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Structural simulation of devices based on patent descriptions

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Abstract

The problem of the interaction of patent law and TRIZ is considered in this paper. A su-field analysis is applied from TRIZ tools. The European claim of the invention is used to describe the device. The claim is divided into technical features for structural simulation. Binary relationships are introduced between features to build hierarchy levels. As a result, an oriented graph is obtained, the nodes of which are features, and the branches show the subordination of features. The elements are at the top level, and the connections between them are at the middle level. The properties of elements and links are at the lower level. The physical operating principle of the device from the patent description is used for the numerical evaluation of the structure. At the middle level of the hierarchy, features of interaction between elements are replaced by mechanical, thermal, electric, and magnetic fields from the Su-field analysis. Further, the inventive fields are replaced by the dimensions of the physical quantities in which the fields are measured. For example, the dimensions of ampere, volt, watt, and coulomb are used for electric fields, depending on the specific design of the device. The dimensions of physical quantities are given in the Bartini basis with two basic units time T and space L. Two-dimensional diagonal matrices are introduced to describe the weights of graph branches. A weighted and oriented graph mathematically describes the structure of the claim. The purpose of the simulation is to calculate the resource intensity of the claim structure, as well as a numerical comparison of the novelty of the claims with the prototype. The novelty coefficient is determined by the degree of asymmetry of the new solution and the prototype. The symmetric part is the inventive features included in the restrictive part of the claims. The inventive features included in the characteristic part form the asymmetry of the claims.

Keywords: claims in the invention, novelty, simulation, Su-field analysis

1. Introduction

An important problem of technical design is the evaluation of inventive solutions. To compare inventive solutions, they must be formalized according to certain rules. One of the well-known methods of comparing formalized solutions is patent examination of inventions. The most structured part of the patent is the claim. Witz and Geisel (2017) indicate the claim has three parts: preamble, transitional phrase, and claim body. The claim body contains features, i.e. components, their connections, and characteristics. In Russia and China, the European form of the claims is used, which has a restrictive and distinctive part. The restrictive part contains the features of the invention common to the prototype and the new solution. The distinctive part contains only the features of a new solution. The features of the invention are used for the mathematical patent model, according to which different indicators of the technical solution are evaluated.

In the work (Bushuev and Chepinskiy, 2007a), a probabilistic mathematical model is proposed, according to which the level of development of the technical system is estimated. A chronological sequence of inventions xk is introduced, in which the invention xk-1 is the prototype for the invention xk, k=0, 1, 2, ... Then each invention can be considered as a state of a single-scale queuing system with waiting, which receives a random stream Si of invention features. The features of the restrictive part come to the kernel for maintenance Ker xk, and the features of the distinctive part form a queue Que xk. The probability pik(Ker xk) | Si∈Ker xk and the probability pjk(Que xk) | Sj∈ Que xk, i≠j are entered. It is shown for $k\to\infty$ pjk(Que xk)≤0.5 and lim pik(Ker xk) = 1. The product of the probabilities of several features included in the kernel gives the kernel density p(k). The product of the probabilities of several features included in the core gives the core density p(k). The graph p(k) gives a discrete S-curve (Altshuller,1999), according to which the level of technology development is estimated.

Weidong et al. (2020) propose a graph-based probabilistic patent evaluation model. In the model, the textual parts are combined with some structured parts of patents. The patent value is initially determined by the internal features of the patent. Given a patent o, the patent value vo is initially formed by the features from the patent and exhibits a prior probability distribution. vo~p(vo|Do) where o ∈ VO and Do denotes some features extracted from the structured and unstructured parts of o. VO={on} where o denotes an object to be valued. Next patent values are changed by the values of the nodes that are associated with the patents.

In the work (Bushuev and Chepinskiy, 2007b), a structural model of the claims in the form of a graph is proposed. The nodes of the graph are the features of the device, and the branches are binary relations between the features. The structural scheme determines the strength of the claims F = 1/n, where n is the number of nodes of the graph. In the refined estimation of the strength of the formula, node weight functions are used, depending on the number of branches of the node.

