The Trend of Functionality Evolution

Valeri Souchkov

Published in the "*Proceedings of ETRIA TRIZ Future 2013 Conference*", Technical University of Paris, Paris, France, October 29-31, 2013, pp 779-788

Abstract

The paper presents a new addition to the TRIZ Theory of Engineering (Technical) Systems Evolution: the trend which studies how functionality of technical systems changes over time and how these changes affect structure and composition of technical systems. Eighteen steps of functionality evolution are described and each step is illustrated with examples.

Keywords: TRIZ; Trend of Functionality Evolution; Theory of Technical Systems Evolution; Innovation Roadmapping

---

1. Introduction

In his earlier works presenting TRIZ G. Altshuller formulated a system of nine laws of technical systems evolution [1]. Later the laws were called "ZRTS" (Russian abbreviation for "Laws of Technical Systems Evolution") and formed the Theory of Engineering (Technical) Systems Evolution (TESE) which has been developed and extended as a branch of TRIZ since.

TESE studies laws, trends and lines of evolution which demonstrate generic patterns governing specific evolution steps for various technical systems. A general criterion for such a pattern to become a part of TESE is its domain-independence since TRIZ studies target at creating a domain-independent system of methods and tools to support innovation. Currently several modifications of the original system of TESE are known [2-7]. While still preserving the original nine laws formulated by Altshuller, these modified versions add new laws, trends, and lines of evolution or refine the existing ones.

The Trend of Functionality Evolution presented in the paper has been formulated and explored by the author on the basis of studies and practical experience. This particular trend studies evolution of a system's functionality over time and focuses on presenting general patterns of functions emergence, development and disappearance during evolution. The trend is based on the definition of function introduced in Function Analysis [8] which considers a function to be an action between two objects (or systems) that produces a certain effect. In addition, we make a link between a function and an operational principle upon the basis of which the function is delivered.

Merriam-Webster Dictionary defines functionality as "the quality of having a practical use: the quality of being functional" [9]. A technical system can be described by its functionalities which represent a multitude of functions produced by the system's parts (subsystems) to enable functioning of the entire system. Types of these functions can be categorized in different ways but from the TRIZ point of view we can distinguish between three top categories of functionalities:

- *internal system functionalities* which exist between the subsystems inside the system,
- *external system functionalities* which interact with a supersystem or environment in which the system exists,
- *supersystem functionalities* which are created to help the system to deliver its internal and external functionalities.

In any more or less complex system its subsystems can be regarded as independent systems for which the other parts of the system they interact with become their supersystem. What we call a system depends on boundaries defined in each particular case.

The meaning of a function is defined by what a system as a whole or any its part does with respect to another system. In most cases a purpose of a function is to provide change of a certain attribute of another component or a system, for example to change temperature of an object. In other cases a purpose of a function can be to either prevent an attribute from change (e.g. to prevent temperature of the object from change), or transmit information, or provide some intangible action.

In the next section the phases of the Trend of Functionality Evolution are presented.

2. Phases of Functionality Evolution

2.1. Step 1: Creation of a Technology-Originating System (TOS) delivering a new main useful function.

A technical system is created to serve a certain purpose which, in turn is realized through the so-called Main Useful Function of the technical system. Appearance of a system which delivers a specific function which has never been delivered before on the basis of selected physical means results from the highest-level invention, which is usually a pioneering or disruptive invention launching a new technology (the difference between a pioneering and a disruptive innovation from the TRIZ view point is explained in detail in [10]). In turn, the Main Useful Function targets at providing the best fulfillment of major features which represent core values of a technical system. For example, the first phonograph device which used a wax cylinder to record sound invented by Thomas Edison originated the entire technology of sound recording which went over hundred of years of evolution and included a number of disruptive innovations: vinyl recording, magnetic recording, digital recording.

Although any later invention which made sound recording possible but used a radically different basic operational principle can as well be regarded as pioneering, it is better to use the term "disruptive innovation" rather than "pioneering invention" since it does not start but only continues evolution of the entire technology. We therefore call invention a "Technology Originating System" (TOS). Not too many technical systems can be considered as originating entire new technologies.

