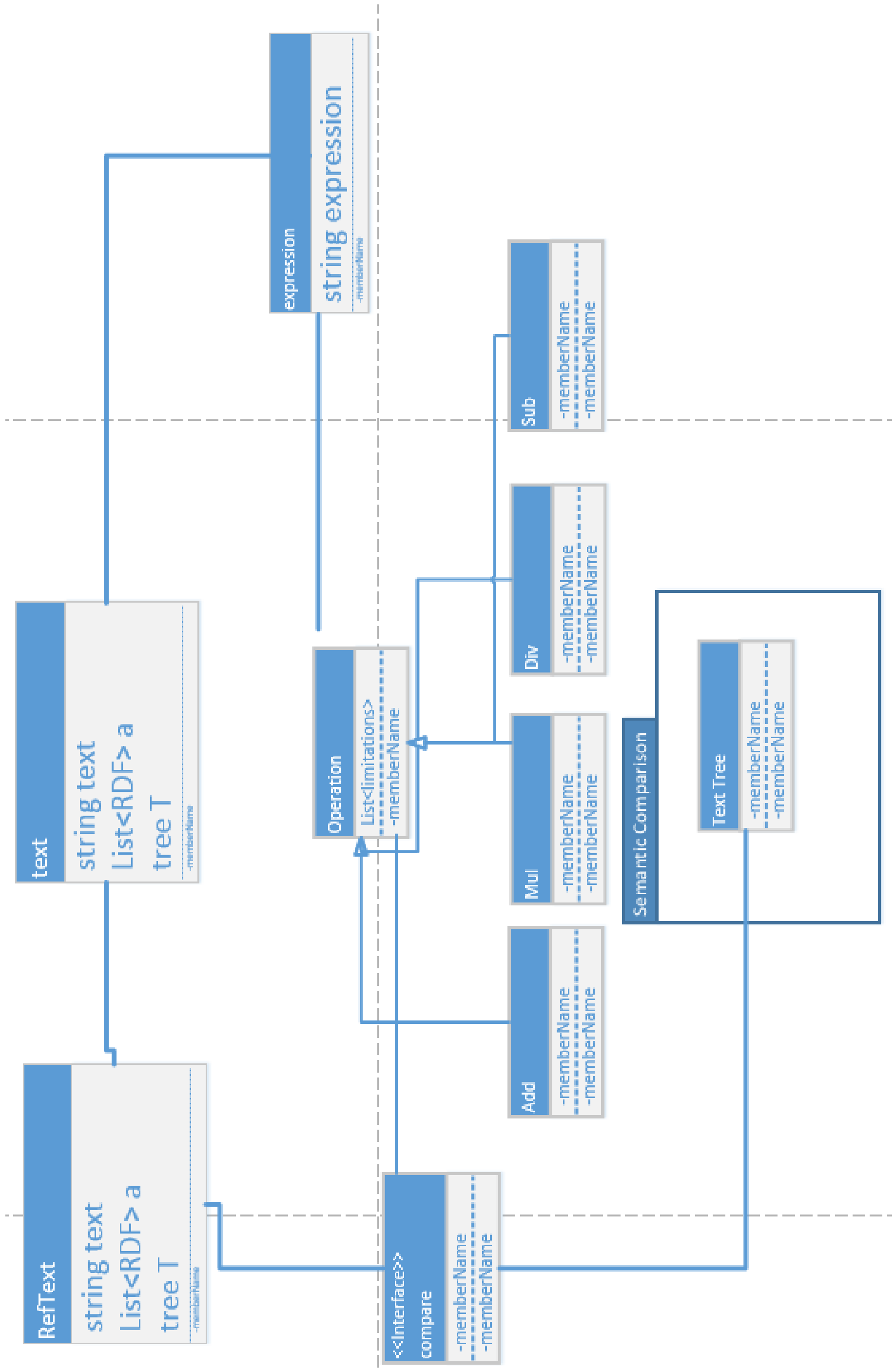

Figure 3. Architectural solution for semantic text comparison

Conclusion

Paper proposes an architectural solution of the software system for semantic comparison of texts that is based on visitor design pattern. Implementation of Visitor design patterns allows to archive the next advantages in semantic texts comparison software systems:

1. High recognition accuracy with given level of details supporting (level of words, sentences, fragments of texts);
2. Usability (flexible architectures and given speed of working) and high security level;
3. Possibility to visualize intermedia results. It will allow to visualize step of comparison algorithms for better testing and teaching of peculiarities of system functionality;
4. Estimation of different comparison algorithms effectiveness multiple solving algorithms. The system should have multiple algorithms to solve the problem because different algorithms can produce different results.

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The main directions of scientific research: computer ontologies and their use in the educational process; information-oriented information systems with processing of natural language objects, ontological approach.

MODEL OF THE RELATION “DIGITAL LEADERSHIP – DIGITAL ENTREPRENEURSHIP” IN THE REALITIES OF INDUSTRY 4.0

Miglena Temelkova

Abstract: *The present article studies the relation between digital leadership and digital entrepreneurship under the conditions of a changed economic reality – the already started Fourth Industrial Revolution. On the basis of analysis of the main characteristics, the functions and the role of the concepts “digital leadership” and “digital entrepreneurship”, there is synthesizing of a model of their interrelation and interdependence achieved. The generated model has a flexible system architecture and it integrates the fundamentally new economic conditions determining the development of Industry 4.0.*

Keywords: *digital leadership, digital entrepreneurship, model, Industry 4.0.*

ITHEA Keywords: *Please use keywords from* http://idr.ithea.org/tiki-browse_categories.php .

Introduction

The turbulent development of technologies and innovations, the ever more persistent advance of artificial intelligence in people’s everyday life and turning it now into an integral part of the economy, the creation of new “smart” materials, machines, technologies, systems, call for the need of a new type of specialists, a new type of managers, a new type of entrepreneurs, a new type of staff, who could not only manage the digital processes, but also integrate in that management the optimal coordination and efficiency of the human resources, who would work in the digital space from various geographical spatial dimensions. The complexity of the emerging processes, gradually evolving and passing from the ecosystem “human – machine” to a blockchain network, and from a blockchain network into cyber-physical systems, requires looking for a new type of leaders, as well as for a new type of entrepreneurs, who should have integrated knowledge and competences enabling them to work in a digital environment, running machines, technologies, systems, processes, people, creating innovative products and/or organizations, and/or penetrating new markets. Thus, gradually, economic reality determines the search by the business organizations of digital leaders and digital entrepreneurs, who together in a relational unity should contribute to obtaining added value of a new type.

Object of study in the present article is the relation "digital leadership – digital entrepreneurship".

Subject of analysis and synthesis in the research is defining the relationship between digital leadership and the digital forms of entrepreneurship under the conditions of Industry 4.0.

The objective of the research is generating a model of the relation "digital leadership – digital entrepreneurship" under the condition of the already started Fourth Industrial Revolution.

The tasks of the paper come down to:

- ✓ synthesis of definitions of the concepts "digital leadership" and "digital entrepreneurship";
- ✓ studying the major characteristics of Industry 4.0;
- ✓ model of the relation "digital leadership – digital entrepreneurship" with the functioning of Industry 4.0.

The restrictions set out in the present article are:

- ✓ the model is not described from the perspective of its added value for the business organizations;
- ✓ the model does not reflect the specific characteristics of the separate business organizations.
- ✓

Nature of the problem

The major challenge nowadays in defining the concepts "digital leadership" and "digital entrepreneurship" is the lack of sufficient research work on these problematic issues.

The basis for defining the concept "digital leadership" should be the definition of the concept "digital environment", which in literature is most often described as a virtual, simulated space, created by using one or more computers or mobile devices.

The aforementioned definition has two cumulatively present elements:

- ✓ virtual space;
- ✓ one computer or mobile device, or a network of computers or mobile devices.

Therefore, the analysis indicates that the digital leader should:

- ✓ operate in the virtual space, where the simulation of processes, phenomena, operations is a tool for forecasting, analysis and evaluation;
- ✓ plan, organize, coordinate and control the work of one or several computers or mobile devices;
- ✓ motivate the human resources, ensuring the work of those computers or mobile devices.

For the realization of those functions that the digital leader has, the latter should:

- ✓ know the principles of working in a digital environment;
- ✓ apply the technologies and tools, which are used for operating in a digital environment;
- ✓ have management skills and competence;
- ✓ integrate in a single and integral system the work of the people and the work of the machines;
- ✓ lead the team or the organization to achieving the strategic orientation targets;
- ✓ facilitate though his/her behaviour in a digital environment the registration of added value for the team or the organization.

Entrepreneurship is nowadays generally defined by theory as a process oriented towards permanent changes, where business alternatives emerge, moderate risk is undertaken and opportunities for implementing innovations and/or innovative products are sought in view of realizing the so-called by Schumpeter [Schumpeter, 1939] "entrepreneurial profit" and ensuring, in a more global aspect, the economic development of a certain macroeconomic system. The entrepreneurial activities can be focused on the introduction of a new product, technology or organization, on entering a new market or using new raw materials and consumables for the production.

Peter Drucker [Drucker, 1985] reached the conclusion that entrepreneurship is predominantly a socio-psychological process, and only to a lesser extent an economic phenomenon, since it is focused on permanent searching for business and innovation opportunities.

Synthesis of definitions of the concepts "digital leadership" and "digital entrepreneurship"

In spite of the lack of sufficient research in the field of digital leadership and digital entrepreneurship, the present article is a specific attempt to upgrade and specify the existing definitions, clarifying the concepts "leadership" and "entrepreneurship", and on this basis, to synthesize essentially new definitions of the concepts, object of the analysis.

The leader's qualities lead to synthesizing the main boundaries of digital leadership, namely: a single, integral, systematically running process in the virtual environment for analyzing a particular situation, establishing and coordinating relations between people, departments, organizations, planning and developing a vision, managing change, adding value. It can be synthesized on this basis, that digital leadership is a concept leading to a higher added value for the organizational system, as well as to integrated comprehensive use of information and communications technology, toolset and human resources in a digital environment in view of achieving the strategic orientation targets of a particular business system through a team interaction between people working through network connected computers or mobile devices, accomplished on the basis of applying a particular leadership style in a virtual environment.

Digital entrepreneurship is focused on generating innovative operative and production business models, whereby realizing higher surplus value. Digital entrepreneurship integrates in itself two major groups of skills:

- ✓ traditional – establishing and maintaining relations with clients, realizing sales, creating partnerships, managing projects, optimizing processes, analyzing the environment, processes and operations, financial management, applying flexible methodology;
- ✓ digital – analysis of large bulks of information, working in a blockchain network, virtualization, creating and developing mobile applications, creating and developing websites, creating and developing information technology architectures and platforms, observing cyber security, working with social media.

On the background of the presented above, it can be summarized that for the purposes of the present study digital entrepreneurship is the possibility to create new organizational forms, products or services, while undertaking a certain risk and by using team interaction and information technology systems.

Studying the major characteristics of Industry 4.0

The research of the major characteristics determining the Fourth Industrial Revolution indicates there is still no single opinion in literature concerning the number, specificity and the particular effects of those factors. On the basis of the method of analysis and synthesis there can be drawn and defined the main characteristics driving the high technology economy 4.0:

- ✓ ecosystem "human – machine" – a hybrid type of ecosystem, created in view of fulfilling certain tasks under certain conditions, where most often interacting are the human factor and roboticized systems based on artificial intelligence and sensor technologies;
- ✓ artificial intelligence – a cyber-physical production system, which has the capacity to analyze the surrounding environment and undertake actions, which enhance the possibility to achieve certain goals, an innovative technology based on sensors, which through abstract symbols try to reproduce human thinking on a hierarchical, logical level, or which imitate human brain through neurons and neural networks, organized in layers, connected between themselves by simulated lines, while those neural networks have the capacity to upgrade the acquired knowledge by gathering experience and growing.
- ✓ virtual reality – a branch of the physical reality, representing an interactive graph in real time with three-dimensional models in a combination with a display, which enables the user to directly immerse in a modeled world;
- ✓ augmented reality - a system, integrating elements from the real and the virtual world, representing an improved version of reality, where certain objects or surroundings in it are enriched with virtual images, that are

overlaid on the real ones, thus improving contemporary perception of reality;

- ✓ 3D printing - additive manufacturing, creating actual public goods through digital printing from material in amorphous form of layer after layer on the basis of a digitalized 3D model, where the customization of the printed product is easily enabled – i.e., there is a possibility to fulfill specific customer requirements;
- ✓ 4D manufacturing - a process of creating a new generation of public goods, which are able to change themselves over time as well as in respect to the changes in the surrounding environment;
- ✓ large-size data - a bulk of data, which size exceeds the capacity of the typical data bases for information storage, management and analysis (Manyika, J., Chui, M., Brown, B., Bughin, J., Dobbs, R., Roxburgh, C., Byers, A., 2011);
- ✓ the Internet of things - a system, created on the basis of connected technologies and platforms via the interrelation and interaction between products, services, places, buildings and people;
- ✓ blockchain networks - specific block chains, combining powerful cryptographic algorithms with systematic decentralized computational capacity, representing a tool for transferring content (information).

These major characteristics produce a driving effect on the high technology economy 4.0, but at the same they prompt the need for a new generation of leaders and entrepreneurs having high technology knowledge, digital skills and competences, guaranteeing for them that they will cope with the global economic challenges, transforming both the real-life production into an additive one, and the linear traditional economy, based on the property over the assets, into a circular economy, based on asset sharing.

Model of the relation "digital leadership – digital entrepreneurship" in the realities of Industry 4.0

When taking into account the interrelation and interdependence between the concepts "digital leadership" and "digital entrepreneurship", the model acts as a perfect tool supporting the decisions with the process-oriented, planned and predispositioning strategic steps and actions of the business organizations, operating under the conditions of Industry 4.0. The dynamic processes are reproduced through the model in the business units, which are related and/or resulting from the developed forms of digital leadership and digital entrepreneurship therein. At the same time, the model as a tool produces a flexible system architecture, bearing realistic and adequate information about the structure, processes and functional areas of the studied objects.

The model is a managerial building block, which makes it possible, in spite of its restricted conditions and resources, to analyze the essential and functional dependencies between the objects, their similarities and differences, their relational involvements, while observing the conditions of the environment, the input and output information and the goals and tasks of the study. Thus, in an abstract and simplified way, a picture is drawn of the actual relation in the business organizations between the studied concepts, which characteristics are described only through their main attributes having an impact on the specific relations in the economic entities.

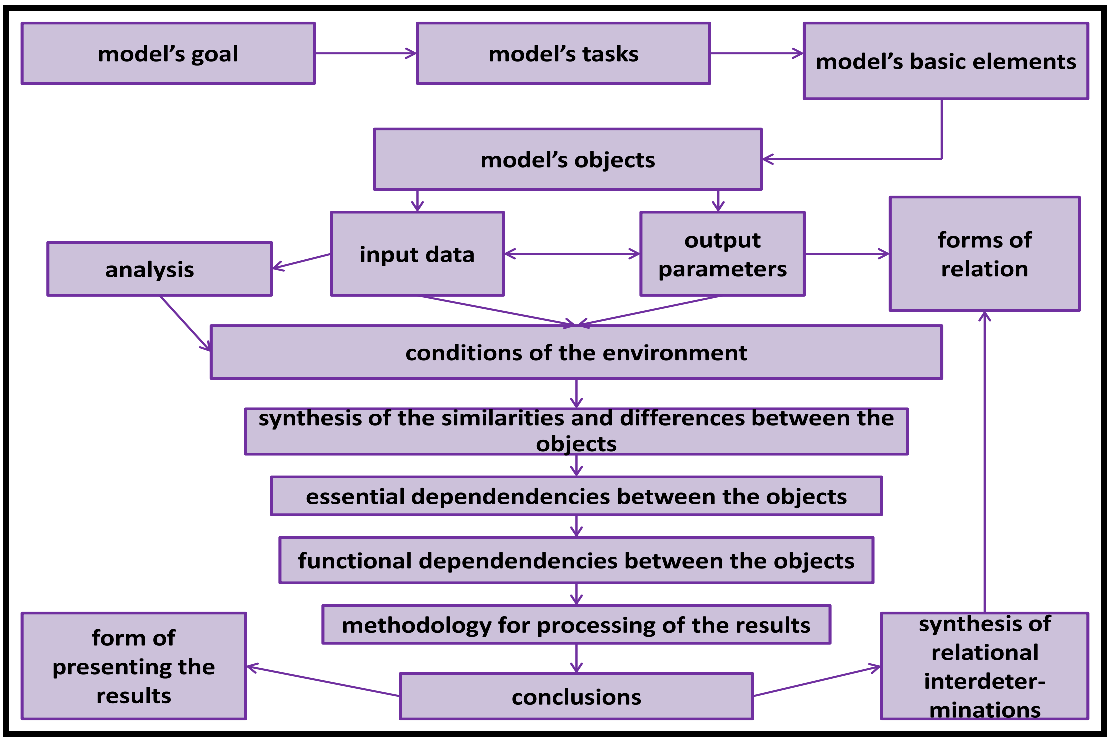

Figure 1. Model of the relation "digital leadership – digital entrepreneurship"

auhtor's adaptation

Conclusion

On the basis of the generated model of the relation "digital leadership - digital entrepreneurship", there are concepts defined, which determine to a large extent the two studied objects. Those concepts are:

- ✓ digital economy – a combination of related digital technological solutions facilitating the development of automation, integration and real time data exchange in the production processes, which generates times higher added value rate (economic and/or social) compared to the traditional economic system;
- ✓ digital business organization – an enterprise from any sector of the economy, which on the basis of digital technological solutions improves its business and production processes and intellectual resources, and as a result of that generates times higher added value rate (economic and/or social) compared to the traditional economic entities.

On the background of the presented major characteristics of the digital economy and the digital business organization there can be synthesized the main dependencies, interrelations and inter-determinations between digital leadership and digital entrepreneurship:

- ✓ the digital leader and the digital entrepreneur should have competence in the field of the computer systems and technologies, mechatronics, robotics and artificial intelligence;
- ✓ the digital leader and the digital entrepreneur should have business knowledge, insight and potential.