The considered methods of stimulation have a disadvantage. The features of the claims are considered equivalent since the claims represent the device in a static stationary state. The importance of the features is found in the dynamic state. The physical operating principle of the device is presented in the patent description, but not in the claims. The dynamic action of the device represents an unstructured part of the patent description. In TRIZ (Goldovsky and Weinerman, 1990), a simulation of the structure by an oriented graph consisting of substances Si and fields Fj is proposed. Mechanical, thermal, electric, and magnetic fields are used. In the graph F1→ S1 → F2→ S2 → … Fi → Sj, the direction of energy conversion is shown by arrows. The nodes of the graph are not equivalent, but their numerical weight is missing. Differential equations are used to simulate a dynamic graph. In (Zaripova et al, 2015), for any node of the graph, the differential equation of thermodynamics dQ = PdE is used, where dQ is the differential of the generalized work, P is the generalized force, and dE is the generalized coordinate. The graph model turns out to be dynamic, but it is redundant for patent protection of the device.

In TRIZ, the use of the theory of dimensions of physical quantities is also known. The inputs and outputs of the nodes of the graph are encoded by the dimensions of physical quantities on one or another basis. For example, in (Coatanéab et al, 2015) the MLT-basis (mass-length-time) is considered. The topology of a technical system is represented by a graph, the nodes of which are variables of three types The first type includes variables at the input of the device. The second type includes variables at the output of the device. The third type includes intermediate variables that form chains of transformations from inputs to outputs. The branches of the graph are constructed according to the expert assessment of the cause-and-effect relationships. The graph matrix in the MLT-basis is used to check the reliability of the structural model and find nodes with a violation of cause-and-effect relationships. In (Bushuev and Kudriavtseva, 2019), the LT-basis (length-time) is used to numerically estimate the resource intensity of the graph. Shibayama et al (2021) propose a numerical evaluation of scientific documents on semantic text analysis. The novelty of the document is assessed by the frequency of references in the cited literature. However, such an estimate has weak validity for patents, since a patent can have only one reference to a prototype.

The work aims to obtain numerical estimates for comparing a new solution and a prototype according to their patents. Let's pose the following search problem.

2. Problem statement

The new technical solution is specified in the patent description with the claim. Therefore, the description and claim of the prototype invention are known. We will assume that the claim has features from three levels of hierarchy. The highest level of the hierarchy includes features of the presence of structural elements. The middle level of the hierarchy includes features of a connection between elements and their mutual arrangement. The lower level of the hierarchy includes features that define the shape of the element and the form of the relationship between the elements, as well as features that define the parameters and other characteristics of the element.

The set of features is denoted by {Di}, where i is the number of the feature, i = 1, 2, ... We introduce the binary relation Di R Dj, where R means that the attribute Di does not exist without the attribute Dj, i≠j. The binary relation establishes the subordination of

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features, which is indicated by arrows in the graph, and the nodes in the graph are the features of the device.

Let's explain the concept of hierarchy levels in the following example. The claim is written as "the device has block A mounted on block B". Here we have three features: block A, block B, and mounted on. Let's exclude the mounted on feature. Then we will get a claim like "the device has block A and block B". This is a logically valid expression that can be used in the restrictive part of the claim. The indication of the relative position of blocks A and B can be indicated in the distinctive part of the claim for the operability of the device. If we exclude the features block A and block B, then we get the claim "the device has a mounted on. This is a logically incorrect expression. In patent rules, it is customary to exclude all connections of an element with other elements if this element is excluded. Mathematically, these rules are confirmed by graph theory. There are disconnected graphs in which some nodes do not have branches. The simplest structure model can consist only of nodes. However, a model consisting only of branches or links does not exist. Thus, elements, blocks, and nodes form the highest level of the hierarchy of the model, and the connections between them form the middle level.

