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Conceptual Foredesign of Functional Systems

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Abstract

Today's fast-developing world requires a special method to the evaluation of future events. Conventional expert approaches often do not allow to obtain an acceptable result, since they use linear techniques that do not take into account the emergence of new technologies.
For this purpose, in contemporary TRIZ there is a section that includes the trends of functional systems evolution. But the existing ways to work with trends, unfortunately, are not sufficiently algorithmized. So, it is necessary to rely either on intuition, or on passing through all conceivable options of changes. This makes it very difficult to evaluate ideas, and can lead to the fact that some of the ideas will be missed.
In the paper a systematic algorithm for conceptual foredesign of functional systems is offered. The algorithm is based on:

(1) conceptual modeling of real objects as functional systems;
(2) triple analysis of the models with decomposition of form, structure and functions;
(3) life cycle analysis of considered systems and evolutionary cycle analysis of systems as classes;
(4) analysis of functional super-systems and the immediate environment as well as stakeholders.

A visual representation of the structure of key trends of systems evolution and the principle of their application to the modification of functional systems are also considered.
Keywords: conceptual foredesign, evolution trends, forecasting, functional system, S-curve, TRIZ.

1. Introduction

Innovation process in technology advancement requires continuous methodological support. Forecasting is one of the most important areas of such activity. Innovative activity planning is carried out on the basis of forecasts. At that, results of such forecasts should be sufficiently stable for systems of any type.

Attempts are repeatedly made to predict the future in different areas of the national economy. An example of one of such early predictions is presented in the work by Thomson (1955). There are various forecasting methods in the main areas of human activity. All these methods are aggregated in such discipline as prognostics, and they can be divided into two large groups: (1) regulatory and (2) research or pioneering methods.

Regulatory forecasting is rather the projection activity based on the existing technologies. Research forecasting can be divided into the following types:

- expert approach (e.g. Delphi method);
- assessment of future events through extrapolation of the existing technology development trends – this approach is, in fact, continuation of the regulatory forecasting and implies that the current development trends of any system will continue in the future;
- group sessions on compilation of the development roadmaps through brainstorming (foresight techniques).

But, in general, they all rely on knowledge and intuition of the experts or on insights of the brainstorming participants. Lack of scientific approach leads to situations when trivial ideas are most often accepted while promising original ideas can be discarded. A forecast based on extrapolations of the obvious trends can produce relevant results only at short-time intervals and does not account for fundamental transitions in the system development leading to breakthrough innovations.

Moreover, forecasts are more typical for random events which laws of variation we do not know (yet). This may be, for instance, natural or even social phenomena. When it comes to technical systems or enterprises, controllability is rather high here which means that it is possible to directly design the future generations' systems. Foredesign is aimed at solving this problem by minimizing risks of linear forecasts.

Foredesign, though related to forecasting, is based on TRIZ methodology, conceptual modeling and trends in functional systems development, which rest on laws of the dialectics. Therefore, such approach can be used as the basis for designing (not forecasting) future systems.

2. Background

Before proceeding to consideration of algorithm for conceptual foredesign of new functional systems, it is necessary to look into the basic concepts: functional systems (FS), mechanism of FS development – and rules of work with them. These concepts will be briefly presented here with references to the sources describing them in more detail.

(2.1) Target object modeling

One of the objects of study in science of creativity and contemporary TRIZ is reality objects. The subject here will be functional systems, rules of their construction and transformation as well as mechanisms of their development. Another object is individuals. Here the subject of study will be productive thinking with rules of its development and application. Schematically it can be represented as follows (**Fig. 1**).

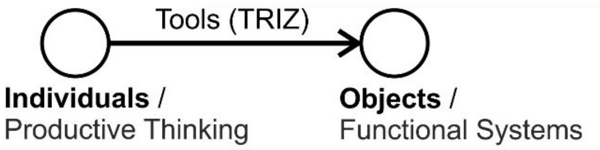

Fig. 1 Representation of the main objects and subjects of study in science of creativity and their relationship in the form of algorithmic approach.

Within framework of the proposed algorithm, it is necessary to build functional system architecture (**Fig. 2**) using object modeling at the upper level with selection of the key functional elements (functional subsystems). These elements provide functional flow for implementation of the main useful function.

