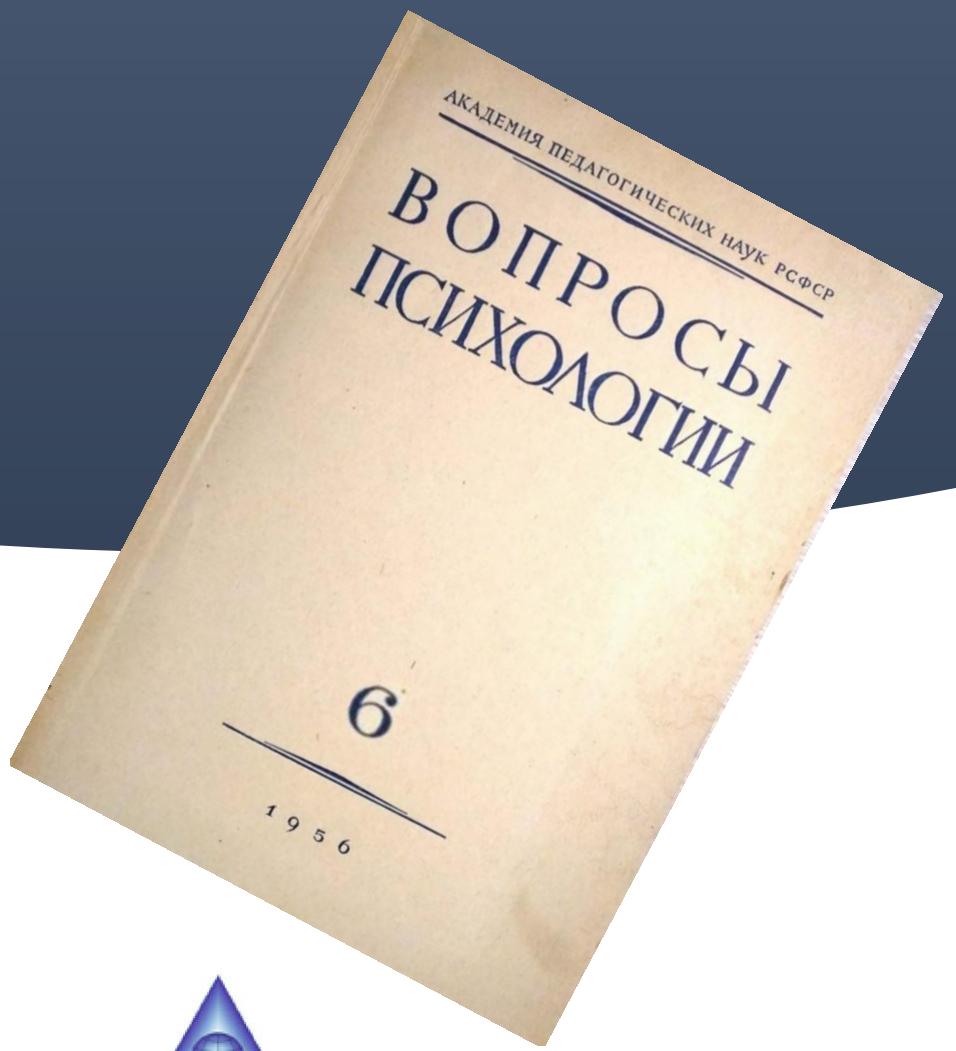


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# TRIZ Review



Journal of the International TRIZ Association – MATRIZ

## **TRIZ Review: Journal of the International TRIZ Association – MATRIZ**

### **Vol 1, #1, February 2019**

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TRIZ Review is an official journal of the International TRIZ Association (MATRIZ) aimed at building an international and multidisciplinary community of TRIZ developers, researchers and users and providing a platform for publishing high quality papers related to the research and development of TRIZ, best practices with TRIZ, cases of practical application of TRIZ, and issues of TRIZ training and education.

All presented papers are double blind peer-reviewed.

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Photo at cover page: The cover page of the magazine “*Voprosy psichologii*” (Issues of Psychology), Academy of Pedagogical Sciences of Russian Federation, Vol. 6, 1956

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[www.matrix.org](http://www.matrix.org)

Dear Colleagues!

The long-awaited moment of the first publication of our new electronic magazine: *TRIZ Review*. Many members of the TRIZ community have repeatedly spoken of the need for such a periodical. Finally, after overcoming a number of difficulties and differences, we have been able to realize these wishes.

Our opening issue reveals the earliest publication of G.S. Altshuller, which was the first step towards public recognition of TRIZ and laid the foundations of the wide dissemination of the recent and challenging theory. The article is followed by the first selection of the most interesting contemporary publications, which demonstrate the current state of the art of TRIZ. In subsequent issues of the magazine, these publications will be continued.

We thank the editorial staff of the magazine for the hard work done by them, and we wish the magazine continued success. We are waiting for your and all TRIZ colleagues' comments and suggestions, as well as your participation in the future work on the magazine.

*Yuri Fedosov*

MATRIZ President, PhD, TRIZ Master

Dear Readers,

It is with great pleasure and pride that we present to you this first issue of *TRIZ Review*: an interdisciplinary peer-reviewed journal published biannually by the International TRIZ Association (MATRIZ). *TRIZ Review* is brought to provide a platform for academics and practitioners to present their research, hypotheses, ideas and overviews as well as to share information about the latest TRIZ advances to the world.

*TRIZ Review* is as relevant to developers as it is to users working in the field of TRIZ and related areas that develop theory, methods, and tools of systematic innovation for engineering, business, education, and so forth. The journal targets at ensuring the highest quality of professional publications related to TRIZ.

In the first issue, we included a collection of papers previously presented at the annual MATRIZ International Conference *TRIZfest*. We intentionally selected those papers which demonstrate various aspects and directions of development of modern TRIZ.

We are also very proud to present the English-language translation of the pioneering paper by G.S. Altshuller and R.B. Shapiro “*The Psychology of Inventive Creativity*” published in the Russian-language academic journal *Issues of Psychology (Voprosy Psichologii)* in 1956. It was the first ever paper which introduced key concepts of an organized and systematic approach to support technical creativity. The paper has never been published before in English. Therefore, we hope you will enjoy discovering presentation of the original ideas which later contributed to the creation of TRIZ: The Theory of Inventive Problem Solving.

We hope *TRIZ Review* will serve as a premiere outlet for ground-breaking and seminal work in the field of TRIZ. *TRIZ Review* plans to publish papers with the following topics:

- Research and development of TRIZ theories and methods;
- Development of TRIZ tools for practical applications;
- Applications of TRIZ in science, engineering, business, and social environments;
- Innovation process with TRIZ;
- TRIZ-based pedagogy, education, and training;
- Case studies with TRIZ;
- Integration of TRIZ with other process, design, and innovation management methodologies.

Papers on systematic creativity, methods for automated inventing and innovation management in the dialog with TRIZ or any other topic related to TRIZ are also invited.

The aim of *TRIZ Review* is building an international and multidisciplinary community of TRIZ developers, researchers and users. Encouraging authors to submit manuscripts in the following issues, we hope that this first issue arouses our readers' interest so that the papers published in *TRIZ Review* may motivate new research, new ideas, new results, and new publications.

If you have any feedback, please do let us know.

*TRIZ Review* Editorial Board

*Dr. Mark Barkan*

*Dr. Sergei Ikovenko*

*Dr. Stéphane Savelli*

*Mr. Valeri Souchkov*

*Dr. Yongwei Sun*

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# THE PSYCHOLOGY OF INVENTIVE CREATIVITY

G.S. Altshuller, R.B. Shapiro

*Original paper was published in “Voprosy psichologii” [Issues of Psychology], No. 6, 1956. pp. 37-49*

An investigation into the human psyche that improves the instruments of labor, has great significance for research and an understanding of the laws of technical creativity, which is the basis of technical progress.

Unfortunately, scholarship has thus far failed to address the evident rift between the enormous significance of technical creativity and the attention accorded it in the field of psychology. Suffice it to say that the only monograph on this issue in Soviet scholarship in psychology is P.M. Jacobson's book dating back to 1934, *The Process of the Creative Work of the Inventor* [7]. Despite the author's dubious initial assumption, due to the lack of any other studies, Jakobson's work has had, and continues to exert, a serious impact on how issues related to the psychology of technical creativity are presented in general psychology courses, monographs on the organization of the work of scientific workers, and, finally, in popular science literature.

The work is based on D. Rosman's formal chronological system for classifying the stages of the creative process [8].

Rather than exploring the internal laws of the creative work of the inventor, D. Rosman and P.M. Jakobson equated such different psychological processes as the stage of searching for a solution and the stage of designing the invention. This results from the fact that neither Rosman, nor Jakobson uncovered the special features of technical creativity in general, and inventive creativity in particular. The fundamental issues of the psychology of inventive creativity remained unresolved, and, rather than studying them, the authors based their research on such general scientific matters as “insight,” “breakthrough,” “guessing,” “conception,” “gestation,” etc. The corresponding sections of the monograph by K.G. Vobliy, *The Organization of the Work of the Scientist*, were written from the very same false stance. According to Vobliy, “*In the initial stage of the creative process one can distinguish between the stages of preparation, gestation, ripening, and breakthrough. In the daily train of thoughts, these stages often overlap.*” [2; 123-124] Of interest is that this “analysis” is by no means a step forward in comparison with T Ribot's statement made more than 50 years ago: “*When this hidden work has been fulfilled to a sufficient degree, the idea behind a solution suddenly appears, resulting from a willful mental tension or a certain cerebral observation, as if a veil has been lifted, behind which was hidden the image of the proposed solution.*” [5; 228]

These views are based on the theory of "constructive intelligence" advanced by A. Ban, which reduces the entire panoply of processes related to technical creativity to a "mental experiment," which follows the "rule of trial and error." The influence of this theory was manifested even in such a seminal work as S.L. Rubenstein's *Foundations of General Psychology*: “*When the point*

*that requires rationalization, change, the introduction of something new, is found, noted, realized and, as it were, planted in the mind of the inventor, a certain process begins in which a wide variety of observations and all kinds of knowledge that enters his mind are concentrated and tied to this point: All these observations and facts are as if applied to the central point and correlated with the problem occupying the mind of the inventor, and at times a lot of the most unexpected associations sometimes are made in his head.”*[6; 576]

At the same time, for the first time, Rubinstein correctly noted the characteristic features of inventive creativity: “*The specificity of the invention, distinguishing it from other forms of creative intellectual activity, is that it must create something, an actual object, mechanism, or technique that solves a certain problem. This is what determines the originality of the inventor’s creative work: the inventor must introduce something new in the context of reality, in the actual course of some kind of activity. This is something that differs significantly from solving a theoretical problem, in which a limited number of abstract conditions must be considered. At the same time, reality is historically mediated by human activity and technology: embodied in it is the historical development of scientific thought. Therefore, in the process of inventing, one must proceed from the context of a reality which requires the introduction of something new, considering the corresponding scientific context. This determines the general direction and specific character of the various elements in the process of inventing.*” [6; 575].

However, this process is not entirely accurate. Take, for example, the architect, who has to create a “real object,” introduce something new “into the context of reality” and consider the “relevant scientific context”.

Because of this inaccuracy, a very fruitful and valuable thought actually slipped by without notice: In the textbook widely used in schools, thus far they speak only about creativity "in general".

The psychology of creativity is one of the most least developed branches of psychology.

**Creativity** is a complex process, the laws of which are diverse and elusive. But the specific nature of inventive creativity to a certain extent simplifies the task of the researcher. The results of creativity in art depend not only on objective reality, which reflects the work of art, but also on the author’s world view, on his aesthetic ideals, and on many even random factors. Inventive creativity is connected with a shift in technology that develops in accordance with certain laws. The process of creating a new instrument of labor, regardless of the state of mind pertaining to it, is subject to objective laws. Its reflection in art, generally speaking, can largely separate it from reality (for example, in fairy tales, legends, myths). Whatever the technical problem is, it cannot be solved unless it complies with the laws of science and depends on the laws of technological development.

Research on the psychology of inventive creativity cannot be conducted in isolation from research on the basic laws of technological developments. The inventor’s activity is aimed at creating new technological objects, because the inventor is a participant in technological progress. Therefore, the psychology of inventive creativity becomes clear only with a deep knowledge of the laws of technological developments. This, of course, does not mean that the researcher should be engaged only in studying the mechanism of technological progress. The unique nature of the psychology of inventive creativity as a scientific discipline consists of the need to simultaneously consider the objective laws of technological development and subjective, psychological factors. The psychology of inventive creativity first and foremost pertains to the field of psychology. Therefore, the focus is the mental activity of the inventor, the person improving and adding to the technology. The psychology of inventive creativity acts as a bridge

between the subjective world of the human psyche and the objective world of technology, and therefore, regarding research on inventive creativity, it must consider the laws of technological development.

There are two sides to the inventive process: materially substantive and psychological. To identify the materially substantive aspect of an invention, we need to know the history of technological development, as well as understand the basic laws of technological progress. The study of materials on the history of technology, an analysis of specific inventions are one of the most important sources to a psychology of technical creativity.

To identify the psychological patterns of the inventive process, we must systematically observe the process of the creative work carried out by inventors, generalize the experience of innovators, and experimentally study the process of inventive creativity by conducting experiments in conditions as close as possible to the real world.

Work in this direction has been underway since 1948. Numerous materials on the history of technology, and extensive memoirs related to the work of major inventors have been studied. Descriptions of inventions in the Code of Inventions of the Soviet Union, as well as patent literature from abroad, have been systematically examined. We devoted special attention to summarizing the experience of innovators from the foremost enterprises of Soviet industry. We also used the results of our own observations on the creative work carried out by the inventors and efficiency experts in Azerbaijan's petroleum industry. Our findings were subjected to practical tests at two machine-building plants, at the Vano Sturua cracking plant and at the *Leninneft N8* oil-field operations.

In order to truly understand our findings, we must be familiar with the basic laws of technological development. These laws are complex and diverse. Since these laws are outside the scope of this article, we shall limit ourselves to information required for an understanding of the essence of the creative process.

In *Capital*, Karl Marx provided the structural and functional characteristic of a machine:

*“All fully developed machinery consists of three essentially different parts, the motor mechanism, the transmitting mechanism, and finally the tool or working machine. The motor mechanism is that which puts the whole in motion. It either generates its own motive power, like the steam-engine, the caloric engine, the electromagnetic machine, etc., or it receives its impulse from some already existing natural force, like the water-wheel from a head of water, the wind-mill from wind, etc. The transmitting mechanism, composed of fly-wheels, shafting, toothed wheels, pulleys, straps, ropes, bands, pinions, and gearing of the most varied kinds, regulates the motion, changes its form where necessary, as for instance, from linear to circular, and divides and distributes it among the working machines. These two first parts of the whole mechanism are there, solely for putting the working machines in motion, by means of which motion the subject of labor is seized upon and modified as desired.”*

[Translation from *Capital*, 1; Chapter 15, pp 378-379. Translated by Samuel Moore and Edward Aveling, Progress Publishers, Moscow, USSR]

There is a definite correlation between the main components of the machine – the working body, the transmission mechanism (transmission) and the engine, because all these parts are in a close relationship and interact with each other. Biologists have long known a law that Darwin called the law of the ratio of growth: a change in the individual parts of an organic being is always associated with a change in its other parts. This law is an isolated instance of the well-known

position from the Marxist dialectic about the universal interconnection of phenomena. The interdependence of individual components of a machine in the process of its development is another isolated instance in the general law of dialectics.

The fact that there is a relationship between the main components of the machine leads to the fact that the development of one or another part is possible only to a certain limit – until there is a contradiction between the modified part of the machine and the remaining unchanged other parts. For example, even a simple "*increase in the size of the machine, and in the number of its working tools, calls for a more massive mechanism to drive it... In the 17th century attempts had already been made to turn two pairs of millstones with a single water-wheel. But the increased size of the gearing was too much for the water power, which had now become insufficient...*" [1; 382-383] The contradictions that have arisen between the individual parts of the machine act as a brake on overall development, because further improvement to the machine is impossible without making changes to its relevant parts, without a radical improvement in their properties.

Let us consider the basic facts of the history of the bicycle. In 1813, the Austrian forester Drais built a “running machine” – the prototype of a modern bicycle. In Western Europe, the self-propelled carriages designed by the remarkable Russian mechanics L. Shamshurenkov and I.N. Kulibin were not known, and the first bicycles created by Drais lacked something that the carriages of the Russian inventors had: a transmission: you had to push it along with your feet. Without a transmission, a subsequent improvement in the working bodies (wheels) and controls made no sense, and so the bicycle turned out to be a fun toy, but not a means of transportation. Only when pedals mounted on the axle of the front wheel were introduced were there any new opportunities to improve the bicycle. The pedals let riders increase how fast they could go, but with an increase in speed, operating the bicycle became more dangerous, as the controls were inadequate. The invention of brakes (1845) addressed this issue: it was possible to further develop the working body, increasing the diameter of the drive wheel and thereby increasing the distance traveled on the bike with one revolution of the pedals. The diameter of the front wheel increased from year to year: So-called ‘spider bikes’ were created featuring a huge front wheel. Finally, the quantitative path of development exhausted the options: a further increase in the diameter of the front wheel dramatically increased the dangers inherent in cycling. The resulting contradiction was eliminated by changing the transmission by means of a chain transmission, which made it possible to reach a high speed not due to the large diameter of the wheel, rather due to an increase in the number of revolutions. An upgrade in the transmission again paved the way for a development of the tools: In 1890, pneumatics were introduced. The resulting increase in the speed of bicycles led to a new change in the transmission: the use of a free wheel mechanism. That’s how the modern bicycle was created.

Even a cursory outline of its development allows us to draw the following conclusions:

1. The individual elements of the machine, mechanism, process are always in a close relationship.
2. Developments take place by fits and starts: some elements outstrip others in their development, while other developments lag behind.
3. The orderly development of a system (machine, mechanism, process) is possible until the contradictions between the more advanced element and its less advanced parts are manifested and become more acute.
4. This contradiction act as a brake on the overall development of the entire system. The elimination of the contradiction is an invention.

5. A fundamental change in one part of the system necessitates a number of functionally conditioned changes in other parts.

Consequently, every creative solution to a new technical problem — no matter to which field of technology it belongs — includes three main items:

1. The formulation of the problem and the determination of the contradiction standing in the way of the solution to the problem using standard, already well-known technological methods.
2. The elimination of the causes of the contradiction aimed at achieving a new, higher technical effect.
3. Bringing the other elements of the improved system in line with the upgraded element (the system is given a new form corresponding to the new entity).

Along with this, the process of creatively solving a new technological problem usually includes three stages that are different in purpose and method that we conditionally call *analytical*, *operational*, and *synthetic*.

The analytical stage aims at analyzing the development of a given machine, mechanism, process (or, more generally, a branch of technology) to identify the main contradiction at this stage and determine the direct (physical, chemical, etc.) causes of this contradiction. The operational stage is a systematic and expedient, focused study of possible ways to eliminate the cause of the contradiction that has been identified. The synthetic stage is directed at introducing additional changes to the other elements of the system resulting from the method that has been found to eliminate the technical contradiction.

The inventor's creative work begins in the first phase of the analytical stage, i.e. when the problem is selected. Rubinstein's opinion that the inventor must develop a tendency to look closely at what "can be changed, redone, improved" is completely erroneous. It is possible to change and improve all tools and equipment without exception; there is nothing that can't be changed. The goal of the inventor isn't in the mechanical choice of whatever matter he happened to take a look at, but in the creative study of the dynamics of the development of a certain system and in identifying what problem is decisive at this stage, what is it that acts as a brake on overall development.

This is especially typical of Soviet inventiveness, which is associated with planned production. Modern production, especially specialized, is comprised of a series of consistent, interrelated processes. An enterprise's total production capacity is usually limited by one of these processes which acts as a bottleneck for production as a whole. When inventors haphazardly do everything that "can be changed, overhauled, improved," in some parts of the production process an excess in production capacity is created, and this remains untapped because of the "bottleneck" inhibiting overall development.

Of considerable interest is the experience of the inventors and efficiency experts of the *Baku Metal Oil Storage Vessel Plant*. The production process at this plant requires that all of the workshops be coordinated in their operations. Initially, streamlining production was carried out here by each innovator at his production site. At the same time, despite the large number of introduced innovations, the total production capacity at the plant saw virtually no increase. For example, the innovators from the welding department made significant improvements to the design of the automatic welding machines. This allowed a speed increase in the welding process. When the machine was working, a more products were produced per unit of time. And yet

in tandem with this, machine downtime increased because the productivity of the preparatory department remained the same. In this regard, at the beginning of 1948, a systematic survey of the plant was conducted to identify "bottlenecks" that hindered improvements to production as a whole. This made it possible to identify and formulate the most urgent problems requiring an orderly, consistent solution, at which, subsequently, the entire team of inventors and efficiency experts would direct its efforts. As a result, between 1948 and 1955, labor productivity at the plant saw an eight-fold increase.

The second phase of the analytical stage is identifying the main element in a problem. When solving each specific technological problem, one must choose what characteristic (element), what change is both necessary and enough to achieve the desired technical effect in the machine, mechanism, or process.

A classic example of how to correctly identify the main component in a problem is provided by the famous English inventor James Watt in his work creating a better version of the steam engine. Having set for himself the goal of creating such a machine, Watt analyzed in detail all of the characteristics of the steam engines existing at that time. These engines had a number of significant drawbacks: the bulkiness and explosiveness of the boiler plant, the huge heat losses in the cylinder of the engine, flaws in the transmission. Watt correctly identified the main element in the problem: reducing heat losses in the cylinder of the engine and, therefore, increasing the overall efficiency of the machine as a whole. Watt's improvements to this characteristic allowed the creation of a steam engine of a sufficiently high power. Subsequently, Watt set for himself a new challenge: to make the steam engine universal. The power of the cutting-edge steam engine fully met the requirements of the day. And so, the main element now was improving the transmission, which was adapted to generate only infrequently used in and out movements. By changing this basic aspect of the problem, creating a transmission capable of generating a circular motion, Watt succeeded in creating a universal engine.

The selection of a problem and the definition of its main element is only the first half of the analytical stage of the creative process. When an attempt is made to solve a problem with already known technical means, contradictions arise that impede the attainment of the desired technical effect. The identification of a crucial contradiction is the third phase of the analytical stage.

For example, an attempt to increase the efficiency of a boiler plant by introducing additional screens and economizers weighs down the unit and increases the amount of metal required in the construction. As we attempt to improve one of the issues using conventional methods, we simultaneously worsen the others: "*To some extent, the desire to reduce the weight (economize on metal) and the desire to increase efficiency (economize on fuel) contradict each other. The resolution of this contradiction is one of the most important factors in the progressive development of boiler equipment ...*" [4; 146]

This contradiction, obviously, is a consequence of defined causes. The problem in the last – fourth – phase of the analytical stage of the creative process is determining the immediate (mechanical, chemical, etc.) causes of the contradiction. Let us provide an example. The last stage in the prefabrication of dial gauges is that of checking them by comparing them with a verified reference sample. The instruments are placed side by side, and the controller checks the readings at several points on the scale. It is obvious that in order to increase the accuracy of the controls, one must take the greatest possible number of control points, but this slows down the verification process, leading to a decrease in the controller's labor productivity. In our effort to gain in accuracy, we undergo a loss in the speed of the verification process. The direct cause of

the contradiction is the physical impossibility of combining the scales in the two instruments: the controller has to look from one device to another, and he needs to see both at the same time. In this case, the contradiction is eliminated by introducing a binocular system that optically combines the instrument dials, making it possible to quickly and accurately verify the coincidence of the readings of both instruments throughout the entire scale.