A main difference between the digital leader and the digital entrepreneur is the circumstance that the digital leader knows and applies the mechanisms of the strategic business leadership and the leadership in an organizational environment.

Therefore, it can be summarized that the digital leader represents a system of integrated interdisciplinary comprehensive knowledge, skills and competences, which can generally be differentiated in two main groups:

- ✓ social, economic, legal and management knowledge, skills and competences in the field of:

- leadership in a business organization – achieving certain organizational goals through a team interaction, which is planned, organized, coordinated, motivated and controlled on the basis of trust, by a particular person, who has specific distinguishing personal and organizational characteristics – a leader;
- strategic business leadership – achieving leadership by a particular business system (economy, sector, organization, team) in a particular environment, according to a certain criterion or a system of criteria;
- management – goal setting, administering, maintaining and developing the systems and structure of a certain economic entity on the basis of permanent monitoring and control;
- entrepreneurship – the readiness to take risks, adapting to the novelties, making use of the opportunities of the environment (both internal and external);
- digital entrepreneurship – the possibility to create new organizational forms, products or services, while undertaking a certain risk, and by using team collaboration and information technology systems.

✓ engineering-and-technical knowledge, skills and competencies in the field of:
- computer science;
- physics;
- robotics;
- mechatronics.

The aforementioned interdisciplinary knowledge, skills and competences prompt the summarization that digital leadership represents a single and integral concept, based on the integrated comprehensive use of the information and communications technology and human resources, an intrinsic part of which is digital entrepreneurship.

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Major Fields of Scientific Research: management, leadership, controlling

MATHEMATICAL MODEL OF MULTICRITERIAL DISTRIBUTION OF TRANSPORT FLOWS IN THE MULTIMODAL TRANSPORT NETWORK

Tetiana Konrad

***Abstract**: The article proposes a mathematical model of multicriteria distribution of transport flows in a multimodal transport network. The model is based on the presentation of the problem in a multicriteria form according to the efficiency-cost model using a nonlinear scheme of compromises. The problem of choosing the optimal route is formalized and solved as a problem of multicriteria choice of the graph bypass option. The assessment of the reliability of the optimal route is carried out by an integrated assessment using a fundamental rating scale.*

***Keywords**: Multimodal transportation, multicriterial optimization, indicator, criterion.*

Introduction. Problem statement

Intensive growth of demand for freight transportation by rail, road, sea (river) modes of transport necessitates the interaction of two or more modes of transport in one transport process. These modes of transport can be discharged by the shipper as an alternative, however, there are certain resource limitations in the use of each of the modes of transport, which make it impossible to deliver goods "door to door" only one mode of transport. In such cases, multimodal transportation is appropriate, which makes it possible to combine the advantages of interacting modes of transport.

The distribution of traffic flows will be considered on the example of the rail freight system, which is indicative, as hub railway stations are points of interaction of rail with other modes of transport, and passenger and freight railway rolling stock is shared, and require internal distribution of passengers and freight. This organization of traffic overloads railway infrastructure facilities and causes deviations in train schedules and subsequent successive reloading of cargo on other modes of transport. Therefore, for the effective organization and management of freight and passenger traffic in a multimodal transport network, the solution requires the applied problem of choosing the optimal route for the transportation of goods.

Therefore, there is a need to find new solutions for the efficient distribution of traffic flows in a multimodal transport network. One such solution is the use of mathematical approaches to solve the problem of allocation of limited resources, namely the separation of freight and passenger traffic in Ukraine with the allocation of separate tracks for exclusively freight trains. Progressive in this sense are the methods of multicriteria (vector) selection, evaluation and optimization [Voronin, 1997]. Methods for solving multicriteria problems are considered in the works of G.I. Ankudinov G.I., Antushev G.S., Voronin A.N., etc. [Ankudinov, 1986], [Antushev, 1986], [Vermishev, 1982]. In the field of view of modern domestic and foreign scientists are the issues of the mode of operation of modes of transport. In particular, it is worth noting the contribution of the American scientist Jean-Paul Rodrigo, who studies the modality of road and rail modes of transport [Rodrigue, 2013]; theoretical and practical problems related to the strategy of international integration of the transport and road complex of Ukraine in the processes of integration into the world and European transport systems are considered by scientists Yu. Ye. Pashchenko, O.I. Nikiforuk in [Pashchenko, 2008]; rational schemes of distribution of train flows are considered [Tkhoruk, 2019], [Kujala, 2018], [Kyrychenko, 2018], [Papakhov, 2016], [Galaburda, 1996]. The work of scientists Vorkuta A.I. is devoted to the study of the process of interaction of modes of transport during freight transportation, in particular the organization, transportation management, and operational work scientists [Vorkut, 1986], [Abramov, 2004], [Pravdin, 1997]. These approaches are used to increase the efficiency of the transport process on certain modes of transport, which does not provide a solution to the complex problem of the distribution of traffic flows in a multimodal transport network. The methods used in solving multicriteria and methods of parametric synthesis and design are discussed in detail in [Brahman, 1992], [Baranov, 2018], [Baranov, 2015], [Berdnik, 2016], [Ziatdinov, 2015]. Their analysis shows that the most effective are the methods of multicriteria optimization, which consist of reducing the problem to a single-criterion form by a certain criterion and finding its extremum [Keeney, 1981], [Voronin, 1997], [Brahman, 1992]. Since the traditional formalization of the optimization problem in a single-criteria form does not provide a solution to the complex problem of traffic flow distribution and selection of the optimal route of cargo delivery in a multimodal transport network, it is necessary to solve the problem using multicriteria approaches [Voronin, 2017], [Kharchenko, 2015], [Saaty, 1984]. Therefore, it is necessary to solve the problem of choosing the optimal route of transportation using multicriteria approaches.

Presentation of the main research material

Multimodal transportation of goods is carried out with the participation of two or more modes of transport involved in one transportation process and is an integral part of a single transport system of Ukraine. The points of interaction of modes of transport and segments of freight routes form a multimodal network, which by its nature is an undirected graph, the vertices of which are the points of interaction, and the edges - the paths. Roads and other infrastructure facilities (port, station, station, etc.) of multimodal transportation are a limited resource that can pass a certain number of units of rolling stock per unit time.

To characterize the subject area, we use the following terminology and take into account the following features.

Multimodal transportation of goods – transportation of goods by two or more modes of transport, which is organized under the responsibility of the operator of multimodal transportation on the basis of a single contract for multimodal transportation.

The stage of multimodal transportation is a segment of the route of multimodal transportation of cargo by one mode of transport.

The route of multimodal transportation is the way of transportation of cargo determined by the contract of multimodal transportation.

Multimodal terminal is a production and transshipment complex of an economic entity of any form of ownership, which provides the organization of multimodal transportation of goods.

To solve the applied problem of choosing the optimal route of cargo delivery in a multimodal transport network, a multicriteria mathematical model of traffic flow distribution has been developed. The model belongs to the class of optimization and involves determining the optimal delivery route and confirmation of the authenticity of the determined optimal route. The developed model is based on the presentation of the problem in a multicriteria form and its solution by a nonlinear scheme compromises.

The essence of the formation of a multicriteria model is explained by the structural-logical scheme shown in Figure 1.1.

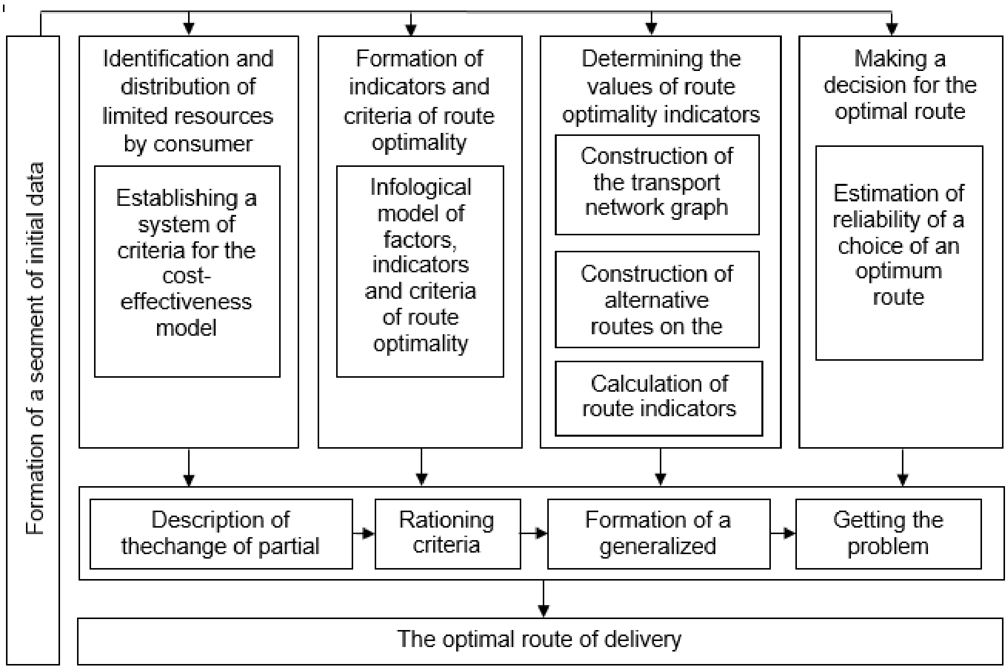

Figure 1.1. Structural and logical scheme of formation of the multicriteria mathematical model of traffic flow distribution

1. Identification and distribution of limited resources by consumer groups

Railway tracks, which carry freight and passenger rolling stock – a limited resource. Rational allocation of limited resources is needed by consumers of transportation services - passengers and shippers.

The optimal (rational) distribution of limited resources in complex the ergatic systems is performed to organize the efficient allocation of resources. Given the wide variety of tasks on the optimal allocation of resources, it should be noted some of its features:

- Diverse resources (stocks) are subject to distribution.
- The distribution of resources is characterized by the diversity of needs of consumers of stocks.
- The requirement of optimality (rationality) of resource allocation is the highest efficiency of performance of target tasks by consumers on

purpose after distribution of resources at their minimum expenses. There are no conditions for the distribution of all stocks (resources).

- The situation is possible when the target tasks are performed by the consumer for the intended purpose in the case of meeting at least one of his needs (in general, the supplier's resource is allocated).

Given the above, we can formalize the problem of optimal allocation of limited resources, as follows. Let the set of consumers be given $SP=\{SP_i\}$, $i=1\ldots I$ – number of consumers) each of which has limited set of disparate needs $SP_i \subset \{P_{otij}\}$, $j=1\ldots J$ – number of needs i-th consumer) certain limited resources (stocks). It is possible to set priorities in customer service and meet their needs. The set of suppliers is set $PS=\{PS_k\}$, $k=1\ldots K$ – number of suppliers) with a list of heterogeneous limited stocks $PS_k \subset \{Z_{apkm}\}$, $m=1\ldots M$ – the number of stocks of a certain type). The number of suppliers and their stocks of resources is much smaller than the number of consumers and the list of their needs. It is necessary to distribute limited stocks Z_{apkm} suppliers PS_k by consumers SP_i so as to meet their needs P_{otij} provided the best efficiency of performance of target tasks by consumers. The distribution of stocks should be implemented taking into account the priorities in customer service. Thus the condition of distribution of all available stocks (resources) is not put forward and the situation of effective performance of target tasks by the consumer at the satisfaction of at least one need is possible.

To solve the formulated problem, the first step is to form a table of consumer rankings by selecting from the set $SP=\{SP_i\}$ – $l=1\ldots L$ groups for each of which there are requirements to meet their needs and efficiency in the implementation of target tasks P_l. The ranking table is formed following the directive requirements for the efficiency of distribution, the experience of solving this class of problems, and external factors.

In each l-th group, the needs of each i-th consumer are ranked on priority, and efficiency of performance of target tasks at the satisfaction of its j-th needs P_{otij} and resource consumption k-th supplier Z_{apkm}. Thus, we will have a ranking of consumers and their needs according to the priority of service, which provides a conditional distribution of limited resources, based on the requirements for the effectiveness of this process, Table 1.1.

Table 1.1.Consumer ranking table

Group number / consumer number in the group	Priority of consumer needs	Hierarchy of consumer needs	The effectiveness of the target tasks by the consumer	Consumed resource of the supplier
Consumer groups 1				
1/1	Consumer 1			
	1	P_{ot11}	E_{11}	R_1
	2	P_{ot12}	E_{12}	R_2
	…	…	…	…
	J_1	P_{ot1J1}	E_{1J1}	R_K
1/2	Consumer 2			
	1	P_{ot21}	E_{21}	R_1
	2	P_{ot22}	E_{22}	R_2
	…	…	…	…
	J_2	P_{ot2J2}	E_{2J2}	R_K
…	…		…	
Consumer groups 2				
2/1	Consumer 1			
	…	…	…	…
	…	…	…	…
…				
Consumer groups L				
L/1	Consumer 1			
	…	…	…	…
	…	…	…	…

The second stage involves the formation of a system of partial criteria of optimality and a description of their change. To do this, set a variable parameter - the number of suppliers allocated to serve the needs of the consumer n_i, with restrictions on the total number of suppliers N:

$$n_i, \sum_{i=1}^{I} n_i \le N; \tag{1.1}$$

therefore, it will be allocated for the first consumer i_1, for the second – i_2, supplier, and the value n_i = 2, means selection for i-th consumer suppliers to meet P_{ot1} needs (with the first priority) and needs P_{ot2} with the second priority. A cost-effective model of partial criteria will be used to optimally allocate limited resources. The criterion of efficiency will be the quality of the consumer's performance of target tasks while meeting his needs $P(n) \Rightarrow max$. The criterion of cost is the generalized cost of the supplier's resource to meet the needs of the consumer for high-quality performance of their target tasks $S(n) \Rightarrow min$. Then, for several consumers within one group of importance, we will have a system of partial criteria

$$\begin{cases} P_1(n_1) \Rightarrow max, S_1(n_1) \Rightarrow min, P_2(n_2) \Rightarrow max, S_2(n_2) \Rightarrow min, ..., \\ P_i(n_i) \Rightarrow max, S_i(n_i) \Rightarrow min, ..., P_I(n_I) \Rightarrow max, S_I(n_I) \Rightarrow min. \end{cases} \tag{1.2}$$

The contradiction of partial criteria (1.2) is a sign of bringing the problem of the optimal distribution of limited resources to a multicriteria form. The description of the change of criteria (1.2) is determined by the specifics of the problem and in the first approximation is carried out in discrete form with subsequent approximation by polynomial models

$$P_i(n_i) = P_o + P_1 n_i + P_2 n_i^2 + ..., S_i(n_i) = S_o + S_1 n_i + S_2 n_i^2 + ..., \tag{1.3}$$

where the parameters of the models – P_0, P_1, P_2 ; S_0 S_1 S_2 consistent with discrete data, such as the norm.

The third stage of the methodology is a direct solution to the optimization problem by reducing the set of partial criteria to a generalized functional. To form a generalized criterion for the optimal distribution of limited resources, a nonlinear scheme of compromises will be used following the convolution of Professor A.M. Voronin, [Voronin, 1997], [Voronin, 2017]. Compared to other optimization schemes, the convolution has the following advantages: optimization problems are solved in the presence of constraints within which the unimodality of the generalized criterion function is guaranteed; relatively small computational complexity of the solution search algorithm. The convolution for the analog representation of partial criteria has the form

$$\chi^* = \underset{\chi \in G}{\operatorname{argmin}} \sum_{l=1}^{b} \gamma_{l0} \left(1 - \varphi_{ol}(\chi)\right)^{-1} = F(\chi), \tag{1.4}$$

where l =1…b – the number of included in the convolution of partial optimality criteria; χ – optimized parameter; G – area for determining the functions of partial optimality criteria; $\varphi_{ol}(\chi)$ – normalized function l-th partial criterion of optimality; χ^* – the optimal value of the system parameter. The rationing of partial criteria is carried out to bring them to a dimensionless minimized form relative to the maximum (minimum) on a limited interval of consideration of the criterion. Thus, the rationing of analytical models (1.3), from the list (1.2) is carried out on a limited (when obtaining discrete values) interval of change of argument n_i, which allows to take into account the needs i-th consumers in the rationing of efficiency criteria $P(n_i)$, and limited stocks k-th supplier when rationing the cost criterion $S(n_i)$.