The lowest level of the hierarchy is formed by features characterizing the internal properties of elements, and blocks, as well as the connections between them. For example, the device has a round block A mounted rigidly on block B. The features "round" and "rigidly" are at the lowest level of the hierarchy. They disappear if features of a higher level are excluded from the claim. In graph theory, the weight of nodes and branches is a feature of the lowest level of the hierarchy. Such a graph is called weighted or colored when each node is assigned its color.

Some of the Di features are common to the new solution and the prototype. Common features are included in the restrictive part of the claims for a new solution. We denote the set of features of the prototype by {Do}, and we denote the set of features of the new solution by {Dn} where o and n are integers denoting the feature number. Then the restrictive part of the claims of the new solution will be equal to the intersection {Do}∩{Dn} of the sets. We will consider the intersection as the symmetric part of the new solution-prototype pair. The set of features of the new solution-prototype pair is shown in Fig. 1 where the symmetrical part is indicated in green. The distinctive part of the new solution forms the set {Dn} - {Do}∩{Dn}. If {Do}={Dn}, then {Do}∩{Dn} = {Do}={Dn}, and such an invention has no novelty {Dn} - {Do}∩{Dn}={∅}. In this case, the new solution and the prototype are completely symmetrical. Therefore, the inventor needs a minimum of information to get a new solution from a known prototype.

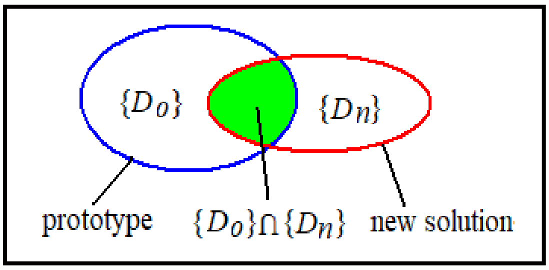

Fig. 1. The set of features of the new solution-prototype pair

This information is that the new solution and the prototype are completely symmetrical. A new solution turns out to be more asymmetric when the inventor has to generate more new information so that this solution can be reproduced. Thus, we will evaluate the degree of novelty by the magnitude of the asymmetry. The paper (MacCormac, 1998) discusses in more detail the use of symmetry and asymmetry in science and technology.

3. Defining the similarity function

Brown (2021) considers the similarity function S (A, B) of two objects A and B as a function f of three arguments three arguments

$$S(A,B) = f(A \cap B, A \setminus B, B \setminus A), \quad (1)$$

where A∩B are features belonging to A and B, A \ B are features belonging to A but not belonging to B, B \ A are features belonging to B but not belonging to A. For patent features, you can write A∩B= {Do}∩{Dn}, A \ B={Do}-{Dn}, B \ A={Dn}-{Do} where object A is a prototype, in object B is a new solution. Eq. (1) for the degree of symmetry E is written as

$$E = f(\{D_o\} \cap \{D_n\}) \,/\, [f(\{D_o\} \cap \{D_n\}) + \alpha f(\{D_o\} - \{D_n\}) + \beta f(\{D_n\} - \{D_o\})], \quad (2)$$

where α and β are some feature weights. It is necessary to take two steps to find the function f and the coefficients α and β. The first step is called structural simulation, and the second step is called dimensional simulation.

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3.1 Structural simulation

We will show a structural simulation of some Di features using a simple example. Let the claim of an optical device (Fig. 2) be given: a radiation source on the optical axis of which a photodetector is installed. Let's make a block diagram of the claim. The scheme has two upper-level features D1 - the radiation source and D2 - the photodetector.

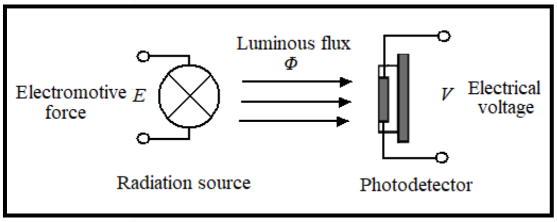

Fig. 2. The design of the optical device

Installation on the optical axis D3 is a feature of a middle level, since D3 R D1 and D3 R D2. A structural simulation of the claim is shown in Fig. 3, where the graph of features and its nodes are shown on the left, and an equivalent Su-field structure is shown on the right. The nodes of the Di graph are placed in circles; the directions of subordination are indicated by arrows. To obtain an equivalent Su-field structure, the description of the work and the design of the device in Fig. 2 are used. Top-level features D1 and D2 are replaced with full Su-fields consisting of three elements F→S→F. Such a structure has problems to detect (Petrov, 2014). The feature of the middle level D3 is replaced by the field F2, since the radiation field passes along the optical axis between the radiation source S1 and the photodetector S2. Such a Su-field is called an incomplete Su-field.