The analytical stage is the most “logistical” part of the creative process. With an experienced inventor it represents a logical sequence of judgments, the catalyst to which are historical, statistical, technical, economic and other facts. And only in rare cases, when at some stage there is not enough factual material, we must conduct a few, always targeted experiments.

That being said, the analytical stage is an extremely important part of the creative process. In many cases, a properly conducted analysis allows one to immediately eliminate the cause of a technical contradiction or to greatly facilitate the next — operational — stage of the creative process.

What determines the success of creative work at the analytical stage? A background in the relevant technological field, an understanding of the dialectic laws for its development, having all of the factual information necessary for an analysis and the ability to conduct a logical analysis. It follows that **to develop one's inventive abilities, one must constantly train one's analytical skills**. Before he starts operating on living people, the surgeon spends a long time working with cadavers. Similarly, the inventor must systematically study already existing inventions. Also of great importance is a background in the history of technology, and an ability to imagine changes and developments in each branch of technology. Finally, the actual totality of technical knowledge, the totality of actual material that is available, is also important.

The second part of the creative process – the operational stage – differs in many ways from the first. In most cases, the operational stage is a combination of logical and non-logical operations. In this regard, the inventor has to search, try, or, using an old and not quite accurate term, conduct a “**thought experiment**,” which – this must be emphasized – takes precedence only at the operational stage of creativity. And the main thing is that it should not be carried out haphazardly. If the “thought experiment” was “a process of trying to and incorporating in this point all kinds of information” (S. L. Rubinstein), then the creative solution to each technological problem would require many years. Each more or less experienced inventor systematically carries out work on the operational stage of the creative process. As a result of long practice, inventors gradually develop their own, often rather unconscious, but objectively rational system for conducting searches. The analytical stage of the creative process greatly simplifies these searches: the inventor is not looking for an abstract “idea,” rather he seeks out concrete ways of eliminating a specific technical contradiction.

In our opinion, the most rational is a system in which the search for a way to eliminate the cause of a technical contradiction is conducted in the following sequence:

1. Researching typical solutions (prototypes):
  - a) The use of naturally occurring prototypes,
  - b) the use of prototypes from other areas of technology.
2. Seeking out new solutions through changes:
  - a) within the system,
  - b) in the external environment,
  - c) in adjacent systems.

With this sequence, searches go from simple to complex, and so we generate solid solutions with minimal effort and time.

In many cases, the technical contradictions that we encounter while carrying out creative work have direct analogies in nature and technology. Therefore, it is advisable that the first step we take is an investigation of similar contradictions and typical ways to eliminate them. Often, this lets us use natural or technical prototypes to eliminate the cause of the technical contradiction.

Let us provide an example. During WWI, ships began to use hydrophones – instruments that would detect the noise made by submarine propellers. To use these hydrophones, the ship had to be stationary, or the speed had to be seriously cut: the sounds made by the ship's movement through the water at the receiving hole of the hydrophone drowned out everything else. One of the engineers who worked on improving the hydrophone knew that seals could hear perfectly even as they sped through the depths of the ocean. At the suggestion of this engineer, a hydrophone was built with a receiving hole that was similar in shape to a seal's auricle. The result was a massive improvement in the capacity of the hydrophone to detect sound even when the ship was moving through the water.

In 1933, a device was invented in the USSR to drop cargo from a plane without a parachute (*Author's Certificate No. 41356*, published in the USSR). When solving a problem, the inventor used the well-known property of maple seeds, which, when they fall, level out and slowly gyrate toward the ground. He built a device that reproduces the maple seed's shape and so, when dropped from an airplane, gradually descended, spinning around its center of gravity.

A typical example of the use of technological prototypes is provided by the work of the designer E.V. Kostychenko (machine-building plant), who focused on the problem of increasing the wear resistance of valves used in deep-well pumps. Submersible pumps for extracting oil from wells quickly fail because the valves are abraded by the sand contained in the oil. Attempts to increase the service life of valves using hard alloys did not meet with success: they managed to increase the endurance of the valves, but along with this, the valves were much more difficult to process and manufacture, and they were also much costlier. To eliminate this contradiction, Kostychenko employed a technique that is widely used in mechanical engineering. Self-sharpening cutters, wherein the outer layers are made of soft metal, had been used for some time in metal processing. During the work process, these layers are uniformly ground, while the overall shape of the cutting edge is maintained. By using soft metal to cover some of the valve parts, the inventor succeeded in ensuring that they wore down evenly, and so the valve shape was maintained even when 9/10ths of the parts were worn out. Currently, over 100,000 pumps at use in oil fields are equipped with Kostychenko's valves.

The use of natural or technical prototypes is not, of course, limited to simple copying. Natural and technological prototypes are the result of long, ongoing development. When deriving a solution from nature and technology, the inventor develops it, bringing it to a logical finish.

In cases where a study of natural and technological prototypes does not produce a positive result, the inventor then proceeds to the next phase of the operational stage – a search for new solutions. Along with this, potential changes to the system itself are investigated. This is the usual group of the simplest changes. In some cases, to eliminate the cause of the technical contradiction, all we have to do is change the dimensions, materials, and the sequence in which the individual parts of the system interact. A typical example is the creation of a cutting machine with a long bar. The standard bar used to cut into a coal vein is 2 m long. In this process, explosives are used to crush the coal. Under favorable geological and geological conditions, it is possible to use cutting-edge machines with a 3-5 m bar. By increasing the depth of the cut,

the coal is crushed by the movement of the coal cutter: as it settles, the coal is broken into large, transportable pieces. A quantitative change – an increase in the length of the bar – thus provides us with a new qualitative effect: it eliminates the need for drilling and blasting operations.

A significant group is comprised of changes in the external environment. When studying the feasibility of making changes, the inventor must study the external – for the system – environment and its impact on the system. In particular, consideration should be given to changing the parameters of the medium (for example, pressure, temperature, speed of movement) or replacing this medium with another that has more favorable characteristics. Often, a simple transition from one environment to another, or the introduction of additional components into the environment leads to a successful solution to the problem. For example, in the manufacture of concrete in conventional concrete mixers, in a concrete mass, even with prolonged mixing, a significant number of small air bubbles remain, and these reduce the concrete's strength. Therefore, the so-called vacuum method for preparing the concrete was proposed. In vacuum concrete mixers, the concrete mass is mixed in a rarefied medium created inside a drum. A quantitative change in one of the parameters (pressure) of the environment provided a new qualitative effect: the strength of the concrete was doubled.

A technical contradiction can also be eliminated by amending adjacent systems, adjacent machine parts, and other stages of the process. Sometimes, all one needs is to simply establish a relationship between previously independent processes. We know, for example, that direct current is used for lighting modern film studios. This is called for by the fact that the shooting speed (24 frames every 2 seconds) does not match the frequency of the alternating current used in industry (50 Hz). When using alternating current to power lamps, the shutter of the lens on the movie camera may open when there isn't much light, and so some frames will be too dark. The shutter speed for each frame as it is shot is usually 1/1000s, so only 2.4% of the light energy falling on the lens is useful. If the fast-response lamps are powered by current pulses, synchronous and common-mode rotation of the lens shutter, the light will turn on only when the lens is open. Artists will see a significantly weaker uninterrupted light, since even at 10-16 pulses per second the human eye perceives light flow as continuous. By establishing the relationship between how the camera and the lighting system operate, we get a new technical effect – a sharp reduction in power consumption which also makes the work of artists easier.

The analytical stage of the creative process almost always results in an unambiguous answer, which is in contrast to the operational stage: A single technical contradiction can be resolved in various ways. Therefore, at the operational stage, an experiment doesn't play a secondary role, rather, the main one. This is because, in many cases, it serves as the criterion for the final choice of a particular technique, method, approach, etc.

A solid background in the natural sciences, the ability to observe, a familiarity with related areas of technology, an understanding of the technology involved in the experiment – these are the qualities necessary for success at the operational stage of the creative process.

The last – synthetic – stage of the creative process encompasses four stages: The introduction of functionally determined changes to the system, the introduction of functionally determined changes to the methods of applying the system, testing the applicability of the resulting principle in solving other technical problems and assessing the invention. Like the analytical stage, the synthetic stage is primarily comprised of a chain of logical judgments that, if necessary, can be verified through experiments.

The method employed to eliminate technical contradictions almost always requires additional changes to the system. These changes are aimed at providing a new form to the system that

corresponds to the new content. Psychologically, the transition to a new form presents the inventor with considerable difficulties. This is due to the fact that each system (machine, mechanism, process) involves presenting people with old, well-established forms. Because of this, even when a system is fundamentally changed, the inventor often retains its “traditional” form. Thus, for example, an early version of the electric motor was designed to look a lot like a steam engine: instead of a cylinder, the motor employed an electromagnetic coil, and a metal rod replaced the piston, which used reciprocating motion to switch the current. As was the case with the evolution of steam engines, a crank-and-rod mechanism was used to transform this motion into a rotational movement. Only later were rotating motors used in electric engines, thereby eliminating the need for a crank mechanism.

The next phase of the synthetic stage of the creative process is the introduction of changes to the methods used to apply the system. Creating any new system (or changing from a previous system) requires finding new methods for its practical use. Here's a classic example. Previously, coal miners extracted coal manually, using pick axes. Periodically, they would stop the extraction process, and set up fortifications and goafing. In the early 1930s, they started using pneumatic jackhammers in the mines, which was a powerful tool for breaking up the coal. However, the way the work was carried out didn't change in that periodically, the miner still put down the hammer to work on fortifications. Because of these irrational working methods, there wasn't much improvement in overall production. Then a new method was proposed for organizing operations: one group of miners would keep on breaking up the coal with jackhammers, while another group worked on fortifications. This new approach made it possible to take full advantage of the jackhammers, resulting in a tenfold increase in coal production.

Despite the obvious importance of this stage of creative work, inventors often largely overlook it, as efficiency experts use empirical methods to employ new inventions. As in the previous stage of the creative process, this is due to the influence on the inventor's mindset of established, traditional work methods.

The third phase of the synthetic stage of the creative process is verifying how applicable the new method is in eliminating technical contradictions for solving technical problems. Sometimes the resulting principle behind the invention is even more valuable than the actual invention itself, and can be successfully applied to other, more important problems. At this stage, the inventor's technical prowess, his acquaintance with other technological realms, his knowledge of current issues prevalent in various industries are of particular importance.

Everybody knows that in 1867, a French gardener by the name of Monier secured the first patent for reinforced concrete. Monier lacked a strong technical background, and so his patent application was only for manufacturing reinforced concrete ... flowerpots.

The last stage of creative work is the assessment of the new invention. At this stage, the goal is to identify the relationship between the technological benefit of the invention and the costs of its implementation. The value of the invention is directly dependent on how great this relationship is. In particular, if there are several solutions found at the operational stage, the final selection of the best option is made in conjunction with an assessment of the invention. Also, at this stage, inventors usually analyze the work done thus far in an attempt to identify any flaws and to fully work out new creative approaches to solving the problem.

The general course of the creative process is illustrated by the following example. In 1949, the USSR Ministry of Coal Industry announced an all-Union competition for the creation of a refrigeration suit for mining rescue workers, who encounter high temperatures and a poisonous atmosphere in their work. The technical conditions of the competition indicated the key to the

task, that being the need to ensure long-term refrigeration in a light-weight suit (8-10 kg). This is because, in their work, the mining rescue workers had to carry a device for respiratory protection (12-14 kg), as well as tools, and the total permissible load for each person couldn't exceed 28-29 kg.

The work on creating the refrigeration suit was launched by the authors of this article with their identification of the main technical contradiction. It was as follows. To ensure that the suit would hold up for a sufficient length of time in terms of its protective qualities, the supply of refrigerant (ice, dry ice, Freon, etc.) had to be increased, and, consequently, the weight of the suit also had to be increased. Any attempt to reduce the weight of the suit would inevitably reduce the service life of the suit, as well. Thus, there was a contradiction between the two main characteristics (weight and service life) that could not be eliminated by standard engineering. The analysis of this contradiction showed that the primary factor was the low weight limit established by the conditions of the competition.

While exploring how to eliminate these contradictions, we found that in other branches of technology this is often achieved by the so-called “method of combining functions”: the functions of one system are added to this system, and by their elimination [from the first system] we now create the option of increasing the weight of the first system. In this case, the solution to the problem was achieved by transferring to the refrigeration suit the functions of the apparatus for respiratory protection. As a result, the total allowable weight of the combined suit could be increased to 20-22 kg. Such a formulation of the question predetermined the choice of refrigerant: It had to be oxygen stored in a liquefied state. The undergarment worn inside the suit was first cooled by evaporated oxygen, which then was used for breathing once it heated up.

At the synthetic stage, changes based on function were made to the system: Due to the large supply of oxygen, instead of a circular (regenerative) breathing system, an open system was used (with exhalation into the atmosphere), which made it possible to dramatically simplify the design of the respiratory functions of the suit. We also made changes to the way the suit was used, as well. Since the suit rapidly becomes lighter as it is used thanks to the evaporation of oxygen, it was now possible to first load the suit with extra liquid oxygen, thereby increasing the suit's service life.

Projects based on these principles were awarded both the first and second prizes by the judges at the competition [3].

Based on all of the above, the creative process can be schematically laid out as follows:

### **I. Analytical stage**

1. Selecting a problem.
2. Defining the key to the problem.
3. Identifying the key contradiction.
4. Determining the immediate cause of the contradiction.

### **II. Operational stage**

1. Researching typical solutions (prototypes): a) in nature, b) in the technology.
2. Seeking out new solutions through changes: a) within the system, b) in the external environment, c) in adjacent systems.

### **III. Synthetic stage**

1. Introducing functional changes to the system.

2. Introducing functional changes to the system based on changes to how the system is used.
3. Testing how applicable the principle is to solving other technological problems.
4. Evaluating the resulting invention.

Of import is that the scheme we are planning can be attributed only to the creative work of an experienced and highly skilled inventor. As regards the work of a novice inventor, as a rule, there is not enough logical judicial symmetry, and chance, and lucky finds, and such play an important role. That being said, the great inventors of the past often achieved a high level of creative skill.

Inventions can be made in the process of carrying out research. For example, the discovery of X-rays and the establishment of their properties almost automatically led to a number of technological inventions based on the use of these rays. In this case, the inventor first acquired a means of eliminating many technical contradictions, and the problem was the opposite: find these contradictions.

The scheme we set forth is typical, but not comprehensive. Moreover, even within the limits of applicability, it is approximate. In many regards, one must still refine, deepen, and to some extent modify this scheme.

To solve this problem, one must further study the relationship between the objective laws of technological progress and the mental processes of technological creativity. One must also systematically study the experience of efficiency experts and inventors, and identify and study general methods of creative work.

The formation of the psychology of inventive creativity as a branch of psychology is impossible without the wide application of the experimental method. The findings should be verified not only by referring to materials related to previous inventions, but also experimentally, because the ultimate goal of the psychology of inventive creativity is the practice: Known patterns should be used in the development of scientific methods of work on the invention.

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# ADVANCED FUNCTION APPROACH IN MODERN TRIZ

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## Abstract

Advanced Function Approach (AFA) was introduced in 2010 at TRIZ Future Conference conducted by ETRIA. At that time, it was shown how utilizing the spatial-temporal parameters can further enhance such a powerful analytical tool as Function Analysis for Engineering Systems. Since then, AFA has proved its practical efficiency in dozens of TRIZ projects. Methodological recommendations for applying AFA have been developed and verified in the following areas:

- Specifics of Function Analysis for Engineering Systems at the exploitation stage (TRIZfest 2012);
- Revealing and describing the synergetic effect of combining two Engineering Systems (TRIZfest 2013);
- Novel approach to categorizing functions that Engineering Systems perform (TRIZfest 2014).

Here we reflect milestones in developing Advanced Function Approach and incorporating it in Modern TRIZ. The main recommendations of AFA are also summarized in this paper.

*Keywords: Function Analysis, Spatial-temporal Parameters, Advanced Function Approach.*

## 1. Introduction

The history of developing function approach is described in detail in [1]. Nowadays, about twenty ways to define and utilize the concept of “function” in various fields of science and engineering exist. Those concepts are described and discussed in [2]. Results of extensive research on philosophical and methodological aspects of applying the function approach can be found in [3-5].

In this article we will focus on the practically oriented function approach which is used in Modern TRIZ for analyzing engineering systems.

Function analysis, as defined in Modern TRIZ, is an analytical tool that identifies functions, their characteristics, and the cost of System and Supersystem components [6]. This type of analysis is needed to identify the system’s disadvantages such as harmful functions, insufficiently or excessively performed useful functions, excessive cost of components and, as was proposed recently, the wrong place and time of performing functions, and the absence of the required functions [1]. Another goal of Function Analysis is to prepare a model of the system to be used in the subsequent stages of the analysis: Flow Analysis, Cause-Effect Chain Analysis (CECA) or Root-Cause Analysis (RCA), Trimming, Feature Transfer, Super Effect Analysis.

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## 2. Essence of Advanced Function Approach

1. The function analysis for engineering systems, as developed by specialists of the Leningrad (St. Petersburg) TRIZ school, Vladimir Gerasimov and Simon Litvin, is characterized with the following attributes:

- A concrete, practical definition of function was introduced: "An action performed by one Material Object to change or maintain at least one Parameter of another Material Object"
- A triad for the description of a function was suggested: "function carrier - action - object of the function"
- Rules and algorithm for accurately formulating functions were developed.
- A parametrical evaluation of the level of function performance was suggested
- Also, the concepts of harmful and neutral functions were introduced.

Graphically, a function can be represented as shown in Fig. 1.

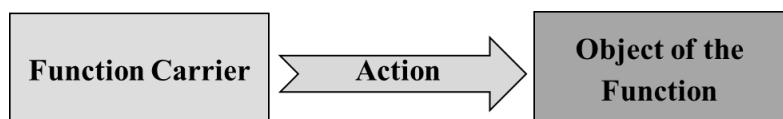


Fig. 1. A traditional graphical representation of function.

The specific steps and detailed procedure of the Function Analysis is described in Russian [6]. In English some highlights can be found in [1]. Formulating specific functions which is the last step of the Function Analysis can be performed according to the soft algorithm proposed in [6]: “there is a certain sequence to defining a useful function of a function carrier:

1. Suggest an initial formulation of a function that seems correct.
2. Ascertain whether the function carrier could perform the proposed function itself (the criterion for this is the presence of at least one element in the carrier that participates in the execution of the function).
3. Formulate a more precise definition of the function by asking the following questions: “what is the purpose of performing the function? “ (if the element mentioned in #2 above is evident); “how exactly is the function performed?“ (if the element in #2 is not evident).

If the initial function is imprecise, procedures 2-3 should be repeated until a precise definition is found. The criterion for finding a meaningful, precise definition is that at least one element of the object being analyzed takes part in performing the function.”

AFA proposes adding the following steps to those above [1]:

4. “Indicate the place the function is performed;

The indication of place should be precise and specific, because the same function could have very different levels of performance in different places.

5. Indicate the time the function is performed.”

These two additional steps seem simple, but they really help to understand the system and identify its disadvantages let us consider a case study presented in [1]:

Based on practical experience, AFA does not take much more time and effort than the classical Function Approach to analyze an Engineering System, but AFA does allow us to find the real non-obvious disadvantages of a system under analysis. Moreover, application of AFA significantly accelerates the subsequent analytical and problem solving procedures.

### **3. Specifics of Function Analysis for Engineering Systems at the Exploitation Stage**

The exploitation stage for any system is the point where the system performs all of the useful functions for which it was designed. It is vitally important that the system performs these functions well and just how well it does this characterizes the overall performance of the system.

Actually, as was shown in [7], exploitation is a process and if we need to analyze the system at the exploitation stage of its life cycle, then we need to apply Function Analysis for Technological Processes which is more complicated than the Function Analysis for Products, it utilizes different rules and ranking of functions. On the other hand, we may use Advanced Function Approach in order to analyze the system at the exploitation stage.

Briefly, the recommendations for Function Analysis of a system at the exploitation stage could be summarized as follows:

- The Function Analysis should be performed at the highest hierarchical level; at the level of the Supersystem. When the system is at the exploitation stage, it is very important to take into consideration its interactions with the Supersystem's components, including the object of the main function – Target.
- Advanced Function Approach can significantly enhance the efficiency of the Function Analysis. In fact, if we apply the spatial-temporal parameters "time of performing a function" and "place of performing a function", we combine features of both Function Analysis for products and Analysis for processes.
- It is also recommended to perform a quick Function Analysis of the system at the exploitation stage, even if we consider any other previous or subsequent stage as a project scope:
- At a previous stage (manufacturing, transporting, etc.), such analysis will allow us to predict and take into account all further important interactions with the Supersystem.
- At a subsequent stage (storage, maintenance, etc.), such analysis will provide a list of actual resources that are available in the Supersystem.

In more detail the recommendations on how to perform the Function Analysis of a system at the exploitation stage can be found in [7].

### **4. Synergetic Effect Achieved when Two Identical Systems are Joined**

Here we will demonstrate a practical example of applying Advanced Function Approach. More specifically, we will demonstrate how the Advanced Function Approach can be used to reveal and describe the synergetic effect of combining two engineering systems. According to a formal definition, "Synergetic (or Synergistic) Effect is an effect arising between two or more agents,

entities, factors, or substances that produces an effect greater than the sum of their individual effects" [8]

The simplest scenario is when two identical systems are joined together [9]. When building a function model of such a bi-system, it is important to know the specifications for "when" and "where" each system in the bi-system performs its function. This will give us a clear understanding of what the best regime for the conjoined operation is.

Let us consider in detail how the synergetic effect can be achieved in the simplest case of combining two identical engineering systems. First of all, we need to consider all possible conditions in which the actions of the systems we are combining perform. Table 1 summarizes these conditions.

Table 1. Conditions of performing actions when combining two systems. Possible combinations.

		<i>Temporal description of performing actions</i>	
		Simultaneously	Sequentially
<i>Spatial description of performing actions</i>	In different places	1	2
	At the same place	4	3

Let us now consider how the expected results depend on the conditions of actions performed.

No.1: the results are additive, but they can be achieved in a shorter period of time.

No.2: does not lead to reducing the time needed to achieve the results; the results are simply summarized.

No.3: the result doubles, but the time for achieving this doubled result remains the same.

No.4: the time needed to achieve the result is reduced, but the value of this result strongly depends on the exact interaction of the two systems in the zone of co-action. That is, the systems could even impede each other.

So, in order to make an informative conclusion about the efficiency that can be achieved when combining two systems, the first step is to understand the spatial-temporal parameters of their functions.

In order to illustrate the above approach, let us look through a case study. Imagine there are two identical excavators that are digging a ditch together. It is assumed that the ditch has a simple shape: its cross-section is rectangular and there are no turns along the ditch. The width of the ditch is equal to the width of one excavator bucket.

- No.4: if two buckets are directed into the same place simultaneously, then the result achieved is rather harmful.

- Nos. 2 and 3 do not really make sense in this specific example.

- No. 1 is the most interesting one. If the functions are performed in completely different places (i.e. the excavators dig from opposite ends of the ditch), the achieved results will simply be summarized. However, if both excavators dig simultaneously and the place where the functions are performed is properly organized, then a synergetic effect can be obtained. For example, the first excavator removes the ground from the upper half of the ditch and the second one removes

it from the lower half, see Fig. 2. In this case we will dig the ditch more than two times faster since the excavators do not need to adjust the positions of their buckets along the vertical extend. So, each of them works more efficiently.