The formation of the generalized functionality according to criteria (1.2) will be carried out using the technology of nested convolutions (convolution convolutions) in stages for each subgroup of consumers. Then, the use of convolution (1.4) provides a system of generalized criteria for important groups.

$$\begin{cases} \delta_1(n_{11}, n_{12}, \ldots, n_{1i}, \ldots, n_{1l1}) \Rightarrow \min, \delta_2(n_{21}, n_{22}, \ldots, n_{1i}, \ldots, n_{1l2}) \Rightarrow \min, \ldots, \\ \delta_l(n_{l1}, n_{l2}, \ldots, n_{li}, \ldots, n_{ll1}) \Rightarrow \min, \delta_L(n_{L1}, n_{L2}, \ldots, n_{Li}, \ldots, n_{LlL}) \Rightarrow \min, \\ S_1\begin{pmatrix} n_{11}, n_{12}, \ldots, n_{1i}, \ldots, n_{1l1}, n_{21}, n_{22}, \ldots, n_{1i}, \ldots, n_{1l2}, \ldots, n_{l1}, n_{l2}, \ldots, n_{li}, \\ \ldots, n_{ll1}, n_{L1}, n_{L2}, \ldots, n_{Li}, \ldots, n_{LlL} \end{pmatrix} \Rightarrow \min. \end{cases} \tag{1.5}$$

where

$$\delta_1(n_{l1}, n_{l2}, \ldots, n_{li}, \ldots, n_{ll1}) = \gamma_{ol1}\left(1 - \varphi_{ol1}(n_{l1})\right)^{-1} + \gamma_{ol2}\left(1 - \varphi_{ol2}(n_{l2})\right)^{-1} + \ldots +$$
$$+ \gamma_{oli}\left(1 - \varphi_{oli}(n_{li})\right)^{-1} + \ldots + \gamma_{oll}\left(1 - \varphi_{oll}(n_{ll})\right)^{-1},$$

criterion of efficiency of customer service l-th groups of importance,

$$S_1(n_{11}, n_{12}, \ldots, n_{1i}, \ldots, n_{1i1}, n_{21}, n_{22}, \ldots, n_{1i}, \ldots, n_{1l2}, \ldots, n_{l1}, n_{l2}, \ldots, n_{li}, \ldots, n_{ll1}, n_{L1}, n_{L2}, \ldots, n_{Li}, \ldots, n_{LlL}) =$$
$$= \gamma_{oS11}\left(1 - S_{o11}(n_{11})\right)^{-1} + \gamma_{oS12}\left(1 - S_{o12}(n_{12})\right)^{-1} + \ldots + \gamma_{oS1i}\left(1 - S_{o1i}(n_{1i})\right)^{-1} + \ldots + \gamma_{oS1l1}\left(1 - S_{o1l1}(n_{1l1})\right)^{-1} + \ldots$$
$$+ \gamma_{oS21}\left(1 - S_{o21}(n_{21})\right)^{-1} + \gamma_{oS22}\left(1 - S_{o22}(n_{22})\right)^{-1} + \ldots + \gamma_{oS2i}\left(1 - S_{o2i}(n_{2i})\right)^{-1} + \ldots + \gamma_{oS2l1}\left(1 - S_{o2l1}(n_{2l1})\right)^{-1} + \ldots$$
$$+ \gamma_{oSl1}\left(1 - S_{ol1}(n_{l1})\right)^{-1} + \gamma_{oSl2}\left(1 - S_{ol2}(n_{l2})\right)^{-1} + \ldots + \gamma_{oSli}\left(1 - S_{oli}(n_{li})\right)^{-1} + \ldots + \gamma_{oSll1}\left(1 - S_{oll1}(n_{ll1})\right)^{-1} + \ldots$$
$$+ \gamma_{oSL1}\left(1 - S_{oL1}(n_{L1})\right)^{-1} + \gamma_{oSL2}\left(1 - S_{oL2}(n_{L2})\right)^{-1} + \ldots + \gamma_{oSLi}\left(1 - S_{oLi}(n_{Li})\right)^{-1} + \ldots + \gamma_{oSLl1}\left(1 - S_{oLl1}(n_{Ll1})\right)^{-1} + \ldots$$

criterion of generalized value (costs) to meet the needs of consumers, γ_{0ij}, γ_{0sij} – ration weights that characterize the advantage (importance) of the relevant criterion in solving the problem of optimal allocation of resources. Double indexing of parameters n_{li} by index l – characterizes the number of selected groups, and the index i – number of consumers in the group.

From the generalized criteria (1.5) the integrated criteria of optimality of distribution of limited resources are formed (expression (1.6). Rationing (1.5) is carried out concerning the size which is defined at the worst variant of distribution of resources of suppliers between consumers:

$$\Omega\begin{pmatrix} n_{11},n_{12},\dots,n_{1i},\dots,n_{1l1},n_{21},n_{22},\dots,n_{2i},\dots,n_{2l2},\dots,n_{l1},n_{l2},\dots, \\ n_{li},\dots,n_{ll1},n_{L1},n_{L2},\dots,n_{Li},\dots,n_{LlL} \end{pmatrix} = \\ = G_{o1}\left(1-\delta_{o1}(n_{11},n_{12},\dots,n_{1i},\dots,n_{1l1})\right)^{-1} + \\ + G_{o2}\left(1-\delta_{o2}(n_{21},n_{22},\dots,n_{2i},\dots,n_{2l2})\right)^{-1} + \\ + G_{ol}\left(1-\delta_{ol}(n_{l1},n_{l2},\dots,n_{li},\dots,n_{ll1})\right)^{-1} \\ + G_{oL}\left(1-\delta_{oL}(n_{L1},n_{L2},\dots,n_{Li},\dots,n_{LlL})\right)^{-1} + \\ + F_o\left(1-S\begin{pmatrix} n_{11},n_{12},\dots,n_{1i},\dots,n_{1l1},n_{21},n_{22},\dots,n_{2i},\dots \\ \dots,n_{2l2},n_{l1},n_{l2},\dots,n_{li},\dots,n_{ll1},n_{L1},n_{L2},\dots,n_{Li},\dots,n_{LlL} \end{pmatrix}\right)^{-1}. \tag{1.6}$$

In (1.6) G_{01}, G_{02}, G_{0l}, G_{0L}, F_0 – normalized weights, consistent with the requirements of the effectiveness of the target tasks by consumers after the distribution of resources of suppliers. Integrated criterion (1.6) is an optimization model of optimal allocation of limited resources. Determination of the optimal values of the varied parameters according to model (1.6) is carried out by solving a system of nonlinear equations:

$$\frac{\partial^{(l_1+l_1+\dots+l_l+l_L)}\Omega\begin{pmatrix} n_{11},n_{12},\dots,n_{1i},\dots,n_{1l1},n_{21},n_{22},\dots,n_{2i},\dots,n_{2l2},\dots, \\ n_{l1},n_{l2},\dots,n_{li},\dots,n_{ll1},n_{L1},n_{L2},\dots,n_{Li},\dots,n_{LlL} \end{pmatrix}}{\partial^{(l_1+l_1+\dots+l_l+l_L)} n_{il(1,2,\dots,l,\dots,L)}} = 0. \tag{1.7}$$

The result of the solution of the system (1.7) is the value of the varied parameters n^{*}_{lil}, which, if necessary, are rounded to whole numbers n^{opt}_{lil} with control of condition (1.1).

2. Formation of indicators and criteria of route optimality

The structure of System of Rail Freight Transportation (SRFT) can be represented by the following components - transport work, material and technical base, operational work, economic efficiency. These components of the structure of SRFT, following the main purpose of the system, are determined by a set of factors that affect its effectiveness as a whole and form a system of indicators and criteria of optimality.

The main categories of factors influencing the choice of the route of transportation of goods by rail rolling stock: organizational (technological), technical (operational) and economic.

The category of organizational (technological) factors includes those that characterize the participants in the transportation process, namely the number of modes of transport involved in the transportation process, available rolling stock, responsibility and professionalism of persons planning operations, routes, documentation and directly transportation.

The category of technical (operational) factors should include those determined by the technical component of the system, the capabilities of technical devices. The following groups of factors are included in this category: rolling stock and equipment, infrastructure, cargo, cargo handling point.

The category of economic factors that affect the efficiency of the functions performed by the system reflects the cost of operations, including the cost of transportation of passengers and goods, the cost of achieving high productivity, deductions for system maintenance and more.

To achieve a positive effect from the functioning of the system when considering both organizational (technological) and technical (operational) factors, there is a need to increase certain costs. This resource is limited, so it is natural to try to reduce costs in the system. Thus, the category of economic factors affects the efficiency of the system, and the reduction of economic costs often leads to a deterioration of its properties.

A limited resource is an infrastructure (a category of technical factors) that can pass a certain number of units of rolling stock per unit time (organizational factors), and exceeding this limit leads to depreciation of fixed assets, and instead of a positive economic effect leads to increased costs. Thus, there is an impact of technical factors on the economic and organizational components of the rail freight system.

According to the structure of SRFT and the factors influencing the choice of route, groups of indicators of railway transportations are:

Indicators of transport work (turnover of goods *Pl*, turnover of passengers *Al*, volume of cargo transportation q_g, volume of passenger traffic q_p);

Indicators of material and technical base (operating length of tracks between stations L_E, network density d_S, load capacity of a rolling stock unit P_n);

Indicators of exploitation work (average distance of cargo transportation l_c, average distance of passenger transportation l_{cp}, speed of cargo delivery v_d, traffic intensity *W*);

Indicators of economic efficiency and financial (the cost of transporting passengers C_p, the cost of transportation of goods C_v, productivity of work P_p, revenues *D*, costs *E*, profit *Y*, cargo transportation fee *N*).

Each factor influencing the choice of the optimal route of transportation is reflected by one or more indicators and criteria. Therefore, indicators and criteria can be unitary or combinatorial, ie those that are generalized for a particular decomposition link and are formed from partial indicators and criteria. For the case of combinatorial indicators and criteria, a hierarchy is built for each of them, from which a system of efficiency criteria is formed. The generalized hierarchy of partial and generalized criteria for organizational (technological), technical, operational, and economic categories can take the form of structural schemes (Figure 2.1).

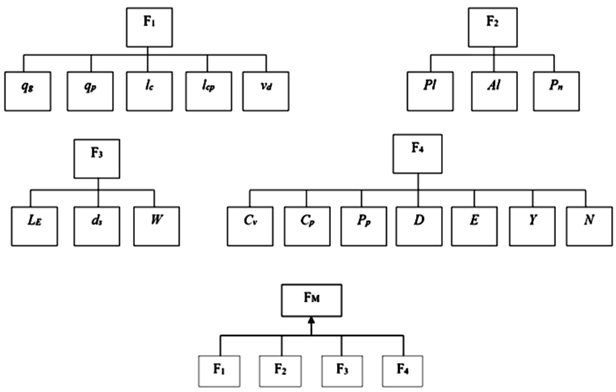

Figure 2.1 Hierarchy of partial and generalized criteria

Following, we obtain a system of criteria that will characterize the optimal choice of the route of transportation of goods by rail rolling stock F_M for indicators of the unitary type in the form:

$$F_M = \begin{cases} F_1 \to min; \\ F_2 \to min; \\ F_3 \to min; \\ F_4 \to min. \end{cases} \tag{2.1}$$

$$F_1 = \begin{cases} q_g \to max; \\ q_p \to min; \\ l_c \to max; \\ l_{cp} \to min; \\ v_d \to max. \end{cases} F_2 = \begin{cases} Pl \to max; \\ Al \to max; \\ Pn \to max. \end{cases} F_3 = \begin{cases} L_E \to max; \\ d_s \to max; \\ W \to max. \end{cases} F_4 = \begin{cases} C_v \to min; \\ C_p \to min; \\ P_p \to max; \\ D \to max; \\ E \to min; \\ Y \to max; \\ N \to max. \end{cases} \tag{2.2}$$

Combinatorial indicators of the optimal route will be characterized by the expansion of the system of criteria (2.1) following the model subsystems of partial criteria (Figure 2.1).

Thus, partial criteria of efficiency of the process of choosing the route of cargo transportation by rail rolling stock in the form of unitary (2.1) and combinatorial systems of partial criteria (2.2) are formed.

The main criteria for the effectiveness of the choice of the route of transportation of goods by rail rolling stock are the following:

F_1 – duration of cargo delivery;

F_2 – productivity of rolling stock and equipment;

F_3 – capacity of the transport network (infrastructure facilities, track facilities);

F_4 – economic efficiency.

The model shown in Figure 2.1 allows to form a system of contradictory partial criteria of route optimality, which indicates the receipt of a multicriteria optimization problem for determining the optimal route of transportation, equation (2.3):

$$\delta = \begin{cases} q_p \to max; q_p \to min; l_c \to max; l_{cp} \to min; \\ v_d - max; Pl \to max; Al \to min; \\ P_n \to max; L_E \to max; d_s \to max; \\ W \to max; C_p \to min; C_v \to min; P_p \to max; \\ D \to max; E \to min; Y \to max; N \to max. \end{cases} \tag{2.3}$$

The formed system of partial criteria is contradictory, which follows from such considerations. The simultaneous increase in freight and passenger traffic on one line will negatively affect the capacity and carrying capacity of the elements of the transport network. Thus, the set of contradictory partial criteria of route optimality indicates the reduction of the synthesis problem to a multicriteria form. Then the formation of the mathematical model of SRFT will consist in establishing the relationship between the partial criteria of system optimality by solving a multicriteria optimization problem.

The explanation of the physical essence of established indicators and criteria of optimality according to the notations and explanations of the order of calculation, describing the change of partial criteria, are given in Table 2.1. Data are formed for each point of interaction of modes of transport and are initial for the further calculations of alternative routes.

Table 2.1. Calculation of partial criteria of route optimality

Indicator	Equation	Explanation of the calculation
q_g	$q_g = \sum_1^n q_E$,	q_E – elementary cargo flow (volume of transported cargo per unit time).
q_p	$q_p = n$,	n – number of tickets sold.
l_c	$l_c = \frac{Pl}{q_g}$,	Pl – turnover of goods; q_g – the volume of cargo transportation.
l_{cp}	$l_{cp} = \frac{Al}{q_p}$,	Al – turnover of passengers; q_p – the volume of passenger traffic.
v_d	$v_d = \frac{l_g}{T_g}$,	l_g – distance shipment; T_g - total time of cargo stay on transport.
Pl	$Pl = p_1 l_1 + ... + p_i l_i$	$p_1 l_1, p_i l_i$ – turnover consignments of goods (p_1, p_i), transportation distance (l_1, l_i).
Al	$Al = A_1 l_1 + ... + A_i l_i$,	A_i – number of passengers sent, distance l_i .
P_n	$P_n = \frac{p_0 m_0}{1 + k_t}$,	p_0 – permissible axial load; m_0 - the number of wheel pairs; k_t - technical coefficient of packaging.
L_E	L_{Ei}	reference data, values of real distances between stations
d_s	$d_S = \frac{1000 \cdot L_E}{S}$,	L_E – operating length of tracks between stations; S – area of territory.
W	$W = \frac{\sum Pl + \sum Al}{L_E}$,	$\sum Pl$ – turnover of goods; $\sum Al$ – turnover of passengers; L_E – operating length of tracks between stations.
$C_{p(v)}$	$C_{p(v)} = \frac{C_i}{l} + c_{p(v)}$,	C_i – cost of initial and final operations; $c_{p(v)}$ – cost of passenger (goods) movement operations; l –

Indicator	Equation	Explanation of the calculation
		distance
P_p	$P_P = \dfrac{\sum Pl_c}{H_e}$,	$\sum Pl_C$ – the yearly volume of transport work; H_e – the average number of workers employed in operational work
D	$D = D_G + D_P$,	D_G – revenues from freight transportation; D_P – revenues from passenger traffic
E	$E = E_G + E_P$,	E_G – freight costs; E_P – costs of passenger transportation
Y	$Y = D - E$,	D – total income for manufactured and sold products, work, and services; E – operational expenses
N	N	reference data, according to Tariff rules №4 of railways of Ukraine

3 Determining the values of route optimality indicators. Construction of the transport network graph

To construct a graph of a multimodal transport network, the points of interaction of modes of transport are chosen by the vertices, namely, nodal railway stations with access roads (interaction of railway transport - road transport); sea (river) port with access railways and highways (interaction sea (river) transport - railway transport - road transport). Segments of the route of multimodal transportation of goods by one mode of transport - the edges of the graph. The characteristics of the edges of the graph are the real distances between the vertices.

Table 3.1. Generalized table of indicators of transportation routes

Indicator / Route		M1			Σ_1	…	Mn			Σ_{14}
		Vertice i_1	…	Vertice j_1		…	Vertice i_{14}	…	Vertice j_{14}	
Generalized indicator	Partial indicator									
F_1	q_g	q_g^{i1}	…	q_g^{j1}	Σq_g^{ij1}	…	q_g^{i14}	…	q_g^{j14}	Σq_g^{ij14}
	q_p	q_p^{i1}	…	q_p^{j1}	Σq_p^{ij1}	…	q_p^{i14}	…	q_p^{j14}	Σq_p^{ij14}
	l_c	l_c^{i1}	…	l_c^{j1}	Σl_c^{ij1}	…	l_c^{i14}	…	l_c^{j14}	Σl_c^{ij14}
	l_{cp}	l_{cp}^{i1}	…	l_{cp}^{j1}	Σl_{cp}^{ij1}	…	l_{cp}^{i14}	…	l_{cp}^{j14}	Σl_{cp}^{ij14}
	v_d	v_d^{i1}	…	v_d^{j1}	Σv_d^{ij1}	…	v_d^{i14}	…	v_d^{j14}	Σv_d^{ij14}
F_2	Pl	Pl^{i1}	…	Pl^{j1}	ΣPl^{ij1}	…	Pl^{i14}	…	Pl^{j14}	ΣPl^{ij14}
	Al	Al^{i1}	…	Al^{j1}	ΣAl^{ij1}	…	Al^{i14}	…	Al^{j14}	ΣAl^{ij14}
	P_n	P_n^{i1}	…	P_n^{j1}	ΣP_n^{ij1}	…	P_n^{i14}	…	P_n^{j14}	ΣP_n^{ij14}

F_3	L_E	L_E^{i1}	…	L_E^{j1}	ΣL_E^{ij1}	…	L_E^{i14}	…	L_E^{j14}	ΣL_E^{ij14}
	d_s	d_s^{i1}	…	d_s^{j1}	Σd_s^{ij1}	…	d_s^{i14}	…	d_s^{j14}	Σd_s^{ij14}
	W	W^{i1}	…	W^{j1}	ΣW^{ij1}	…	W^{i14}	…	W^{j14}	ΣW^{ij14}
F_4	C_v	C_v^{i1}	…	C_v^{j1}	ΣC_v^{ij1}	…	C_v^{i14}	…	C_v^{j14}	ΣC_v^{ij14}
	C_p	C_p^{i1}	…	C_p^{j1}	ΣC_p^{ij1}	…	C_p^{i14}	…	C_p^{j14}	ΣC_p^{ij14}
	P_p	P_p^{i1}	…	P_p^{j1}	ΣP_p^{ij1}	…	P_p^{i14}	…	P_p^{j14}	ΣP_p^{ij14}
	D	D^{i1}	…	D^{j1}	ΣD^{ij1}	…	D^{i14}	…	D^{j14}	ΣD^{ij14}
	E	E^{i1}	…	E^{j1}	ΣE^{ij1}	…	E^{i14}	…	E^{j14}	ΣE^{ij14}
	Y	Y^{i1}	…	Y^{j1}	ΣY^{ij1}	…	Y^{i14}	…	Y^{j14}	ΣY^{ij14}
	N	N^{i1}	…	N^{j1}	ΣN^{ij1}	…	N^{i14}	…	N^{j14}	ΣN^{ij14}

The graph of the multimodal transport network, Figure 3.1 is undirected, as transportation can be carried out both in the forward and in the reverse directions.