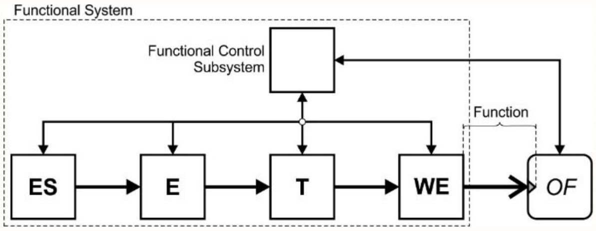

Fig. 2 Architecture of executive level of functional system; *where ES – Energy Source; Converters of Energy: 1st kind – "Engine" (E), 2nd kind – "Transmission" (T); WE – Working Element; OF – Object of Function.*

Object model can be recognized as functional system under the following conditions:

- The system executive level architecture contains efficient elements as energy converters.
- Elements are interconnected and provide for conversion and free flow of energy from energy source (ES), through working element (WE), to object of function (being part of another FS).
- Functional control system is available (external or as subsystem of the target system) – exchanging energy, serving an information carrier, with FS elements and with function object. When designing the system, it is sufficient to ensure minimal controllability – with possibility of turning the energy flow on and off.

Modeling allows to cope with complexity that arises when considering the target object, and, in the future, to achieve better situation understanding with analytical tools. Modeling objects as functional systems and other important definitions were proposed in the author's previous work (Smirnov, 2018).

Besides, element-functional model of the object (see **Fig. 2**) is universal – specialists in any sector of the national economy can use it in practice.

Below, emphasis will be placed on trends of functional systems evolution and methodological tools for their application through productive (creative) thinking.

(2.2) Trends of functional systems evolution and its structure

What trends does evolution of functional systems follow? Both the first trends and machine structure version (analogue to FS) were proposed by Marx (1906 [1867]). Marx described the following trends: mechanization, development of energy source, increased number of working elements; and he wrote about the machine structure: "All fully developed machinery consists of three essentially different parts, the motor mechanism, the transmitting mechanism, and finally the tool or working machine".

In the framework of classical TRIZ these trends were broaden based on patent analysis and available technical solutions (Altshuller, 1979). Many variations of these trends exist today, though mainly in the form of disconnected "lines", for instance, in the works (Altshuller et al., 1989, Mann, 2003, Shpakovsky, 2006). Such representation does not give new quality.

However, unique relationships and regularities in the trend application sequence can also be highlighted. For example, to increase system controllability, engineers are to prepare it for this stage: it is necessary to add transmission (executive level deployment), increase dynamization of the existing links, match new elements with those already present in the system, etc.

Thus, it is possible to determine approximate time intervals of trend application start within evolutionary cycle of classes of systems which will allow to more accurately determine systems development potential. It is most convenient to make such representation on S-curve distributing – very approximately – available basic trends of functional systems development by evolutionary stages. This will allow engineer to see the priority sequence of their implementation. All trends have many sub-trends – mechanisms to support their implementation.

The S-curve is plotted as relation of value and time (**Fig. 3**), which reflects character of development of functional systems tending to increase value (or degree of ideality). The first version of such approach was published earlier (Smirnov, 2007).

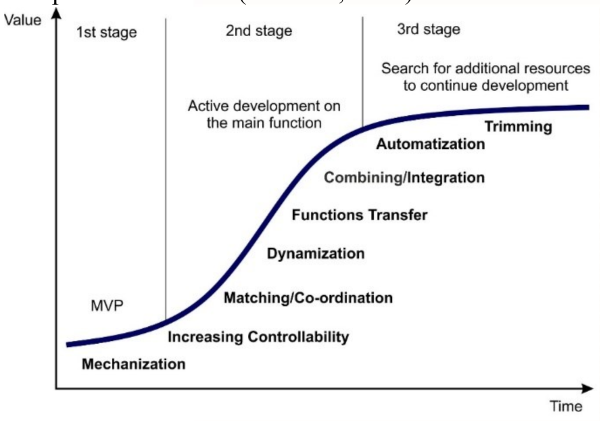

Fig. 3 S-curve with primary trends.