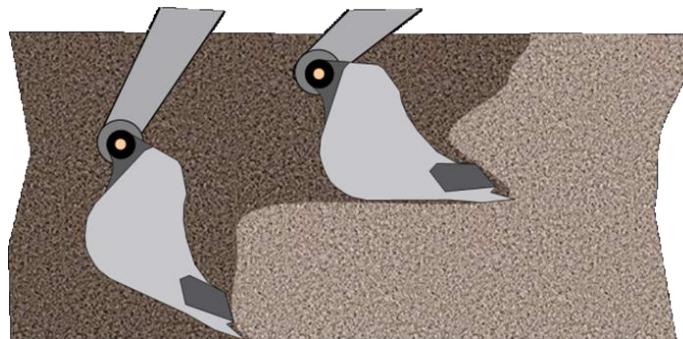


Fig. 2. Excavators joined into a bi-system.

But the opposite effect can also be achieved - when such separation of place (where the functions are performed) leads to increasing the total time of the operation. To work properly, each excavator should operate at its respective depth, and one excavator must remove ground from the ditch at a distance sufficient so as not to hinder the second. However, if the ditch is not long enough, there is no positive effect at all from combining the two excavators.

So, in order to reveal a synergetic effect and describe it in terms of functions, it is necessary to use the spatial-temporal parameters of actions. When two identical systems are combined into one system as discussed above, there was no way to explain the expected results without clarifying the two parameters "time of performing a function" and "place of performing a function". So, we have illustrated another important practical application of the Advanced Function Approach.

## 5. Approach to Categorizing Functions that Engineering Systems Perform

Function Analysis, as presents in Modern TRIZ, is one of the most developed and formalized analytical tools. However, a complete list of recommendations for selecting the most appropriate function(s) is still lacking.

The recent fundamental research published by Yury Fedosov [10] recommends “the most simple and obvious way of formulizing the procedure for formulating functions” is to choose the appropriate function for the current situation from “the list of elementary functions.” This empirical study [10] is based on the representative statistical data taken from TRIZ consulting projects performed successfully in different engineering and scientific areas.

Another approach for formulating the functions of the system’s components is based on the application of detailed algorithms. The first algorithm for formulating functions was proposed by Vladimir Gerasimov and Simon Litvin [6]. Recently, Alexander Kynin and Alexander Priven [11] developed an algorithm for selecting the elementary functions from the matrix  $4 \times 4 \times 4$ , which simplifies and standardizes the procedure, thereby reducing the risk of erroneous formulations.

Hybridization of these two known approaches allows us to propose a novel approach for performing Function Analysis that is simple enough and not time consuming, but still sufficient for describing complex engineering systems and revealing their function disadvantages.

A hypothetic-deductive method of creating scientific theories is applied. This is when a whole working theory is built upon assumptions. Basically, this method organizes knowledge that existed before and extends the range of applications where that knowledge may be applied.

The novel approach described here is based on the two following statements:

- According to recommendations of AFA, the spatiotemporal parameters should be used when describing an Engineering System functionally: "time of performing a function" and "place/location of performing a function" in each specific situation. This leads to increasing the accuracy of the system description. Such detailed description allows us to identify function disadvantages in the system that are difficult to observe with the classical function approach.
- The original supposition is that the vast majority of functions that engineering systems perform can be covered by four base types of functions described in AFA format. The appropriateness of this supposition is supported by its testing with concrete empirical data.

Thus, we can formulate the main assumption: When the AFA format of function description is utilized, the vast majority of actions (the verb related part of a function formulation) can be described with the following verbs:

- **To move** (Note: when AFA format is applied the specification of direction, speed, distance is taken into account);
- **To hold / to stop** (Note: the final choice depends upon the initial stage of the function recipient. E.g., “to hold” can be applied if it was a stationary stage; “to stop” is more appropriate if the object was moving);
  - To combine / to join;
  - To separate / to divide.

Actions covered by the verbs above are general enough; they can be used for describing what any material objects (including substances and fields) do. This approach is illustrated in Fig 3.

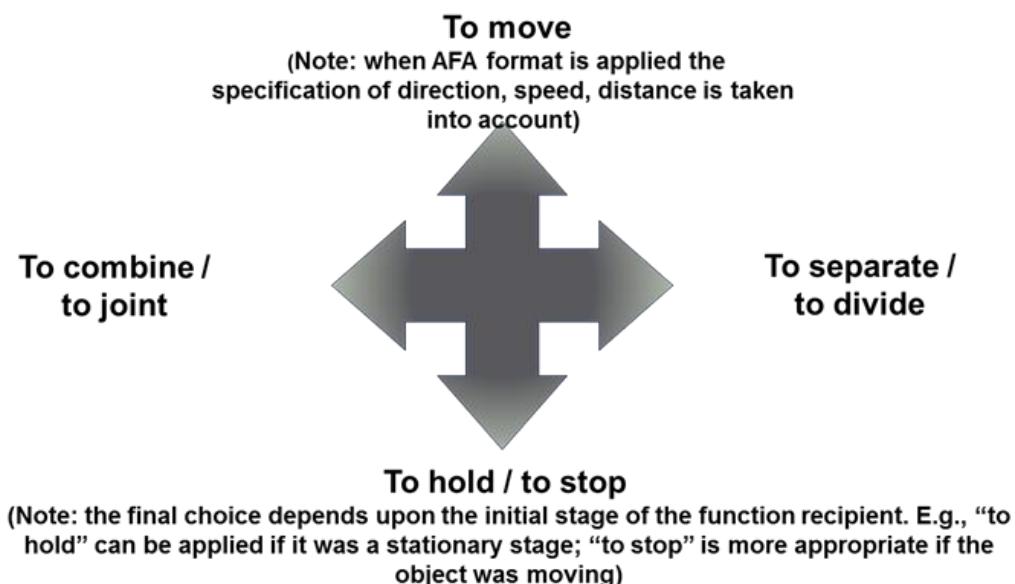


Fig. 3. Four Generalized Types of Functions.

At first glance the proposed approach may look oversimplified and insufficient for describing complex engineering systems. However, in our opinion it is sufficient because special attention is given to the parametric characterization of each function including its object, subject and action.

The first version of the “Elementary Functions” Handbook proposed in [10] has been used to validate the proposed approach. The Handbook is based on a statistical approach: 32 function models of actual complex engineering systems from different industries were analyzed. In total, 256 components performing 2132 functions were considered.

In fact, we substituted each function in the Handbook with one of the base/underlying functions proposed above and parameters of performing this function. More details of this research can be found in the recent publication.

Not only is the novel approach described here ready for application in actual projects, but it can also simplify introducing and explaining the function analysis to people who are not familiar with this analytical tool.

Basically, we can start with a general undefined description of the system we are analyzing. This will give us an initial understanding of the problem as seen by the client (a person or a project team) that owns the problem. Then, we need to create a function model by reformulating what the client knows using the set of base/underlying functions. Of course, all of the parameters of each function, including parameters of its object, subject and action, should be taken into account.

Since the number of base/underlying functions (actions) is limited by four types and seven verbs, creating the function model does not take much time. Actually, creating a function model can be performed together with the client in real time facilitation mode. The results of such facilitation can be vitally important for a complete final understanding of how the system works and what its function disadvantages are.

In general, the novel approach to categorizing functions is characterized by the following features:

- Simplified procedure and reduced time of the function analysis without compromising quality of its results;
- Ease of introducing/explaining the function analysis to people who are not familiar with this most important analytical tool in Modern TRIZ.

## **6. Conclusions**

Based on an evolutionary analysis of the effectiveness of applying parameters for formulating functions, it was assumed that not only the object and the recipient of the function, but also the action (the verb) should be characterized by some parameters. It was suggested that the spatial-temporal parameters "time of performing a function" and "place of performing a function" are the most universal to characterize any action. In fact, any action takes place within a certain period of time and in a certain space. This approach was given the name "Advanced Function Approach".

Several applications of AFA have been developed since it was introduced in 2010. Those applications lead to increasing efficiency of analysing Engineering Systems within TRIZ-based innovative projects. They allow TRIZ practitioners to identify system disadvantages that are hard to reveal using the Classical Function Approach.

Finally, we introduced a novel approach to categorizing functions that engineering systems perform. This makes the Function Analysis procedure simpler and, at the same time, enhances the value of analytical results.

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# APPLYING TRIZ ACROSS COMPANIES

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## Abstract

TRIZ is a very powerful tool for innovation generation. In the last years this method has spread across industry and revolutionized innovative thinking.

Industrial reality is up to now often organized in a way that engineers follow processes that cover the span from idea to maturity of a product. In that time span only a short piece is using TRIZ to generate ideas systematically. The major part is compiling the boundary conditions that are seldom of physical nature and evaluating and then demonstrate, prototype and finally design the mature product. Considering a development time of average about 2 year for a complex part, only very few times TRIZ is used, mostly as brainstorming aid tool in the concept phase or occasionally when specific problems arise during project execution.

TRIZ is a tool that needs to be trained and continually used in order to make most use of it. If working conditions do not allow this, one has to search for other ways to realize this. This paper shows how a solution was found to work the conventional way industrial processes are operated and at the same time keeps up using TRIZ continuously and in surplus to widen one's technological knowledge.

The solution is to set up a group of TRIZ knowledgeable persons from different institutions and to periodically set up meetings at the different facility sites to solve a company specific problem for which no IP or competition issues are present with TRIZ tools. This kind of open access innovations keeps up TRIZ application and trains its usage, it is fun, serves widening of technology knowledge and comparing different application approaches, enables learning from other innovators and sets up a network.

This paper is a report on an example of application of TRIZ effectively in a company and cross companies. It is not targeted to add novel contributions to the TRIZ methodology, rather to introduce new frameworks for application.

*Keywords:* TRIZ, heterogenic groups, cross companies working, learning TRIZ, innovation method.

## 1. Today's situation

When dealing with complex hardware challenges, companies have processes in place on how to best develop the technology and to solve problems. At GE for example we have been using SixSigma as a methodology for decades. Design for SixSigma (DFSS) is a great process for the complete hardware development, dealing from the initial goal (not a problem to solve) until a mature product dispatch. The SixSigma process looks at defining the task explicitly, defining customer pain points and needs, looking at a team charter, etc. The “measure” step is for identifying how the system shall be measured and how success is defined. In “analyse” we look at

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the system and tasks in order to design and optimize a solution. This is checked against the requirements in the “verification” step.

SixSigma is very powerful in structuring this development process. However, when it comes to generating solutions for a problem, it provides weak suggestions. In this space TRIZ is the valuable tool (Fig. 1).

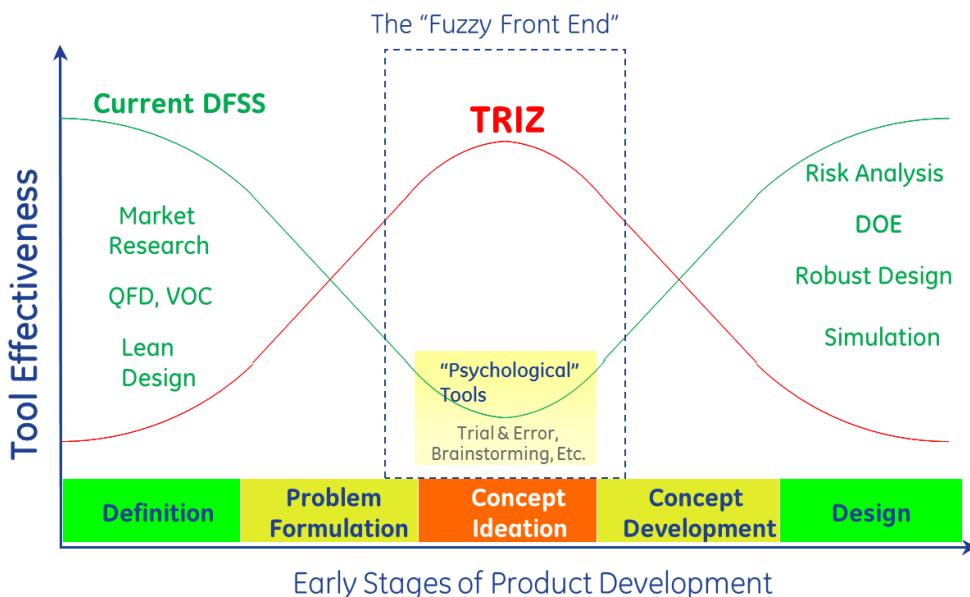


Fig. 1: Tool effectiveness of SixSigma and TRIZ over the product development stages

(Source: Adapted from *Risk Free Business Innovation*, Mark Barkan, 8/5/2006, [3])

This approach however limits TRIZ adoption within a team, with the effect that it is only used during a short time and for short tasks. But this is not the most effective usage for the TRIZ toolbox, since TRIZ is not only a methodology for generating breakthrough solutions in a shorter time, rather it is a mind-set. Using TRIZ on a regular basis in daily work reshapes the way of thinking, of approaching and seeing technical solutions. This is at least the experience that we gained in GE Global Research looking at the projects performed and the people that are using TRIZ. But as we know from psychology [1], it requires continuous application of TRIZ thinking in order to change the mind set and approach to problem solving, boost creativity and overcome psychological inertia. Practicing creativity is instrumental: the peak point of creativity lies during childhood, where indoctrination with knowledge is not yet so extreme and only starting at school (Fig. 2).

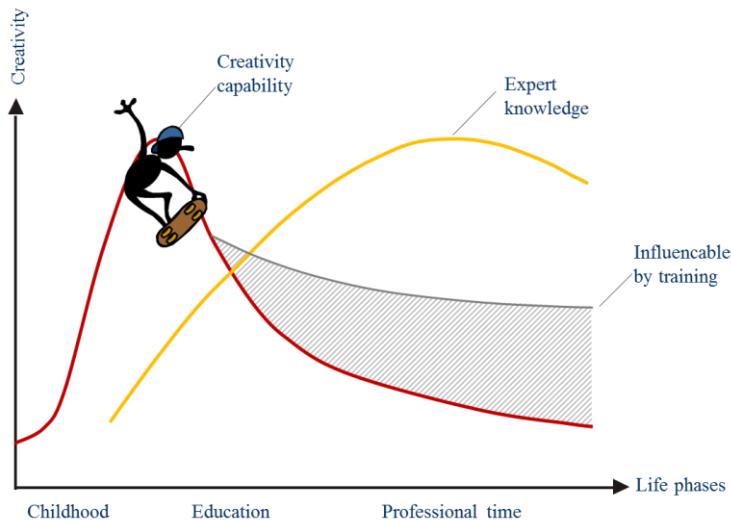


Fig. 2: Creativity evolving over time

[Source: Adapted from *Innovationen Systematisch Erarbeiten*, Uwe Metzger]

The more knowledge people gain, the more creativity declines. In this case people become the well-known experts in a field, with the side effect that solid experience tends to impair creativity with their experience on “what does not work”. Still the level of creativity can be influenced by training and practise. The more someone is involved in working creatively, the less he will be influenced by his experience. One way to achieve this is to promote regular application of TRIZ. We solve the problem of increasing TRIZ adoption in a corporate environment to enhance capability using TRIZ itself.

## Approach to a Solution

Looking at the situation we can apply TRIZ and find the following main contradiction:

IF      scientists use TRIZ only in the inventive problem solving phase of a project  
 THEN the product will be developed to maturity  
 BUT    scientists are not continuously trained in TRIZ and don't change their inventive capabilities

This can be (amongst others) translated into improvement of productivity and worsening of reliability. The suggested principles are: Segmentation, Parameter Change, Pneumatic / Hydraulic and Oxidation.

### *Translation of Principles into Specific Solutions*

A brainstorming was done on how to translate the suggested principles into specific solutions. The major ideas generated were:

- Define a dedicated team that only gets active in the inventive problem solution phase but for different projects.
- Get external consultants that are TRIZ trained into the inventive problem solving phase.
- Get GE internal TRIZ experts involved in external company inventive problem solving phases.

## *Implementation of the Selected Solution*

We decided to go for the most exciting idea: collaboration with external companies. This is especially useful in joint innovation between a company and its customer and/or supplier(s). In Bavaria there is a governmental initiative that shall promote innovations in the country: Bayern Innovativ. Within this initiative an association called quer.kraft was founded [2]. The members of this group are from different companies. A new member can only be added to the group if there is no objection from the existing members. By this it is ensured that no competitors are engaged in the same topic.

Every member of the association can suggest a topic / problem that they need to solve. Two to three times a year the group is meeting at the location of the company that puts the problem. All members work for one day on solving the challenge with TRIZ methods. The next time the problem of another company is solved. This method has been applied in the last 1.5 years 5 times in the areas of piston development, cable tights, bottle packaging, cranes and car wheels. As a result 13 patents have been generated.

The procedure of a meeting is following the rules:

The representative of the company suggesting the topic gives an introductory presentation of the company and the problem. Afterwards the team focuses on the production process of the device under evaluation. After this the group does a brainstorming on what ideas are already on the minds of the participants. This normally takes the morning time. After lunch the group splits up into subgroups and applies TRIZ tools to generate more solutions during the whole afternoon. In average we generate about 40% more ideas than with the brainstorming only.

The participation in the association has two significant advantages for companies like GE Global Research and Siemens:

- The teams use much more often TRIZ and by this stay trained and improve our innovative capabilities.
- We see how others are using the TRIZ methodology.
- We get educated on different technologies and by this broaden our capabilities especially for applying the method of “was already solved by someone else”.

Due to meeting at the company site, travel cost can get a burden and usually the number of attendees is limited to that. So only a small number of people are trained. As an alternative we tested offline collaboration. In this case within the companies TRIZ teams were set up. We had a telephone conference with other companies and the problem was stated. Then the teams worked on the subject in the morning and afternoon. In the evening we joined again for a telephone conference and presented the results. In this case it was as well interesting to see what kind of ideas were the same across the participants and where there were differences. This method was tried within the regional TRIZ associations in Europe, led by Robert Adunka and showed a fast, cost efficient international collaboration opportunity.

One example was a TRIZ European Workshop, were the working groups were participants from three countries. Two teams were from German companies, one from a French company and one from an Italian university, member of Apeiron (Italian TRIZ Association). Over a telephone conference the French group proposed a problem to be solved by the different groups separately. The problem to be solved was explained by a PowerPoint presentation via WebEx platform (exchange of PC screens among the participants) and the groups were given 3 hours to work on solutions on their own, free to choose whichever method they preferred. After this, the

groups reconnected via a remote session and each gave a report out on the activity of the day and the list of ideas.

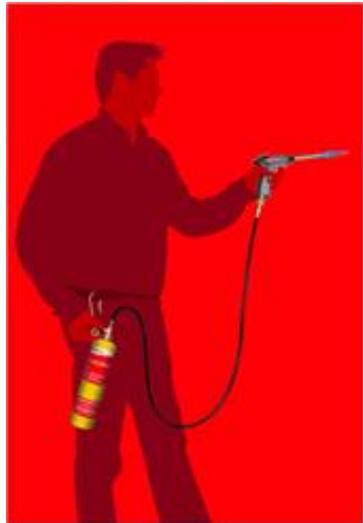


Fig. 3: Handheld torch

The problem was to improve the usability of a handheld torch. As main requirement ergonomics have been identified: low weight at higher or at least same operational time (Fig. 3):

German working group A went for a free brainstorming at the beginning to „clear the brain“ from biased ideas and get rid of psychological inertia by emotional attachment to the “own concept”. Those ideas are documented on a blackboard and served as preliminary storage for ideas. After that, the application of the actual TRIZ tools started. The group began with the classic function analysis methodology, going as far as component analysis, noticing at that point that for such exercise, as well as for a structured ARIZ application, 3-4 hours were not enough. So, the Ideal Final Result was identified applying a subset of the ARIZ steps, in order to formulate contradictions as soon as possible. The group worked all together, without splitting into subgroups. The tool used to document function analysis, contradictions and principles was Innovation Navigator™.

Apeiron working group used a different TRIZ approach using functional analysis, Su-Field modelling and System Operator X application (Fig. 4).

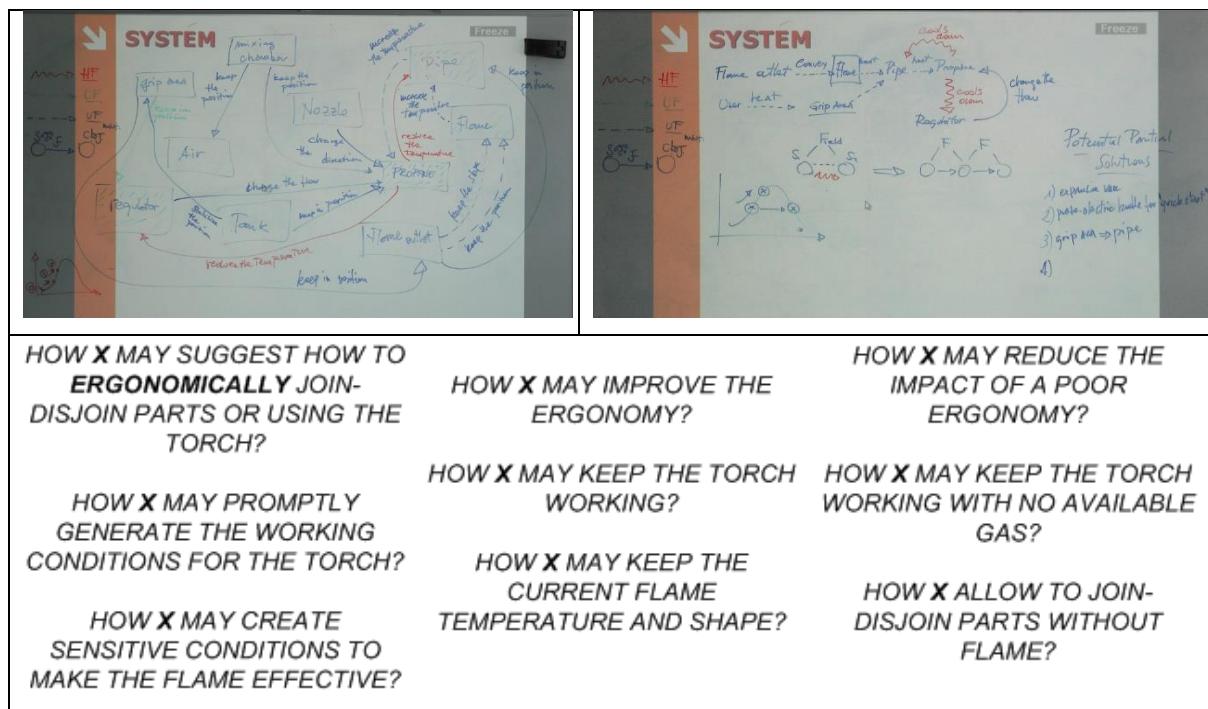


Fig. 4: TRIZ tools used by Apeiron

German working group B used the software TechOptimizer™, compiling a list of problems, and documenting ideas by means of a template for ideas including space for sketches (Fig. 5).