From that point of view invention of a bicycle which we will be using throughout the rest of this article can probably not be called really pioneering since the function of personal transportation had already been executed by earlier technical systems – for example, by a cart with two or more wheels driven by other men or a horse. However the first bicycle made it possible to travel without help of external force and therefore it was both radical and disruptive innovation thus it can be called TOS.

Although some ideas of a bicycle can be found in sketches by Leonardo da Vinci and his students, the first working bicycle known as "Hobby Horse" was invented in 1817 by Baron von Drais [11]. The machine included a frame, two wheels, a steering wheel, a saddle, and was made entirely of wood. The first bicycle did not have pedals and was moved by a rider using his feet to push on ground. However it was the first technology originating system which included the lowest number of subsystems to implement the main function of transporting the rider by using the operational principle of utilizing muscular force of his legs.

2.2. Step 2: Emergence of primary interface functions.

As follows from the TRIZ Law of Technical System Completeness, a technical system can only provide value if it interacts with its supersystem. There are three key types of supersystem components: energy source, a product which is processed by the technical system, and someone or something that controls the technical system.

Depending on a situation, interface functions can be delivered by already existing subsystems within TOS which are responsible for producing the Main Useful Function and often emerge together with it. For instance, a handle of a hammer provides two functions: to connect to the energy source which is a person's hand and to control movement of the hammer's head.

By definition, a technical system always needs external energy to perform operations with its product. There must be at least one subsystem in a TOS that enables connection to the energy source so the TOS can operate. For example, a washing machine needs a subsystem which connects the machine to the external power socket.

Second important type of primary interface function is provided by a working unit of the TOS. The working unit of a bicycle is wheels since they interact with ground.

The third type of interface function is a function of control over the subsystem(s) delivering the main useful function which in case of the bicycle is delivered by a handlebar.

In case of a fully automated technical system the interface functionality of control is needed to organize interaction with supersystem. For example, a fully automated driverless car still must be able to locate other cars and obstacles on a road to avoid collisions and connect to a satellite navigation system.

It is obvious that during further evolution all the subsystems delivering interface functions can change and grow their complexity thus introducing their own new subsystems and extending their functionalities [12].

2.3. Step 3: Emergence of primary auxiliary functions which bring the main useful function delivery to the required performance level, correct and prevent failures of the main useful function delivery.

Once it has been proven that the main useful function can be physically implemented, the next phase of functionality evolution starts. As a rule, the first working prototype might provide insufficient performance, can be bulky or unreliable; it can fail or create dangerous situations, and so forth. Since that moment some of its subsystems are upgraded or new subsystems are added which deliver auxiliary functionality supporting and servicing the delivery of the main useful function, prevent failures, correct errors, and ensuring that the main function is delivered without any fail and with the required performance.

Regarding the bicycle such new subsystems were pedals which made it possible to increase and stabilize the speed of the bicycle. The first pedals rotated the front wheel. Later, a transmission subsystem was added which enabled the back wheel rotation. In the modern bicycles transmission is rather complex and enables switching between different riding modes.

2.4. Step 4: Emergence of direct secondary auxiliary functions related to usability, ergonomics, convenience, control, utilization, etc.

Once a working prototype has evolved to a reliable and robust system, the next step of functionality evolution consists in emergence of functions that make the use of the TOS easier, increase the degree of operational comfort, and so forth. These new functions might be not directly influencing parameters describing the main useful function of TOS but improve ergonomics, usability and control.

In the bicycle, rubber was added to metal wheels to improve smoothness of ride; plastic handles were placed on the bicycle’s handlebars to improve grip, the pedals were made rotating to increase convenience of a ride, a bell and a headlight were added; braking with pedals was replaced by handbrakes. Functions delivered by these subsystems are not really essential for delivering of the main bicycle’s useful function but increase control, make the ride easier and help with preventing accidents.