The first stage is characterized by appearance of the system as a class and its formation. It is necessary to ensure stability of the system through presence of all key elements and maintaining their joint work aimed at fulfillment of the system main useful function.

If the system is not yet available and only an individual performs all functions, the system will start with mechanization – introduction of artificial working element (WE). Further, the system deployment (complication) continues at executive level – with human action replacement by technology.

If new system relies on a prototype at birth, then the first evolutionary stage is usually linked to change in operating principle of one of the key functional elements at executive level of the prototype – energy source, engine or working element (revolutionary transition – jump to next S-curve). So, it is necessary to check ratio of "technical" elements and those which functions are performed by an individual.

Functional deployment results in necessity to increase controllability and to check matching of new elements with the existing structure and supersystem conditions. This can be done in various ways, for example, through dynamization of basic entities: elements and functions.

By end of the second stage, time for automatization comes – deployment at control level. Qualitative transition starts – to increased controllability through human action substitution by technology at this level. Decision-making function is also transferred to automatic machinery.

The third stage is usually associated with more active interaction of the system and its environment. In particular, at this stage combining of systems takes place, also named "transition to the supersystem". But if the supersystem is already defined, then the system belongs to it, anyway – that is, being its element or subsystem. Then, what does this "transition" mean in this case?

To interpret these principles more accurately the following division makes sense: (1) transferring the functions up a level to the supersystem (for example, when instead of teaspoon, sugar cubes in tea are mixed by mechanism built into the mug); (2) combining systems that are not in hierarchical relationship with each other (for example, fork and spoon can be combined – these are the same level objects) with partial trimming; (3) integration with promising systems being at the first stage, which makes it possible to obtain new resources for further development (for example, conventional glasses with addition of face recognition function).

Active development of functional systems (steep part of S-curve) leads to increase of number of components (complication) and to accumulation of errors, which can be corrected with the use of special tools: functional-ideal modeling and trimming. Also, development process is uneven for different FS elements. At initial stage more attention is paid to WE, which leads to its advancing development. After that, efforts and resources are transferred to pull up remaining elements. But how is it possible to use such approach in the context of improving functional systems?

(2.3) Applying trends to functional systems

Based on the above, option of direct application of trends to system elements is obvious. Shpakovsky (2006) proposed similar technique, but in his work there is no tools to justify choice of trends and there is no procedure for its application. In addition, direct use of combinatorics can lead to huge number of transformation options, which will make it difficult to evaluate them and choose the most promising ways to improve functional systems.

Reason for lack of such tools is that functional structure of the systems, although available, is not used in practice to the full because functional approach was not sufficiently developed within the framework of classical TRIZ. Direct use of well-known trends in relation to the technical system main parts is presented in the work 'Trends and patterns ...' (Leon, N, 2006). However, functional approach is not used here, as in many other works, and there is no procedure for working with the table. All this leads to situation when this topic, though important, lacks for further development in practice.

Nevertheless, when using system-functional approach, it is possible to build effective morphological table. It is proposed to use simplified combination: to apply the primary trends (see **Fig. 3**) for the main entities of the target object model – FS (see **Fig. 2**). Scenario of combining FS architecture and the primary trends is shown in **Fig. 4**.

		ES		E		T		WE		OF
	in/F	El/OP	F	El/OP	F	El/OP	F	El/OP	MF/out	El
Mechanization										
Controllability										
Matching										
Dynamization										
Functions Transfer										
Combining										
Automatization										
Trimming										

Fig. 4 Selection table for FS development strategies; *where F – Function; MF – Main Function; El – Element; OP – Operating Principle.*

Practical application of the presented morphology is possible after functional system analysis described below.

3. Algorithm for Conceptual Foredesign of Next Generation Functional Systems

Proposed morphology (see **Fig. 4**) is the final stage of triple (value) analysis, element-functional analysis and FS evolutionary analysis.

This algorithm can be used to achieve the following goals:

- for "pure synthesis", in the absence of a direct prototype;
- for designing system modifications – for different operating conditions and different needs;
- for designing new generation systems – this option is also named "forecasting".

Step 1. Selecting object for consideration

First, it is necessary to set boundaries for situation consideration, since initially only target is available in the form of general description of inconvenience or desire to do something with object under consideration.