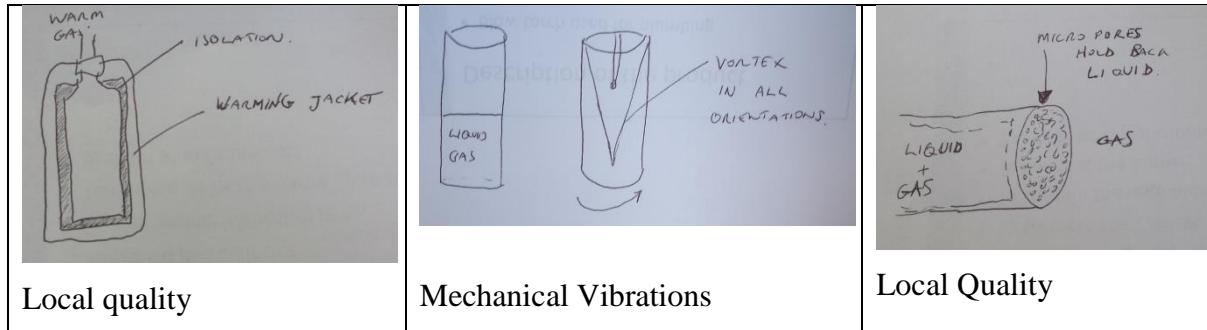


Fig. 5: TRIZ triggered ideas from the German groups A and B

The French Group focused on the definition of Main Function and Ideal Final Results.

This working day was an excellent opportunity to see a problem analysed from different point of views and solved by several TRIZ tools, reinforcing knowledge, experience and confidence in the application of TRIZ methodology. Most enriching was the number and quality of the ideas generated by very diverse approaches, shared during the report-out.

## Learning & Duplication

With this experiment, that shows as single event no statistical relevance, we transferred a process of application over several levels.

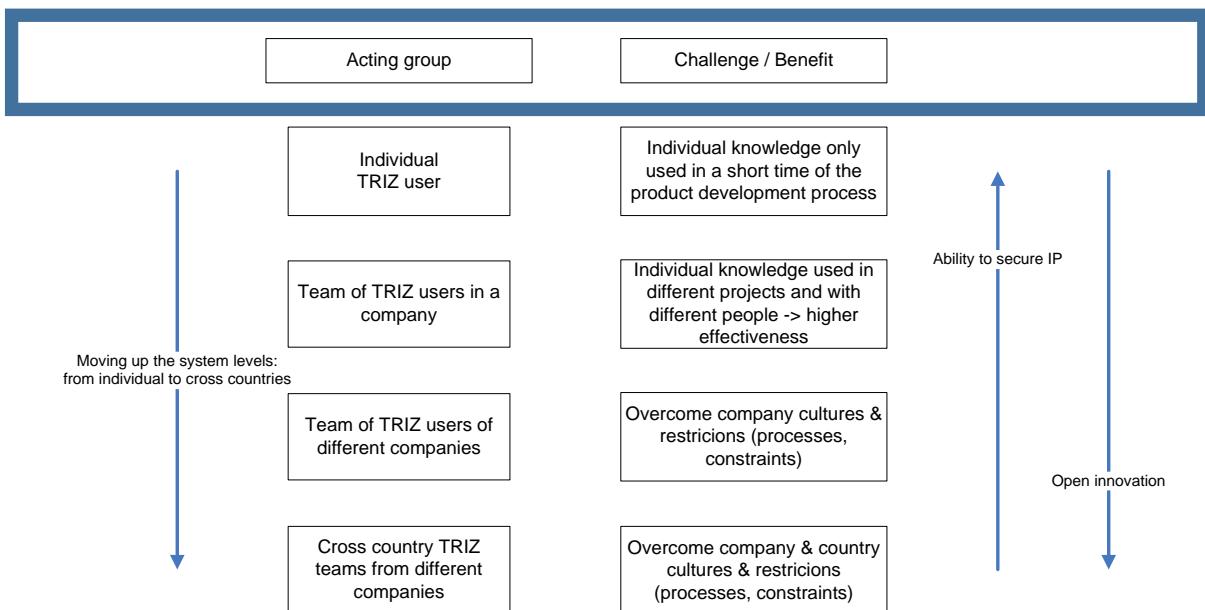


Fig. 6: Structuring for usage of TRIZ expertise

Figure 6 shows how the TRIZ expertise can be structured to improve effectiveness of trained persons. The basic idea is to use TRIZ expertise in a similar way that Altshuller rated the patent levels (from level 1 “apparent solution” resulting from personnel knowledge to level 5 “discovery” being knowledge of the world). This is especially interesting when teams from different,

non-competing areas are collaborating (e.g. car industry with airplane industry). Similar developments can be found e.g. when today there is a movement from individual experts to crowdsourced knowledge (like in Wikipedia) or from node-concentrated calculation to cloud computing (also for data storage).

When using this approach, one has to consider that there is a difference between Small / Medium sized Enterprises (SMEs) and big companies (> 20.000 employees). The layout shown suites well for corporate sized enterprises. They have the capacity to run such processes. SMEs often struggle with such an approach. For them outside facilitation is needed. The already mentioned “quer.kraft” offers such possibilities.

## **Summary**

The evaluation showed that there is great value in creating kind of “TRIZ innovation teams” that are used to facilitate the relative short time of idea finding in an engineering project. By this experienced TRIZ applicants ensure thorough results and the TRIZ experts are continuously trained in order to keep up and improve their capabilities. This concept can be used within companies but as well across companies, especially when they are not competing on products.

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# APPLICATION OF TRIZ IN BUSINESS SYSTEMS

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## Abstract

This article describes application of TRIZ to solving inventive problems that we face while implementing projects for customers at EPAM Systems – a company that provides services for global product development and digital platform engineering.

Based on our practical experience, we consider the nature of inventive problems typical for business systems and discuss the most efficient TRIZ tools and other adjacent tools to use for identification and solving such problems.

*Keywords:* business system, inventive problem, opportunity map, RCA, contradiction, ARIZ.

## 1. Introduction

Technology evolution drives development of our civilization. More and more new engineering systems are entering our life to solve our problems creating a completely new experience. This new experience, in turn, results in new needs and related problems, which requires next systems to be developed.

To improve our life with a new engineering system is not enough just to build it. Many people should get access to the system and use it in their everyday life. This is the business, who solves the task of scaling the invented solution and delivers it to people as products (goods and services).

At the dawn of the civilization development, the task of scaling was solved by goods manufacturers, and merchants who delivered goods to remote regions of the Earth. Today, the task of scaling is solved by companies and organizations: from individual entrepreneurs and small companies that conduct their business in a small area (on the street or in the city), to transnational corporations such as Amazon, Google, Tesla Motors, which operate globally and constantly are in contact with their Consumers all over the world.

In this article, we consider business systems as systems consisting of companies and organizations manufacturing and marketing products (goods and services), buyers who purchase and use these products and market relations between companies and buyers, built on a free exchange of values [1]. The creation of new and the improvement of existing business systems often requires solving of inventive tasks, where the use of standard solutions is impossible or insufficiently effective.

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We are presenting EPAM Systems. Since 1993, EPAM Systems, Inc. (NYSE: EPAM), has leveraged its core engineering expertise to become a leading global product development and digital platform engineering services company.

Our customers often come to us with requests that require not only the development of some solution, but also the solution of complex tasks related with the development of their business. In this case, the problems can be formulated generally; the solution of such problems involves the analysis of the client's business system, the identification of a large number of requirements from different stakeholders. Usually such an analysis leads to contradictions, which converts such problems into the category of inventive problems [2].

In this article, we will share our experience of identifying and solving inventive problems, which we faced within the projects at EPAM Systems. In addition, we will present examples of the use of TRIZ tools, which we apply in our practice.

## 2. Transition from Engineering System to Product

Engineers and inventors during the Engineering System (ES) development traditionally deal with already defined requirements for the system. Research activities users' behavior, experience of using ES in specific (often, very different) conditions goes beyond the scope of the engineer; this is the work of marketers, UX researchers, industrial designers and interface designers, business analysts, and product managers who coordinate this activity and make decisions about System requirements.

Usually product is oriented to be used in different solutions by different customers. Figure 1 shows diagram of ES, which performs some useful function – F on objects 1 and 2 (O1 and O2). This system is used by different customers - Customer 1 and Customer 2 in scope of different solutions - Solution 1 and Solution 2 for achieving customer goals, defined as Value 1 and Value 2. In Solution 1- Customer 1 performs actions - A1 and A2, in Solution 2 - Customer 2 performs actions A3, A4 and A5, but at the same time, Customer 2 is using additional ES.

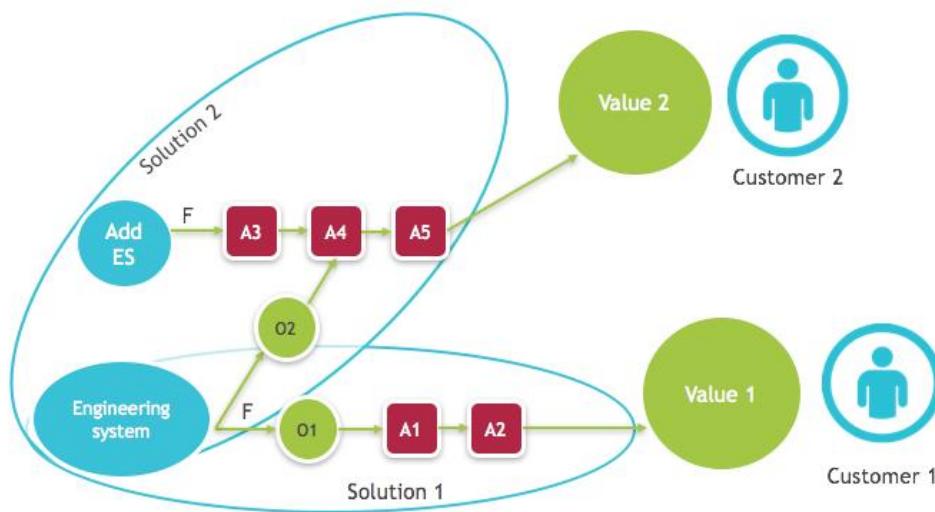


Fig. 1. Usage of engineering system in different solutions by different customers.

Because of using the product, User reaches the goal expecting to receive certain benefit. In fact, these expectations are the source for the requirements to the engineering system which underlies

the product. In this case, the user is the main source of uncertainty of the requirements. Unlike functions within the engineering system, which parameters can be definitely described, the parameters of human interaction with engineering systems are much more difficult to describe. This is the reason for rising uncertainties in the description of the business system.

A big number of different users of the product is a kind of multiplier of this uncertainty. The product must meet the requirements of a big number of users with different wishes, needs and understanding of the value that they want to receive from using the product.

### 3. Transition to Business System

Business system is a system consisting of companies and organizations that produce and sell products (goods and services), consumers who purchase and use these products and market relations between companies and consumers, built on a free exchange of values [3].

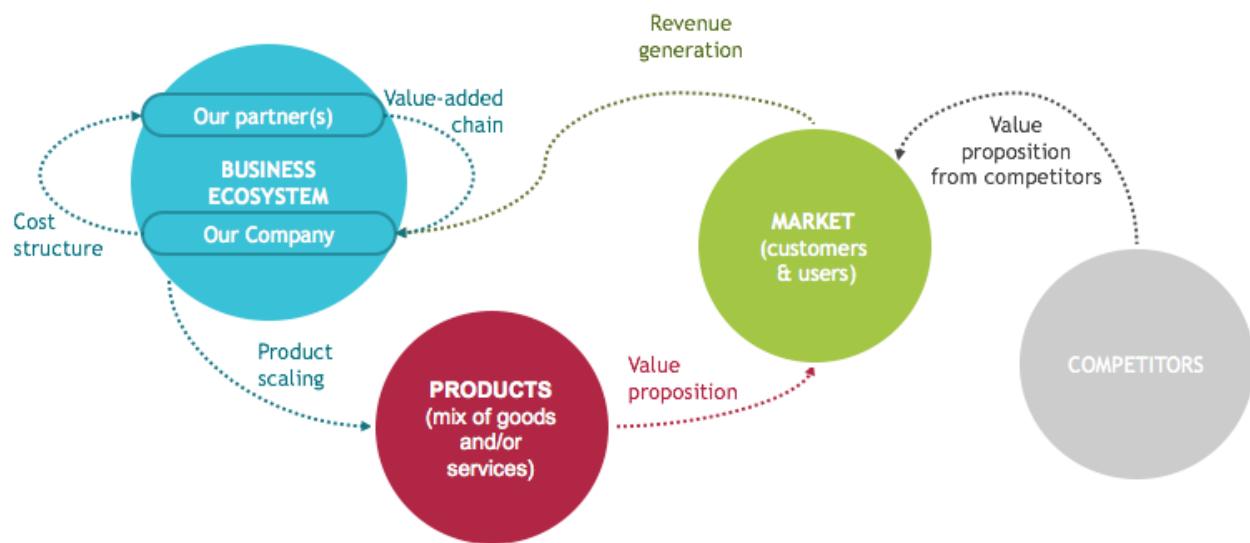


Fig. 2. Business-system

Business system produces value for stakeholders, including ultimate customers. In the most simplified version business system structure can be presented as illustrated on Figure 2. Business system includes various engineering systems that implement functions necessary for useful work of the business system.

The main components of the business system [4] are as follows:

- Market which consists of lots of consumers and users of the product represented by the business system as well as competitors and their products;
- Product itself, which is created and produced in the business system and delivered to the consumers, including additional services;
- Business ecosystem, which includes one or more companies which interact with each other within a single value chain, creating, producing and delivering the product to consumers.

An essential feature of business system is a big number of stakeholders. Except product users, business system includes customers (who are not always users of the product), business stakeholders (business owners, managers and employees), as well as society, the state, etc. Different

stakeholders have different interests, which also need to be investigated and accounted within the business system.

One of the key functions of the business system is scaling of the value for a big number of users of products which are produced within the business system, as well as other stakeholders. In this case, scale plays a role of multiplier not only for the value, but also for any undesirable effects that occur in the business system.

## **4. Invention Problems in Business System**

Per research [6], conducted for 150+ business models, an inventive problem containing a contradiction may arise in different components of the business system: consumer markets, product, companies entering the business ecosystem, and interactions between components of the business system.

Usually Client comes with a complicated problem especially in the cases when he has already made attempts to solve it and received unsatisfactory results. Information that the Client comes with, may contain results from early attempts to solve it, or may not contain such information. Solution for the problem is still actual for the Client, as this solution can have significant impact on his business.

At the first stage, we are performing research of the Client's business system in general and clarifying components of the business system that relates to the Client's problem. For this stage, we use several analytical tools from service design [5] approach and business analysis like:

- Investigation of the value proposition [6]
- Research of the business ecosystem [7]
- Business Process Analysis AS IS [8]

### *4.1 Value Proposition Analysis*

One of the EPAM Clients – US online Car Information Aggregator. Aggregator Portal with a set of accompanying mobile apps includes prices for new and used vehicles, dealer and inventory listings, a database of national and regional incentives and rebates, vehicle test drive reviews, and tips and advice on all aspects of car purchases and ownership. Company looked for strategy forming for the next years and asked EPAM for recommendations in this field.

Analyzing the value proposition, we use the Osterwalder's Value Proposition template, which is presented on Fig.3 (Customer Profile with gains and pains) and Fig. 4 (Product value map with gain creators and pain relievers) for the Client Portal.

The Value Proposition template allows to understand Consumers and the value they expect from our product, on one hand, and to understand how our product allows the Consumer to receive the value, on the other hand.

Purpose of analyzing the Value Proposition is identifying gaps between Gain Creators and Gains, on the one hand, Pains and Pain Relievers, on the other hand.

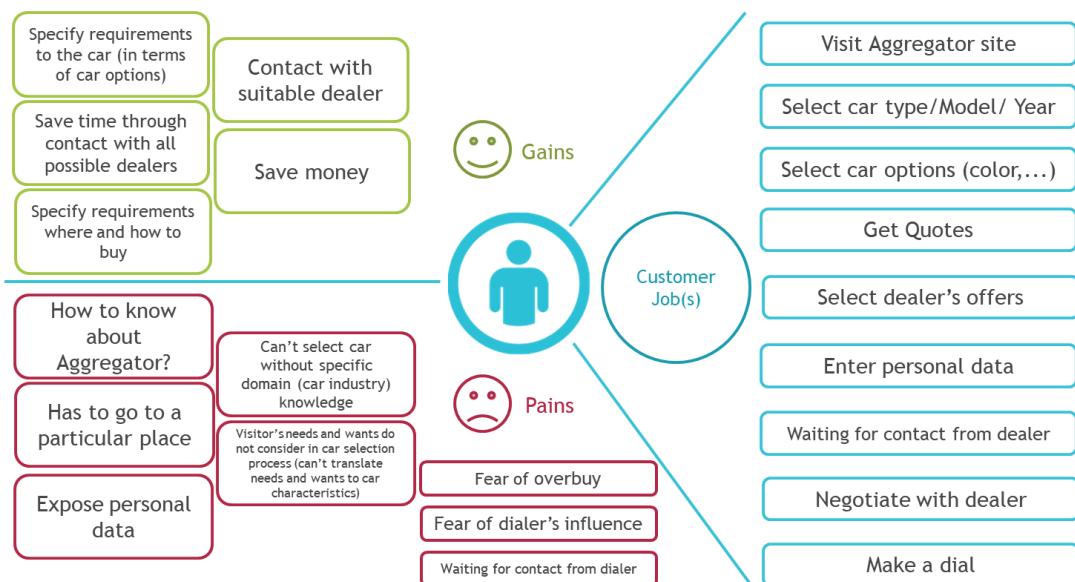


Fig.3. Value Proposition Model: Customer Profile

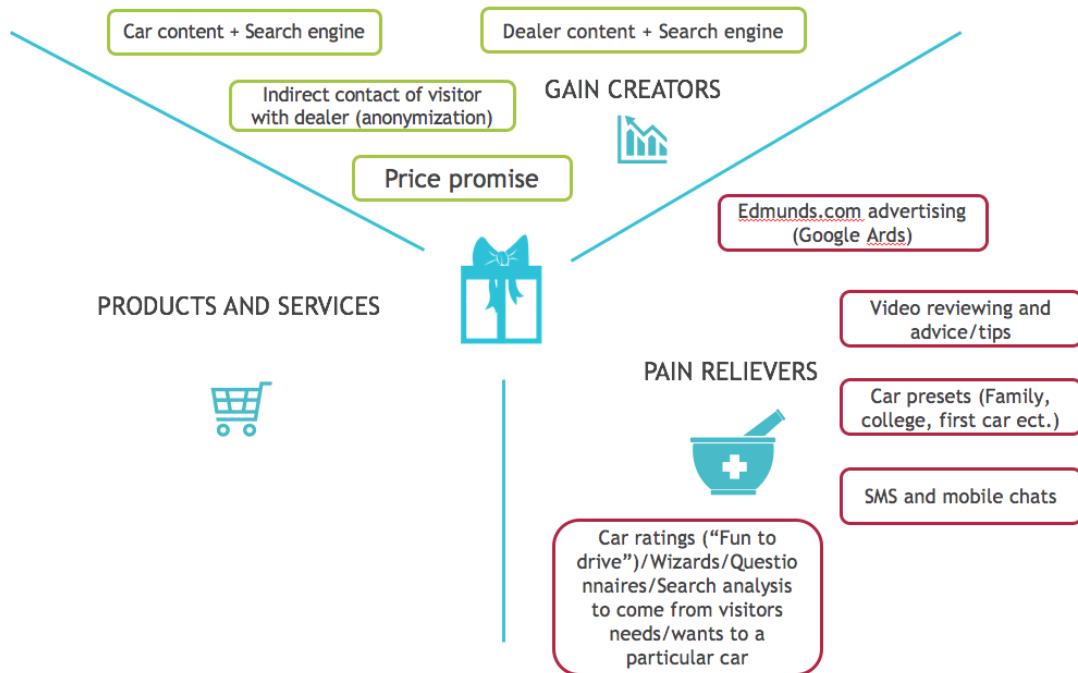


Fig. 4. Product Value Map

As a result, we get a list of Gaps for the product which need to be fixed. Gaps are potentially sources of inventive tasks. Thus, because of the further analysis we identify number of inventive problems. They are presented in the table on Fig. 5 in the form of contradictions:

Known solution	Requirements	Negative Effects
Dialog with visitors	<ul style="list-style-type: none"> <li>allows to get info about visitor's needs and wishes</li> <li>Make visitor more happy and informed about what car he/she needs</li> </ul>	<ul style="list-style-type: none"> <li>Visitor have to spend a lot of time and efforts</li> <li>Decreases dealer margin due to buyer know what car he/she needs</li> </ul>
Creation of car classificatory based on needs and wishes	<ul style="list-style-type: none"> <li>allows to select car without domain specific knowledges</li> <li>increase conversion of visits to leads</li> </ul>	require to develop this classificatory (hard and time expensive process)
Closing of visitor's needs and wishes for dealer	compliance with the broker's law	dealer will have not information about buyer (visitor) requirements
Opening of visitor's needs and wishes	Make visitors more happy and increase conversion of visits to leads	Decreases dealer margin due to buyer know what car he/she needs
Usage of proxy during contact of visitor with dealer	Defenses visitor from dealer's spam	<ul style="list-style-type: none"> <li>Visitor have to wait the respond from dealer</li> <li>Creates delays in communications</li> </ul>
Auction for hot leads	Increases Edmunds revenue from leads	Dealers have to pay for leads not for deals

Fig.5 Table with List of Contradictions

#### 4.2 Business - Ecosystem

Our client was a company that produces coffee machines and drink packs. These machines are installed in offices. Our client needed to collect detailed drinks consumption data to better plan production and development of new products. Distributors of our client's drinks either did not have detailed data or did not want to share it with drink producer. Then our client came up with an idea to connect the coffee machine and directly collect consumption data. However, they faced the following issue: the office owner did not allow to connect the machines to the company network, while installing a separate GSM modem into the machines was too expensive.

We analyzed the value chain (see Fig. 6) and identified the following contradiction. Our client produces tons of different flavors of drinks. The merchandizer, that is placed next to the coffee machine can store limited number of different flavors. As it is too much effort for the machine owner to collect individual preference of the office employees it orders predetermined sets of flavors. Employees would like to have specific flavors at their machines, but only can ask the machine owner to switch for another predetermined set, which would not fit the all employees' preferences either.

We proposed to create a new additional value for the consumers and let them select drinks, that are supplied to their machine. Moreover, we proposed to exchange this additional value for communicating consumption data through the consumer's personal devices. The proposed solution is based on using an application, which is loaded to consumer's phone and allows the consumers to order their favorite drinks to be available at the machine they are using. The machine identifies the consumer when he or she approaches it by communicating with the application through Bluetooth connection. The consumer data accumulated in the machine is passes through the application directly to our client.

This win-win solution gives value both to the consumers as they are now able to select exactly what they want to have in their machine and to drink producer as it gets a direct communication channel with its clients (see Fig. 6). Also, the machine owner does not have to care about selection of supplied drinks any more.