In another example ultrasonic measurement of a distance between a car and an obstacle during parking might probably be not needed for an experienced driver while it helps to park a car by an inexperienced driver. In this example a secondary auxiliary function of providing a sound beep when the car is too close to the obstacle improves the control over the car and brings additional value to avoid an accident and damage to the car and property around the car.

We call this kind of functions secondary auxiliary functions. The word “secondary” does not mean that these functions should be neglected. Rather often, especially under conditions of strong market competition they can provide considerable advantages.

2.5. Step 5: Appearance of other systems in the TOS environment which provide supersystem functions to maintain and extend the functionality of TOS.

At this stage TOS usually does not change. New functionality is acquired due to the emergence of new systems within the supersystem of TOS which enhance, serve or improve the use of TOS but remain independent. Among the functions delivered by such external systems are the following:

- Supersystem functions which maintain the existing TOS functionality.
- Supersystem functions which improve the existing TOS functionality.
- Supersystem functions which add new TOS functionality.

For example, an air pump for inflating a bicycle tire is not a bicycle’s component but an essential tool without which the main useful function of a modern bicycle may not be delivered, and therefore the pump belongs to the category of external systems that maintain the existing bicycle functionality. A rear-mounted bicycle transport system designed to attach to a car helps to deliver and use bicycles in remote locations.

An example in the second category is a new tire made of advanced material which can be purchased separately and replace the existing tire. The function of the tire still remains the same but the new tire can provide a better grip and a longer lifespan.

The external systems in the third category add new functions, for example, a bicycle computer can be installed on the steering wheel to measure speed and distance travelled. In addition, these systems can indirectly influence the functionality of main system. For example, a bicycle lock provides safety of the bicycle which is not a built-in function of a bicycle.

2.6. Step 6: Emergence of additional functions.

Additional functions do neither directly relate to the delivery of the main useful function of TOS nor to any auxiliary functions but they can add value within a specific context of the use of TOS. Sometimes the additional functions can indirectly influence the performance of TOS. For instance, a car radio or a blue-ray player provide entertainment during ride both for passengers and a driver.

In a bicycle, a children seat might be installed to ride a child.

In general, emergence of additional functionalities is more typical for consumer products rather than to industrial equipment.

2.7. Step 7: Emergence of secondary interface functions which provide connectivity of additional functions with supersystem.

Secondary interface functions are different from primary interface functions since they do not directly affect main purpose of TOS but increase the convenience of the TOS use and enable connecting to supersystem functions.

These functionalities are well known in computer hardware industry where a PC has various ports enabling connecting the PC to various periphery devices like printers, scanners, USB drives, and so forth.

Modern bicycles as well include a number of subsystems which provide such extra functionality. For instance, rear and front racks can hold cargo, bottle rack is designed to hold a water bottle.

2.8. Step 8: Integration of supersystem functions to TOS.

Sometimes if an external system that delivers a supersystem's functionality proves its value, a TOS might incorporate it as its own function and the external system can become a subsystem of the TOS. For example, a headlight first had started to sell as an external system supplied independently but later the bicycle manufacturers integrated it to the TOS.

Another well known case is a satellite navigation system. In the past cars and navigational systems were separated, but today many cars are produced with built-in navigation systems. Similarly, an independent camera flash became the subsystem of a camera.

2.9. Step 9: Emergence of TOS variations to function within different application contexts.

Usually till this phase there are just a few versions of the basic TOS design to enable its use either universally or within a single narrow application context where the TOS is demanded most. At this phase new designs of TOS are created to enable it to work with different types of products. The result is emergence of different modifications of the TOS with the same main useful function but adapted to operate with a variety of products or under different conditions.

For example, a bicycle originally was designed to be used universally, but later different innovative designs were created such as bicycles for riding on different types of roads or on rough surfaces ("mountain bicycle").

Meeting diverse customer demands might lead to considerable redesign of TOS. For example the third wheel was added to provide stability of riding for children or elderly people. Another example is a folding bicycle which can be easily and quickly folded and unfolded to be taken to train or placed in a car's trunk. Each of these niche-targeted systems further evolved in its own way.