If it is entrepreneur who formulates the target, then it can be something like this: it is possible to make bottle caps of any shape, but it is necessary to beat competition and surpass similar products in key product features (KPF) ensuring high product value for consumers.

It is assumed that the prototype is selected. On the one hand, existing solutions cause a number of psychological barriers associated with action of mental inertia of thinking according to the following features (habitual): form, function, operating principle, terms (names), sequence of operations, etc. All this complicates transition to new product versions.

On the other hand, prototypes are triggers of a kind for our thinking that allow thoughts to push off from them and go further. Not coincidentally, progress is incremental, step-by-step: the more objects been created world over, the newer objects (products) can be obtained. For this, it is only necessary to learn to cope with factors that are on the "first hand".

If, for any reason, there is no prototype, it is possible to either choose the most effective alternative system by the key feature or to build the most general element-functional model of the object and the main external interactions based on required system functions.

Step 2. Object modeling and analysis

To start with work on achieving one of the three goals described above – improvement of selected object or synthesis of new one – it is necessary to make model of this object in FS form (see **Fig. 2**), components of which ensure realization of the main useful function at usage stage of the life cycle. If necessary, it is possible to consider other stages of the life cycle of certain system starting with production.

When disadvantages are identified, element-functional models of conflicts will be made, and tools to eliminate these conflicts will be selected (see Step 3 below).

When system is complex, triple (value) analysis is required which will allow to better understand the made object model and to localize conflicts.

If there are many conflicts or there is time-or-space coextensive process, it makes sense to carry out cause-effect analysis and/or flow analysis. This will not only reveal all conflicts but also identify the key ones.

Further, it is possible to formulate problem in more functional terms, for example: it is necessary to develop special cap containing vitamin powder for standard bottle ensuring vitamin easy migration to still drinking water contained in the bottle.

Step 3. Revealed conflict analysis

During model analysis new conflicts may be found out. It is necessary to localize such conflicts and to build element-functional model for each of them (Smirnov, 2016) with further model analysis.

In case of contradiction of conditions, it is necessary to switch, for instance, to ARIZ-85C, which will, recommend solving the so-called “mini-problem”. This is relevant if there are constraints or resources are insufficient, and new functional system has to remain within bounds of the previous operating principle. The maxi-problem will be connected with change of the condition in contradiction of conditions.

Step 4. Identification of external functional relations

Here, relationships with other systems and nonsystematic external factors should be taken into account. For this, it is necessary to select stages of the system life cycle on which attention will be focused.

(4.1) Selection of supersystems

The main process, in which the system participates at usage stage, is selected. Such process will play role of functional supersystem for the first system. Another device, integrating the considered system, can also play supersystem role. For example, for vitamin drink, morning run in park can be the supersystem.

(4.2) Building system hierarchies

Functional elements of the improved system (Step 2) will act as subsystems, and the processes or devices highlighted in Step 4.1 will act as the nearest supersystems. All together, they form system hierarchy (or vertical) for given function.

When several life-cycle stages are considered, it is also possible to build system operator of life-cycle (SO.LC). Unlike system operator of evolutionary cycle (SO.EC), which will be built below, this structure relates to certain system and reflects the path that the product travels from production to disposal or recycling.

(4.3) System hierarchies analysis

For each stage of life cycle the system will have its own functional supersystem. This gives additional understanding of the system, its role in various processes and new ideas. For example, ideas that vitamins can be in other (besides powder) forms – they can be not in the cap only, but also in user pocket or glued to the bottle, etc. Is it possible to change supermarket shelf – to make it functional, customized for product type displayed on it? Then the shelf itself will activate the vitamin drink for buyer.

System operator also helps to evaluate the following:

- functional interest of stakeholders and their position in relation to the system;
- remaining external relations, including non-obvious ones, through functional driven search;
- available and possible drivers (requests, needs, market and technology trends) and constraints "from below" and "from above" (**Fig. 5**).