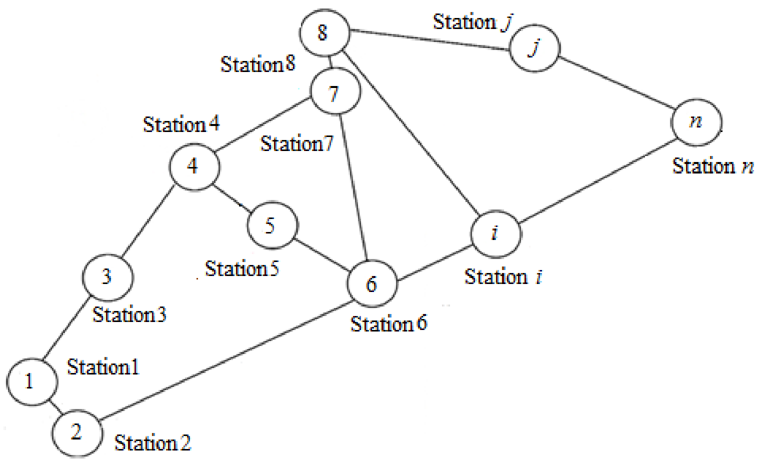

Figure 3.1. Graph of the multimodal transport network

Construction of alternative routes of cargo delivery on the graph of the multimodal transport network is carried out from the top of the shipment to the top of the destination. Partial indicators of stations of the laid routes are generalized in Table 3.1.

4. Elaboration of a decision on the optimality of the route

To make a decision about the optimality of the route according to contradictory criteria (3.1), their reduction to an integrated assessment according to a nonlinear scheme of compromises following the convolution of Professor A.M. Voronin [Voronin, 1997], [Voronin, 2017], using the technology of nested convolutions. The convolution uses a nonlinear scheme of trade-offs, which allows to obtaining a Pareto-optimal solution at low computational costs. The optimization problem is solved in the presence of constraints, which ensures the unimodality of the function of the generalized criterion and in any case guarantees a single solution. Convolution allows to using the minimax approach, ie to concentrate on extremization of the dominant partial criterion of optimality.

The rationing of partial optimality criteria is carried out by expression (1.4), rationing of weights coefficients according to equations (4.4) – (4.4):

$$Y(y_0) = \sum_{l=1}^{b} \gamma_{0l} (1 - y_{0l})^{-1} \to min \tag{4.1}$$

where *l=1…b* – the number of included in the convolution of partial optimality criteria; γ_{0l} – normalized weighting coefficient; y_{0l} – normative partial criterion.

The requirement to use the convolution (4.1) is the normalization of the parameters that are part of them. Rationing provides a reduction to a single dimensionless scale of estimates of partial criteria of optimality with different physical essence and different absolute values. This allows you to equally influence the result of solving the optimization problem of each of the partial criteria.

Weights are normalized by the equation:

$$\gamma_{0l} = \frac{\gamma_l}{\sum_{l=1}^{b} \gamma_l}, \tag{4.2}$$

where γ_l – the current (unregulated) value of the weighting coefficient.

Since the convolution (4.1) is minimized, ie will include criteria requiring their minimization, then the partial discrete optimality criteria are normalized relative to the sum of current values separately for those that are minimized:

$$\varphi_{0l}^{min} = \frac{\varphi_l^{min}}{\sum_{i=1}^{N} \varphi_{li}^{min}},, \tag{4.3}$$

and for those who maximize:

$$\varphi_{0l}^{max} = \left(\varphi_l^{max} \cdot \sum_{i=1}^{N} \frac{1}{\varphi_{li}^{max}} \right)^{-1}. \tag{4.4}$$

The formation of generalized optimality criteria (1.1) for each route is carried out by equations (4.5) – (4.8).

$$F_{1_i} = (1 - q_{g_i 0})^{-1} + (1 - q_{p_i 0})^{-1} + (1 - l_{c_i 0})^{-1} + (1 - l_{cp_i 0})^{-1} + (1 - v_{d_i 0})^{-1} \to min; \tag{4.5}$$

$$F_{2_i} = (1 - Pl_{i0})^{-1} + (1 - Al_{i0})^{-1} + (1 - P_{n_i0})^{-1} \rightarrow min; \quad (4.6)$$

$$F_{3_i} = (1 - L_{E_i0})^{-1} + (1 - d_{s_i0})^{-1} + (1 - W_{i0})^{-1} \rightarrow min; \quad (4.7)$$

$$F_{4_i} = (1 - C_{v_i0})^{-1} + (1 - C_{p_i0})^{-1} + (1 - P_{p_i0})^{-1} + (1 - D_{i0})^{-1} + (1 - E_{i0})^{-1} + (1 - Y_{i0})^{-1} + (1 - N_{i0})^{-1} \rightarrow min; \quad (4.8)$$

In equations (4.5) – (4.8) the index $i=1\ldots N$ characterizes the corresponding partial and generalized criteria for different variants of construction of a route, the index normalized criteria are marked by an index zero.

The maximum and minimum values of the minimizing and maximizing criteria are grouped in the form of an abstract (worst) M_A route. The rationing of partial criteria is carried out relative to the maximum (minimum) values by equations (4.9), (4.10), which makes it possible to obtain generalized criteria for the optimal route.

$$\varphi_{0l}^{min} = \frac{\varphi_l^{min}}{max\varphi_l^{min} + \Delta}; \quad (4.9)$$

$$\varphi_{0l}^{max} = \frac{min\varphi_l^{max} - \Delta}{\varphi_l^{max}}. \quad (4.10)$$

where $max\varphi_l^{min}$, $min\varphi_l^{max}$ – maximum and minimum values of minimizing and maximizing criteria in the interval of their consideration; Δ – stock ratio, $\Delta = 0{,}03$; $i=1\ldots N$ – the number of discrete values describing the change of partial optimality criteria.

The rationing of the generalized criteria is carried out under the conditions of their minimization according to the equation (4.11):

$$F_{0i} = F_i / F_{max} , \quad (4.11)$$

where F_{max} – the worst assessment of a particular option for building a system.

The parameter F_{max} is determined separately for each generalized criterion (4.5) – (4.8) and is formed from the worst (for normalized - maximum) values that describe the change of partial criteria when considering all the formed options for its construction.

The integrated optimality criterion is determined by normalized generalized criteria, which is a multicriteria optimization model (4.12).

$$F_{Mi} = (1 - F_{10})^{-1} + (1 - F_{20})^{-1} + (1 - F_{30})^{-1} + (1 - F_{40})^{-1} \rightarrow min. \quad (4.12)$$

The choice of the optimal route is to analyze the values that describe the change of the integrated criterion of optimality. In this case, the optimal route will be assumed (*i=1…N*), for which the requirement of minimization of criterion (4.12) will be fulfilled.

$$N_{opt} = i,\ if\ \ F_{M\,i} \to min. \tag{4.13}$$

To assess the reliability of the choice of the optimal route of transportation in a multimodal transport network and make a final decision on the integrated assessment (4.12) it should be normalized according to the equation:

$$F_{M0} = 1 - \frac{F_{Mi}}{maxF_M}; \tag{4.14}$$

$$\begin{aligned} maxF_M = (1-[maxF_{10}-\Delta])^{-1} + (1-[maxF_{20}-\Delta])^{-1} + (1-[maxF_{30}-\Delta])^{-1} \\ + (1-[maxF_{40}-\Delta])^{-1}. \end{aligned} \tag{4.15}$$

Integrated evaluation is normalized to the worst-case scenario of evaluating the effectiveness of the system as a whole. Such rationing allows to make the decision on the optimality of a route and to establish a comparative estimation of alternative routes. After normalization of the integrated estimate, we will have its change within in the range from zero to one with the highest score - close to one, and the lowest - close to zero. The integrated assessment of system efficiency takes into account its tasks, functions, and factors, as well as indicators of optimality criteria. It is according to the integrated assessment that the final decision on the optimality of the delivery route is made. The decision is made subjectively on the basis of an integrated assessment in the form of a linguistic category "good-bad". Therefore, it is natural to use a fundamental scale of assessment, which allows you to move from a numerical measure of efficiency to a linguistic category. This transition scale may have the form given in Table 4.1.

Table 4.1. Fundamental rating scale

Integrated assessment of the effectiveness, F_{M0}	Linguistic category of efficiency
1,0 – 0,7	High
0,7 – 0,5	Good
0,5 – 0,4	Satisfactory
0,4 – 0,2	Low
0,2 and less	Unsatisfactory

As a result of calculations, the correspondence of alternative delivery routes to certain categories is determined, Table 4.2.

Table 4.2. Distribution of routes by linguistic categories

Integrated assessment of the effectiveness, F_{M0}	Linguistic category of efficiency	Route
1,0 – 0,7	High	M_i
0,7 – 0,5	Good	…
0,5 – 0,4	Satisfactory	…
0,4 – 0,2	Low	…
0,2 and less	Unsatisfactory	M_j

Provided that the evaluation of the effectiveness of the i-th route M_i is belongs to the linguistic category "High", it is considered that the optimal route is established reliably.

Thus, the mathematical model of multicriteria distribution of transport flows in a multimodal transport network includes the following steps:

1. Definition and distribution of limited resources by consumer groups Table 1.1, equation (1.1) - (1.7).
2. Formation of indicators and criteria of route optimality, Figure 2.1, Table 2.1, equation (2.1) - (2.3).
3. Calculation of the values characterizing change of the established indicators and criteria of optimality of a route:

   3.1 Construction of the graph of the transport network, Figure 3.1;

   3.2 Calculation of partial criteria for the optimality of alternative routes Table. 3.1.
4. Development of a decision on the optimal route:

   4.1 Formation of an integrated criterion of route optimality according to the mathematical model (4.12);

   4.2 Selection of the optimal route from the set of alternatives under condition (4.13);

   4.3 Estimation of the reliability of the defined optimal route on the integrated estimation of optimality of a route in the form (4.14), (4.15) and definition of a linguistic category of efficiency on a fundamental scale, Table 4.1, Table 4.2.

Conclusion

To solve the applied problem of choosing the optimal route of cargo delivery, a mathematical model of the distribution of traffic flows in a multimodal transport network was proposed. The model based on multicriteria optimization obtained using nested convolutions according to a nonlinear scheme of compromises. This ensures that a significant number of criteria are taken into account in the solution, the diversity of consumer needs and suppliers' stocks, and limited resources. The calculation of partial criteria of route optimality is carried out on the graph of the transport network. Elaboration of the decision on the optimality of a route of transportation is carried out on the integrated criterion of optimality on the performance of requirement of minimization of criterion. The reliability of the determined optimal route of transportation is carried out according to the integrated criterion in the form of the linguistic category "good-bad".

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ONE APPROACH TO STUDY SOFTWARE ECOSYSTEM PROPERTIES

Olena Grinenko, Sergiy Grinenko

***Abstract**: One of the factors that determine the effectiveness of software ecosystems is their structure. To build a quality model, it is necessary to use modeling methods that accurately reflect the properties of software ecosystems. Approaches that characterize them as discrete asynchronous models play an important role in modeling software ecosystems, because these models have all the basic properties: discreteness (a finite number of components, each of which has a finite number of states); the presence of processes and their components, clearly expressed in the phases during which the state changes; publication of information on the completion of each phase of the process; consistency (the beginning of each subsequent phase of the process requires the completion of all previous phases necessary to begin its implementation); parallelism (possibility of simultaneous transitions in several subprocesses and simultaneous execution); asynchrony (no restrictions on the duration of each subprocess and the transition from one phase to another). It is necessary to develop opportunities for modeling real software ecosystems using these approaches, which will create conditions for improving the quality of their design and operation. This article presents an approach to study software ecosystem properties using Petri nets.*

***Keywords**: software ecosystem, Petri nets, properties.*

Introduction

The concept of "software ecosystem" is widely used by companies and researchers of the software. According to [Grinenko, 2012] researches of software ecosystems are represented by several definitions depends on their goal, aims, actors etc. That’s why throughout this thesis we will consider a few definitions of software ecosystems. So, software ecosystem is a set of actors functioning as a unit and interacting with a shared market for software and services, together with the relationships among them. These relationships are frequently underpinned by a common technological platform or market and operate through the exchange of information, resources and artifacts. The transaction between two software vendors is centred around software components and software services. In this thesis a definition of software components is used: software component a bundle of software functions accessible through a single interface or carrying a single name which is or can be used as an element in other software packages but of which the core functionality is developed separate from these packages. A software service is a software component accessible via communications outside the users native environment. User can be both human and non-human. Native environment changes depending on the user. If the user is human, the native environment is most probably his or her own computer. If the user is a software package, the native environment consists of the compiled or interpreted code.

Corporation "Microsoft" defines software ecosystem as a set of interactions and mutual influences of organizations (public, educational and commercial) and individuals, which work with software.

Also some authors describe software ecosystems and the typical elements of ecosystems and their context, namely:

- software and its role in IT;
- users of software;
- software creating processes;
- management of the establishment and maintenance of software;
- supply and support of software;
- communication network of state agencies;
- software economy.

According to [Sidorov and Grinenko, 2013] we study the software ecosystems by creating their models. To describe software ecosystems can be used the following tools: i*, UML, Petri nets. Petri nets is the most common nowadays formalism that describes the structure and interaction of parallel systems and processes [Popereshnyak and others, 2019].

According to [Grinenko, 2016] software ecosystems metrics can be the following:

– Productivity. This criterion shows the statistical analysis of nationwide product development and software services for a certain period.

– Diversity. This criterion shows the ranking of IT companies according to the following criteria: "software revenue", "income system integration" and "income from software services."

– Flexibility. This criteria determines which of the fastest growing sectors in IT market.

– Productivity. This criterion determines the impact of investments in the IT industry.

– Sustainability (Vitality). This criterion defines total income in all sectors of the IT market.

– Maturity. This criterion determines the qualitative characteristics of software ecosystems development.

According Petri nets theory these metrics can be analysed using the following structural properties of Petri nets:

– structural liveness
– reachability
– boundedness
– conservatism and partial conservatism
– repeatability and partial repetition.

Usage of Petri Nets to Analyze Software Ecosystem Properties

Petri nets, as well as other methods of modelling systems, are tools of describing the properties of processes of real software ecosystems as asynchronous discrete processes [Kryvyi, 2015]. Like industry standards (UML, BPMN and EMF), Petri nets also describe the basic procedures of discrete graphics processes, including branching (conditional transition, selection), iteration (repetition), and simultaneous (parallel) execution of individual operations or processes. However, the Petri net, in contrast to these standards, mathematically accurately describes the semantics of discrete asynchronous systems, creating the right conditions for their mathematical modeling, analysis and optimization. Simple Petri nets do not have all the properties needed to properly represent the operation of real complex systems. The implementation of simple Petri nets is uncertain: several transitions can be allowed at the same time, and each of them can be implemented. Such a network does not determine the order in which it is executed. Allowed transitions are optional. The allowed transition can be performed or not performed. In other words, a simple Petri net cannot fully automatically reflect the operation of a real system. Simple Petri nets do not consider the concept of transition time, but only indicate the possibility or impossibility of its implementation, so they developed a higher order Petri net, which is also called "time" and "color". In such networks, additional functions (weights) are introduced for positions, transitions and arcs, in particular time [50]. These can be "color" labels, which are perceived only for certain transitions, the time of the transition or the transfer of information by arc, and so on. These networks have greater capabilities for modeling various discrete asynchronous systems, so they have also become widespread.

Mathematical Research of Software Ecosystem Properties

Let us consider SD model (Strategic Dependency model) (fig.1) of software ecosystem. An SD model describes a network of dependency relationships among various actors in an organizational context. The actor is usually identified within the context of the model. This model shows who an actor is and who depend on the work of an actor [2].

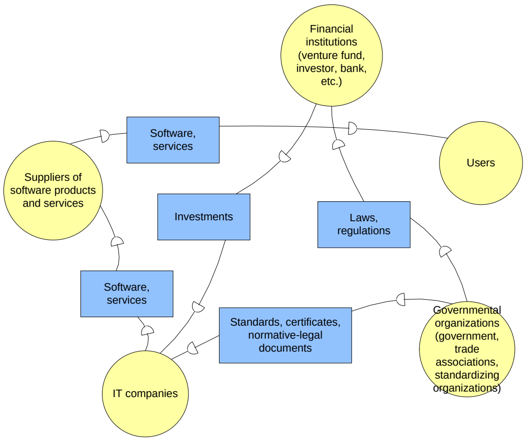

Figure 1. SD model of IT ecosystem

An SD model consists of a set of nodes and links connecting the actors. Nodes represent actors and each link represents a dependency between two actors.

According to SD model it is appropriate for analysis of properties of such system to use transition system, which is defined as

$$TS = (S, T, \alpha, \beta, s_0) \tag{1}$$

where

S is a finite or infinite set of states (places),

T is a finite or infinite set of transitions,

α and β are two mappings from T to S, which gives every $t \in T$ two transitions $\alpha(t)$ and $\beta(t)$, and which are called beginning and end of t transition,

$s_0 \in S$ is an initial state of TS.

As a rule this system is denoted as an oriented graph, vertices of which are states and edges are transitions. In our case and according SD notation, actors' functions and their decomposition are states and their dependency relationships are transitions. Transition system is a kind of Petri nets, that's why all its properties are easy to be researched.

Incidence matrix.

Consider the following order of vertices in the incidence matrix: $u, u_1, u_2, v_2, d_4, w, s_1, d_5, v_1$ (9 places).

Consider the following order of vertices in the incidence matrix:

The order transitions: $u \to u_1, u_2$; $u_1, u_2 \to u$; $u_1 \to v_2$; $v_2 \to u_1$; $v_2 \to d_4$; $d_4 \to v_2$; $d_4 \to w$; $w \to d_4$; $w \to s_1$; $s_1 \to w$; $s_1 \to d_5$; $d_5 \to s_1$; $s_1 \to v_1$; $v_1 \to s_1$ (14 transitions).