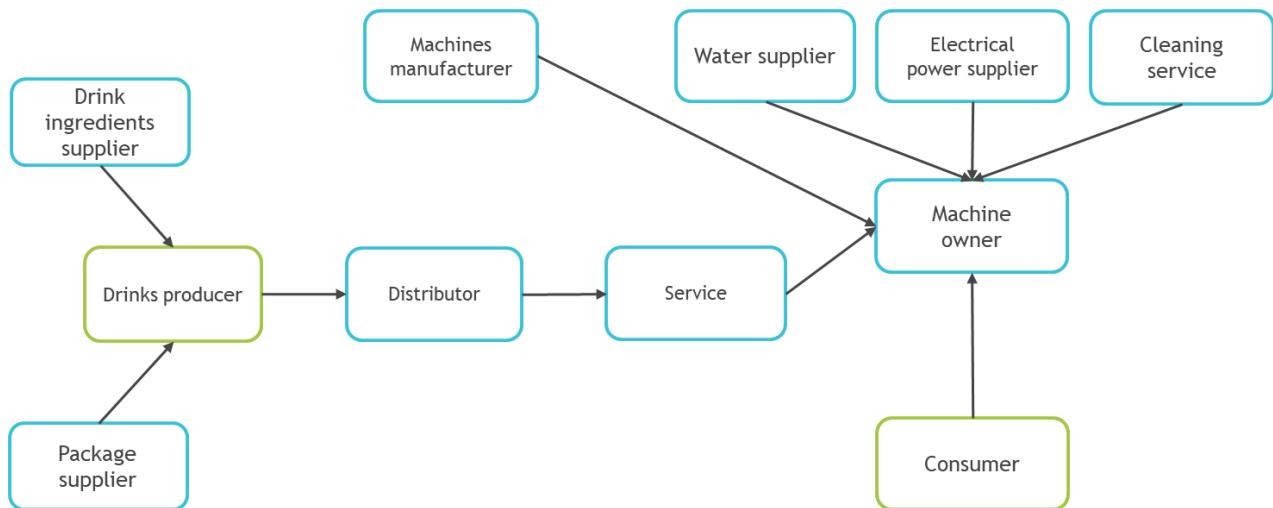


Fig. 6. Simplified value chain for the current of coffee machine business.

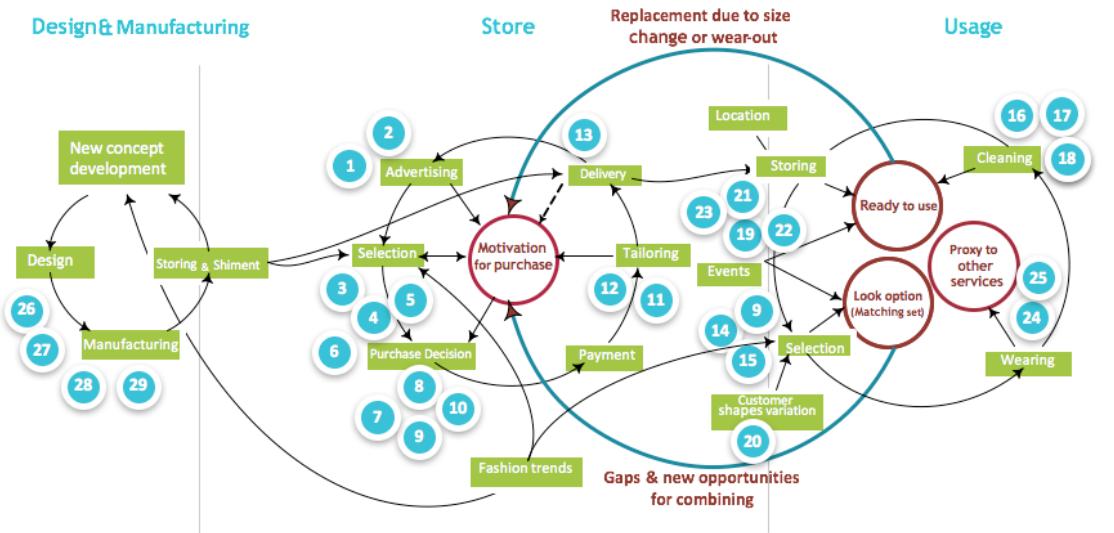
Analyzing the relations between participants of the business ecosystem makes it possible to identify the various flows that exist in the business system, including the flows of raw materials and products, information and financial flows.

The purpose of analyzing flows in the business ecosystem is to identify "bottlenecks" and negative effects, which in their turn are the sources of inventive tasks.

#### 4.3 Opportunity Map

Another EPAM Client – World famous garment brand came with request to fix problem with logistics and number of returns. It turns out that sizes of the same clothing item may differ depending on the fabric where it was manufactured. And again, before diving into the solving of this problem, we analyzed business system in general, but from another point of view.

During business system (BS) analysis we detected challenges, problems, gaps, undesirable effects and etc... As the next step, we execute impact analysis and prioritization and define what problems have the biggest influence on company's business. As an outcome of the process, so called “opportunity map” (you can see example of such Map on Fig. 7) was created.



- 1. 360 degree show
- 2. Virtual store
- 3. Style adviser
- 4. Holo-fitting
- 5. Body tracking
- 6. Size detection
- 7. Friend's approval
- 8. Chatbot
- 9. Virtual try-on
- 10. Self-360 degree view
- 11. 3D models for tailoring
- 12. Adjusted clothes
- 13. Actual clothes size detection
- 14. Style adviser
- 15. Integrated fashion trends
- 16. Time-adjusted cleaning service
- 17. Customized cleaning service adjusted to clothes design and conditions
- 18. IoT to set cleaning conditions
- 19. Planned appearance
- 20. Size variation detection
- 21. Event tracking
- 22. Virtual closet
- 23. Weather tracking
- 24. Profile storage
- 25. Priority storage
- 26. Customized fit
- 27. Customized printing
- 28. Limited editions/series
- 29. Designed by customer

Fig. 7. Opportunity Map

## 5. Using TRIZ tools to identify and solve inventive tasks.

The statistics based on our projects shows that in about 80% of cases it is enough to formulate the right problem and use known solutions. In the remaining 20% - we encounter a problem that contains contradictions, that is, an inventive task. Often to eliminate contradictions, it is enough to use simple tools of TRIZ: methods of eliminating contradictions, inventive standards. But in some cases, there are contradictions that are not solved quickly. For such tasks, we use more complicated tools, including ARIZ.

Below there are examples of using of various TRIZ tools for solving inventive problems in business systems.

### 5.1. Analyzing the process of using drinks

The same client we described in section 4.2 had another challenge of scaling their solution. To collect consumption data from their coffee machines they needed to install an additional module

in to it. This module detected the type of the drink, which was loaded into the machine and consumed. The client already has many machines around the world and these machines had different design. Retrofitting of all these machines represented a great challenge for the client.

To address this challenge, we considered even more complicated problem, which would give us an ideal solution – how can we identify drink without changing the machine design at all?

To solve this problem, we reviewed the lifecycle of a drink pack in terms of identification of consumption event (see Fig. 8). Our client was focused on this event as the moment of loading the pack into the machine. Therefore, they thought that they needed to do something with the machine to make it able to detect the loaded pack. However, if we look at the pack lifecycle, we would see that the consumer makes decision about which drink to consume when he or she picks it from the merchandiser – a container, that stores drinks near the machine. If we change the merchandizer design in a way that the consumers should “tell” the merchandizer which drink they want, then we would not need to detect anything and would automatically get the information about consumed drink. The advantage of this solution is that modified merchandizer would fit any model of already installed.

Another potential solution is to work with consumed packs when they are removed from the machine and deposited.

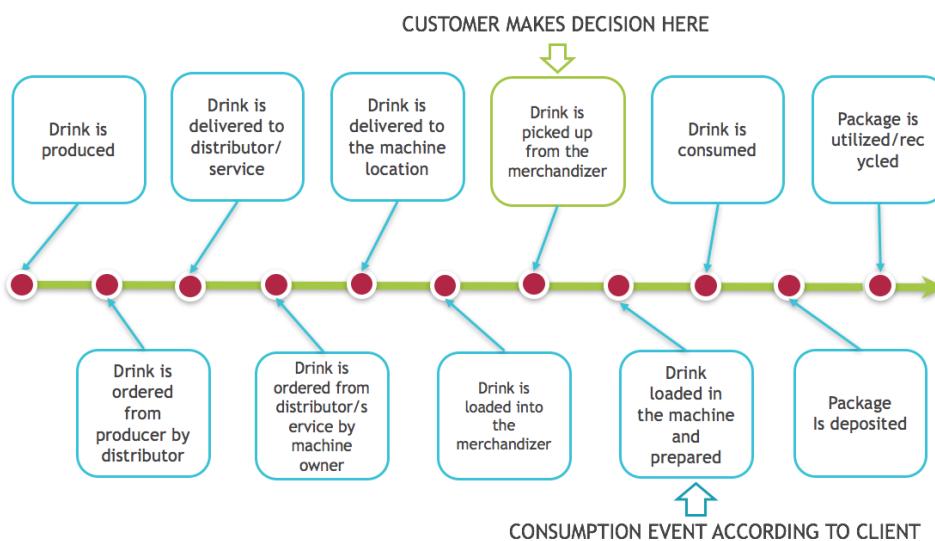


Fig. 8. Life cycle of the drink

## 5.2. Identifying and solving the contradictions in business process of evaluation the credit rating.

In this case study, we used the following TRIZ methods:

- Root-Conflict Analysis Plus (RCA+)
- Inventive problem solving by ARIZ

The source problem was defined as follows:

Sales department of logistical company working with providing cargo shipping service attracts new customers. Given the fact that shipping services are provided with deferred payment, customer engagement procedure involves a preliminary assessment of the creditworthiness of the

client and makes approval of client credibility by Credit Council. Conversion ratio of sales leads to real orders is only 30%, which means that 70% of Credit Council's effort is a waste of time.

What to do in such situation?

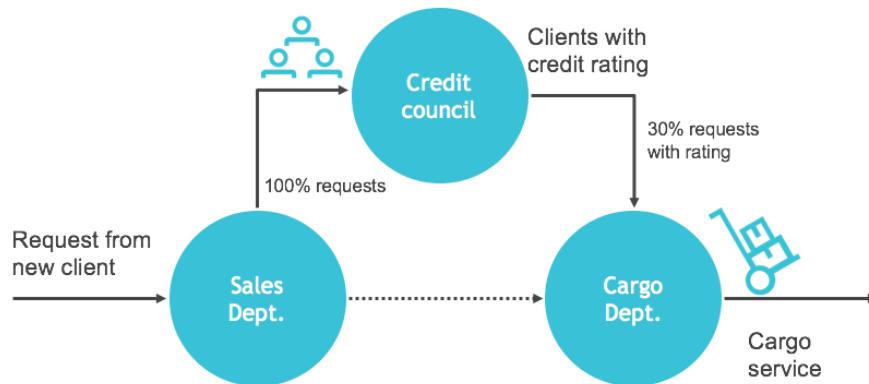


Fig. 9. Credit rating business process

Next figure presents result of RCA+ Analysis of the initial problem and contradiction in requirements.

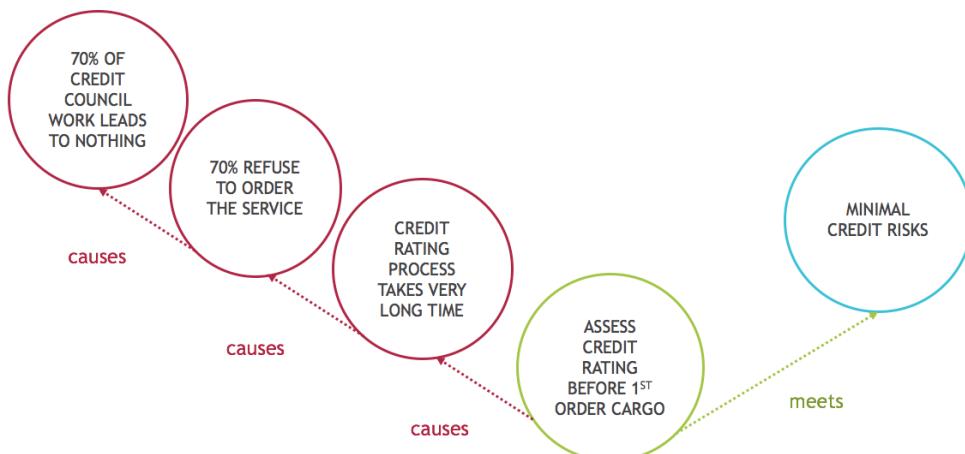


Fig. 10. RCA+ diagram for credit rating problem analysis

**Contradiction in requirements.** If we save the existing solution as “Assess Credit Rating before 1<sup>st</sup> order for Cargo” then (+) credit risks are decreased but (-) clients refuse to make the order for Cargo Service. From the other hand if we change existing solution to “Forward request of new customer to cargo dept.” then (+) Clients confirm buying Cargo Service but (-) Credit Risk are increased.

**Contradiction in property** was defined for Credit Rating process time: this time has to be long in order to decrease Credit Risks, and this time has to be minimal (= 0) in order to Clients confirms buying Cargo Service.

**Operational time analysis.** Credit rating process duration must be long and minimal in the same time. **Operational zone analysis.** Credit rating process duration must be long in Credit Council and minimal In Sales Dept.

Ideal final result: Duration of the credit rating process itself changes from 0 in Sales Dept. to the required time in Credit Council.

Solution idea. After receiving request from new client, the sales person makes shortened creditworthiness evaluation procedure and sets initial credit rating sufficient for 1-2 orders. After the start of the 1st Cargo sales person sends a request to the Credit Council to execute full credit rating assessment procedure.

### 5.3. Solving the problem about dialogue with the visitor (by ARIZ)

The last example which we plan to stop-by is about solving one of the contradictions detected for *car information aggregator* (see Fig. 5 in section 4.1) using ARIZ tool.

Source contradiction: when visitor searches for the car, dialog with the visitor allows to get info about his needs and wishes and find most appropriate cars for him, but visitor must spend a lot of time answering the questions.

Solution idea: After Resources analysis and going with this contradiction through ARIZ the Solution called “Virtual Assistant” has been found. *Car information aggregator* portal uses almost all famous social networks like FB, Twitter, Google Services and others. From the social network profile with a help of data analytics we can form virtual representation of the end-user lifestyle. The last but not the least is that visiting set of web portals and sites Users fill a lot of registration forms answering similar questions.

Solution of the idea. Let the user have own virtual avatar which knows about life style (wishes, needs, fears, etc.) and information about the owner. With this solution *car information aggregator* portal knows almost instantly what car models to offer to the end-user:

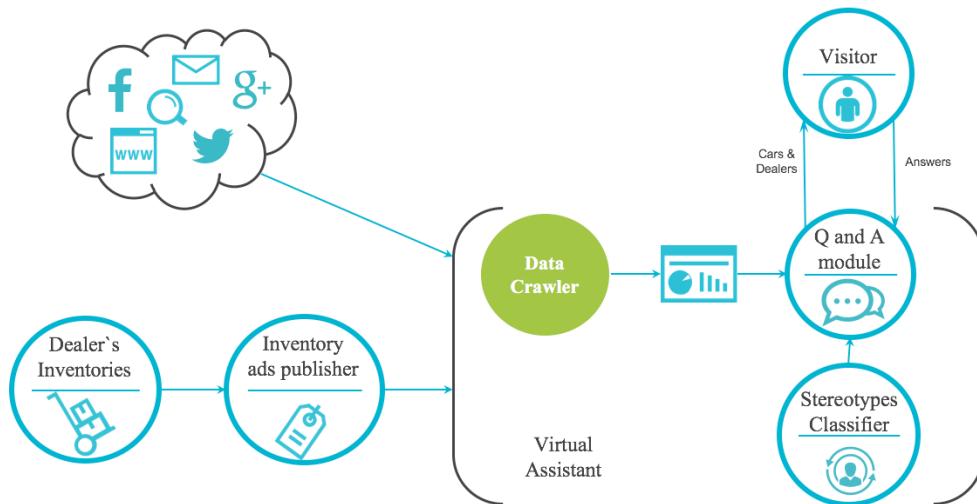


Fig. 11. “Virtual Assistant” Architecture

Speaking on the completely engineering language assistant becomes ChatBot on the user side (User associate) which communicates to the different online services (“Counteraction” TRIZ Principle).

## **Conclusions**

Classical TRIZ oriented on contradiction analysis in engineering systems, finding and solving invention problems in these systems. At EPAM we are constantly facing Client requests which relates not only to engineering system but also to business system of the Client and they expect solutions that make significant impact on the business.

Usage of existing Service Design and Business Analysis tools allows us to analyze the Client's business system and discover existing problems, including inventive problems containing contradictions.

To solve inventive problems in the business system, we use TRIZ tools, such as: functional and lifecycle analysis, techniques for eliminating contradictions, inventive standards and ARIZ. Application of these tools allows to obtain solutions that have significant positive impact on the Clients' business systems and often creates essential competitive advantage.

## **Acknowledgements**

We are enormously grateful to all the members of the EPAM TRIZ team as full co-authors of ideas and solutions presented in this paper.

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# DEVELOPING CREATIVE AND CRITICAL THINKING SKILLS IN NEXT GENERATION WORKFORCE

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## Abstract

The latest World Economic Forum took place January 20-23 2016 in Davos, Switzerland, with the theme “Fourth Industrial Revolution”. One of the outcomes – future workforce will have to align its skillset to keep pace. Five years from now, over one-third of skills (35%) that are considered important in today’s workforce will have changed. The top 4 skills, necessary for success in 2020, are:

1. Complex problem solving – a person must understand the root cause and to address the root cause rather than a symptom;
2. Critical thinking – a method of thinking in which a person questions all incoming information and even their own convictions;
3. Creativity – in a broad meaning, an ability to see something which doesn’t exist yet;
4. Cognitive load management – in a world rich with information streams, formats and devices, the ability to discriminate and prioritize, to filter out what is most important.

Unfortunately, modern school doesn’t teach these skills on any level. In this paper we describe our approach to developing these skills in grade school and university students.

*Keywords: Skills for 21<sup>st</sup> Century, creativity, critical thinking, education*

*“Today, teaching creativity is more important than teaching literacy 200 years ago”.*  
*Sir Ken Robinson*

## 1. INTRODUCTION

Educational system, as we know it today in most countries, was developed at the behest of the first industrial revolution. Literacy was necessitated by changing industrial relations. The predominately verbal forms of communication were no longer sufficient for the support of technological and business processes. Yet, the only available, at the time, industrial workforce consisted of the former agrarian workers, who were moving to the big cities in search of gainful employment at the factories since they were forced from working the land by newly introduced agricultural machinery. These people could not read, write or count. At the time, there was no educational bureaucracy, the schools were created and financed by the companies, in need of the literate workforce. In the process, the needs of the first industrial revolution were satisfied

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<sup>2</sup> Education for a New Era, Moscow, Russia

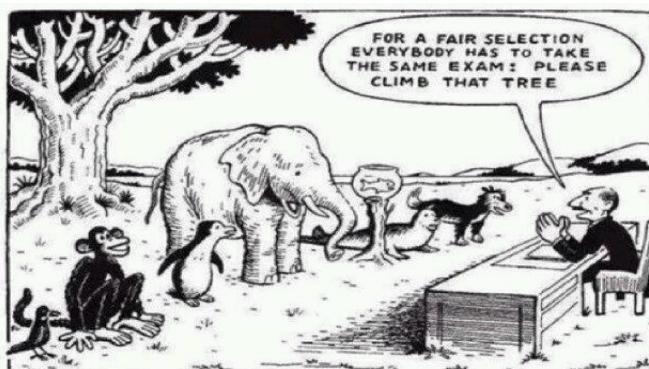
to the extreme. Grade schools produced factory workers and soldiers. Uniformity of skills and knowledge was placed at the base of the educational pyramid. Limited media resources made lecturing the main method of instruction. Technological advances notwithstanding, lecturing continues to be the main teaching method. Lately, an epidemic of standardized tests swept the world. However, even the best of tests do not test all of the important traits and skills of the future associates of the companies large and small.

At the time, it was believed that plants and factories were the most progressive and efficient production entities, thus every attempt was made to extend their practices to other areas of activity. This explains why schools, hospitals, prisons, government bodies and other institutions have many features of factory production, namely the division of labor, hierarchy and complete facelessness.

Ironically, we continue to employ Industrial Era educational system for education of the Knowledge Era workforce. To compete in the knowledge economy, it is true that our students need core skills like STEM – science, technology, engineering and math – but to thrive, in addition to these, they also require other elements, including critical thinking, creativity, leadership, global awareness, collaboration, an eagerness for lifelong learning, and the ability to deal with constant change and ambiguity. Yet, we don't teach nor test these skills. In short, we need to teach kids how to think, not what to think.

We live in a rapidly changing world, and, accordingly, life in this world is increasingly complex. Dynamism has become a characteristic phenomenon of our time. Not only is the amount of information increasing at a rapid pace, so are new technologies, and in tandem with this, public viewpoints are ever-changing as online social networks proliferate. Today, the ability to respond to abnormal situations is vital, to quickly and seamlessly immerse oneself in unfamiliar activities, to establish productive relationships with colleagues and partners, to work in a team, to take risks, to try, to be ready when the opportunity arises.

But a successful life in these conditions requires very different competencies, a different kind of education, and other technologies for assimilating the "new".



## Our Education System

*"Everybody is a genius. But if you judge a fish by its ability to climb a tree, it will live its whole life believing that it is stupid."*

*- Albert Einstein*

Fig. 1 Standardized testing in nature.

Personal Qualities Not Measured by Tests	
CREATIVITY	SELF-AWARENESS
CRITICAL THINKING	SELF-DISCIPLINE
RESILIENCE	EMPATHY
MOTIVATION	LEADERSHIP
PERSISTENCE	COMPASSION
CURIOSITY	COURAGE
QUESTION ASKING	SENSE OF BEAUTY
HUMOR	SENSE OF WONDER
ENDURANCE	RESOURCEFULNESS
RELIABILITY	SPONTANEITY
ENTHUSIASM	HUMILITY
CIVIC-MINDEDNESS	

Adapted from Maria Montessori

Fig. 2. The things we don't teach nor test

## 2. THE PRESENT SITUATION

Every country on earth, at the moment, is reforming public education. There are two reasons for it.

The first of them is economic. People are trying to work out, how we educate our children to take their place in the economies of the 21st century. How do we do that? Even though we can't anticipate what the economy will look like at the end of next week, as the recent turmoil has demonstrated. How do you do that?

The second though is cultural. Every country on earth on earth is trying to figure out how we educate our children so they have a sense of cultural identity, so that we can pass on the cultural genes of our communities. While being part of the process globalization, how do you square that circle?

The problem is they are trying to meet the future by doing what they did in the past. And in the process, they are alienating millions of kids who don't see any purpose in going to school. When we went to school we were kept there with the story, which is if you worked hard and did well and got a college degree, you'd have a job. Our kids don't believe that, and they are right not to, by the way.

The way we address education for areas as different as medicine, physics, computer science, law and art needs to also be very different. Some of these areas require strong theoretical understanding, others require knowledge of a vast body of work, others require constant contact with a fast-changing industry, and others require lots of practice and experience. As individuals grow and blossom in their own fields according to their own strengths, our approach to education must support them in their particular development.

An analysis of today's global trends conducted by the International Laboratory of "Education for a New Era" in 2000 revealed the key contradictions in the sphere of education. Paradoxically, we continue to use Industrial Era educational system for Knowledge Era. They relate, in particular, to the secondary education system, which by dint of its inertia and lack of effective mechanisms for change is in a serious crisis. The crisis of the educational system, first and foremost, of the grade schools, is especially acute in wealthiest countries, and is associated with a rapid drop in student motivation when it comes to education.

In the U.S., Russia, and elsewhere, the educational system has changed significantly in recent years. And yet, the influx of equipment provided to educational institutions, the use by teachers of new technologies, the appearance of new mechanisms for measuring and managing education quality has not really exerted a positive impact on the educational outcomes of students in public secondary schools. We see this in the frustration of young adults unable to forge a path in life, or even conceptualize one.