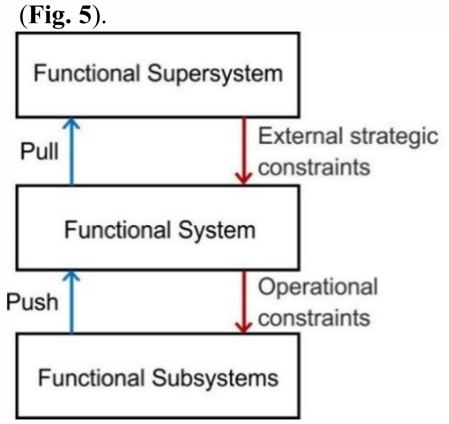

Fig. 5 System hierarchy with evaluation of drivers and constraints.

Pull “from above”: it is necessary to evaluate the supersystem request (motivation) for the system change and to search for resources required for implementation of these changes and support of system development. External strategic constraints: it is necessary to verify prohibitions or barriers for manufacture, distribution or usage of the product. Push “from below”: what stimulates product market launch if there is no direct demand for it? Operational constraints: what are technological challenges for manufacturing new system?

Thus, demand (supersystem requirements) “pulls” the functional system into high-value area. The system built-in capabilities, including use of new materials, new operating principle and other trends – “push” the system to the same area of increased value. In contrast, external and internal constraints hold on these processes (see **Fig. 5**).

Step 5. Evolutionary analysis

Evolutionary analysis is carried out using S-curve by defining ideal representation of functional system as landmark, and applying development trends as guidelines to ideal image.

To evaluate the past experience of system class development, it is necessary to carry out retrospective diagnostic analysis of its evolution. This will allow to estimate development potential of today's system. After that, it is possible to make the most accurate recommendations for designing the next stage system or even the next generation system.

(5.1)Determination of evolutionary stage in system development

Evolutionary stage determination will allow to understand which trends need to be applied first. To do this, it is required to know by what criteria to correlate the system and stages of development.

Stage indicators:

1st stage. There are single working samples, but there is no mass product on the market. End of the first stage can be described as “question mark” or “problem child” according to the BCG matrix.

2nd stage. Active market seizing and introduction to various areas of people's lives. In the second part of this stage the product can be named “star” in case of seizing high share of fast-growing market.

3rd stage. The product holds stable position in low growth market. This is “cash cow”.

4th stage. The product moves into narrow niche or leaves the market being forced out by new generation product. This product is “dog”.

Example. Today drinks with smart caps are exactly at this stage – slipping past the second and third stages they moved to the fourth stage and became a niche product with small market share awaiting the opportune time, that is – resources for more active market entry. There are at least two reasons for this behavior: high cap design costs and market appearance of vitamins, which can retain their quality in water for a long time.

(5.2) Construction of system operator of evolutionary cycle

System operator of evolutionary cycle will rather relate not to a certain system but to a class of systems. Here, for the present time, the system hierarchy will coincide with the system hierarchy for the usage stage (by main function) of the system life cycle (see Step 4).

Construction of system hierarchies for previous generations of the system allows for the first estimated assumptions for further system development. To do this, it is necessary to perform diagnostic analysis of transition from the past system to the present-day system. Further, the same techniques, which stimulated the system development at that time, will be applied. However, the necessary condition for such approach is presence of similar type conflicts in both systems.

(5.3) Selecting landmark in system development

Since it is not always possible to know the system desired future state, it is convenient to build its functional-ideal image right away.

Based on the formula: Value ~ Functionality/Cost, – ideality is achieved by striving value to infinity.

The maximum value for the system can be obtained in several ways by changing the ratio of functionality and costs. For example, this can be achieved through elimination of harmful functions, normalization of inadequate functions, addition of new relevant functions or even through increased manufacturing costs with significantly greater increase in functionality, etc.

It is also convenient to identify ideal representation of the target functional system for each selected stage of the life cycle. This representation will depend on the main functions and results to be obtained at each such stage. For example, the ideal system at transportation stage – with a minimum volume and weight; at stage of “demonstration” on supermarket shelf – with additional functions to attract attention of the target audience; at stage of vitamins activation – with minimal user time needed for learning and implementation; at disposal stage – completely missing bottle and cap.