To determine the Petri net incidence matrix, we have:

$$a_{ij} = I(t_j, p_i) - I(p_i, t_j),$$

where I is incidence relation of the network. Moreover, given the ordinariness of PN, $\mathrm{I(x,y)} = 1$, if $\mathrm{(x,y)} \in \mathrm{F}$, and $\mathrm{I(x,y)} = 0$ otherwise**.**

The incidence matrix (size 9 on 14) looks like:

$$A = \begin{matrix} -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & -1 & 1 & -1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{matrix}$$

1. Boundedness. A PN is structurally limited if it is limited by an arbitrary finite markup. A PN is boundedness if each of its places is limited, that is, for each of its places there is a number *k* such that for arbitrary attainable marking the number of chips in a given vertex will not exceed *k*. Indeed, the top estimate of the number of chips in any vertex is the total number of markup chips that remains constant because the network contains no sources.

We also apply the criterion of structural constraint. According to Theorem 55, MP is structurally bounded if and only if system of linear homogeneous diophantine equations (SLHDE) $A^T y \leq 0, x > 0$ has at least one solution over has at least one solution over $\mathbb{N}$. This system is:

$$\begin{gathered} -y_1 + y_2 + y_3 \leq 0 \\ y_1 - y_2 - y_3 \leq 0 \\ -y_2 + y_4 \leq 0 \\ y_2 - y_4 \leq 0 \\ -y_4 + y_5 \leq 0 \\ y_4 - y_5 \leq 0 \\ -y_5 + y_6 \leq 0 \\ y_5 - y_6 \leq 0 \\ -y_6 + y_7 \leq 0 \\ y_6 - y_7 \leq 0 \\ -y_7 + y_8 \leq 0 \\ y_7 - y_8 \leq 0 \\ -y_7 + y_9 \leq 0 \\ -y_7 + y_9 \leq 0. \end{gathered}$$

If $y_1 = 2$, $y_2 = y_3 = y_4 = y_5 = y_6 = y_7 = y_8 = y_9 = 1$ the left side of all the inequalities rotates to zero, so this is the solution to this SLODN. Therefore, in accordance with the statement of the theorem, this MP is limited.

2. Absence of inaccessible places and dead transitions (Reachability). A place is attainable if, with some attainable layout, the number of chips is positive. With this single-chip Petri net layout, all places are accessible: there is a path for each place that the chip can reach from its original position.

A transition is called dead beyond the markup M unless it is potentially alive beyond that markup. That is, there is no reachable markup from which the transition could work. In this PN, all transitions are potentially alive. That is, for each transition, there is a reach from the initial markup that can trigger it.

3. Liveness. This MP is structurally alive because there is a live network layout. That is, in which at least one transition is possible.

4. Repeatability. This Petri net is repetitive, since for each transition there is a sequence of transitions σ, in which it triggers an infinite number of times.

MP is repeated if and only if SLHDE $\boldsymbol{Ax} \geq \boldsymbol{0}$, $\boldsymbol{x} > 0$ has at least one solution over has at least one solution over $\mathbb{N}$. This system is:

$$\begin{gathered}
-x_1 + x_2 \geq 0 \\
x_1 - x_2 - x_3 + x_4 \geq 0 \\
x_1 - x_2 \geq 0 \\
x_3 - x_4 - x_5 + x_6 \geq 0 \\
x_5 - x_6 - x_7 + x_8 \geq 0 \\
x_7 - x_8 - x_9 + x_{10} \geq 0 \\
x_9 - x_{10} - x_{11} + x_{12} - x_{13} + x_{14} \geq 0 \\
x_{11} - x_{12} \geq 0 \\
x_{13} - x_{14} \geq 0.
\end{gathered}$$

The solution of this inequality system is

$$x_1 = x_2 = x_3 = x_4 = x_5 = x_6 = x_7 = x_8 = x_9 = x_{10} = x_{11} = x_{12} = x_{13} = x_{14} = 1$$

$$x_1 = x_2 = x_3 = x_4 = x_5 = x_6 = x_7 = x_8 = x_9 = x_{10} = x_{11} = x_{12} = x_{13} = x_{14} = 1,$$

for which the left side of all inequalities is zero.

5. Absence of deadlocks and livelocks. A non-empty set Q, which is a subset of a set of places, is called a deadlock, if $\mathrm{Q}^{\circ} \subseteq {}^{\circ}\mathrm{Q}$.

This PN is all a deadlock, the fragments in it perform the specified relation, although it has no other deadlocks. However, for this PN not to be a deadlock, it is necessary that it has at least one source that contradicts the condition of structural limitations of the PN.

Conclusion

The study demonstrated an ecosystem model and described an approach to the specification of the properties of this model. In this case, the system is labelled TS, which can be studied as Petri net with properties which are defined using this mathematical tool.

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RESEARCH AND DESIGN OF PRODUCTION PROCESS CONTROL INFORMATION SYSTEM

Anastasiya Vecherkovskaya

***Abstract**: The article reviews the creation prerequisites of the information system for polypropylene fibrous filter elements production. The problem of creating information systems for process control is described. The parameters that allow to control the technological process are defined. The functional requirements to the production management information system are determined, and the client part of the polypropylene filter elements production control information system is designed.*

***Keywords**: information system, technological process, technological process parameters, functional requirements.*

***ITHEA Keywords**: H. Information Systems - H.0 General, D. Software - D.0 General.*

Introduction

The technological processes control software implementation is the most important method of increasing labor productivity, reducing the materials and energy cost, improving product quality, introducing advanced methods of production management and improving the work reliability.

Currently, there is a problem when creating information systems to solve specific problems in the chemical industry, as complex multifactor models. . The final result is affected by simultaneous influence of the raw materials physical and chemical parameters and the technological production process various parameters

The processing of polymers, in particular polypropylene, is preceded by the design of the product pattern, the choice of the optimal method of processing, technological equipment design and manufacturing, polymer composition formulation development, its preparation and formation arrangement.

The actual processing of the polymer involves the products formation and their further processing in order to improve the polymer material properties (heat treatment, radiative crosslinking, etc.).

At the beginning of the 20th century polymers into products processing methods copied known ways of processing such materials as clay and soft metals (molding, pressing, stamping), and only in the middle of the 20th century new technological polypropylene-made products forming methods appeared, based on the polymers specific properties use, pneumatic and vacuum forming, calendering, and others.

Now the number of target methods and polymers processing techniques is calculated by dozens. Filter materials and polypropylene filters for different liquids and gases purification levels are made of polymer. [1]

The information obtained in the control process is used to influence the technological equipment in the form of operation instructions in order to ensure the polypropylene technological processing flow in full accordance with its planned progress, that is for the technological process control.

In other words, along with the widespread use of computers, equipment with software control has been applied, which is the executive body of computer technology. This suggests that, even if there are software systems that simulate the polypropylene fibers production process, considering the individual characteristics of each production, the research topic is relevant.

Published data analysis and problem definition

The fibers obtaining from polymer melts recieved widespread development around the world in the direction of synthetic fibers modification, which refer to so-called third-generation fibers [2].

The use of polymers opens an entirely new way of obtaining small diameter fibers (from several micrometers to tenths of a micrometer) - ultrathin synthetic fibers, or microfiber. At the same time, unlike the usual methods of forming chemical fibers, complex threads of tens and hundreds of thousands of microfiber are formed by pushing the melt mixture through one hole [3,4]. This phenomenon, discovered in 1954 by the chemists of Du Pont, was patented in 1968 [5]. Experimental data indicate that during the polymers melting through the molding hole, the acts of fiber formation are not realized as usual, after the melt out of the hole (filer), and even at the entrance to the hole channel [6]. Experimental data indicate that during the melting of polymers through the molding hole, the acts of fiber formation are not realized as usual, after the melt out of the hole (filer), and even at the entrance to the hole channel [6]. By dint of fiber filters it is possible to achieve a significant increase in the efficiency of the filtration, and the pressure drop moderately increases[7].

This creates ultrathin fibers, which are then used to create treatment plants, and filter materials.

Currently, in many industries, the task of purifying and separating liquid and gas media is very acute. The degree of purification determines the quality of products; the separation of mixtures solves the issues of catching valuable substances, saving raw materials and, finally, the environmental problems - the protection of the environment from harmful emissions into the atmosphere, water and soil.

Below is a classification of solutions membranic separation processes, colloidal systems and suspensions [8]:

Table 1. Classification of solutions membranic separation processes

Process	Process purpose	The size of molecules and separated particles, μm
Reverse osmosis	Separating molecules of low molecular weight and polymer compounds from solvent	5*10-4- 10-2
Ultrafiltration	Separating of substances with the size of the molecules from the solvent	5*10-2- 10-1
Microfiltration	Separation of colloidal and suspended particles from the liquid phase	10-1- 10
Conventional filtration	Separation of suspended particles from the liquid phase	More than 2,5*10

The division of multicomponent (or multiphase) systems is carried out with the help of porous partitions (membranes, filter materials), which delay some phases of these systems and skip others. When comparing ultrafiltration, reverse osmosis and filtration, it can be noted that these processes are determined by the general law, according to which the process speed is proportional to the driving force and inversely proportional to the resistance. For these processes, the driving force is the pressure difference on both sides of the membrane or partition, and the resistance depends on the properties of the latter, as well as on the characteristics of the divided system and the division conditions. However, reverse osmosis and ultrafiltration differs from conventional filtration by the fact that the first two are single-phase systems (solutions) being divided - on a solvent and a solution with a high concentration of dissolved substance. In the case of conventional filtration two- or multiphase systems (suspensions, aerosols) undergo division (purification). In the recent publications, new technologies in the field of filter materials, filter structures, raw materials are often considered by researchers [9-14]. But as for the porous polypropylene elements production control software by the pneumatic extrusion method, then there is no similar research in this direction to date.

Purpose and objectives of the research

The conducted studies are aimed to determine the features of the polypropylene filtering element manufacturing process by the pneumatic extrusion method and factors that affect the polypropylene fiber thickness during the production process, to create different filter layers and different diameter fibers.

To achieve this goal the following tasks were solved:

- to study the polypropylene granules melting temperature regime in the extruder influence on the formed at the outlet fiber diameter.

- to investigate the influence of air pressure at the output of the forming head on the thickness and density of the filtering layer.

- to offer the production parameters control information technology system and the production process management prototype software.

Research methods for influence determination on polypropylene production process factors by the pneumatic extrusion method, and the quality of filter materials

Research materials and equipment used in experiment

For more than 60 years of extrusion technologies existence, a large variety of machine designs has been introduced for their implementation.

The principle of extruder action is determined by the essence of the extrusion process.

Extrusion complex physical and chemical process that takes place under the influence of mechanical effort provided by the presence of moisture and high temperature exposure.

The product that is being processed heats up due to the conversion of mechanical energy into heat, which is released when overcoming internal friction and plastic deformation of the product (gas mode) or due to external heating (Polytron mode).

Variable parameters of the extrusion process are the composition of the raw material, its nature, humidity, but these parameters can not be changed during the production process, so we will not consider their influence.

In the process of extrusion, changes in temperature, pressure, duration and intensity influence on raw materials are possible.

For the extrusion process implementation, a screw extruder is used, the main working organ of which is a special construction screw, that rotates in a cylindrical body. A shaping matrix is installed at the output of the body. Characteristic features of the working part extruder design is that the cameras and screws are adjusted in accordance with the set of technological tasks.

One of the methods for obtaining ultrathin fibers (diameter 0,11-0,22 microns) is the dispersion of the polymer melt (solution) by hot air jets [15].

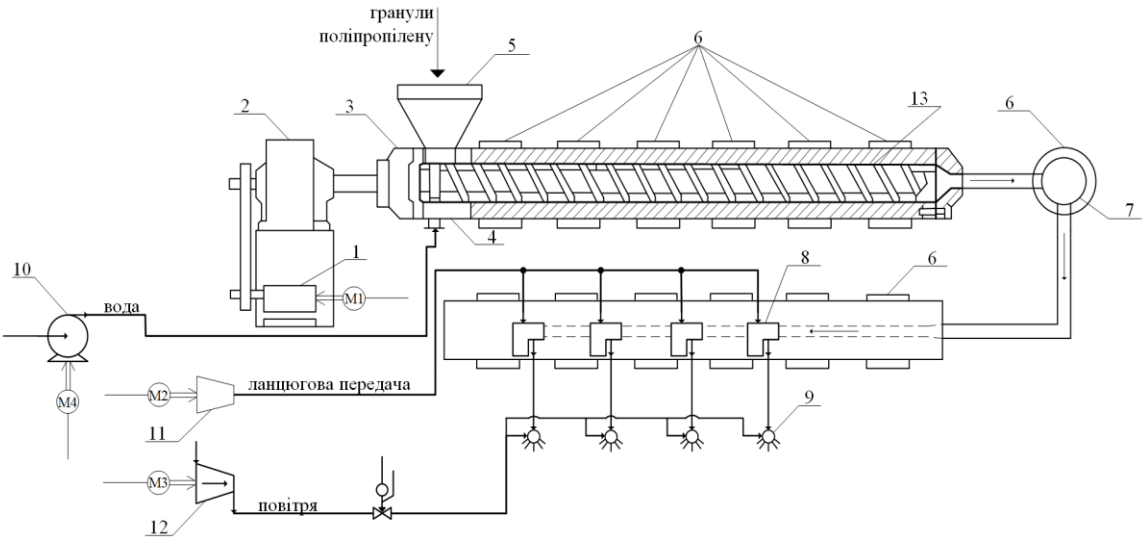

Fig. 1 The filter elements production technological scheme

1 – engine; 2 – reduction drive; 3 – thrust bearing; 4 – water shell; 5 – the raw materials loading bunker; 6 –ring heaters; 7 – elbow; 8 – dosing pumps; 9 – spraying heads; 10 – pump; 11 – reduction drive; 12 – compressor; 13 – screw.

Methodology for determining the properties of samples

In continuous technological processes automation , a special case of control - “regulation” is of great importance. Assignment of automatic control systems (ACS) - support for given or optimal values which determine the course of the technological process.

Let's review the filtration elements manufacturing process by the method which consist of forming molten polypropylene through a filier, followed by the stretching of the uncongealed extrudate with a hot air stream and applying on a rotating cylindrical rod. The design of the receiving device (the same one rotates, the screw rod) allows the continuous forming process of a frameless element (Fig. 1).

In any type of control, the following steps are performed in one degree or another:
- receiving information about the control object state;
- received data processing and analysis, on the basis of which the decision about control object necessity and impact nature is formed;
- implementation of the decision, for example, by changing material or energy flows.

The fulfillment of the first stage is connected with the definition of values that characterize the control object state: pressure, temperature, costs, level in technological apparatus, physical and chemical indicators of substances, which are processed at different stages of the technological process, etc.

In the process of producing filter elements by the pneumatic extrusion method, you can change a significant number of the technological process parameters, to provide a certain fiber structure.

These are basic parameters like:

• Melting point in the extruder and head heating zones;
• Metering pump revolutions and accordingly, the mass of the polymer fuse;
• Pressure and temperature of air supplied to the forming head;
• The receiving mechanism rotation speed and its distance to the forming head.

With manual control, a person performs all functions on the filter elements manufacturing process analysis and the process impact adoption and implementation decisions. Hand-held remote control is also used, when a person is influencing the process remotely using special devices. In this case, it receives information about the parameters of the process using automatic control systems by the automatic control devices indicators.

Due to this automated control systems (ACS) became widely used. They are intended both for technological processes control and for enterprises organizational management.

Research results

Production parameters control automation system

The first contour regulates the extruder polypropylene melt temperature: The temperature sensor is a resistance thermometer TCM – 50M, its signal enters the microprocessor controller MIK-25, control influence forms in the regulator, which through the converter EPP-63 affects the executive mechanism of the IEE type (pos.1g), and changes the amount of steam in the apparatus and normalizes the polypropylene melt temperature in the extruder.

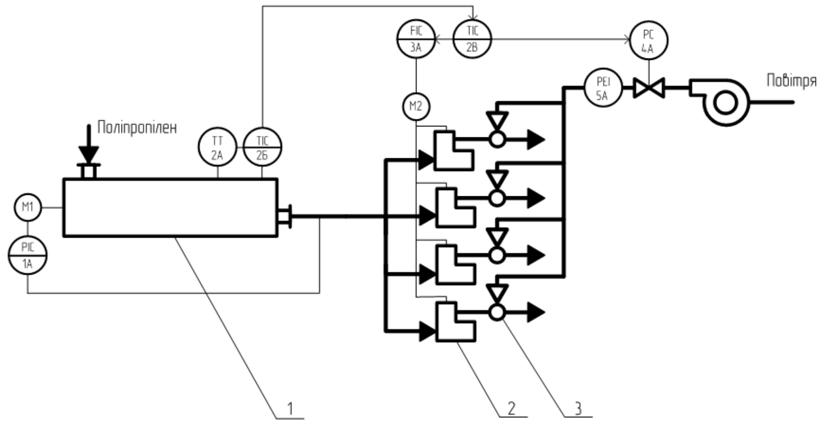

Fig. 2 Production parameters control automation system

1 - Extruder; 1B - frequency converter;
2 - Dosing pump; 3 - Head of the dosing pump

The second contour is the regulation of air pressure on the molding head:

Information about the massif level comes from the primary converter of the Vegason 62 type (pos.2a) in the form of a standardized current signal 0...5mA and gets on the regulator (pos. 2b) from which control is converted trough EPP-63 (pos.2v) into the pneumatic signal 20 -100 kPa and moves an executive mechanism of the MEO type (item 2g) which changes the amount of the input product leading to a change in level.

Information system design

Let us review the requirements that were set for the "Process Control" system, which we design to control the polypropylene filtering fibrous elements production process. At the beginning of the design we will highlight the main functional requirements that can be put forward to such systems. Here are just a some of them:

1. The software should be able to show the object of management state data;

2. The software must be able to obtain and change the performance characteristics during the technological process;
3. The software tool should allow the creation of a new filter element pattern;
4. The tool should allow you to delete existing patterns of filter elements, depending on user requirements;
5. The software should display the state of the technological process and the state of the control object data;
6. The software tool must notify the head of the department (enterprise) about the progress of the technological process, and the introduction of new patterns
7. The tool must be able to work in two modes - transmission of the technological process state data with a certain time interval or data transmission on request;
8. The software must be able to stop or resume the control object state, and the technological process state data transmission;
9. The software must allow control object quick or emergency shutdown, depending on the data received from the control object;

In In Fig. 3 shown a diagram of use cases, built as a result of the functional requirements analysis. It is also worth noting that all relationships that extend the use cases have a condition of user software selection in the interface and successfully passed authentication.