It is important to note that the basic operational principle in all the examples still remains the same.

2.10. Step 10: Evolution of supersystem functions which provide TOS lifecycle and expand TOS functionalities.

At this phase external systems which add value to the functionality of a TOS and its modifications emerged at the previous step might start evolving. Evolution of their functionality can follow the Functionality Evolution Trend independently of the evolution of the TOS or its later modifications. In some cases such systems become independent and are adapted to work with other systems. For example, a car navigation system based on GPS can be used by cyclists and hikers as well.

In certain cases, many new external systems are invented around TOS. Market demands can lead to creating entire industries to provide all kinds of external systems which can be used together with different types of TOS. For example, one can find numerous producers of different kinds of bicycle locks, children seats, rack bags, bicycle helmets, bicycle road signs, and so forth.

If we look at the photo cameras industry we will find many systems which are produced by companies which do not manufacture cameras. Such systems are all kinds of supplies, accessories, and so forth. Among these are memory cards, batteries, filters, lens. Some of these external systems might not be directly related to adding value to the main useful function of a camera but provide functions which increase lifespan of a camera, for instance, a camera bag.

2.11. Step 11: Adaptation to Changing Conditions.

Continuous evolution of TOS supersystem often results in change of demands and requirements for the TOS. Till a certain moment TOS provides functionalities to satisfy a number of specific main parameters of value. At a certain moment these parameters can change. In the 1970th bicycles in big cities were used primarily for leisure activities outside city centers while today they are used to commute between homes and offices even in large city centers. Such a change of value parameters requires reconsidering priorities in the designs of bicycles and adaptation of their subsystems and their functionalities to new requirements. Primary efforts are placed on changing those functionalities of a system which provide the best fulfillment of its main useful function under new requirements. For example, a modern city bicycle has to be small, lightweight to be carried out, safe, resistant to theft, well visible in low lightning conditions.

A similar situation can be observed with city cars. If in the 1970th consumers were willing to invest to bigger and more powerful cars, while currently much attention is paid to economics and compactness of the cars due to smaller parking spaces and dense traffic conditions.

2.12. Step 12: Convolution and trimming of primary and secondary auxiliary functions.

After a particular TOS has reached a level where it delivers top performance, possesses the required degree of quality and provides demanded functionality, certain subsystems which deliver primary and secondary auxiliary functions can be trimmed, or some of their functions can be removed. It is done for a number of reasons:

- to increase robustness of TOS,
- to eliminate harmful functions and reduce harmful effects,
- to lower manufacturing costs and price of TOS,

– to utilize newly emerged advanced technologies by TOS subsystems.

This phase matches the TRIZ Trend of Ideality Increase which suggests that a technical system evolves to minimize mass, dimensions and energy consumption. The functions might not disappear completely but the subsystems which are carriers of these functions might cease to exist. A certain function can be moved to another carrier which already presents in the TOS. For example, a bicycle headlight does not need to have a separate housing since the light source can be directly mounted inside the frontal part of the bicycle frame (head tube). In this case the function of a separate housing "to hold the light source" is transferred to the frame but other functions which were needed to fix the housing disappeared. In general, a number of functions can be removed from a system, as for example in a so-called "bicymple" in which "a direct-drive, freewheeling hub joins the crank arm axis with the rear-wheel axis, shortening the wheelbase and minimizing the design". [13].

2.13. Step 13: Reduction or elimination of supersystem functions.

Often when a TOS changes or replaces certain technologies behind its auxiliary functions to utilize new inventions, the need for certain supersystem components that maintain or expand the functionality of the system and which were introduced at Step 5 becomes obsolete.

Two cases are possible:

- Elimination or reduction of supersystem parts which service and maintain a main useful function.
- Elimination or reduction of supersystem parts which service and maintain auxiliary functionalities.

For example, if a bicycle uses a technology of self-inflating tires or the tires do not need to be refilled with air, the air pump becomes obsolete since it is not demanded any longer.