(5.4) Using guidelines to ideal image

At this step of evolutionary analysis, the system evaluation is envisaged at selected stages of the life cycle by degree of approximation to the ideal images. This can be conveniently done by comparing “path covered” with limit of development according to the primary trends (see **Fig. 3**) for all entities included in the functional system architecture: elements, functions, connections. It is better to perform such evaluation visualizing results with the use of graphs such as Radar Plot, for example.

Trends are sequences of recommended transformations of the above entities in direction of functional systems value (degree of ideality) increasing. Such transformations are easy to perform according to the scheme proposed in **Fig. 4**. Table of choices for FS development strategies can be filled in the following way: (1) to make necessary basic transformations, (2) to evaluate results of transformations and choose strategies for further work, (3) to draw plan of work with selected strategies –

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through formulation of tasks and their distribution between the innovative project participants.

Similar tables, if necessary, can be built for the control subsystem, and, if there are no restrictions in the task conditions – for the FS-“product” on the side of the function object, which plays the working element role in the system architecture.

Step 6. Evaluation of results

Transformations can lead to conflicts with system stakeholders. To eliminate conflicts, it is necessary to use special principles and algorithms in case of single problem functions (Smirnov, 2019), and more complex analysis-synthesis tools in presence of contradiction of conditions (see Step 3).

Influence of changes in the system on different spheres of public life can be examined with special classifications used in foresights, for instance, STEEP or EGETEC.

It is also possible to carry out an inverse analysis, for example, Anticipatory Failure Determination, to check stability of the obtained solutions to various random factors that may be present in the environment where the new system will be after manufacture – this relates to the specific system life cycle.

It remains to perform ranking of the selected concepts by effectiveness and feasibility based on overall situation in the sphere which the system belongs to as well as drivers and constraints available by the moment of decision making (see Step 4.3).

4. Summary

The principle of conceptual modeling of objects, and the algorithm for designing functional systems were introduced. This algorithm is convenient to use as a checklist in a new product development (NPD) process. A brief block diagram of the conceptual foredesign of functional systems is shown in **Fig. 6**.

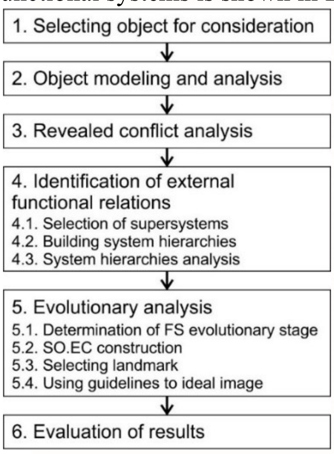

Fig. 6 Algorithm for conceptual foredesign of functional systems block diagram.

The proposed conceptual foredesign of new systems is based on the following theses:

(1) It is necessary to use functional approach in building the system architecture – this makes it possible to use it in practice.
(2) If the structure is fairly complex, it is necessary to use preliminary triple (value) analysis of the system for better understanding and localization of hidden conflicts.
(3) Localized conflicts are to be modeled and resolved by applying special rules to these models.
(4) The systematic analysis shows points of concentration of engineering efforts.

This approach makes it possible:

- to design new systems, which includes predicting emergence of new operating principles;
- to obtain multiple patents and create "patent umbrellas" taking into account all the most promising modifications of future systems;
- to determine enterprise development strategies by creating a powerful vision for change.

5. Conclusions

Element-functional modeling makes it possible to work with objects of any nature, representing them as functional systems of various types: technical, informational, social, organizational, including business-systems, that differ only in the degree of controllability.

To successfully use the tools of contemporary TRIZ, it is necessary to design thinking for creativity (see **Fig. 1**). The educational process didactics is largely responsible for it. To increase the efficiency of thinking to improve both products of companies and companies themselves, in addition to knowledge of tools, it is necessary to take into account factors consistent with the laws of dialectics, which were proposed to describe the mechanisms of nature development (Engels, F., 1940 [1878]): psychological readiness for groundbreaking [the law of the negation of the negation]; ability to work with contradictions [the law of the interpenetration of opposites]; need to evaluate the magnitude of any changes and the possibility of breakthrough innovations [the law of the transformation of quantity into quality and vice versa].

This study has introduced a tool for new product development based on contemporary TRIZ methodology that is holistic, although not easy to use.

But this approach will allow companies to create new products without missing any key solutions.

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