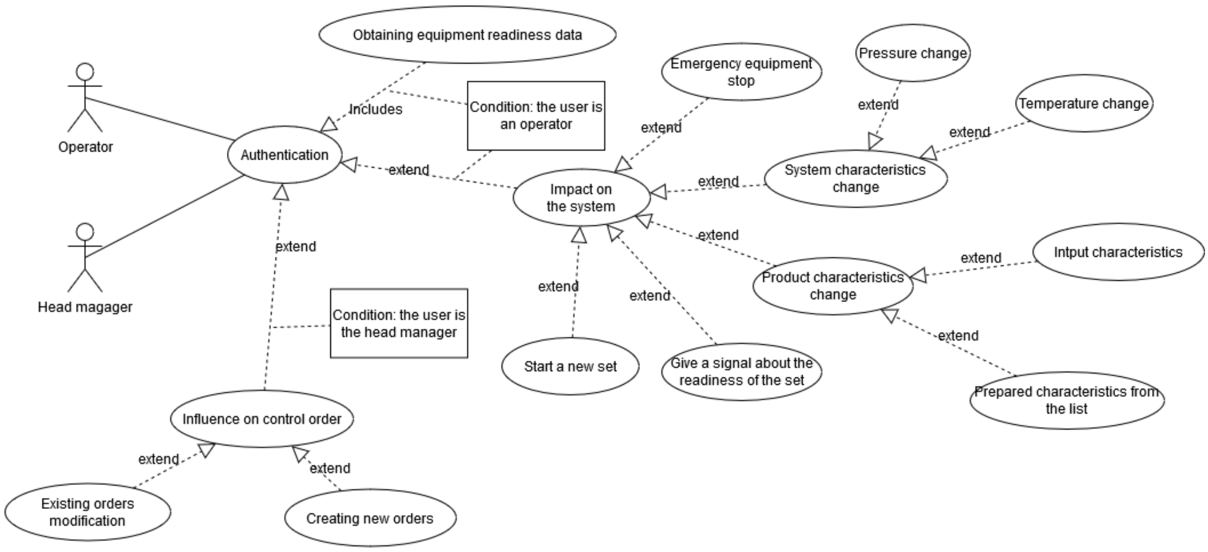

Fig. 3 Diagram of use cases

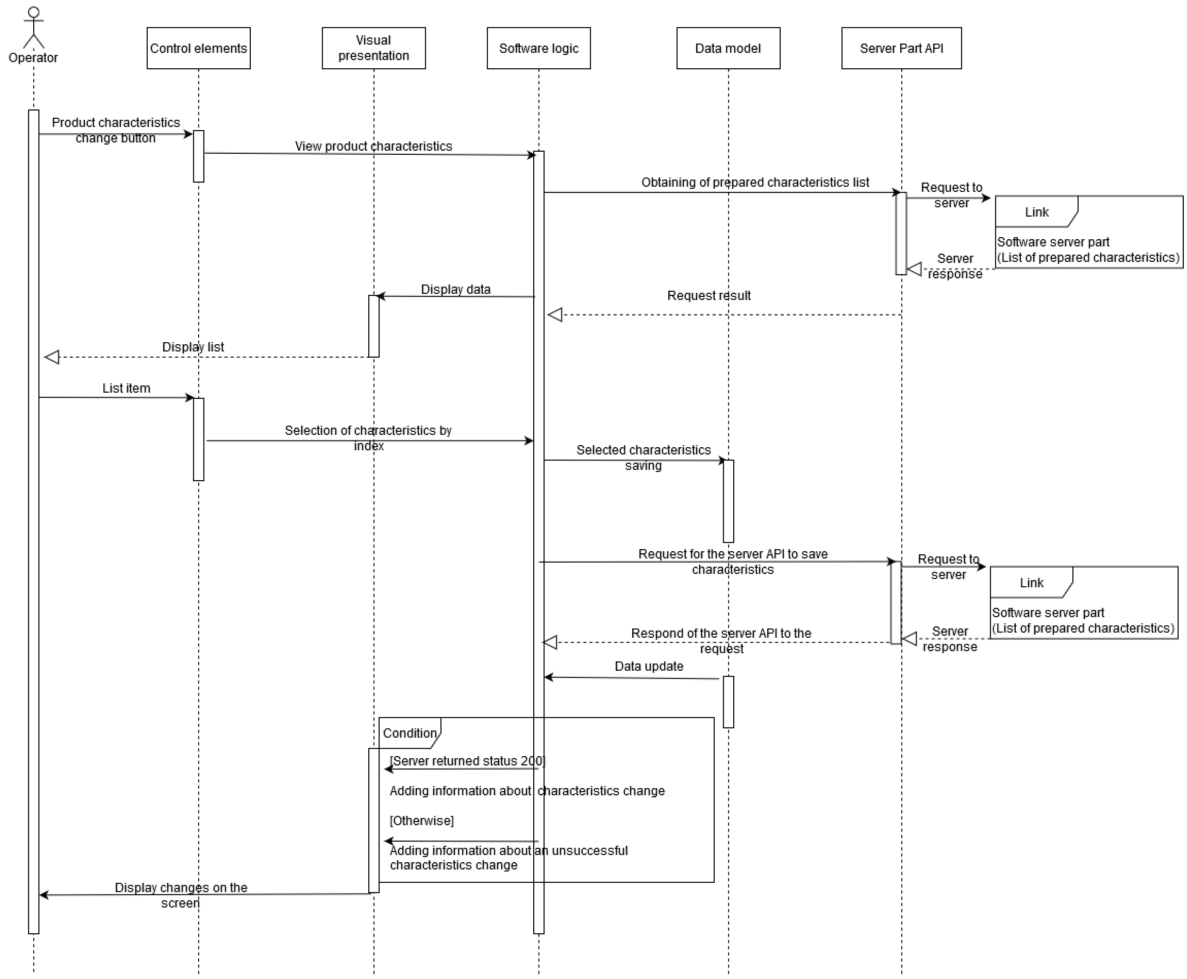

Fig. 4 Sequence diagram of the client software part.

In Fig. 4 shown a sequence diagram of the "Change of the product characteristics" case use, which shows the of the client part of the software components interaction.

This system is focused mainly on small and medium-sized businesses (up to 200 employees), and can be used by workers in any industry, entire companies or individual departments.:

Data, obtained with the help of sensors, is transmitted to a computer program, the prototype of which is shown on (Fig. 4), which allows for a model calculation of the FE.

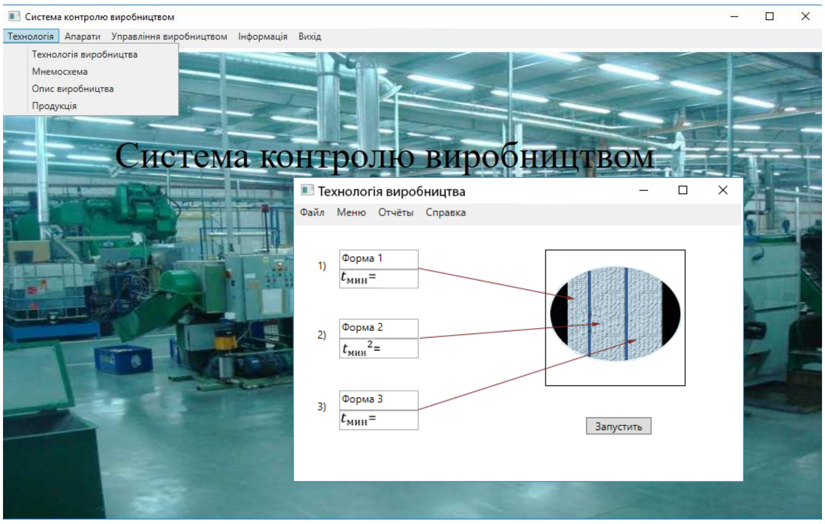

Fig. 5 The computer program prototype

This prototype allows you to select the structure and size of FEs, depending on the field of application and environments. (Fig. 5)

Conclusion

The technological processes control software implementation is the most important method of increasing labor productivity, reducing the materials and energy cost, improving product quality, introducing advanced methods of production management and improving the work reliability.

The conducted researches have reached the set purpose, and have defined the polypropylene filtering element manufacturing process features by the pneumatic extrusion method and factors which influence a polypropylene fiber thickness in the manufacturing process, for a various filter layers creation , and different diameter fibers.

In the research process, the temperature mode influence of the polypropylene granules melting in the extruder, on the fiber diameter formed at the outlet, and the air pressure effect at the forming head output on the filtering layer thickness and density were investigated. Based on the conducted research the production automation scheme was designed, and the production process management software tool prototype was developed.

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ONTOLOGICAL PRINCIPLES OF THE PROBLEM OF CHOICE

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Abstract: *The complexity of the decision-making process for experts in various topics is in the problem of the initial processing of unstructured information. This problem of Big data requires the latest solutions that provide a structural reflection and integrative use of information descriptions under consideration by experts. It takes the process of information and analytical evaluation and decision-making beyond one subject area and raises questions about the ontological consideration of the problem itself. The ontological principles of such consideration are based on multiple hyperproperties of information for the realization of the categories of integration, systematicity and continuity and providing tracking and modification of their structures and their behaviour during activation. For this, there is the ontology of the problem of rational choice based on means of a ranking of alternatives on a set of indicators. It provides the creation of a system designed to solve the rank-ing problem based on the ontological model of the subject area. From the point of view of software engineering, a software system is considered as a set of descriptions presented as mathematical models, formalisms and modelling techniques. Hyperproperties of ontological representation of large amounts of information ensure the implementation of meta-tasks of its analysis, its structuring, synthesis, and most importantly support the process of rational choice of the most optimal solutions. Such an approach to ensuring the information and analytical activities of experts in the decision-making process creates the conditions for optimal processing of a large number of diverse information arrays. The component architecture of decision-making support services is based on ontological management.*

Keywords: *Ontology, Taxonomy, Hyperproperty, Alternative, Ranking, Choice, Criteria.*

ITHEA Keywords: *I.2 ARTIFICIAL INTELLIGENCE - I.2.4 Knowledge Representation Formalisms and Methods, H. Information Systems – H.2 DATABASE MANAGEMENT – H.2.4 Systems, G. Mathematics of Computing – G.1 NUMERICAL ANALYSIS – G.1.6 Optimization*

Introduction

The decision-making process is based on the analysis of information and requires structured information. Moreover, this structure must meet the conditions of systematology, i.e. to include processing rules. This presentation of information is the most effective when based on the ontological approach. Ontology [Guarino, 1997; Sismondo, 2015; Buckingham Shum, 2000; Gladun, 1994; Noy, 2001; Palagin, 2008] is an attempt for a comprehensive and detailed formalization of some knowledge area using a conceptual scheme. Typically, such a scheme consists of a hierarchical data structure containing all relevant classes of objects, their relations and rules of this area. The conceptual scheme means a set of concepts (concepts) and information about the concepts (properties, relations of constraints, axioms and statements about the concepts needed to describe the processes of solving problems in the selected subject area).

Ontology is the vision of an expert in the subject area SA, expressed formally, which allows the use of this understanding of the structure and meaning of information elements in its automatic processing. It's the formalization of the representation of connections between concepts in the ontology that makes it possible to use them in a wide range of decision-making support systems (hereinafter – DMSS).

The links between concepts have particular importance in ontology. Due to them, the ontology is not just a structure of concepts, but also reflects the complex relations between them and comprehensively represents the subject area. There are three main types of connections between concepts:

taxonomic relations – express "is a species of" relations or the "general/specific" relations, i.e. relations that put the two entities in "general – partial" relations;

compositional connections – express "is a part of" relations;

topological connections – reflect how different components of the system are connected to each other through certain connections, or show the "paths" of physical interactions between components, as well as provide information about the spatial location of these components.

N. Noy and D. McGuinness in their article pay a lot of attention to the method of creating ontologies [Noy, 2001]. The authors form the basic rules of ontology development:

1. There is no right way to model the subject area – there are always viable alternatives.

2. The development of an ontology is definitely an iterative process. The iterative process means a repeated passage through the ontology in order to clarify it: i.e. a "draft" version should be made at the initial stage; then you need to check and refine the compiled ontology, and by adding details, it’s possible to partially or even completely change the initial ontology.

3. The elements of the ontology should be close to the objects (physical or logical) and relations in a particular subject area SA.

Therefore, it’s possible to consider the problems with the construction and use of ontologies [Guarino, 1997; Palagin, 2008]:

1. The conceptual unit structure – the choice problem and level of detail of units (concepts), the status of service units, the boundary between concepts and lexical variants, the recognition of units in texts.

2. Formal model – formalized, using a certain language of knowledge, a description of the conceptual system, which specifies:

- used classification of concepts;
- a set of acceptable paradigmatic relations between concepts;
- axioms and inference rules.

3. Computational functionality, determined by the following:

- unification of terminology;
- representation and logical processing of taxonomic relations;
- representation and logical processing of volume compatibility/incompatibility relations;
- representation and logical processing of subject and associative relations;
- presentation and logical processing of quantitative data support;
- regulation of object description procedures;
- axiomatization of processes descriptions, causal links and procedures.

Taking into account that the ontology is an information and computing resource, which is based on expert knowledge and qualitatively represents the subject area and can be used by any intelligent information technology, in particular, as a source of information. Then objects (alternatives) and their properties can be separated from it for the direct solution of the multicriteria ranking problem. Thus, the use of ontology as a basis for presenting alternatives is a very important issue in the creation of decision making support systems.

1. Ontological Representation of the Choice Problem Based on Ranking Alternatives

Each ontology contains information descriptions, based on the object-oriented formalization procedure, as well as descriptions of interpretive functions, which are a functional manifestation of the objects (concepts) properties of the ontology, and which control the process of information resource delivery on all stages of decision-making. Therefore, it’s quite useful to present an information model in the DMSS environment as a certain ontology [Palagin, 2008; Stryzhak, 2019; Gorborukov, 2013].

As you know, the ontological methodology is based on an object-oriented approach, in which the subject area is represented as a set of objects, and interaction between them can be represented by semantic linking of expressions, statements and judgments [Noy, 2001; Stryzhak, 2019; Booch, 2007; Weisfeld, 2013].

An object is a certain essence (real or abstract) with its inherent state, behaviour and individuality.

The state of an object is a list of all its possible properties i.e. the structure and values of each property.

Object’s behaviour (or its functionality) characterizes how an object interacts with other objects or is influenced by other objects, showing its individuality. The behavior of the object is realized as functions called methods. The structure of the object is available only through its methods, which together form the interface of the object.

The individuality of an object is characterized by such properties that distinguish it from all other objects.

To form a proper DMSS operating environment, two types of hierarchical dependencies between objects are of particular interest:

- connections – denote equal relations between objects; the object cooperates with other objects through the connections with them;
- aggregation – describes the relations of whole and part, leading to the corresponding taxonomy (hierarchy of objects).

Computer ontology of a certain subject area (SA) will be considered as a certain non-empty set of objects that meet the following requirements:

1. Objects are organized in a hierarchical structure of a finite set of concepts that describe a given subject area;

2. The structure can be represented by a set of bigraphs, where the vertices are concepts, and the arcs are semantic relations between them;

3. Concepts and attitudes are interpreted according to the general functions of interpretation, taken from electronic sources of knowledge of a given SA;

4. Definition of concepts and relations is based on the axioms and limitations of their scope;

5. Functions of interpretation and axioms are described as a formal theory.

1.1. Taxonomy of the Choice Problem

In general, the ontology of the subject area is formally represented by an ordered trio [Guarino, 1997; Palagin, 2008; Stryzhak, 2019; Gorborukov, 2013; Gruber, 1993]:

$$O = \langle X, R, F \rangle \tag{1}$$

where X is a set of concepts (concepts, terms) of the subject area (SA), which is the basis for the subject component of the operating environment;

R is the set of relations and properties between them (we will assume that properties are the interpretation of relations, ie there is a transformation that matches each relation to certain property);

F – interpretation functions (definitions) X and/or R, which are a functional part of the operating environment.

Consideration of boundary cases of sets of expression (1): $R = \varnothing; R \neq \varnothing; F = \varnothing; F \neq \varnothing$ in all four combinations of R and F meanings and gives different variants of ontological constructions, starting from a simple dictionary and taxonomy to the formal structure of the conceptual knowledge base. According to the procedure of constructing an ontology-based on its certain functional completeness and degree of formality, there are following types of ontologies: primary, final and set of intermediate ontologies.

Thematic ontology ($R \neq \varnothing$; $F \neq \varnothing$) – is such an ontology where sets of concepts and conceptual relations are as complete as possible, and axioms, definitions and restrictions on the subject of this SA are added to the functions of interpretation. The description of all components is represented by some formal language, which can be interpreted by some procedure (algorithm). The scheme of the formal model of thematic ontology is described as follows:

$$O = \langle X, R, F, \tilde{A}, D, R_S \rangle \tag{2}$$

where X is the set of concepts, $X = \{x_1, x_2, ..., x_i, ..., x_n\}, i = \overline{1,n}, n = \text{Card}X$, the finite set of concepts (concepts) given in the DMSS operating environment;

$R = \{R_1, R_2, ..., R_k, ..., R_m\}$, $R_k \subseteq X \times X, k = \overline{1,m}, m = \text{Card}R$ is a finite set of semantically significant properties (relations) between the SA concepts. They determine the type of interaction between concepts.

F is a finite set of interpretation functions given on concepts and/or relations.

$\tilde{A}$ is a finite set of axioms used to write always true statements (definitions and restrictions) in terms of the SA subject;

D is a set of additional definitions of concepts (concepts) in terms of the SA topic;

R_S is a set of constraints that determines the scope of conceptual structures of a particular SA topic.

R^+ is a set of properties that characterize the SA concepts $(R^+ \subseteq R_S)$.

One of the system components of the ontological system is a taxonomy [Shatalkin, 2012], which reflects a certain hierarchy of concepts interaction. In this case, the hierarchy itself is set using binary relations that determine the nature of the interaction between the concepts of the ontology.