Unfortunately, we must conclude that today's educational crisis, the essence of which can be summarized as: "Life requires one thing, while the schools teach something else," has not yet been adequately addressed. Life demands that we ourselves seek out what we need to know, while the schools feed us information as a finished product, although it is obvious to everyone that the transition from the introduction to the assimilation of a large volume of information to an understanding of new types of activities – design, artistic, research, promotes the formation of such basic competencies of modern man, as "processing information" (the ability to work with large sets of poorly organized and often unreliable information, analyze it, reformulate it, apply the information to a variety of complex problems), "communicative" (the ability to co-operate effectively with other people, be part of a team), "self-organization" (the ability to set goals, plan, make full use of personal resources), "self-education" (the willingness to design and implement one's own educational trajectory throughout life, to acquire new competencies that ensure success and competitiveness), "creative" (the ability to solve creative problems that lack established algorithms in terms of a solution process).

We still educate children by batches; we put them through the system by age group. Why do we do that? Why there is this assumption that the most important thing kids have in common is how old they are. It's like the most important thing about them is their date of manufacture. Yet, any teacher can list a plethora of differences, which have nothing to do with age.

However, reality shows that although the school curriculum is designed to take age and the students' psychological characteristics into account, the focus is still on the so-called average student without any option for displays of personal interest, both as regards the content and the process of organizing lessons. At the same time, beyond the teacher's ability to see them, there is often a special group of students, children who are gifted in different ways.

Thus, our analysis of the situation indicates that most educational institutions today fail us in how they resolve individual problems, in how they socialize and instruct their students, such that there is an absence of optimal mechanisms for self-organization, both self-driven and collective action by adolescents and also upper-class students.

This is happening against the backdrop of the friction caused by contradictions in education:

- between changes in the environment that lead to changes in the values and goals of education and the existing system in which the school functions;

- between the new problems set before the school, new requirements for organizational and pedagogical conditions and the stereotypes that have developed about how to organize the educational process;
- between the appearance of a new position in the education system (tutor) and the unwillingness of teachers to change their professional and established positions to new professional competencies (supportive, moderator, facilitator, etc.);
- between the appearance of complex new educational technologies (open education technologies, critical thinking technologies, TRIZ technologies, etc.) and teachers who hold fast to traditional methodologies and standard teaching practice;
- between the new challenges faced by the family in raising their children, the new roles parents play and the complete absence of preparation for today's parents by the institution.

Then there is an issue of motivation. Learning requires motivation – an individual matter. If a group format of education is used, then how to resolve a contradiction between group and individual education requirements. If an individual format of education is used, then where the motivational resource may come from? (Teachers don't know how, students don't have the habit, and tutors are too expensive).

As a result, students are missing out on some great opportunities to develop various intellectual abilities and acquire competencies outside the scope of the subject matter — competencies that will equip them for the challenges they will face in today's world.

This is why it is vital that we teach children to perceive the world not through the eyes of an outside observer, but as active participants in shaping their own destinies. Indeed, this is in line with proposals for greater latitude in both the format and content of education. In this regard, the introduction of original pedagogical technologies to develop creative, non-standard thinking in children rejuvenates the learning process, energizing the students and increasing their desire to explore unchartered territory.

On top of this, scientific thought for some time now has recognized the need for substantial changes in educational didactics and is prepared to introduce technologies for the development of new didactics and its practical application in the family, pre-school, and grade school areas of education.

The new curriculum is based on globally-known methods for generating new ideas (from brainstorming to the theory of inventive problem solving), adapted to the education system.

The methodological framework for the development of the new didactics includes methods for generating new ideas, based primarily on TRIZ, which has been accepted around the world, having proved its productive capacity in engineering, design, inventive and project-based education. These methods are adapted to the age and general education of the children, and are complemented by interactive games, practical activities, and more.

### **3. WHAT'S NEXT**

The three most important skills, companies are looking for when hiring new college graduates are: knowledge of the subject matter, problem solving, and team work attitude. All three are solely dependent on an individual ability to think. And most importantly, to be a divergent thinker. “Divergent thinking is creative, open-ended thinking aimed at generating fresh views

and novel solutions”<sup>1</sup>. However, one needs to be skilled at both, divergent and convergent thinking modes, to be a skilled problem solver.

Divergent thinking isn't the same thing as creativity. We define creativity as the process of having original ideas which have value. Divergent thinking isn't a synonym, but it's an essential capacity for creativity. It's the ability to see lots of possible answers to a question. Lots of possible ways of interpreting a question. To think not just in linear or convergent ways. To see multiple answers and not one.

These skills must be supported by:

1. An ability to see problems – is a prerequisite for problem solving
2. An ability/skill to learn – is a prerequisite for cognitive load management

Not all of the contradictions mentioned above can be addressed by our program; however, given that modern education today serves as an important means of self-realization for a person who is aware of the purpose, meaning and value of their own existence in a global world built on the principles of openness and the free exchange of intellectual and human resources, the situation can change for the better, and conditions can be created at the local level that facilitate the development of creative thinking in the next generation.

To begin with, we need to switch from curriculum, teacher, centered to learner centered education model.

Table 1. Educational models

<b>Learner-centered</b>	<b>Curriculum-centered</b>
Child centered	Teacher centered
Constructivist driven	Standards driven
Progressive	Traditional
Information age model	Factory model
Criterion-based	Norm (bell curve) based
Depth	Breadth
Thematic integration	Single subjects
Process and product oriented	Product oriented
Block scheduling	Short time periods
Collaboration	Isolated teaching and learning
Experiential knowledge	Rote knowledge

The switch is a must considering an enormous increase in the number of choices we face on a daily basis. These days it became a genuine open problem. Due to a huge variety of choices, selecting a trade or a place of study, changing residence and finding a new job, even making a purchase has become an open problem. And we need to learn to live in this world of enormous

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<sup>1</sup> <http://www.businessdictionary.com/definition/divergent-thinking.html#ixzz4ChZnkGRQ>

variety. And again, we have a choice – do we continue to think linearly or develop dynamic thinking skills.

There is another fine distinction that makes all the difference. If a person is unable to cope with piling up problems, they are more and more difficult to deal with. It is common knowledge that you sow a temper and reap a destiny. If you want children to be happy and problem-free, teach them properly in accordance with their actual needs and the new realities of life. Incidentally, in this case children display no such reluctance to study as they usually do at an ordinary school.

The big question is how to properly orient education? Here are some effective remedies defined as principles in Anatoly Guin's book *Principles of Teaching Technology*. These principles build a bridge between the present and the future. They are already put into practice in today's best schools and will be just as relevant in future, though applied technically in a different way.

## **Basic Principles of Teaching Technology:**

### **FREEDOM OF CHOICE**

#### **Definition**

In any action of training or management, wherever possible grant the student the right to choose. Provided that the choice is always balanced by the conscious responsibility!

This can be done within the framework of the present education system. Here are just some examples of free choice, offered by world's finest educators. Give the students an assortment of tasks, and they themselves decide what problems to solve. Offers the students to choose themselves what difficult words the teacher should write on the blackboard. Gives the students only the topic and the students themselves determine which object to make and out of what material.

### **OPENNESS**

#### **Definition**

In the process of teaching use open problems; while sharing the knowledge to show the latter's confines; confront students with problems, solutions to which go beyond the scope of the studied course.

Students have a very vague idea of the scope of their information awareness, let alone the boundaries of scientific knowledge. No wonder, they display no curiosity, without which any teaching comes down to upbringing of obedient doers.

At school students learn to solve closed problems (from point A to point B...), while life puts forward open ones. The students' interest and, accordingly, all our educational efforts vanish in the gaping chasm between them.

### **ACTIVITY**

#### **Definition**

Organize development of the students' knowledge, skills, abilities and purports mainly in the form of activity.

While knowledge tests come down to glib answers, resembling a tape-recorder playback, while learning and reviewing are carried out in the mode of memorizing, 90 per cent of school efforts are futile and bear no fruit.

To make knowledge a tool rather than a trashcan in the backyard of the mind, students must work with it. By this we mean that students should assess, apply, convert, extend and complement it, as well as find its new connections and relationships, see it in different models and contexts.

## **FEEDBACK**

### **Definition**

Regularly monitor the learning process through an advanced system of feedback methods.

The more developed technological, economic, social and educational systems are, the more feedback mechanisms they contain. The pilot in-flight monitors the outside temperature, the amount of fuel left in the tanks and other instrument readings all the time. This is a must for a safe flight. The same approach is true for a successful lesson, too. During a lesson the teacher constantly monitors the mood of the students, their interest, the level of understanding and other factors.

## **IDEALITY**

### **Definition**

Improve education efficiency and make it cost-effective by taking full advantage of the opportunities, knowledge and interests of students.

Activity and self-organization of students increases the ideality and effectiveness of teaching and monitoring efforts of the teacher. If we manage to adapt the content of studies and forms of training to the development and academic needs of the class, the students will crave for the knowledge themselves. If we manage to agree on the pace, rhythm and complexity of learning with the abilities of students, they will feel successful and want to further sustain it. This principle implies active involvement of students in management of the team they belong to and, accordingly, in teaching each other. The teacher does not get tired while the efficiency of the teaching effort goes beyond the limit. Certain quite useful teaching techniques have been rejected in view of their low ideality: they require either too much effort on behalf of the teacher or too rare qualities of character.

Principles of teaching technology are declaratory per se. It is the methods and technologies that make them practical. But even the best teaching technique makes only half the work. The second half is the content of education. What exactly shall we teach?

## **What Shall We Teach?**

Education is based on the transfer of knowledge, which often becomes outdated before becoming part of educational programs. It is impossible to keep up with the science.

We are facing a paradox: we must teach children to live in the world of future which is a closed book for ourselves. This paradox appeared relatively recently, when technological and scientific paradigms started to change within one generation. For example, technological paradigms of radio-design changed four times in one generation: vacuum tube – transistor – micro-circuitry – large-scale integrations.

Strictly specialized education does not meet the challenges of life any longer. A domain expert is hard to retrain and knows little if anything of related branches of knowledge. Solution of modern problems requires a systems approach, the ability to see long-term consequences. A successfully solved problem creates new opportunities. A badly solved one brings trouble. This is true not only for academic and other professional activities, but for everyday life as well.

At the present, neither higher nor secondary education meets this requirement. Large commercial companies are increasingly trying – with varied success – to solve the problem in-house. In an attempt to counter narrow specialization, the US Bell System has established The Humanitarian Institute for promising managers.

After many years of educating “subjects and portions” it is hard to expect that systemic thinking will come into existence all by itself. Here is how an eminent Russian educator K. Ushinsky figuratively described the results of such education for an average student. “Concepts and even ideas are arranged in his mind in dead strings, resembling rows of swallows benumbed by the cold. Despite being very close, the swallows are yet unaware of each other's existence; and similarly, the two closely related ideas can exist in such a truly murky mind for decades, failing to take notice of each other.”

A renowned physicist Leo Szilard gave a very elegant illustration of the unknown. It is the space outside a ball, which symbolizes all the knowledge of the mankind. The greater the ball is the greater becomes the border area with the unknown. And each spot of this area is nothing other than a new open problem.

There is nothing that prevents saturating school education with open problems. Regular confrontations with exploratory and creative problems of unknown solutions are as critical for the development of mind as vitamins for a growing body. There are such problems in every subject and interdisciplinary area. And it is these problems that shape and develop creative intuition. After all, apart from being a nature-given talent, intuition is a specifically organized and embedded in the subconscious creative experience of solving unusual problems.

Methods of developing imagination and inventive thinking have already come to education. Here are some facts. The Young Engineers Club in Britain runs regular national competitions, publishes its own magazine. The U.S. Patent and Trademark Office initiated a special partnership PROJECT XL, designed to support the development of inventive thinking curriculum for all student populations. The PTO has also developed the Inventive Thinking Resource Directory for teachers.

Albert Einstein noted that “imagination is more important than knowledge, for imagination embraces the world”. To this we would like to add: knowing how to think outside the box, that is, how to imagine, is even more important. The Theory of Inventive Problem Solving develops and puts into practice high-order thinking skills. Although this theory has already gained ground the world over, the most interesting experimental platforms for its application in education are found in Russia. Of course, these are only tiny sparks in the awakening volcano of new education but they are quite capable of sparking a flame.

However, inventive thinking development alone is not enough for success. To reach the desired goal, it is necessary to acquire teaching skills for creative work organization. This includes scheduling and time recording, ability to work with databases, creation of scientific development evaluation criteria and, of course, discipline. But discipline should be conscious and creative as well, different from the primitive implementation practice. And all this is quite feasible.

## **4. CONCLUSIONS**

***The ideal didactics*** means no didactics at all. A student strives for knowledge so vigorously that nothing can stop them. Without electricity they would read by candlelight.

***The ideal management*** means absence of management while its functions are performed. Everyone knows what to do and does what he should because he wants it himself.

The future of the school is determined by neither the head ruler nor by education minister nor even by teacher. Each education process participant makes his own decision whether to keep pace with the future or turn back on it.

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# DISRUPTIVE TECHNOLOGIES AND DISRUPTIVE INNOVATIONS

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## Abstract

The paper presents one of the previously unknown internal mechanisms of disruptive innovations: achievement of positive economic results disproportionate to the invested effort via mobilization of previously underutilized natural, technological or market (social) resources.

*Keywords:* innovations, technologies, disruptive, planning.

## 1. Introduction

### 1.1. Background

At present innovations are one of the principal engines of economic development. In the recent past much attention was paid to revolutionary (breakthrough) innovations that provide a radical improvement of product parameters, usually by using new principles. Now, however, there is increasing interest in disruptive innovations capable of radically changing the rules of the game and the situation on the markets. The term was introduced by Clayton Christensen fairly recently, in 1995, but it generates over 30M Google results by now.

Prior art approach (1) considers disruptive innovations as those that create new markets, often by making the product significantly cheaper including via sacrificing quality. Classic example of such an innovation is the assembly line manufacturing of Ford's Model T cars (Fig. 1).



Fig. 1 Ford assembly line

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<sup>1</sup> GEN3 Partners, Boston, USA

This significantly reduced price via employment of inexpensive low skilled workers and considerable reduction in quality on many parameters (speed, comfort etc.) compared to higher end models; thus allowing for expanded consumer base and creating an entirely new market segment.

### *1.2. Disadvantages of the existing approach. Goal of the paper.*

Interest in disruptive innovations is understandable: by creating new market segments they are able to generate significant profits, whereas simultaneous collapse of existing segments can cause equally significant losses to competitors. Hence it is essential to have a practical and reliable tool allowing planning this kind of innovations or at least predict them somewhat reliably.

We believe that the existing approach does not fully provide this ability because it allows identifying a disruptive innovation only retrospectively when its main characteristics -- creation of new markets -- is demonstrated. The second of the currently known criteria -- significant price reduction -- also does not seem to us sufficiently reliable. E.g. introduction of the iPhone radically altered the mobile devices market even though it did not involve significant price decrease (in fact, prices rose).

Thus the goal of this paper is to eliminate these weaknesses (insufficient practical utility and mostly retrospective validity) and to identify underlying mechanisms that allow innovations to become disruptive.

## **2. Hypothesis**

To find out mechanisms of disruptive innovations we can proceed as follows: create a sufficiently representative list of past innovations of this type and try to identify common ways in which they achieved disruption i.e. changed the rules of the game and completely altered the situation in their market segments.

Table 1: Disruptive innovations

Use of fire	Sewing machine	Batteries
Agriculture	Steam engine	Antibiotics
Ceramics	Internal combustion engine	Refrigeration
Metallurgy	Electrical starter motor	Pasteurization
Glass making	Telephone	Vacuum tubes
Gun powder making	Electric lamp	Computers
Paper making	Plastics	Internet
Book printing		Iphone

This list is clearly far from complete, but it is sufficient to identify commonalities. The first thing immediately apparent here is that the majority of technologies underlying disruptive innovations are of the breakthrough type i.e. based on new mechanisms of action. But not all of them! For example, book printing, sewing machine and many other such machines and contraptions large and small including spinning machine, mechanical weaving loom, “cotton gin”

device for removing seeds from fiber etc. use well known mechanisms of action; it is just a matter of adding mechanical transmission (and subsequently engine) to the slightly modified working tool (seal in printing press, sewing needle, flying shuttle, brush). Also, development of new mechanisms of action usually takes lots of time and money with no certainty in good final outcome. So, we ought to look for something else.

We note another characteristic feature -- the effect from such innovations is disproportionately large compared to efforts invested. For instance, let's compare two innovations in cars: electrical starter motor and power windows. In terms of technical complexity these two innovations are not equal but nevertheless comparable. Yet, the results are very different. Power windows slightly improved comfort and safety of driving but did not yield any major change. Starter motor, by contrast, allowed widespread use of cars by women since starting a car manually used to be too physically taxing and likely to cause injury to suit an average housewife (Fig. 2).



Fig.2 Crank starter

The car, in turn, allowed them to find employment in industry providing millions of new jobs and giving working women economic independence and possibility of career advancement. Thus, a relatively minor local improvement affected such apparently unrelated areas like divorce rate, birth rate and sexual morality.

There exists a type of phenomena characterized by high output amplitude given small initiating impulse -- these are so-called autowave processes that occur in environments with dispersed energy sources (2). Forest fire and snow avalanche are examples of such processes, using the chemical energy of wood and potential energy of snow on the mountain side, respectively.

If we assume that disruptive innovations (that, in the same way, provide a disproportionately large output) follow a similar pattern, we may conclude that they also **put into use some sort of previously underutilized resources**. Sure enough, any of the technologies in the above list puts into use some kind of resources: natural (e.g. metallurgy turns useless rocks into a construction material with phenomenal properties while glass making does the same with sand) or social ones (starter motor turns housewives into car buyers and employees, and social networks turn regular bloggers into public opinion leaders).

Quite likely it is also possible to have the unused (or underused) resources consist of already existing technologies. In this case disruptive innovation serves as a type of capstone or missing link that joins them into unified chain. For instance, the same starter motor apparently joined

the chain “housewives - cars - jobs” where cars and jobs are technologies and housewives a social resource.

Both statements can be illustrated with the “cotton gin” – a machine that separates cotton fibers from their seeds (Fig. 3, 4):



Fig. 3 Cotton fibers with seeds

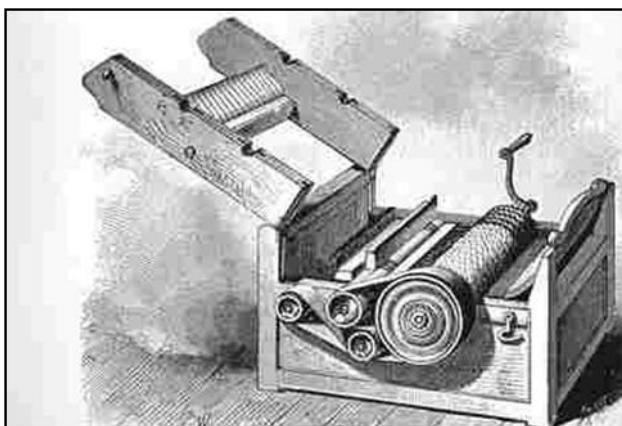


Fig. 4 Cotton gin

In the end of 18th century the major problem of the South was: how to produce enough cotton to meet the demands of England's newly invented spinning and weaving machines. A black-seed, long-staple cotton was easily cleaned, but it grew only near the coast, while a green-seed, short-staple variety grew in inland areas but resisted cleaning since its fiber stuck to the seed. Nevertheless, before cotton can be used, the fibers must be separated from the seeds. Done by hand, it takes a day to get a pound.

Never having seen raw cotton, inventor Eli Whitney within days made a crude model. Based on simple principles, the Cotton Gin was finished in 1793. By 1800 cotton production had increased from about 3,000 bales a year to 73,000. His cotton-cleaning invention brought prosperity to the South.

One can say that there were two effective technologies: green-seed cotton cultivation and fabric manufacturing. They could not work together due to the barrier: extremely ineffective cleaning.

Cotton gin broke this barrier, and 3 underused resources: inland areas, green-seed cotton, and slaves (well, it is history...) were mobilized.

There are also innovations entirely in the realm of business that provide for access to new resources purely via organizational changes. An example of that is franchising i.e. easily scalable business model based on mobilizing the market resource of independent business proprietors (Fig. 5).



Fig. 5 Franchising

Another example is outsourcing: outsourcing companies mobilize inexpensive labor resources of other countries.

We also note that significant price reduction mentioned earlier as a necessary attribute of disruptive innovations is simply one of the ways to get access to the typical market resource - the mass consumer base.

### 3. Conclusions

We have identified one of the previously unknown internal mechanisms of disruptive innovations: achievement of positive economic results disproportionate to the invested effort via mobilization of previously underutilized natural, technological or market (social) resources. In some cases this requires creating a fundamentally new (breakthrough) technology, but this usually involves long and expensive development and deployment. For best results it is thus preferable to develop “missing links” i.e. relatively uncomplicated products that allow to join already existing technologies and other resources into workable chains.

This paper does not answer the question of how and where we should look for promising resources and design chains that may be “completed” with the missing link technologies. Nevertheless, an understanding of the autowave nature of disruptive innovations and their underlying mechanism is useful both for correct problem definition (i.e. if we need a disruptive innovation we should look for underutilized resources and technological chains in need of completion) and for estimating the value of planned innovations (i.e. whether they are likely to prove disruptive through access to extensive resources and/or completing technological chain).

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# **EVOLUTION MAP BASED ON ADVANCE INVENTION, PROCESS, AND CASE STUDIES**

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## **Abstract**

While the boundary between industries has become blurred and changed faster, the patent has become more significant day by day. It is crucial for a company to proactively explore the industry's future in advance before the existing and potential competitors recognize and dominate it. Unfortunately, the engineers are able to compose patents within their knowledge boundary because of insufficient knowledge of other industry as well as lack of understanding customers' desire of another field. The usual engineers are lack of both of innovation knowledge. Even if the engineers have enough knowledge of the needs of the customers, such needs reflect just current point of view. Customer survey shows basically passive/reactive opinion of existing technology or product, which is far from pro-active long-term evolution. If a company launches a new business of unchallenged direction, it is urgently required to identify the past and present of the industry and to predict future image and generate patents for 3-5 years after.

Based on the TRIZ evolution theory and the evolution map, Samsung Electronics TRIZ team has designed a practical application of evolution theory and tried to create patents for them. This article introduces the evolution map based in advance invention of Samsung TRIZ team and the field application cases of home robot invention. The whole process is as following. Firstly, patents were collected as many as possible from the major players in a specific industrial field and classified based on similarity of them. Secondly, the participants who classified the patents have extracted the evolution theme and evolution drivers through internal workshop. Evolution theme is the hypothesis of the ultimate goal of the evolution, and evolution driver is the hypothesis of the direction and path of the actual system change toward the evolution theme. If a couple of patents are discovered during classification process to support the hypothesis, the hypothesis is accepted and visualized as a map so called evolution map. An evolution map is composed of an evolutionary theme and an evolution driver with support patents information in a tree or matrix form. Along the evolution driver axis, the current location can be pin-pointed, and the next stage of the evolution driver becomes a next patent theme of the future. Combining evolution theme and context, new patents could be drafted in advance. The patents derived from this process are pending in Korean, US, World patent office. The result of this technique proved to Samsung Electronics that TRIZ is able to predict future image and compose future patents systematically as well as to solve existing problem of current industry.

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**Keywords:** technology evolution; in advance invention; patent evolution map; EMS (evolution map system); TEOM (technology evolution opportunity mining)

## 1. Introduction

### 1.1. Motivation

As IT industry development has been accelerated since 2000 year by year, predicting future divided literally life and death of a company. The boundaries between industries have been blurred, which makes future prediction harder and more complex. It is inevitable to change its business DNA to survive, which means future prediction tools should 'read' as well as 'lead' 'inter-species' evolution across the traditional business boundary. One more requirement for future predicting tool is seamless link to technical solution as well as intellectual property aligned with customer's desire and needs. The authors hypothesized that TRIZ's evolution theory could provide a working frame reading evolution path, estimating future trajectory, creating new intellectual properties.