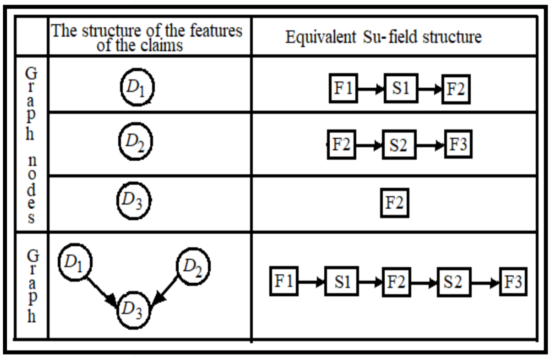

Fig. 3. Structural simulation of an optical device, F1 - electric field, S1 - radiation source, F2 - radiation field or electromagnetic field, S2 - photodetector, F3 - electric field.

The final Su-field structure represents the complex Su-Field F1→S1→F2→S2→F3. If there is no D3 feature in the claim, then the Su-field structure contains two completely unrelated Su-Fields F1→S1→F2 and F2→S2→F3. If there is no D2 feature in the claim, then the D3 feature disappears, and only the D1 Su-Field remains F1→S1→F2. As you can see, the F2 field does not disappear. It defines the operational function of the radiation source.

Let's assume that the new solution has one distinctive feature D4. This feature means that the radiation source is monochromatic with a wavelength of 700 nm. The structural model of the new solution is shown in Fig. 4.

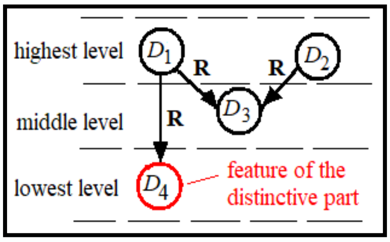

Fig. 4. Hierarchical structural simulation of a new solution, D4 is a feature of the distinctive part

The D4 feature is at the lowest level of the hierarchy since D4 R D1. The feature of the lower level of the hierarchy is introduced intentionally to show the limitations of Su-field analysis. When Su-fields are constructed, the internal properties of substances are not taken into account. Therefore, the equivalent Su-field structure of the new solution F1→S1→F2→S2→F3 coincides with the structure of the prototype. he wavelength characterizes the radiation field F2 which replaces the feature D3 of optical communication between D1 and D2. However, the claim describes the design of the device in static, i.e. in the off state. Fields do not exist in static so the D4 feature is subordinate to the D1 feature.

3.2 Dimensional simulation

The transition from the structural model of the claims to an equivalent Su-field structure also involves the use of a description of the operation of the device. The physical operating principle of the device allows you to determine the types of fields in Su-field analysis. However numerical estimates of the features are needed to compare the prototype and the new solution. Su-Field analysis does not allow making such a comparison. Indeed, it is impossible to answer how much an electric field is better than a mechanical pressure field or a magnetic field is better than a thermal field. The paper (Bushuev and Kudriavtseva, 2019) shows how inventive fields of different types of energy can be numerically compared. In invention problems, the fields differ from each other in the physical quantities by which they are measured. For example, the electric field can be measured in units of electric voltage, current, charge, and field strength. Consider the radiation source D1 in Figure 2 with the Su-Field F1→S1→F2. The input electric field F1 is measured in EMF units, i.e. in volts. The output radiation field F2 is measured in units of luminous flux, i.e. lumens. In the Bartini system of kinematic quantities (Bartini, 2005), the EMF has a volt dimension [L2T-2], and the lumen has the dimension joule/c [L5T-5], where length L and time T are the basic units. We introduce matrices for the input and output values