Taxonomy is a nonempty subset $\breve{T}$ of the set of concepts X of the ontology O over which the ordering relations $R_t, R_t \subset R \mid R_t \neq \varnothing$. If a multiple binary weak order relation is set for a set of concepts X – $\tilde{p}$, then formally the taxonomy can be determined as follows:

$$T = \{t \in X \mid \exists y \left(y \in X\right) : x\tilde{p}y \vee y\tilde{p}x\}, \qquad (3)$$

where $\tilde{p}(\tilde{p} \in R_t \subseteq R)$ is a binary relation that determines the partial order for the set T.

To form a model of the ranking problem based on ontology, it’s necessary to determine a certain $\tilde{H}_{MR}$ transformation.

$$\tilde{H}_{MR} : \left\langle X, R, F, \tilde{A}, D, R_S \right\rangle \rightarrow M_R, \qquad (4)$$

where M_R is the ranking problem model.

The ranking problem is described by a set of alternatives A, and each one has certain indicators (criteria). The solution of such a problem is the establishment of a linear order over the set A. This order, in particular, allows determining the alternative(s) with the best (in total) values of the criteria, which in general are of different importance. Formally, the mathematical model of the ranking problem consists of the following objects:

$$M_R = \left\langle A, K, \tilde{F}, G \right\rangle, \tag{5}$$

where A is the set of alternatives;

K is the set of criteria;

$\tilde{F} : A \times K \to Q$ is a function that determines the value of alternatives by a certain criterion, Q is a set of values of criteria;

G is a ranking rule that allows you to set a linear order for many alternatives.

Depending on the degree of formation of the ranking problem model, the following cases can be distinguished:

$M_R^{1A}(A \neq \varnothing, K = \varnothing, \tilde{F} = 0, G = 0)$ – only alternatives are defined;

$M_R^{1K}(A = \varnothing, K \neq \varnothing, \tilde{F} = 0, G = 0)$ – only criteria are defined;

$M_R^{2}(A \neq \varnothing, K \neq \varnothing, \tilde{F} = 0, G = 0)$ – sets of alternatives and criteria are defined;

$M_R^{3}(A \neq \varnothing, K = \varnothing, \tilde{F} \neq \varnothing, G = \varnothing)$ – values for criteria are set for alternatives. In this model, it’s assumed that the ranking problem is formed;

$M_R^{4}(A \neq \varnothing, K = \varnothing, \tilde{F} \neq \varnothing, G \neq \varnothing)$ – the ranking rule is set for the formed ranking model.

In fact, the mechanism of modelling the ranking problem and its solution based on ontology (4) is a multi-stage process, each one requires separate procedures. The general scheme of such a transformation can be represented by the following process:

$$O \to M_R^{1A} \rightleftarrows M_R^{2} \to M_R^{3} \to M_R^{4} \to O^* \tag{6}$$

where O^* is an extension of the ontology O as a result of ranking, which defines new relations of advantages and properties for the concepts of ontology (alternatives) $A \subseteq X$. It should be also noted that the new properties can be established as a result of post-analysis based on the solution of the inverse ranking problem.

Thus, the first stage of forming an ontological model of the ranking problem is to separate elements that can be considered as alternatives from the set of concepts X. Alternatives can be considered homogeneous objects with common properties. Such choice can be based on the choice function

$$F_{ch}(X) = Y, Y \subseteq X \quad (7)$$

1.2. Interpreting the Functions of the Ontology of the Choice Problem

The classical rational choice functions include those with the following characteristic properties [Gorborukov, 2013; Aizerman, 1990; Malyshevsky, 1998; Saaty, 2001]:

Condition of imitation (H):

$$X' \subseteq X \Rightarrow F_{ch}(X') \supseteq F_{ch}(X) \cap X' \quad (8)$$

Condition of constancy (K), strict imitation:

$$(X' \subseteq X) \wedge (X' \cap F_{ch}(X) \neq \varnothing) \Rightarrow F_{ch}(X') = F_{ch}(X) \cap X' \quad (9)$$

Condition of consent (C):

$$(X' \cup X'') = X \Rightarrow F_{ch}(X) \supseteq F_{ch}(X') \cap F_{ch}(X'') \quad (10)$$

Condition of independence or rejection (R):

$$F_{ch}(X) \subseteq X' \subseteq X \Rightarrow F_{ch}(X') = F_{ch}(X) \quad (11)$$

To construct a class of choice mechanisms that generate a characteristic region of rejection (B) in the function space, you need such type of structures as a hyperrelation $Y \gamma Z$, which connects pairs of sets [Malyshevsky, 1998; Barendregt, 1985].

Then the choice rule on such a structure is determined by the expression:

$$F_{ch}(X) = Y, Y \subseteq X \Leftrightarrow Y \gamma Z, Z \subseteq X \quad (12)$$

Note that if the hyperrelation has the property of hypertransitivity, then the choice function also belongs to the characteristic domain of imitation (I).

Hypertransitivity condition:

$$Y \gamma Z, x \in X, X \gamma z \Rightarrow ((Y \cup X) / \{x\}) \gamma z \quad (13)$$

Let us define the mechanisms of alternative variants choice for ontology (2) with the taxonomic structure $\breve{T}$, over which there is the binary relation of weak ordering $\tilde{p}$. The partial order $\tilde{p}$ can be extended to the transitive circuit relation p^+ .

$$x_i^j \tilde{p} x_l^k \xrightarrow{\alpha} x_i^j p^+ x_l^k \quad (14)$$

Then you can determine the choice function based on the hyperrelation γ_1^+ and γ_1^- and between the $Y \subseteq \breve{T}$ and $Z \subseteq \breve{T}$ sets such as:

$$\begin{gathered}\gamma_1^- Z, Y = \left\{ y \in \breve{T} \mid \exists z \left(z \in Z \right) : z p^+ y \right\} \\ Y \gamma_1^+ Z, Y = \left\{ \nexists x \left(x \in X, x \neq y \right) : y \tilde{p} x \right\}, Y^* \gamma_1^- Z \\ F_{ch}(\breve{T}) = Y, Y = \left\{ y \in Y_1 / Y_2 \right\}, Y_1 \gamma_1^+ Z_1, Y_2 \gamma_1^- Z_2, Z_1 \subseteq \breve{T}, Z_2 \subseteq \breve{T}\end{gathered} \tag{15}$$

The described choice function determines the finite elements of the taxonomy, which are descendants of classes (categories), included in the set Z_1 and aren't descendants of classes defined by the set Z_2 respectively. Elements that belong to common classes (superclasses) can be considered as alternatives because this determines their homogeneity. Thus described function for the directed graph representing the taxonomic structure defines hanging points with common ancestors Z_1. If the sets Z_1 and Z_2 are not defined, they should be specified as follows: $Z_1 = \left\{ \nexists x \left(x \neq z \right) : x \tilde{p} z \right\}, Z_2 = \varnothing$.

Let R^+ be the set of all properties (attributes) that characterize ontology objects. Hyperrelation γ_2 can be used to specify a set of properties for a specific object $P_x = \left\{ P \gamma_2 x \right\}$. Similarly, as for the choice function in the previous case, you can set the corresponding hyperrelation γ_3^- and γ_3^+ keeping the choice rule (15): $Y \gamma_3^+ Z, Y = \left\{ y \in \breve{T} \mid \forall y : (Z \subseteq P_y) \right\}$.

The hyperrelation γ_3^+ can be modified to $\tilde{\gamma}_3^+$ with the threshold value q.

$$\begin{gathered}Y \tilde{\gamma}_1^+ Z, Y = \left\{ y \in \breve{T} \mid \left(\mid Z \cap P_y \mid > q \right) \right\} \\ Y \tilde{\gamma}_1^- Z, Y = \left\{ y \in \breve{T} \mid \exists z (z \in Z) : z \in P_y \right\}\end{gathered} \tag{16}$$

The choice mechanism generated by this hyperrelation suggests that the objects under consideration don't necessarily have all the desired parameters. It's easy to see that the choice mechanisms (15) and (16) are equal, since belonging to a certain class can be considered a property of an object. You can also build a corresponding taxonomy for elements with certain properties, where there will be objects at the lower level of the hierarchy and a hierarchical structure of attributes at the upper ones.

The described choice mechanisms can be adjusted using certain parameters. If such parameters are not specified, then all elements that have the type “object” for (16) and elements of the lower level of the hierarchy for (15) will be chosen as alternatives. Note that the lack of parameters is not a problem for successfully structural taxonomies.

Note that the main feature of alternatives is their homogeneity. Consider the hyper dominant mechanism for choice [Aizerman, 1990; Malyshevsky, 1998] optimal sets based on the hyperrelation γ_4 given by the scalar function $\Phi(Z)$ (hyperscale): $Y\gamma_4 Z \Leftrightarrow \{\Phi(Y) \geq \Phi(Z)\}$.

Then the choice function will look like this:

$$F_{ch}(\breve{T}) = Y, \Phi(Y) = \max_{Z \in \breve{T}} \Phi(Z) \tag{17}$$

$$\Phi(Z) = GH_1\left(|Z|, \left|\bigcap_{z\in Z} P_z\right| - \left|\bigcup_{z\in Z} P_z\right| + \breve{q}, \left|\bigcap_{z\in Z} P_z\right| - \widehat{q}\right), Z \subseteq \breve{T} \tag{18}$$

where function $GH_1(x,y,z) = \begin{cases} x, (y \geq 0) \,\&\, (z \geq 0) \\ 0, \text{otherwise} \end{cases}$,

$\widehat{q}, \breve{q}$ are integer threshold values, P_z is set of element's properties z $(z \in Z)$. Note that the function GH_1 can be determined in another way, which would take into account not only the common properties but also their number. This choice function focuses on finding the maximum number of homogeneous objects. If there is more than one group of such objects in the ontology, then due to the consistent application of this mechanism, they can also be identified.

The function $\Phi(Z)$ can also be determined by direct pairwise comparisons.

$$\Phi(Z) = \left(\sum\nolimits_{x\in Z} \sum\nolimits_{y \in Z, x \neq y} GH_2(x,y,Z) \bullet \Pr(x,y,Z)\right), Z \subseteq \breve{T} \tag{19}$$

where $\Pr(x,y,Z)$ is a function based on predicates, that determines whether a set of objects has minimum requirements.

$GH_2(x,y,Z)$ is a function that determines the degree of similarity of objects x and $y (x \in Z, y \in Z)$ and which can take into account the number of elements in the set, by default it can be set into $GH_2(x,y,Z) = 1$.

$$\Pr(x,y,Z) = \begin{cases} 1, \Pr_1(x,y) \wedge \Pr_2(x,Z) \wedge \Pr_2(y,Z) \\ -\infty, \neg\Pr_1(x,y) \vee \neg\Pr_2(x,Z) \vee \neg\Pr_2(y,Z) \end{cases}$$

$$\Pr_1(x,y) = \begin{cases} \text{true}, \left(|P_x \cap P_y| \geq \breve{q}\right) \wedge \left(|P_x \cup P_y| - |P_x \cap P_y| \leq \widehat{q}\right) \\ \text{false, otherwise} \end{cases}$$

$$\Pr_2(r,Z) = \begin{cases} \text{true}, |P_r| - \left|\bigcup_{z\in Z} P_z\right| \geq \tilde{q} \\ \text{false, otherwise} \end{cases}$$

where P_x , P_y , P_r are sets of properties of elements x , y , and r $(x \in Z, y \in Z, r \in Z)$, parameters $\breve{q}$, $\widehat{q}$, $\tilde{q}$ are integer threshold values.

The described functions (15) – (16) have all the characteristic properties described in (8) – (11), provided that the properties of the objects are unchanged. The choice function described in (17) – (20) has only the property of rejection (R). But keep in mind that this choice mechanism is focused on finding the optimal set unlike the usual situation, where objects can be considered independent. That is, discarding certain elements from a set of objects significantly changes its qualitative characteristics, so the sets themselves must be integral. If this requirement is imposed, then the described function can be considered rational.

The next step after defining a set of alternatives is to establish a set of attributes that can be considered as criteria K. This can be done as follows:

$$K = \bigcup_{z \in A} P_z, F_{ch}\left(\breve{T}\right) = A, A \subseteq \breve{T} \qquad (20)$$

Thus, a set K is formed, which can be used to determine the set of alternatives. That is, it can be used to determine the sets Z_1 and Z_2, which are used to choose alternatives. Thus, these stages of formation of alternatives and criteria are interrelated $M_R^{1A} \rightleftarrows M_R^2$, because the properties of objects allow you to set many alternatives, which in turn are characterized by common features.

1.3. Ontological Representation of Alternatives

The next step in forming a model of the ranking problem is to establish criteria for alternatives. For this, you should separate the values of attributes from the relation (“object”, “attribute”, “value”) from the ontological model. Subsequent paragraphs, however, are indented.

$$(x, y, \tilde{F}(x, y)) \in R_\nu \qquad (21)$$

where x is an alternative from the set A; y is a criterion from the set K; $\tilde{F}$ is a function, which defines the criterion value for the given alternative; R_ν are the trinary relations given for the set X.

After defining a set of criteria and alternatives, and their criteria values, we will assume that the model of the ranking problem is actually set. Further refinement and resolution depend on the direct involvement of the statement.

Based on our formal definition of ontology (1) and the category of choice, which is represented by expressions 7–19, we present the ontology of the *OTPCh* choice problem [Gorborukov, 2013; Velichko, 2017] as the following expression:

$$OTPCh = \left\langle \breve{T}, (\tilde{p} \vee R^+), F_{ch}(\breve{T}) \right\rangle \qquad (22)$$

where $\breve{T}$ is a taxonomy, $\tilde{p}$ is a partial order relation, R^{+} are the properties of concept objects, F_{ch} is a choice function.

So, the object components that determine the ontology of the problem of choice, allow us to interpret them as different information resources, the concepts of which are associated with certain binary relations of partial order and may have unary properties that characterize them in a certain qualitative form.

Now we directly specify the mathematical model of the ranking problem (5), which can be formally described as follows. Each alternative $x \in A\{A_1, A_2, ..., A_n\}$ (A is a set of alternatives) is defined by the values of some set of indicators $f_1(x), f_2(x), ..., f_m(x)$. Each $f_j(x), j \in J = \{1...m\}$ function specifies the value of the j-th criterion [Gorborukov, 2013; Aizerman, 1990; Malyshevsky, 1998; Saaty, 2001; Stoyer, 1992], which belongs either to a predetermined set or is calculated according to certain mathematical rules [Malyshevsky, 1998; Saaty, 2001; Kini, 1981]. In the first case, the options are possible: the set of values is given by a point or linguistic scale [Gray, 2015] or as a numerical interval $\left[f_j^{\min}, f_j^{\max}\right]$, which is formed from all possible values of the function (from minimum to maximum). An example of the second case is the synthesis of local priorities in the method of analysis of hierarchies [Gorborukov, 2013; Malyshevsky, 1998; Saaty, 2001]. Therefore, we can assume that the value of the j-th criterion is always countable, denote it as Q_j:

$$Q_j = \left\{f_j^{(1)}, f_j^{(2)}, f_j^{(3)}, ..., f_j^{(n_j-1)}, f_j^{(n_j)}\right\}$$

where $f_j^{(1)} = f_j^{\min}, f_j^{(n_j)} = f_j^{\max}, f_j^{(1)} < f_j^{(2)} < ... > f_j^{(n_j)}, n_j = \left|Q_j\right|$ is the number of elements of the set Q_j.

So, the problem of ranking alternatives by a set of indicators is to establish a certain order

$$A_{i_1} \succ A_{i_2} \succ ... \succ A_{i_n}, i_1, i_2, ..., i_n \in \{1...n\} \tag{23}$$

based on the calculation of the values of some general indicator $G(x)$ for each element of the A set:

$$\begin{gathered} G(x) = G(f(x), W) = G((f_1(x), ..., f_m(x), (\omega_1, ..., \omega_m)), x \in A = \{A_1, ..., A_n\} \\ W = (\omega_1, ..., \omega_m), \sum_{j=1}^{m} \omega_j = 1, \omega_j > 0 \end{gathered} \tag{24}$$

where $G(x)$ values are calculated according to a certain rule (algorithm), determined by the mathematical method used in each case, and

$$G(A_{i_1}) \geq G(A_{i_2}) \geq \ldots \geq G(A_{i_n}) \qquad (25)$$

and W is the normalized weight vector of criteria [Aizerman, 1990; Malyshevsky, 1998; Saaty, 2001; Stoyer, 1992].

The alternative A_{i_1} , is the best alternative, which is the first one in the order (23), alternative A_{i_n} is the worst respectively. is the worst respectively A_{i_k} in the order (23) is on the k -th place, and k will be called its rating.

It should be noted that no matter how the problem is solved (23) – (25), the reliability of the obtained result significantly depends on the method of converting the $Q_j, j \in J$ values into a unified scale for all criteria. Thus, the formula is often used [Opricovic, 2004; Nogin, 2005]

$$f_j'(x) = q_{\min} + (q_{\max} - q_{\min}) \left(\frac{f_j(x) - \inf Q_j}{\sup Q_j - \inf Q_j} \right), x \in X = \{A_1, \ldots, A_n\} \qquad (26)$$

however, it may not accurately reflect the “essentiality” of the advantage of one alternative over another after transforming the initial $f_j(x)$ values to the $[q_{\min}; q_{\max}]$ scale. As a result, when using the obtained $f_j'(x)$ values in complex factor (24), the solution of problem (23) – (25) may be incorrect. Therefore, there is a need to develop other approaches to the normalization of criteria, which take into account the actual ratio of the strength of alternatives for each criterion properly.

2. Ontological Decision-making Support System Based on Solving the Rational Choice Problem

The solution of rational choice problems based on means of a ranking of alternatives on a set of indicators is the system for the solution of a ranking problem based on the ontological model of the subject area.

From the point of view of software engineering, a software system is considered as a set of descriptions presented as mathematical models, formalisms and modelling techniques.

The structure of mathematical models of IAS DMS (Information Analytical System of Decision Making Support) includes the following models:

1. information model;

2. component function model.

2.1. Information Model of the Ontological System for Solving Problems of Ranking Alternatives

The information model is used to represent and describe data flows, data structures and software modules in the ontological system.