### 1.2. Scope and Objective

Many people want to figure out the future technology. If we investigate the systems with intrinsically same feature in the past, we might estimate how our systems would be likely to change in the future. "Evolution trends of technology" [1] could accelerate this process. After studying 8 trends defined by Altshuller [1], and more detailed versions by other TRIZ researchers [2], Samsung Electronics has also standardized 30 evolution patterns inside I-Spark(Samsung Electronics' own TRIZ software, Figure 1, and applied them for prediction as well as problem solving since 2008 [3].



Fig. 1. Samsung's 30 evolution patterns in I-Spark

Applying the evolution patterns to the technical information such as patents, it is possible to draw a figure that looks like a phylogeny tree of biological evolution, so called evolution tree [4] or TEOM (technology evolution opportunity mining) matrix [5].

## 2. Results and Discussion

### 2.1. Approach

The focus of this research is divided into two fields, firstly, how to interpret patent information effectively and efficiently, and secondly, how to ensure creating future patent concepts which reflects ‘real needs’ of future customers. In order to deliver evolution map from massive number of patents, the authors developed a working infra so-called EMS (evolution map system, Figure 2), a human-computer interface to analyze patents and draw an evolution map in 2014.

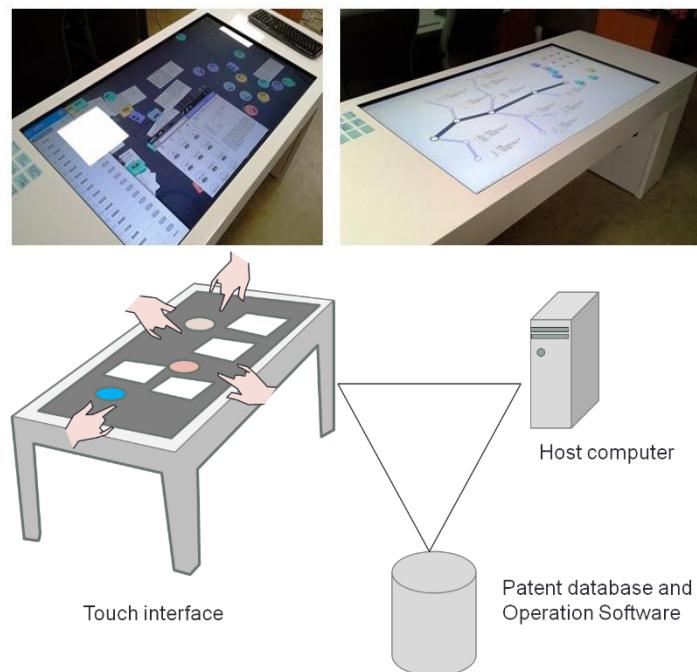


Fig. 2. Multi-touch patent analysis and layout interface EMS (Evolution Map System)

The input of EMS is a large number of patents in excel format and the outcome is a patent database set with a classification structure and an evolution map in which an evolution hypothesis and steps of evolution are visualized. EMS is composed of 2 sub-modules: the first for classifying patent information and the second for laying out an evolution map based on classified information. The first module, patent clustering module, can take up to 10,000 pieces of patent information and visualize data on the screen (titles, applicants, filing dates, representative drawings, abstract, independent claims) as A4 size virtual card format denoted in the following Figure 3.2. The physical dimension of EMS is 60 inch display with usual working table height. On the top of the table display, multi touch interface up to 30 touches has been installed which enables 4 people to handle the virtual patents cards at the same time on the same display.

After reading the information written on the “patent card”, the analyst collected similar patents together using multi touch interface into a same “binder”. At this time, in relation to the similarity of patents, proper name of the binder was defined by the analyst team. To ensure the reliability of the patent classification system, analysts make in depth communication during clustering the cards. Up to now EMS can provide two levels of bottom-up clustering. In deriving the hypothesis of evolution, the authors referred Samsung’s 30 evolution patterns [3] as well as Altshuller’s classical evolution trends [1] as a highest priority. It is impossible to discover the

similar trend which can explain real patents collection; the authors defined our own evolution hypothesis based on the ideality axiom of the classical evolution trend.

Evolution hypothesis could be induced by the discussion of multiple analysts at the same place, which would be used to visualize the evolution map. After clustering the cards and summarizing evolution storytelling, the analysts move to mapping module, where they connect the classified information to storyline to complete the hypothesis map of the evolution. Evolution hypothesis maps can be shaped as tree type or matrix type map so called TEOM [5]. Current EMS v.1.0 supports tree type layout (1.x dimension) only. In 2017, matrix type evolution map (over 2 dimensions) i.e. TEOM also has been systemized as independent software which can be used aligned with EMS.

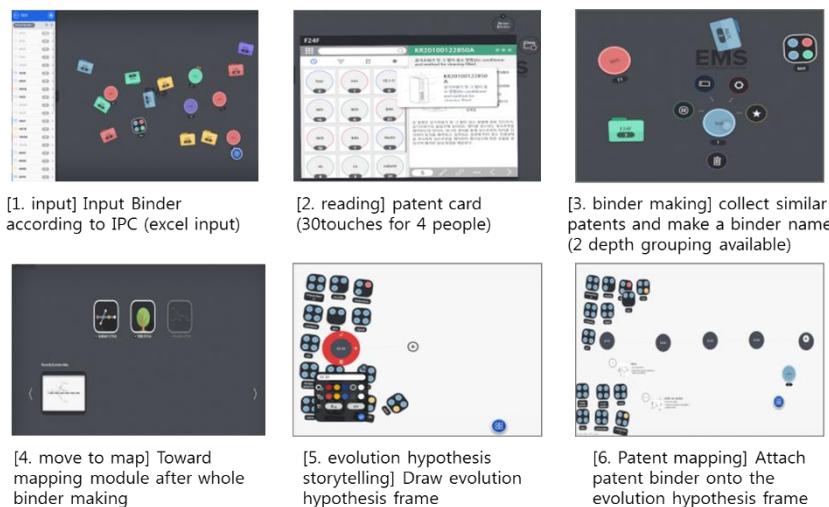


Fig. 3. Working Process with EMS

In order to discover tangible patent items in the near future, the buyers utility map technique [6] from blue ocean strategy, persona, customer journey map [7] from service design were employed to compensated the weak part of TRIZ evolution theory. Buyer's utility map and customer journey map helped the authors to discover unmet needs of the customers. The authors could create new system schema to meet the discovered needs of the customers. When the new concept derived, the ideas was converted to the search keyword for the prior art search to verify the real new-ness of the concept in real time. After such preliminary prior art search, discloser of invention was drafted based on the literally ‘new’ concept. Table 1 summarizes whole procedure of evolution map based in advance invention.

Table 1. Evolution Map Based in Advance Invention Full Process

process	description	input	outcome
1. Define	Define scope and purpose, acquire raw data	Search Keyword	Raw patent/journal information
2. Investigate	Classify raw data, extracting multi-layer evolution hypothesis	Raw patent/journal information	Classified information, evolution hypothesis

3. Visualize	Layout evolution hypothesis with evidence patents	Classified information, evolution hypothesis	Evolution Map (tree type or matrix type), Future evolution direction
4. Evolve	Suggest new ideas aligned on the future evolution direction	Evolution Map, Customer context, Seed Patents	Promising ideas
5. Realize	Verify new-ness by real-time prior art search, verify feasibly	Promising ideas	Prototype, simulation, DOI, Plan for realization

## 2.2. Case 1. Smart Home

In 2014, in order to set up the smart home strategy, the authors were asked to analyse more than 6,600 patents (US patent only) to see the smart home's evolution direction as well as to suggest new concepts of the *novel* patent direction. The collected 6,600 pieces of patents information were loaded up to EMS. 7 analysts (one of them was TRIZ evolution specialist, others were domain experts - mechanics, acoustics, firmware, sensor, UX design, and visual design) classified the big mass of the information into 701 binders under 23 upper groups by bottom-up grouping in 10 working days. The analysts team could induce evolution hypotheses with intensive verbal communication during the binding work. Not only had a simple data clustering function, but also EMS provided a verbal communication environment to unveil the technology evolution and new perspectives of the future shown in the Figure 4.

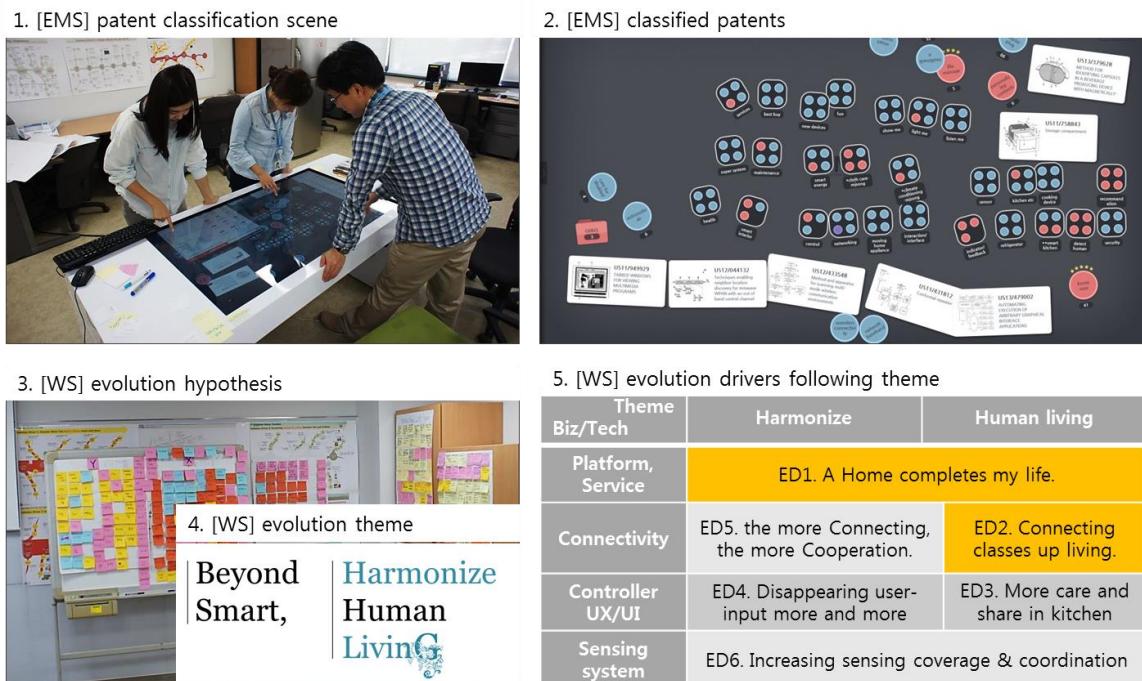


Fig. 4. Smart Home patent evolution map – classification and hypothesis making

Figure 5 presents a map based on the evolution hypothesis "Home completes my life" with 7 evolution steps. The first step starts from a home appliance with basic function only, the second step provides a convenient function, such as remote control, timer, the third step provides functions that makes me free from some risks that might occur. Current home appliances are located on somewhere between the 2<sup>nd</sup> or 3<sup>rd</sup> step. The 4th step is accompanied by the connectivity provided by some smart home start-ups, for example Nest Lab. 5th step provides a chance to create and share something through connectivity in the previous step. At the 6th step, smart home system might touch and organize human's emotion beyond just understanding human being. The final 7<sup>th</sup> step might create absolutely new experience without any system, which corresponds to the definition of ideal system of TRIZ theory [1].

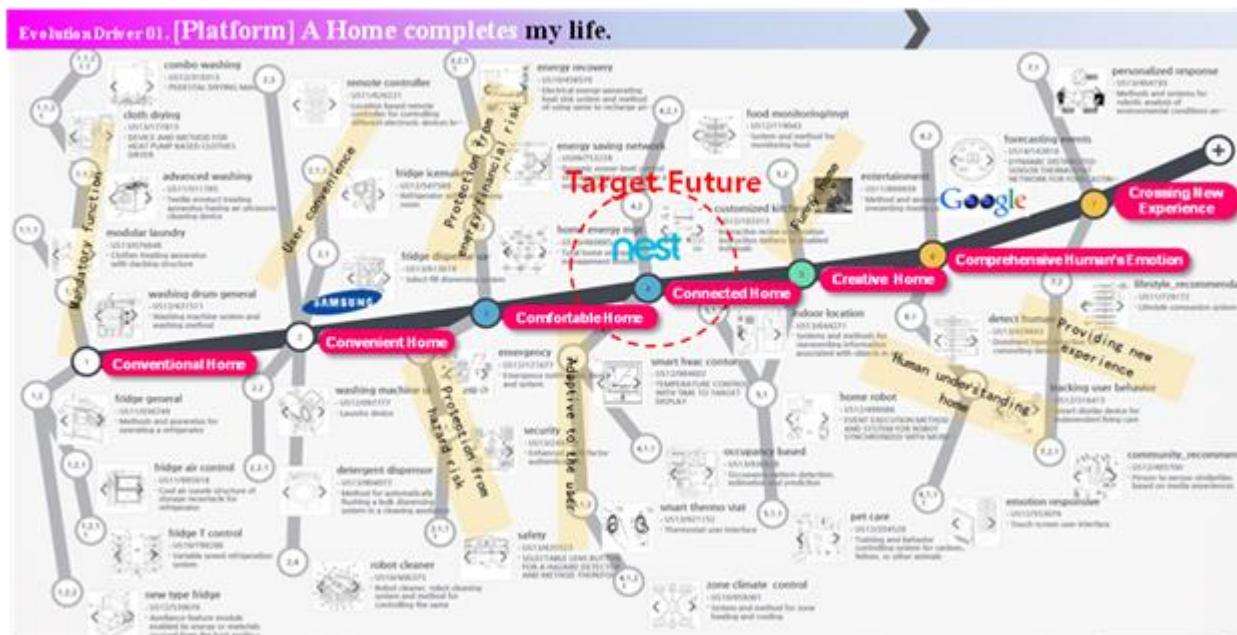


Fig. 5. Smart Home Evolution Map- Home completes my life

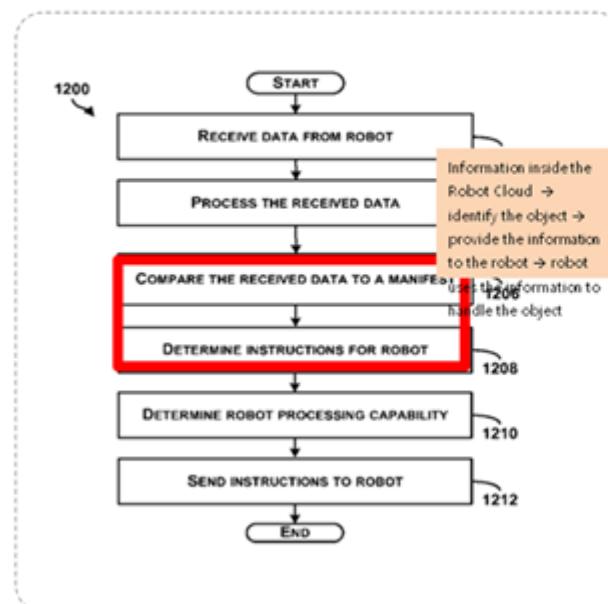
When the authors investigated carefully this evolution map, current status of Samsung was estimated around step 2 and step 3. The goal for near future was the 4<sup>th</sup> or 5<sup>th</sup> step where connecting things could deliver uncovered experiences. The authors asked ourselves what else devices could be connected to the conventional home appliances in the near future. The candidates of new connectivity were as following: family members out of home, family members who are not housewife, infants or handicapped or aged persons, companion animals and plant, home robot and so on. The authors have chosen the issue, 'what' would connect to the smart home around step 4-5 of the evolution map in Figure 5. One of answer that Samsung had never covered was home robot.

There was some evidence a couple of competing company such as Google had great interest in home robot. Google's 2 patents, USP 8380349[8] and USP 8307061[9] were well matched the 4~5 th steps (the next stage of the current evolution step) of the hypothetical evolution map. USP 8380349 makes it easy for Google to dominate robot cloud and search engine as a technology to provide its contents to robot to find a way to manipulate objects using the information stored in the robot cloud. The other patent, USP 8307061 claims the way how the home robot ask query to the robot cloud, where the robot captures an image of the 'identifier' of the object and sends it to the cloud.

The authors analyzed the inevitable problem of query method of the home robot in the usual home environment in USP 8307061 and USP 8380349. One of critical anticipated problems of these home robot patents is so simple. Google's home robot would pick up the identifiers of the object indiscriminately without any prohibition. User context study showed there could be a private object that user doesn't want that the robot 'searches' it as well as 'sees' it. Unfortunately, according to Google's current (published till in 2014) patent set; there was no extrinsic consideration about this privacy problem.

During the enfant stage of the technology in the S-curve, it is likely to miss something critical of the technical system. Acquiring and using the knowledge of the object might be the one of the crucial functions of how the home robot works at home. But the anti-function, i.e. blocking/keeping the knowledge of the object should be considered as the other main function of the home robot. Focusing on the anti-function of current state of art, the authors suggested a special adviser to keep privacy of the users from home robot's indiscriminate query making by taking a picture of the identifier.

(a) US8380349 ~providing instructions to a robotic device  
(Google, 2011.05.06 filed)



(b) US8307061 ~Determining Manufacturer Instructions  
Executable by a Robotic ~ (Google, 2012.09.19 filed)

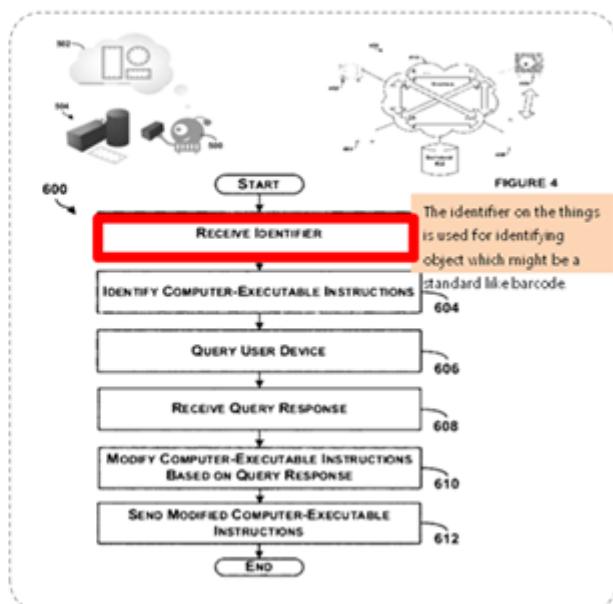


Fig. 6. Core concept of patent (a) US8380349 (b) US8307061

The authors designed a new scheme to allow the robot to recognize the objects and things and perform the query operation, only when the 'things adviser' agreed and/or allowed. After verifying the novelty through the real-time prior art search, the authors drafted the DOI (disclosure of invention) and revised the DOI through a peer review to file up the Korean patent application [10], of which US patents are under processing. There is another patent filed up directly based on the evolution map activity, infant care system of the smart home [11].

The smart home evolution map was delivered to the president of digital appliance business division. Evolution map influenced on the leadership to engage smart home strategic movement as well as to deliver Family Hub where connecting function is installed in the display on the refrigerator door in 2016.

### 2.3. Case 2. Home Robot

In early 2015, the authors started analyzing more than 2,600 patents about home robot to predict evolution hypothesis and design corresponding patent concept design. The main direction was to discover 'new and useful function' of the home robot which was little bit far from mass-commercialization yet.

The authors could induce 14 different evolution driver hypotheses, where 3 evolution drivers were selected to figure out evolution maps as following: 1) Home robot learns me more and more, 2) Home robot has more engagement with me, 3) The value provided by the robot increases. Hypothesis "Home Robot learns me" was likely to evolve following steps denoted in Figure 7. In the 1<sup>st</sup> step, robot is insensitive to learn me. Step 2 corresponds to the present stage "robot starts recognizing me". A robot might understand air around me in the next evolution step 3. Efforts to create new concepts were focused on the step 3 because it was most likely to be the next stage of the 'present'.

The authors simulated various occasion with the aid of buyer's utility map presented in Figure 8 as well as user context studies presented in Figure 9. Buyer's utility map enlarged the vision just focusing on 'use' case only toward whole customer experience from purchasing to disuse as well as inherits. Otherwise, use context study helped breaking the limit of monotonic background, such as male, around age 30, spending very small time at home and so on.