$$EMF = \begin{bmatrix} L^2 & 0 \\ 0 & T^{-2} \end{bmatrix}, \Phi = \begin{bmatrix} L^5 & 0 \\ 0 & T^{-5} \end{bmatrix}, \quad (3)$$

where EMF is the electromotive force at the input of the radiation source, Φ is the luminous flux at the output. We find the transfer matrix W1 of the radiation source from Eq. (3)

$$W_1 = \Phi\ EMF^{-1} = \begin{bmatrix} L^5 & 0 \\ 0 & T^{-5} \end{bmatrix} \begin{bmatrix} L^2 & 0 \\ 0 & T^{-2} \end{bmatrix}^{-1} = \begin{bmatrix} L^3 & 0 \\ 0 & T^{-3} \end{bmatrix} \quad (4)$$

The input value of the photodetector will be the illumination E measured in lux, and the output value is the electrical voltage V in volts. The illumination E in the Bartini system has the dimension of surface power [L3T-5]. Therefore, the transfer matrix W2 of the photodetector is equal to

$$W_2 = VE^{-1} = \begin{bmatrix} L^2 & 0 \\ 0 & T^{-2} \end{bmatrix} \begin{bmatrix} L^3 & 0 \\ 0 & T^{-5} \end{bmatrix}^{-1} = \begin{bmatrix} L^{-1} & 0 \\ 0 & T^3 \end{bmatrix} \quad (5)$$

The transfer matrix W_3 of the feature D_3 is equal to

$$W_3 = E\Phi^{-1} = \begin{bmatrix} L^3 & 0 \\ 0 & T^{-5} \end{bmatrix} \begin{bmatrix} L^5 & 0 \\ 0 & T^{-5} \end{bmatrix}^{-1} = \begin{bmatrix} L^{-2} & 0 \\ 0 & T^0 \end{bmatrix} \quad (6)$$

In Eq. (6), it is assumed that the feature D3 cuts out a part of the spherical luminous flux Φ, limited by the aperture S of the photodetector. The transfer matrix W3 is the inverse matrix of the surface S. In the LT-basis, the surface has dimension [L2T0] or m2. The dimensional simulation scheme of the prototype is shown in Fig. 5. The features of the claims Di are given by the transfer matrices Wi. The transfer matrices differ from each other in exponent m and n with basic units Lm and Tn where m and n are integers.

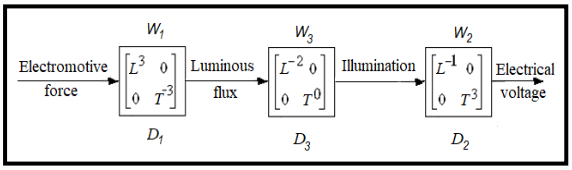

Fig. 5. Graph of the dimensional simulation of the prototype

Let's determine the resource intensity RI of the transfer matrices forming the nodes of the graph for dimensional simulation

$$RI_i = \sqrt{m^2 + n^2} \quad \text{for } W_i = \begin{bmatrix} L^m & 0 \\ 0 & T^n \end{bmatrix},$$

$$RI_1 = \sqrt{(3)^2 + (-3)^2} = 4.24,$$

$$RI_2 = \sqrt{(-1)^2 + (3)^2} = 3.16,$$

$$RI_3 = \sqrt{(-2)^2 + (0)^2} = 2.0 \quad (7)$$

The total intensity of the prototype is equal to

$$RI_o = \sum_{i=1}^{3} RI_i = 9.40. \quad (8)$$

From a physical point of view, the resource intensity of the node Wi means the time and space resources spent on converting the input value into the output value. If a block (or node) spends little resources on conversion, the more it is ideal. The ideal end result (IER) is obtained without spending resources. Therefore, the resource intensity RI is zero for an ideal end result. Space and time are the most important resources for resolving contradictions in the algorithm for solving inventive problems. They define the operational zone and the operational time of the conflict. All other resources, such as weight, speed, pressure, electrical voltage, temperature, and others, can be obtained from the resources of time and space using dimensional theory. The technology of obtaining dimensions for resources is considered in the work (Bushuev A. 2017). The work is based on the system of kinematic quantities by Bartini (2005).