2.14. Step 14: Convolution of TOS to core functionality.

In certain cases a TOS is expected to deliver just one main useful function but to do it with top performance and lowest costs. In general, during Steps 1-10 the growth of the overall performance of a system causes growth of complexity of its structure, introduction of many heterogeneous subsystems, increase of physical dimensions and energy consumption. It is known as the phase of system expansion in TESE. Steps 12-13 indicate that the system entered the phase of convolution and its further evolution follows the TRIZ Trend of Transition to Microlevel which states that a TOS tends to utilize the latest technological advances and scientific discoveries for its subsystems. Their use helps to develop the TOS which still preserves or even increases the degree of performance of the main useful function while decreasing costs, physical dimensions, and reducing energy consumption.

This step of Functionality Evolution means that every auxiliary function disappears and only core functions are left. At this stage TOS still must provide the performance and other qualities achieved during the previous stages of evolution but by utilizing properties of new advanced materials and technologies.

The bicycle has not reached this stage yet, although some attempts are being made, for example, a "Hubless Zigzain Bicycle Concept" [14] in which the bicycle consists of a simplified frame with wheels rotated by a small driveshaft.

At this stage of evolution TOS might tend to become a so-called "ideal object" but it mostly happens as a result of disruptive innovation (see step 16). An example is the use of a color-changing polymer for temperature indication instead of thermometers based on either mercury or digital indication.

2.15. Step 15: Merging with another TOS to produce two or more main useful functions.

As follows from the TRIZ Trend of Transition to Supersystem different TOS can merge and form bi- or poly-systems. Two or more different TOS combined can deliver the same, similar, different, or opposite main useful functions. Most of the time in such combinations one function is still regarded as dominant so it can be identified as a primary main useful function of the new system.

For example, a bicycle can be equipped with components which turn the bicycle to the exercise machine. The bicycle can be used to ride outside during summer and to exercise at home during winter. Another example is merging a bicycle with a catamaran to create a pedal-power boat.

A well-known example is integration of camera and mobile phone.

2.16. Step 16: Transition to a different basic operation principle of main useful function delivery. Repeating steps 2-15 for a new system based on the new principle.

This step identifies a radical change of a paradigm on which the Main Useful Function is delivered. A disruptive innovation happens at this step. While the Main Useful Function still remains the same, a basic operation principle of delivering the function changes.

An example is a transition to solid state memory drives which currently tend to replace traditional hard drives in computer hardware. Due to replacing the basic operational principle of data storage, all the auxiliary functions which were needed to rotate the hard drive disks, transport a magnetic head, and provide all other mechanical actions disappeared.

For a bicycle such disruptive innovation happened when a gasoline engine replaced muscular force. Before that the Main Useful Function was based on using muscular forces only and used a person as an energy source. Sometimes hybrids emerge which combine old and new principles in the same system similarly to electric bicycle where a rider can switch between manual and electric modes.

Two scenarios are possible after a disruptive innovation has emerged: either the old system completely disappears or both systems continue to exist and evolve.

As a rule, transition to a new operational principle requires change of internal and external functionalities either in full or partially. Partial change is more likely since usually a number of auxiliary and interface functions do not require change. For example, handlebars still deliver the same function both in a traditional and in electric bicycles. However often, a new operational principle requires emergence of new auxiliary and interface functions that did not exist in the old system.

After this step a newly emerged system can start repeating all the steps of functionality evolution 1-15 presented above.

One must note that a disruptive innovation can become a node in a sub-tree presenting further evolution of technical systems through creating a variety of systems adapted for different purposes and markets to utilize advantages provided by the use of the new basic operational principle.

A simplified example of such evolution trees for the main useful function “Water transportation” is shown in Figure 1. Note that each node on the main evolution line creates its own evolution tree, however all sub-nodes are still based on the basic operational principle defined by a node on the central line that starts each tree.