The general information model of the ontological system for solving the ranking problems S_A looks like (27). It’s represented by some finite set of integrated S_{A_i} software modules.

$$S_A = \sum_{i=1}^{n} S_{A_i} \tag{27}$$

The set of modules can be considered as a separate independent system created by TODOS technology [Stryzhak, 2019; Velichko, 2017; Mintser, 2018; Stryzhak, 2018]. This set looks like (28).

$$S_A = \{S_{MO}, S_{MT}, S_{OA}, S_{AL}, S_{CO}\} \tag{28}$$

S_{MO} is a module responsible for information representation of the ontological graph and basic operations on it [Gladun, 1994; Palagin, 2008; Velichko, 2017]. The set of functions of this module looks like (29).

$$F_{MO} = \{F_1^{S_{MO}}, F_2^{S_{MO}}, F_3^{S_{MO}}, F_4^{S_{MO}}, F_5^{S_{MO}}, F_6^{S_{MO}}, F_7^{S_{MO}}, F_8^{S_{MO}}, F_9^{S_{MO}}\} \tag{29}$$

Its functions include:

$F_1^{S_{MO}}$ – upload an ontological model from supported data formats (XML and JSON);

$F_2^{S_{MO}}$ – finding the graph node by its unique identifier;

$F_3^{S_{MO}}$ – finding the node (and its unique identifier) by name;

$F_4^{S_{MO}}$ – node attachment to the graph;

$F_5^{S_{MO}}$ – node removal from the graph;

$F_6^{S_{MO}}$ – finding the child elements of a particular graph node;

$F_7^{S_{MO}}$ – finding the parent elements of a particular graph node;

$F_8^{S_{MO}}$ – reading and editing the properties of the ontological graph point;

$F_9^{S_{MO}}$ – downloading of the ontological model into one of the supported formats (JSON);

S_{MT} is a module responsible for the model of information representation of the problem of ranking alternatives. This module consists of S_{MTA} and S_{MTC} (30).

$$S_{MT} = \{S_{MTA}, S_{MTC}\} \tag{30}$$

S_{MTA} is a module responsible for the model of information representation of alternatives in the ranking problem. The set of functions of this module looks like (31).

$$F_{MTA} = \left\{F_1^{S_{MTA}}, F_2^{S_{MTA}}, F_3^{S_{MTA}}, F_4^{S_{MTA}}, F_5^{S_{MTA}}, F_6^{S_{MTA}}\right\} \tag{31}$$

Its functions include:

$F_1^{S_{MTA}}$ –attachment of an alternative to this container;

$F_2^{S_{MTA}}$ – removal of alternative (s);

$F_3^{S_{MTA}}$ – finding an alternative by its unique identifier;

$F_4^{S_{MTA}}$ – finding an alternative (and its unique identifier) by name;

$F_5^{S_{MTA}}$ – uploading and downloading objects from/into supported data formats;

$F_6^{S_{MTA}}$ – reading, setting and editing the properties of objects (alternatives) that can be used as criteria or data for their calculations.

S_{MTC} is a module responsible for the model of information representation of criteria in the ranking problem. The set of functions of this module looks like (32).

$$F_{MTC} = \left\{F_1^{S_{MTC}}, F_2^{S_{MTC}}, F_3^{S_{MTC}}, F_4^{S_{MTC}}, F_5^{S_{MTC}}\right\} \tag{32}$$

Its functions include:

$F_1^{S_{MTC}}$ – creation of criterion objects using the input list;

$F_2^{S_{MTC}}$ – attachment of a criterion to this container;

$F_3^{S_{MTC}}$ – criterion (a) removal;

$F_4^{S_{MTC}}$ – criteria editing (setting scales, optimization direction, etc.);

$F_5^{S_{MTC}}$ – finding the criterion by its unique identifier.

S_{OA} is a module responsible for the analysis of the ontological graph based on its information model, represented by the S_{MO} module. This module consists of S_{TA} and S_{PI}).

$$S_{OA} = \{S_{TA}, S_{PI}\} \tag{33}$$

S_{TA} is a module responsible for taxonomic ontograph analysis and the choice of a subset of points that can be used as alternatives. The set of functions of this module looks like (34).

$$F_{TA} = \left\{ F_1^{S_{TA}}, F_2^{S_{TA}}, F_3^{S_{TA}}, F_4^{S_{TA}} \right\} \tag{34}$$

Its functions include:

$F_1^{S_{TA}}$ – identification of alternatives based on taxonomy. Homogeneous objects at the lower level of the hierarchy are considered alternatives by default;

$F_2^{S_{TA}}$ – marking of valid points based on the initial set of "white" nodes, i.e. only their child nodes should be included in the consideration;

$F_3^{S_{TA}}$ – marking of valid points based on the initial set of "black" nodes, i.e. all their child nodes should be excluded from consideration;

$F_4^{S_{TA}}$ – filtering of the points based on the node(s) of a higher layer of the hierarchy.

S_{PI} is a module responsible for finding the properties of objects that can be used for criterion score. The set of functions of this module looks like (35).

$$F_{PI} = \left\{ F_1^{S_{PI}}, F_2^{S_{PI}} \right\} \tag{35}$$

Its main functions include:

$F_1^{S_{PI}}$ – separation of "criterion" properties and their characteristics from the ontograph points;

$F_2^{S_{PI}}$ – creation (or updating) criteria in a ranking problem model.

S_{AL} is a set of modules responsible for the actual solving of a ranking problem.

The set of functions of this S_{AL} looks like (36):

$$F_{AL} = \left\{ F_1^{S_{AL}}, F_2^{S_{AL}}, F_3^{S_{AL}}, F_4^{S_{AL}}, F_5^{S_{AL}} \right\} \tag{36}$$

Its main functions include:

$F_1^{S_{AL}}$ – calculation of criteria weighting;

$F_2^{S_{AL}}$ – calculation of criterion values, if there is a way to interpret criteria;

$F_3^{S_{AL}}$ – normalization of criterion values of alternatives on a common scale;

$F_4^{S_{AL}}$ – calculation functions (depending on the specific method) to calculate the “rating” value of the alternatives, used to rank them;

$F_5^{S_{AL}}$ – ranking and setting a certain “rating” value for alternatives based on the aggregation of the result of calculations used to solve mathematical methods of ranking alternatives;

S_{CL} is a set of modules (controllers) responsible for preparing data for display in the user’s web interface and for processing his requests. If necessary, controllers use other auxiliary service modules to perform their tasks. The set of functions of these modules looks like (37):

$$F_{CL} = \left\{ F_1^{S_{CL}}, F_2^{S_{CL}}, F_3^{S_{CL}}, F_4^{S_{CL}}, F_5^{S_{CL}}, F_6^{S_{CL}}, F_7^{S_{CL}}, F_8^{S_{CL}} \right\} \tag{37}$$

The main functions of these modules include:

$F_1^{S_{CL}}$ – definition of a set of alternatives.

$F_2^{S_{CL}}$ – fixing a set of criteria and specifying their method of interpretation.

$F_3^{S_{CL}}$ – specification of the range where the criteria can receive values (maximum and minimum score).

$F_4^{S_{CL}}$ – determining the direction of criteria optimization.

$F_5^{S_{CL}}$ – setting the criteria importance using provided methods.

$F_6^{S_{CL}}$ – definition of the system of advantages.

$F_7^{S_{CL}}$ – filter and search for objects.

$F_8^{S_{CL}}$ – data preparation and templating for presentation in the web interface.

2.2. Component Function Model of the Ontological System for Solving Ranking Alternatives Problems

The component function model is used to represent the interactions, relations and dependencies of software modules, as well as to describe in detail the components of the system. In general, this model for the software package for solving the ranking alternatives problems can be represented by the structure.

$$S_R = \{M_D, M_S, M_p\} \tag{38}$$

Elements included in this model:

M_D is a model that determines the behaviour of the system;

M_S is a model that defines the structure of the system;

M_p is a model that defines the structure of program entities.

The model of system behaviour looks like (39).

$$M_D = \{d_{use}, d_{act}, d_{seq}\} \tag{39}$$

It includes:

d_{use} – UML-diagram of options for using the system of solving ranking alternatives problems;

d_{act} – UML-diagram of activity of the system of solving ranking alternatives problems;

d_{seq} – UML-diagram of the interaction of the system of solving ranking alternatives problems;

The main user of the system is DMP (decision making person), who is provided with the means to form and solve the ranking alternatives problems.

The formation of the ranking problem includes:

- identifying a set of alternatives;
- definition of criteria;
- defining a set of criteria;
- establishing the importance of criteria;
- definition of interpretive functions for criteria;
- setting criterion values for alternatives;
- formation of a system of advantages.

The process of identifying a set of alternatives involves an analysis of the taxonomic structure of the ontological graph and finding homogeneous objects with common properties. DMP can control this process, in particular through filtering.

The definition of a set of criteria based on ontology is to establish a set of properties of objects that can be used as criteria. DMP can also choose and define a mechanism for interpreting properties as criteria.

Using the provided methods, DMP can establish the importance of criteria and choose the direction of their optimization. The user can also create a system of advantages. This process involves choosing ways to establish the importance of the criteria.

Solving the ranking alternatives problem involves choosing a way to solve the problem and view the result directly. The ranking result can be presented using diagrams and attribute filtering mechanisms.

The SA expert performs the function of forming thematic ontologies [Palagin, 2008; Stryzhak, 2019; Opricovic, 2004; Mintser, 2018], which can later be published by the administrator in the public library. Forming can be done manually (with an ontology editor) or automatically based on the text structuring process, which is also done by a SA expert.

The expert assists DMP in forming the ranking problem and has all the appropriate DMP tools, but DMP determines the participation and role of the expert in solving the ranking problem. The scheme of using the tools of the ontological environment by experts is presented in Figure 1.

The process of identifying a set of alternatives involves an analysis of the taxonomic structure of the ontological graph and finding homogeneous objects with common properties. DMP can control this process, in particular through filtering.

The definition of a set of criteria based on ontology is to establish a set of properties of objects that can be used as criteria. DMP can also choose and define a mechanism for interpreting properties as criteria.

Using the provided methods, DMP can establish the importance of criteria and choose the direction of their optimization. The user can also create a system of ad-vantages. This process involves choosing ways to establish the importance of the criteria.

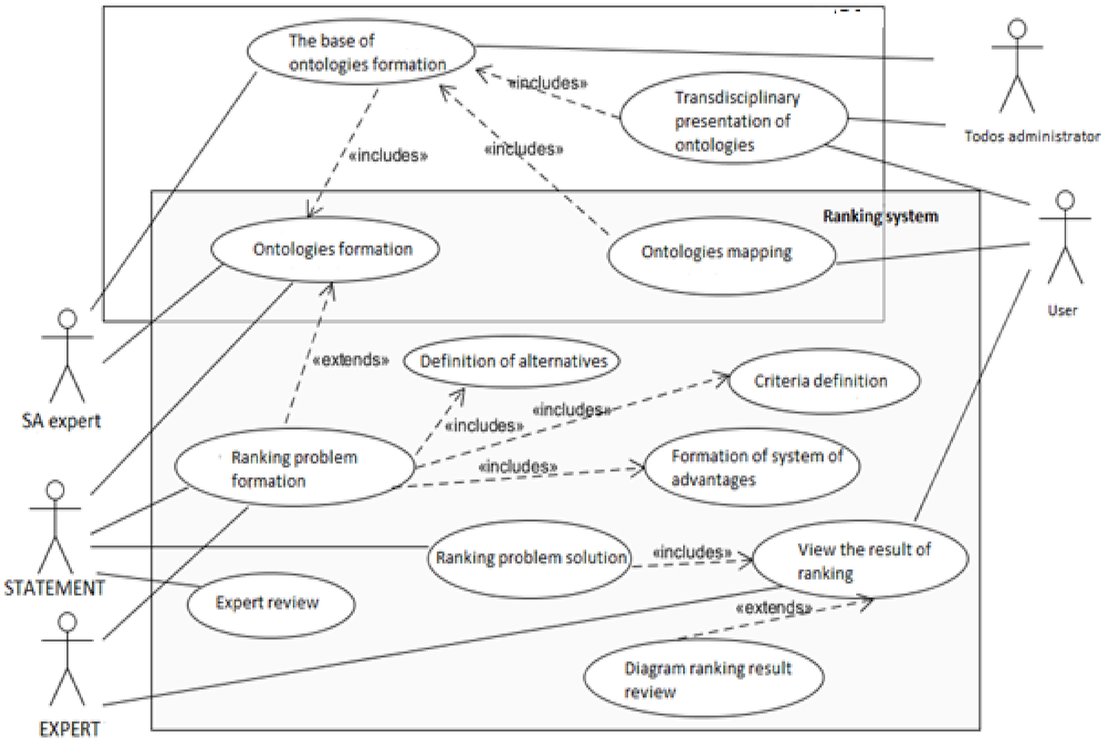

Figure 1. Ways to use the system

Solving the ranking alternatives problem involves choosing a way to solve the problem and view the result directly. The ranking result can be presented using diagrams and attribute filtering mechanisms.

The SA expert performs the function of forming thematic ontologies, which can later be published by the administrator in the public library. Forming can be done manually (with an ontology editor) or automatically based on the text structuring process, which is also done by a SA expert.

The expert assists DMP in forming the ranking problem and has all the appropriate DMP tools, but DMP determines the participation and role of the expert in solving the ranking problem.

The common user can view the ranking result if he has the appropriate access.

The UML-diagram of the activity of the software system for solving the ranking alternatives problems is shown in Figure 2. The diagram describes the algorithm for working with the system of solving ranking alternatives problems.

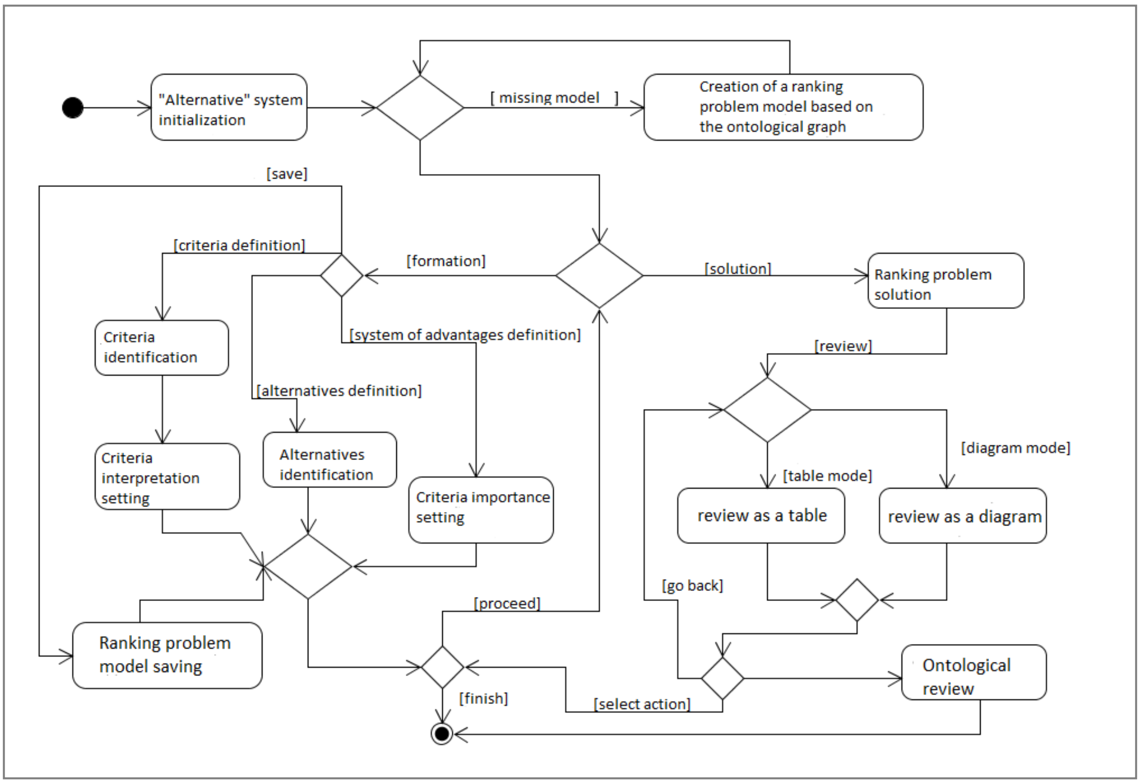

Figure 2. System activity diagram

After switching on the system, it is initialized and the problem of ranking alternatives is formed based on the corresponding ontological graph.

If the user does not save the corresponding model of the ranking problem for this graph, then the set of alternatives is based on the taxonomic analysis. The list of possible criteria is based on the properties of the objects that have been identified as alternatives.

Conclusions

A significant number of applied problems belonging to different spheres of human activity are formalized by models and methods of decision theory and are solved with the help of decision support systems. The most common problems here are related to the choice of a solution from a predetermined set based on multiple-criteria decision analysis and ranking of alternatives. Solving these problems occur in several stages, the key of which is the stage of structuring problems. In order to prevent possible inaccurate results in solving a multicriteria problem, it is convenient to represent the subject area as ontology.

Based on an object-oriented approach, the ontological methodology allows representing the subject area to which specific applications belong, in the form of a hierarchical data structure - a set of objects with certain attributes and relationships between them. Therefore, the effective use of decision support systems is not possible without the development of formal mechanisms for obtaining specific data from the ontological model of the subject area. This allows automating the process of building an information environment of the system, which ultimately increases the success of its use as a practical tool for solving problems of choice and ranking of alternatives.

In the article, the multi-stage process of forming a model of the problem of ranking alternatives by a set of indicators based on the ontological representation of the subject area is described. The method of constructing the information environment of the multiple criteria ranking problem, which carries out the transformation of the ontological model of the subject area based on the interpretive selection functions constructed using hyperrelation over elements of the taxonomic structure of the ontology and properties of its objects, is presented. An informational and functional-component model of the system for solving the problem of ranking alternatives is described.

Transdisciplinary analysis identifies a variety of criteria that characterize different sources.

Transdisciplinary analysis realizes the competitor's normalization of criteria, which ensures their use in processing various topics.

Transdisciplinary analysis provides an integrated use of a variety of criteria when ranking a large number of facts.

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