Let's imagine the Su-field F1→S1→F2 of the radiation source as a physical effect to simulate the distinctive feature D4. This physical effect converts the electromotive force EMF at the input into a luminous flux Φ and the wavelength λ at the output. Litvinov et al (2022) consider the stimulation of multidimensional physical effects. In our example, a physical effect with two outputs has two transfer matrices for dimensional simulation. The first matrix W1 is already defined for the prototype in Eq. (4). Similarly, we define the second transfer matrix W41 for feature D4:

$$W_{41} = \lambda\, EMF^{-1} = \begin{bmatrix} L^1 & 0 \\ 0 & T^0 \end{bmatrix} \begin{bmatrix} L^2 & 0 \\ 0 & T^{-2} \end{bmatrix}^{-1} = \begin{bmatrix} L^{-1} & 0 \\ 0 & T^2 \end{bmatrix} \quad (9)$$

where λ is the dimensional matrix of the wavelength. Note that the specific value of the wavelength λ = 800 nm is not simulated. The feature of a monochromatic light source is simulated here only. Taking into account the numerical values of the parameters of the blocks and inputs and outputs is considered in the work (Bushuev et al, 2021).

Thus, the radiation source model contains two matrices W1 and W41. The matrix W1 stands in the energy channel Φ, and the matrix W41 stands in the information channel λ. The model of the radiation source is outlined with a blue dashed line in Fig. 6. Since the radiation source is monochromatic, the photodetector must receive radiation of the same wavelength. Therefore, the sensing element of the photodetector must have a maximum spectral characteristic at the transmitted wavelength. A physical effect with two inputs has this characteristic. The surface power or illumination E of the photocrystal is the first input. The second input is the wavelength λ of the radiation. The electrical voltage V is the only output of the physical effect. The dimensional model of such a physical effect is outlined with a green dashed line in Fig. 6. Let's define the transfer matrix W42 from the wavelength λ to the electrical voltage V

$$W_{42} = V\lambda^{-1} = \begin{bmatrix} L^2 & 0 \\ 0 & T^{-2} \end{bmatrix} \begin{bmatrix} L^1 & 0 \\ 0 & T^0 \end{bmatrix}^{-1} = \begin{bmatrix} L^1 & 0 \\ 0 & T^{-2} \end{bmatrix} \quad (10)$$

The matrix W43 is a unit matrix that does not change the dimension of the input quantities. The matrix is designed to produce a single photodetector output V. The matrices W41 and W42 simulate the distinctive feature D4, the structure of which is outlined with a red dashed line in Fig. 6.

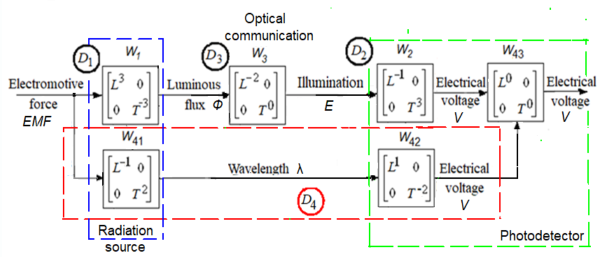

Fig. 6. Dimensional simulation graph for a new solution

Let's determine the resource intensity of the transfer matrices for the distinguishing feature

$$RI_{41} = \sqrt{(-1)^2 + (2)^2} = \sqrt{5}, RI_{42} = \sqrt{(1)^2 + (-2)^2} = \sqrt{5} \quad (12)$$

The total intensity of the distinguishing feature is equal to

$$RI_4 = RI_{41} + RI_{42} = 2\sqrt{5} = 4.47 \quad (13)$$

The total intensity of the new solution is equal to where w_i is the weighting coefficient of the feature i, w_i=α=3 for the highest level of the hierarchy, w_i =β=2 for the middle level of the hierarchy, w_i =γ=1for the lowest level of the hierarchy, The distribution of features by hierarchy levels is shown in Fig. 4.