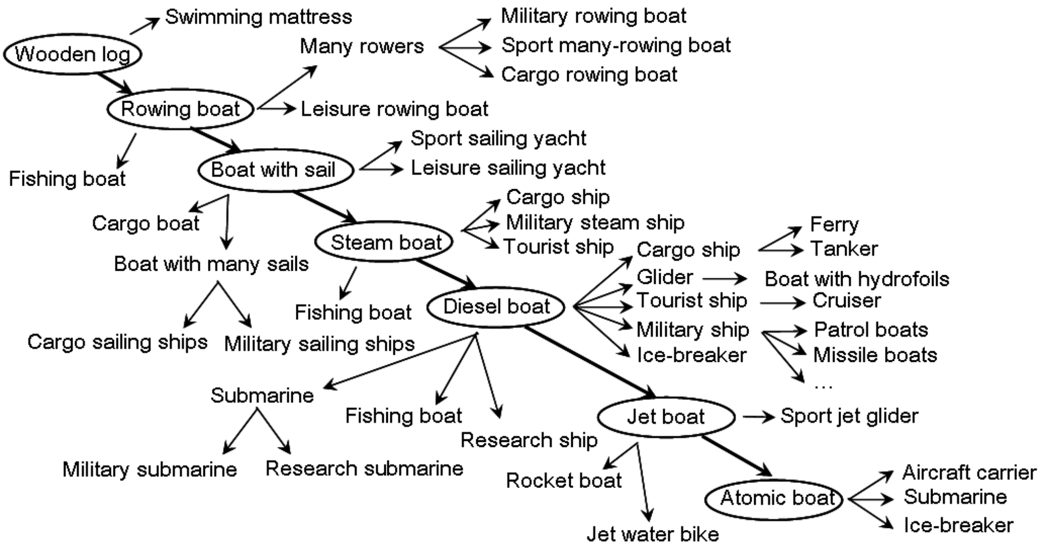

Fig. 1. A simplified model of evolution of water transportation means. Each new TOS is marked by oval.

New systems which result from such change might be called differently. The word "bicycle" is replaced by "scooter" or "motorbike". However it does not always happen. Both analog and digital photographic cameras are still called cameras despite the radical differences of their basic operational principles.

2.17. Step 17: Full transfer of a main useful function to a supersystem. Disappearance of a system.

In certain cases a main useful function of a TOS is transferred to supersystem. It means that the main useful function is still needed but is delivered in a more convenient and economically attractive way by another system and thus there is no need for the system to exist any longer.

For example, digital music players are used to store and play audio files. With emergence of smartphones these two functions were transferred to a smartphone. Although the digital music players still exist, their number tends to reduce. Similarly, there is no need to make GPS navigator as a separate system if it becomes a part of a car's dashboard. The floppy disks and floppy drives disappeared since data is now stored on hard drives and transmitted over the Internet or flash drives.

The bicycle has not fully reached this stage yet.

Step 18: Full elimination of main useful function.

Each TOS is invented to fulfill a certain demand. Further its evolution and evolution of all its further modifications continues as long as the demand remains in force. However there might be a situation when the demand disappears and the main useful function to fulfill the demand becomes therefore obsolete.

There are a number of cases when certain main useful functions completely ceased to exist.

Often a system delivering a certain main useful function disappears because it functions as a servicing and maintaining supersystem for some other system which ceases to exist. For example, disappearance of magnetic tape audio recorders made the main useful function of the cassette which is holding magnetic tape to disappear and therefore the function of holding magnetic tape disappeared completely.

3. Summary and The use of The Trend of Functionality Evolution

Fig. 2 represents the order of steps of the Trend of Functionality evolution presented above and based on correlation with Bell-curve of system structure evolution proposed in [3]. It is important to note that the order of the 18 steps is not obligatory. Some steps can occur earlier and some steps later. For instance, a new TOS based on disruptive innovation can be invented at any time to completely replace the old TOS before the old TOS enters the convolution phase. In general, understanding of the TRIZ Laws and Trends of Technology Evolution provides more accurate roadmapping of future innovations since it reduces risks of failure and helps recognizing new opportunities well in advance.

It is important to note that to increase probability of successful application of the Trend of Functionality Evolution the trend should not be used as a standalone method or tool. Instead, it has to be used in combination with other TRIZ Trends and Laws of Technology Evolution which help to define the current state of the art of a technical system and produce a more exact forecast of its future evolution.

In addition, during several projects it was demonstrated that the same approach to functionality evolution seems to be valid for other type of man-made systems, in particular, for business services and social systems.

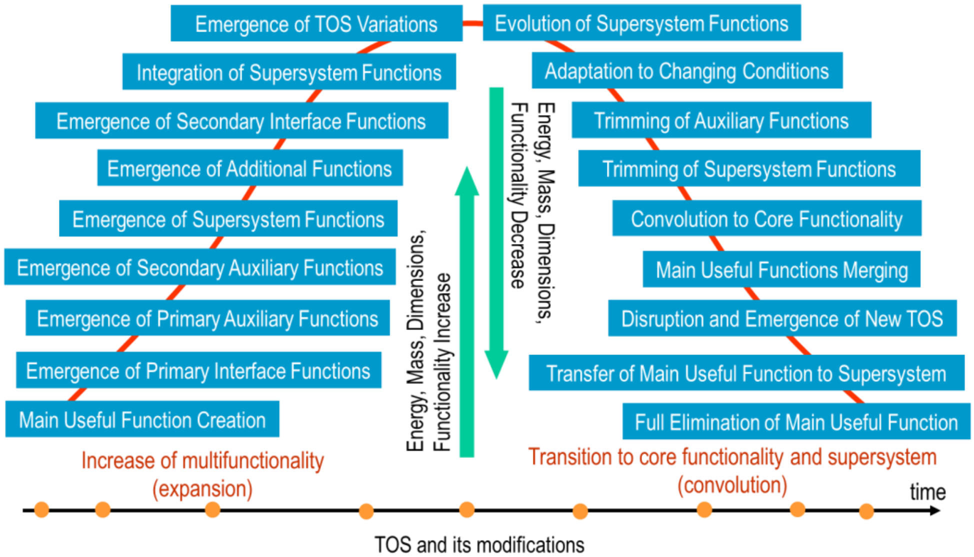

Fig. 2. A general model of the Trend of Functionality Evolution

References

[1] Altshuller G.S., Creativity As an Exact Science: Theory of Inventive Problems Solving, Moscow, Sovetskoye Radio, 1979. (in Russian)

[2] Zlotin B. and Zusman A. Laws of Evolution and Forecasting for Technical Systems, TRIZ Training Materials, Kishinev, 1989 (in Russian)

[3] Salamatov Yu. The System of Laws of Technical Systems Evolution, Petrozavodsk, 1991. (in Russian)

[5] Lubomirskiy A. and Litvin S. Laws of Technical Systems Evolution. Gen3 Partners, 2003. (in Russian)

[6] Mann D. Hands-On Systematic Innovation for Technology and Engineering, IFR Consultants, 2001.

[7] Petrov V. Laws of Systems Evolution, Tel Aviv, 2013 (in Russian).

[8] Litvin S., Feygenson N., and Feygenson O. *Advanced Function Approach*. In: Procedia Engineering 9 (Jan. 2011), pp. 92–102.

[9] http://www.merriam-webster.com/dictionary/functionality, Last seen: May 2013.

[10] Souchkov V. Differentiating Among the Five Levels of Solutions, in The TRIZ Journal, July 2007, http://www.triz-journal.com/archives/2007/07/02/, Last seen: May 2013.

[11] Herlihy D. Bicycle: The History. Yale University Press, 2006

[12] Devoino, I. Unfolding of Technical Systems, Master of TRIZ Dissertation, Minsk, 2009

[13] http://www.bicymple.com/, Last seen: May 2013

[14] http://gizmodo.com/5471462/hubless-zigzain-bicycle-concept-powered-by-simple-driveshaft, Last seen: May 2013