Then the similarity function for the features from the restrictive part of the claims is equal to

$$f(\{D_o\} \cap \{D_n\}) = \alpha RI_1 + \beta RI_2 + \alpha RI_3 = 3\sqrt{18} + 2\sqrt{10} + 3 \cdot 2 = 25.05.$$

Then the similarity function for the features from the distinctive part of the claims is equal to

$$RI_n = RI_0 + RI_4 = 9.40 + 2\sqrt{5} = 13.87 \quad (14)$$

The resource intensity from equations (7) and (13) will be used to calculate the similarity function f in equation (2). Let the similarity function f of the set of features Di be equal to

$$f(\{D_i\}) = \sum w_i RI_i,$$

$$f(\{D_n\} - \{D_o\}) = \gamma RI_4 = 1 \cdot 4.47 = 4.47.$$

We find the degree of symmetry E of the prototype-new solution pair from Eq. (2)

$$E = \frac{f(\{D_o\} \cap \{D_n\})}{f(\{D_o\} \cap \{D_n\}) + f(\{D_o\} - \{D_n\}) + f(\{D_n\} - \{D_o\})} = \frac{25.05}{25.05 + 4.47} = 0.849 \quad (15)$$

The set $\{D_o\}$-$\{D_n\}$ is empty, since all the features of the prototype are included in the new solution and $f(\{D_o\}$-$\{D_n\}) = 0$. In general, the set $\{D_o\}$-$\{D_n\}$ may be nonempty. Next numerically we find the novelty coefficient

N=1- E= 1- 0.849= 0.151.

The novelty coefficient is in the range $0<N<1$, the greater the N, the greater the novelty of the invention. If the novelty coefficient is N=0, then all the features of the new solution coincide with the features of the prototype. A patent for an invention is not issued. The Ideal End Result (IER) is obtained when N =1. It is impossible to get the IER, since there is always at least one common feature. The name of the invention is a common feature of the prototype and the new solution. The name defines the function of the device. The value of the patent is modeled by novelty, inventive step, and other value determining parameters (Reitzig, 2003). Therefore, numerical estimation of novelty helps to find the value of the patent.

4. Conclusion

Structural simulation based on the patent description of inventions makes it possible to establish a link between TRIZ and patent law. Substance-field analysis of the claims allows you to build models of the operating physical principle of devices. The costs of time and space resources for design are based on the model. The exponents m and n for Lm and Tn show the number of integrators and differentiators in time and space in a dimensional simulation of a dynamic model. The complexity of the model depends on the number of integrators and differentiators. The complexity of the model is numerically equal to the resource intensity. The low resource intensity with a large novelty coefficient corresponds to the high quality of the design. Therefore, it is possible to set the task of designing a graph of the physical operating principle of the device with a minimum length and a maximum novelty coefficient. This problem is partially solved by the example of flowmeters (Litvinov et al, 2021). The optimal synthesis of the physical principle of action based on dimensional simulation is considered in the work (Bushuev et al, 2021).

The considered method can be used to compare different projects of technical systems at the first stage of design. To do this, it is enough to describe the design solution according to the patent rules. The claim includes the most essential features of the physical principle of operation of the device. At the first stage of design, different variants of the operating physical principle of the device are compared.

Simulation of methods of action on material objects is an unsolved problem. The features of the method in the claims are divided into three groups: the presence of actions; sequence of actions; the mode of performing actions, devices, and tools necessary to perform actions. The dynamics of features in claims complicate dimensional modeling. For example, there is such a feature as steel heats up at a rate of 100 degrees Celsius per minute in the claims. The dimension of the heating rate in the Bartini system is L5 T-5. Hence, we can find the transfer matrix for this action. However, the numerical value of 100 degrees is not described in dimensional simulation.

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