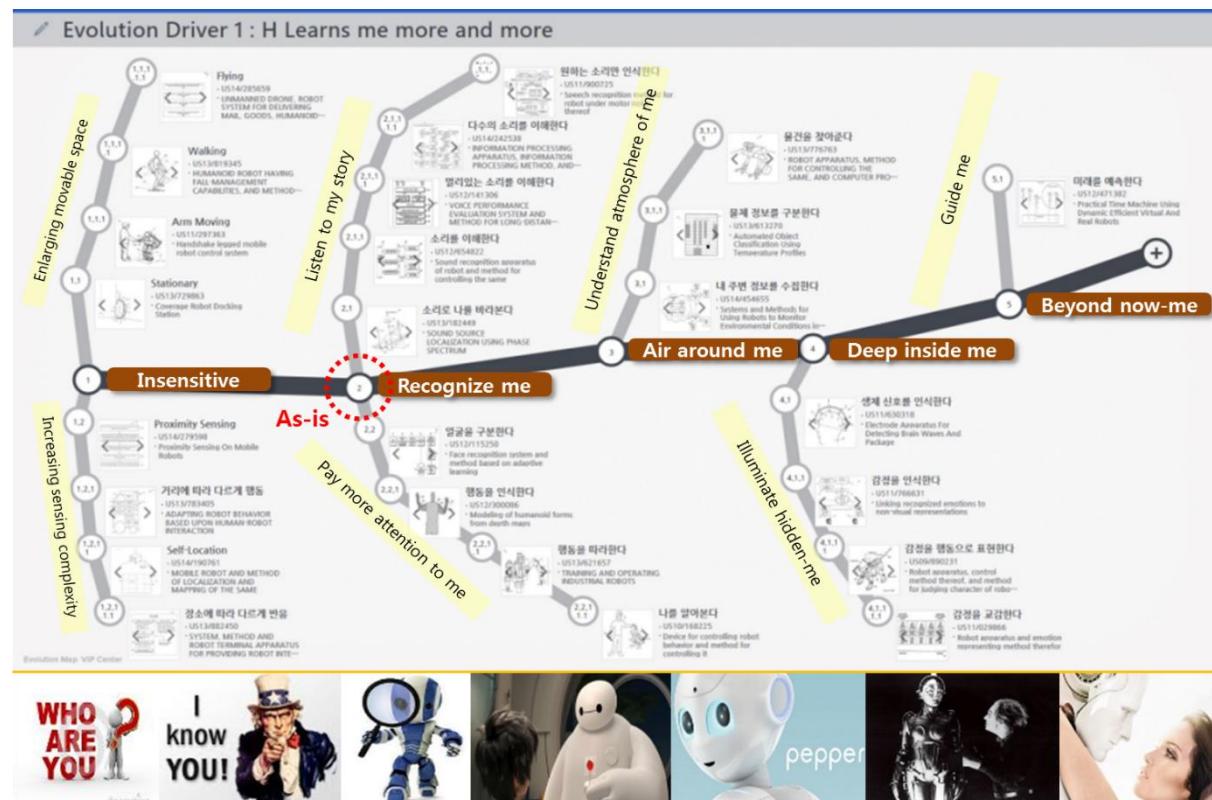


Fig. 7. Home Robot Evolution Map - Robot learns me more and more

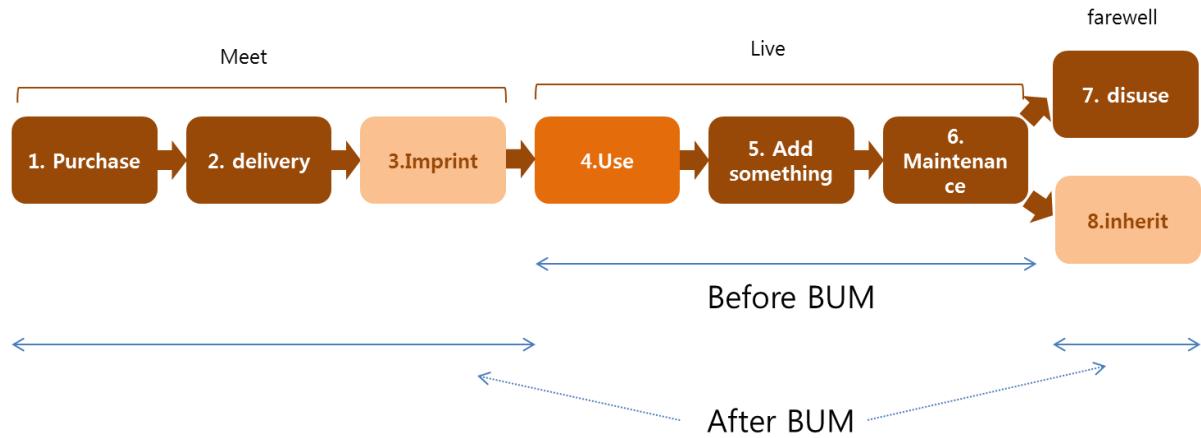


Fig. 8. Buyer's Utility Map for Home Robot

## 1. ROLE PLAY



Mrs. Jeon (age 36, working mom, housewife)

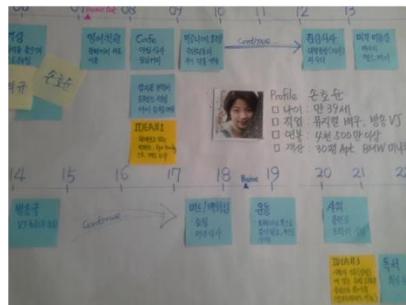


**Ms. Son (age 39, single)**

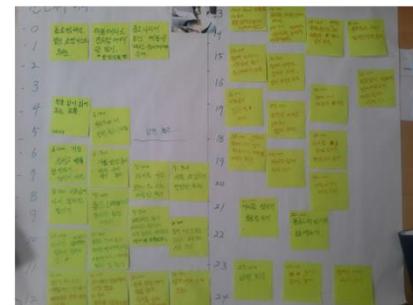


**Map 5a** Map (area 5a - ground area)

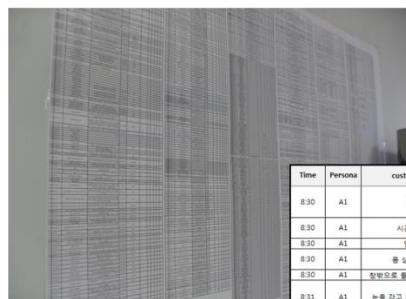
## 2. PROFILE



### 3. USER DAY JOURNEY MAP



#### 4. DETAILED DAY MAP



## 5. IDENTIFY FEATURE, DEVICES

Time	Persons	customer process	Type	detailed description	관련행동, 서비스, things
8:30	A1	장이 끝난	Daily	(설정일) 어제 저녁 카페에서 먹었는 날짜 할로윈과 잘 맞아요 오늘은 날씨가 맑아 한정판 카페에 갈게요. 광고하고 좋아요.	스마트폰
8:30	A1	시간을 확인한다	Daily	시간을 확인하는 행동입니다. 예상되는 시간과 실제 시간이 맞는지 나가기 전에는 예상되는 시간과 실제 시간이 맞는지 확인합니다.	벽걸이 시계
8:30	A1	일정을 끝난다	Daily	지금 일정에서 나온 일을 마무리하는 행위. 조사 대하고 풀어 관리 된 일정은 모두 마무리 됐습니다.	스마트폰
8:30	A1	상황을 확인한다	Daily	지금 일정에서 나온 일을 마무리하는 행위. 조사 대하고 풀어 관리 된 상황은 모두 마무리 됐습니다.	인증, 징계
8:30	A1	앞으로는 예상되는 일정을 확인한다	Daily	내일 예상되는 일정을 확인하는 행위. 내일 예상되는 일정은 전체적으로 예상되는 일정과 잘 맞았습니다.	관련, 커뮤니케이션
8:31	A1	는 걸 깊이 묵을 생각하고자	Daily	날씨가 낮은 온도에 어울려인 걸 깊이 묵을 생각합니다. 날씨가 낮은 온도에 어울려인 걸 깊이 묵을 생각합니다.	비행, 커뮤니케이션

Fig. 9. User Context Study

To ignite 'new S-curve' on the next evolution stage, it is mandatory to imagine 'new function' which might attract the customers' purchasing desire the next stage. Since traditional TRIZ technique has intrinsic limitation to pick up users' unmet needs, persona, role playing, and customer journey map [7] in service design, buyers' utility map of blue ocean strategy [6] were applied to understand real situation of the user. The team investigated the profile of related persona, organized 1,101 conscious, unconscious daily home life event, which were used for investigate opportunity of new function at the 'air around me' steps.



Fig. 10. New concept investigation frame based on TEOM

Figure 10 shows the journey to create the new idea to identify 'me' by the several energy sources where it comes from. Based on the big picture of evolution denoted in Figure 7, system function principle model could be drafted presented in Figure 10 composed of 'bot' as a tool, 'me' as an object, 'F' as an interaction field between the object and the 'bot'. Each element of the principles model follows its own evolution direction, for example, 'F' can follow 'substituting field types' such as MAThChEMEm scale. The authors combine the field evolution hypothesis with the high level evolution driver of 'bot learns me' to make an evolutionable-space so called TEOM [5]. After constructing TEOM matrix frame, the authors could evaluate each patents based on the new developed field evolution lines to 'recognize me'. Visualizing the evaluation results in Figure 10 shows not only the space where the competitors have already occupied (gray cell), but also the space where little/no competitors have occupied (white cell). The authors focused on suggesting new ideas for 'white space', where was 'free' from other intellectual properties. Sound direction idea came from the white coordinate, (3. air around me, 2. acoustic), of Figure 10, which filed up as a new patent after quick prior art search.

Based on combined approaches – evolution hypothesis and customer study, finally TEOM based focused ideation– the team were able to create 72 technically meaningful ideas which meet the next stage customer needs. Following 3 US/Korea/World patents are pending since 2015.

1. Using the sound direction home robot [12] - In providing speech notification, in the actual space, if there is an object related to the notification, the ring will come out in the direction of that object Provide voice notification as if it comes.
2. How to provide optional notifications [13] - Recognize and track feature points of multiple users through sensors, alarm function (indirect alarm / direct), per user (without disturbing others) Alarm) is executed.
3. Action Call [14] - Provide an action call that senses and expresses facial expressions and movements of opponents and users. It has the effect of further increasing the depth, familiarity of social interaction with the conversation partner.

There was one more important outcome of the home robot case study. The team members made their own evolution framework based on TEOM [5] and used it to make patent evolution portfolio map of patent developing engineering division, which means TRIZ evolution theory contributed strategic field of patent development, as well as creation of individual patents.

## *2.4. Analyzing journey of case studies*

### Bottom-up vs. Top-down

There are 2 different ways to make a classification for massive patent data sets. Traditional way is top-down taxonomy; there is pre-defined technology tree structure and the individual patents are attached to the fixed structure. The other way is bottom-up classification; collect similar information and make a common name for the collected information step by step upward. Based on more than 20 experiences of patent evolution mapping of 50,000 patents collection, even if it is clear and fast to classify the big number of information, top-down classification has shown its limitation to re-organize and re-structuralize current function-tree structure to absolutely new ways, which is the essence of 'inter-species' technology evolution. On the other hand, bottom-up classification was very tedious and slow but it could deliver very flexible superimposing cluster structure, which enabled the participants to think more flexible. As the main purpose of the evolution map activity is not only analyzing current technology but also foreseeing novel direction of future 'inter-species' evolution, bottom-up clustering is more recommendable than top-down analysis. At this point, the author recognized a need for a systematic tool supporting bottom-up analysis for evolution map, of which detail is described as following.

### Human interaction vs. Information analysis itself

EMS (Evolution map system), the novel patent information clustering system was developed to facilitate bottom-up classification process. The philosophy of EMS is not just analyzing information itself but also igniting human beings (the analyst team) to make more verbal communication which might enlighten novel evolution direction surpassing conventional paradigm. Patent information could be intuitively grouped through finger movements and active verbal communication between participants, which might induce new classification categories. In bottom-up classification, it is important to analyze the purpose and value of technology rather than technological feature itself. Since the purpose or value of technology is hardly described in the patent documents, it is inevitable to make a common name to describe various technologies under same clustering frame. The naming task naturally requires consensus among the team members. The 30 touches interface with 60 inch visual display of EMS allows 4 people to communicate very freely with their tongues as well as their fingers. EMS won a Samsung work smart award at the end of 2014 for its ability to effectively communicate among participants and classify a large amount of patent information. The information classification user interface was also filed as a patent [15].

### Empathy vs. Technology

Even if the authors could find the direction of future evolution with the help of EMS, which was not enough to create specific intellectual property. It is possible to think the solution that is effective in the future only when participants understand the customer needs in the future. In the beginning of new S-curve, it is the core innovation to make all the 'necessary components' to meet 'new function [1]. Current main function might prolong its identity in the near future, but it is inevitable to introduce 'attractive function' to enchant the heart of the customers, which

means the authors should solve two kinds of meta-problems. The one is to find out 'new functionality, the other is to complete the system without missing part according to system completeness trends [1].

In addition to the direction of the evolution of the big picture, it is crucial to understand where, when, why, for whom the product is to be used, i.e. the actual needs or hidden desire of users. Even if there are lots of variety of users, diversity level of usual Korean society is very narrow. To compensate the lack of diversity in Korean society, the authors implemented special tools such as customer journey map in service design [7] and BUM(buyers utility map) in blue ocean strategy[6] to promote understanding customer problems. Customer journey map promoted the team members to recognize 'un-known' lifestyle and 'unsaid' pain points of our customers following everyday life shadowing or role-playing. BUM helps the team members to think the other part of product before and after 'usual using'.

Analyzing patents is a rational activity. On the other hand, looking for pain points that customers could hardly tell is emotional activity. In the beginning stage of the S-curve, it is most critical activity to complete 'necessary elements' to deliver 'new function'. The first activity is to recognize what function should be delivered. The second activity is to rationalize what elements should be included. The first question could be solved by trying empathic activity, in the other hand; the second question could be solved by patent surveying with assisting with TRIZ evolution theory. The approach of this study, which harmonized emotional activities after rational activity, helped researchers obtain clearer scenario of future.

#### **Impact on the Leadership and the Strategy**

The smart home evolution map was delivered to the highest leadership of digital appliance business division, and it could turn the leader's vision toward more innovative way. New development team had been engaged after reporting smart home evolution map. The first outcome, "Family Hub Refrigerator" could be delivered to the market with the full support of the highest leadership of the appliance division. The keynote speech of Mr. Yoon, BK, and Samsung CEO in CES 2015[16] reflected the core part of smart home evolution map delivered to him around October, 2014 by the authors.

The process of home robot study based on TEOM [5] influenced their own framework to make patent portfolio map, which means TRIZ evolution theory contributes patent strategy, as well as creation of individual patents. For a long time, TRIZ has been well-known methodology of problem solving to Samsung people. The core value of this study is to prove the strategic value of TRIZ evolution theory to the highest leadership of Samsung electronics.

### **3. Conclusions**

To discover promising patents in the near future in advance invention process based on evolution map was designed. In the beginning, large numbers of patent information were classified and corresponding evolution hypothesis map was visualized based on TRIZ evolution theory. Multi touch information-user interface EMS was developed to assist classifying lots of patents and visualizing evolution trend. After visualizing evolution map, the authors could deliver challenging evolution direction as well as tangible disclosure of invention with minimal trial and error. 2 case studies prove how evolution theory have contributed to the big strategic jump of smart home and home robot business of Samsung electronics. The authors expect that evolution map based in advance invention would guide anyone who wants big strategic jump and tangible intellectual properties. The core value of this study is to prove the strategic value of evolution theory on the big picture of R&D beyond just solving mini- problems of the current field work.

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# INITIAL DISADVANTAGES IDENTIFICATION

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## Abstract

Initial disadvantage is opposite of the project goal. However, in many cases, people may set the very obvious disadvantage as the initial disadvantage. But those obvious disadvantages are not the initial ones and therefore, the project goals are not correctly set, and the project scope is very narrow. A new way of how to identify the initial disadvantages is proposed. By keep asking what the consequences it may causes, we can very easily determine which one is the most suitable initial disadvantage and then the project goal can be correctly determined.

*Keywords:* initial disadvantage, obvious disadvantage, project goal, cause effect chain analysis

## 1. What is initial disadvantage?

The initial disadvantage is the invert of the project goal. For example, if our goal is to reduce the cost, then our initial disadvantage is “the cost is too high.” Disadvantages are the facts that prevent us achieving the goal. For example, the insufficient functions, excessive functions or harmful functions identified in function analysis are disadvantages. Cause Effect Chain analysis can find even more disadvantages. We may remove initial disadvantages by removing the disadvantages below the initial one to achieve the goal of the project.

## 2. The importance of determining the initial disadvantages

Cause Effect Chain Analysis is critical when solving practical problems. It can help to identify implicit disadvantages. Removing different key disadvantages can bring different opportunities to achieve the project goal. The more disadvantages we can find, the more opportunities we may have and the more chances we will achieve the goal of the project. A typical Cause Effect Chain Analysis is shown in Figure 1 [1, p.57].

The disadvantage at the top is always set to be the initial disadvantage. And it is the starting point of Cause Effect Chain Analysis. It is like the target of the shooting game. Properly setting the right initial is critical when solving the practical problems.

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<sup>1</sup> NICE (National Institute of low-Carbon and clean Energy), Shenhua Group; NICE, Future Technology City, Beiqijia, Changping District, Beijing, China

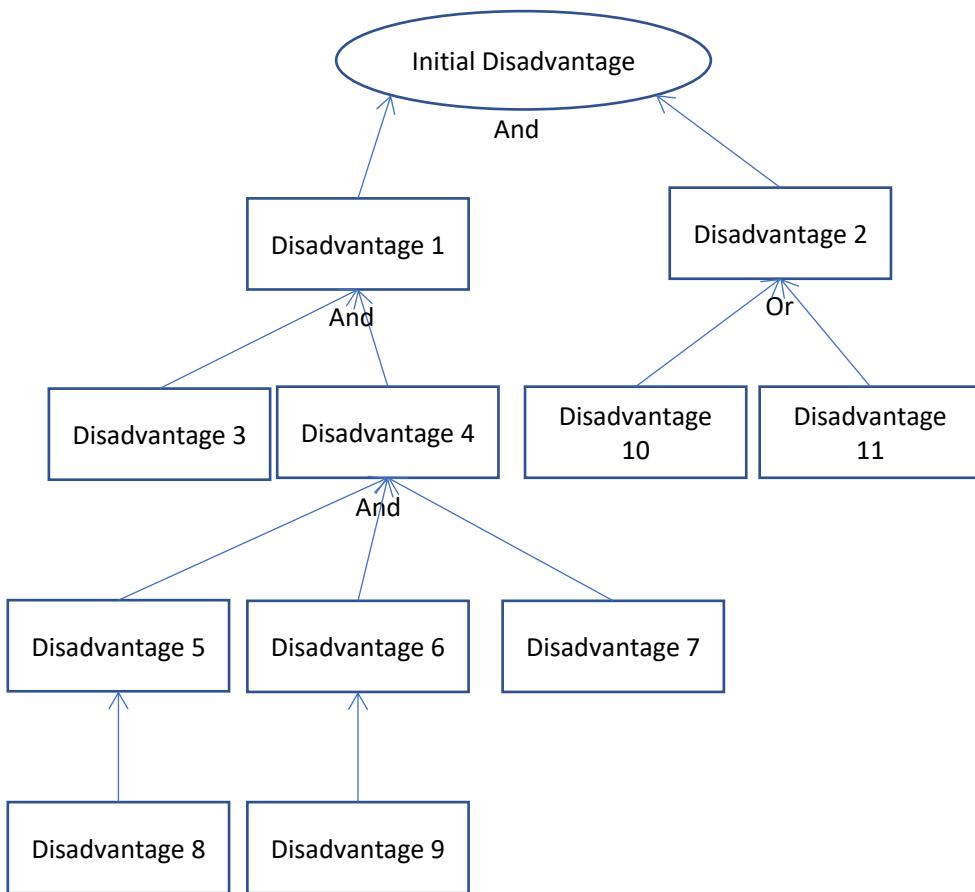


Fig. 1 Typical Cause Effect Chain

### 3. How to determine the initial disadvantages?

In many projects, it is not difficult to determine the initial disadvantages. We only need to invert the goal of the project, and then we set it the initial disadvantage. After that, we can apply routine Cause Effect Chain Analysis layer by layer to find the underlying disadvantages. Those disadvantages (chain) are linked with "And" or "Or" to form a complete chain. For example, if the goal of the project is to "reduce the cost", then "the cost is too high" can be treated as the initial disadvantage. If the goal of the project is to improve efficiency, then "efficiency is very low" can be used as the initial disadvantage.

But when we try to apply this approach to real problem solving, there may be challenges of identifying initial disadvantages. We found that different people may choose different initial problems. In many cases, the initial disadvantages are not that clear as we supposed, some may mistakenly set obvious disadvantage they meet at the beginning of the project as the initial disadvantage. In that case, our Cause Effect Chain Analysis will be led to a wrong direction, and therefore cannot find as many as possible underlying disadvantages, so that we will miss a lot of opportunities. For example, in Figure 1, if we take "Disadvantage 6" as the initial disadvantage, then what we can find out is "Disadvantage 9" only. We will lose the opportunity of identifying more disadvantages, such as "Disadvantage 3", "Disadvantage 5", "Disadvantage 7" ....

For example, there is a very famous case study in TRIZ community developed by GEN TRIZ. In a paint process, the paint overflows because there is too much paint in the tank. [1]. The most suitable initial disadvantage may be “Paint overflows”. However, a lot of people may set “the paint sticks on the float” as the initial Disadvantage. That is because the adhesion between the float and the paint is very obvious and almost everyone can see it. If “the paint sticks on the float” is set as an initial disadvantage, the project scope will be much narrower than the one “Paint overflows”, and many disadvantages or opportunities may be lost. Another example is Triboelectrification problem, which is described in the same book [2, p.67]. The initial disadvantage is “People feel pain (after he / she was hurt by static electricity when they contact the metal object in winter)”. However, most people may treat “Triboelectrification” as the initial disadvantage and therefore, much fewer disadvantages will be discovered and the project scope will be limited in a very small area. The number of potential solutions will also be limited because there are some other disadvantages in the project, but we can't be seen them.

How should identify the most reasonable initial disadvantages? We propose an iteration method to find the right initial disadvantages. In this approach, one of the obvious disadvantages is presumably set as the initial disadvantage. Normally it is not difficult to find one or two that kind of obvious disadvantages. We name this obvious disadvantage as Disadvantage N. After that, instead of finding the causes underlying the Disadvantage N, we will try to look up and find the consequences the Disadvantage N may cause. If we can find the consequence, then we can call it Disadvantage N-1. And then we will compare Disadvantage N and N-1 to see which one is more reasonable to be the initial disadvantage. If we think Disadvantage N is still more reasonable, we will stop the iteration and maintain our original decision. The Disadvantage N will be the most suitable initial disadvantage. On the contrary, if Disadvantage N-1 is better, we will take Disadvantage N-1 as the initial disadvantage and abandon Disadvantage N.

Following the same approach, we will continue to explore the consequences Disadvantage N-1 may cause. After repeating the same process, we will find the other ones, for example Disadvantage N-2, Disadvantage N-3, Disadvantage N-4... After the comparison, we will finally make the decision which one is the most suitable initial disadvantage.

If we take the “paint overflow” problem as the example, even though many people may set the “the paint sticks on the float” as the initial disadvantage because it is obvious. We can follow the approach showed in Fig. 2 and determine the right initial disadvantage. What can “paint sticks to the float” cause? “The switch can't turn off the motor in time” may be the consequence. After the comparison, we may think “The switch can't turn off the motor in time” is better to be the initial disadvantage. And then we will continue to explore. More disadvantages such as “motor moves pump too much”, “pump moves paint excessively”, “paint overflows”, “paint is wasted” and “cost increase due to the paint overflow” will also be identified. After the comparisons step by step, it is not difficult to decide that “paint overflows” should be the best initial disadvantage.

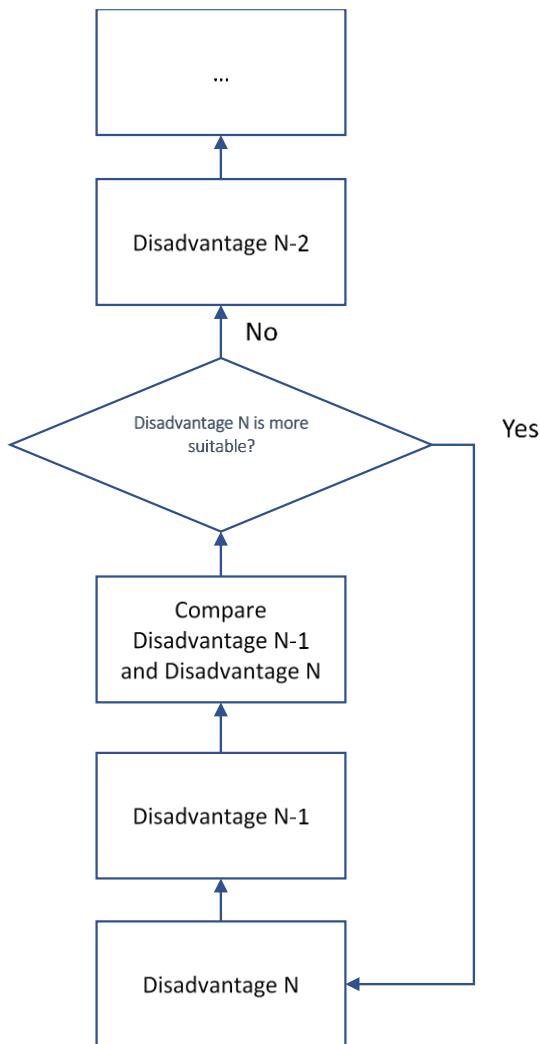


Fig. 2 Determination of Initial Disadvantages

Another example is the “Triboelectrification” problem. It is very easy to find a very obvious disadvantage: Triboelectrification”. And then we can follow the same approach and find out more disadvantages, such as “high voltage in the human body”, “there is current between people and the metal object” and “people feel pain”. After the comparison, we will determine “People feel pain (after he / she was hurt by static electricity)” to be the most suitable initial disadvantage.

After the initial disadvantages are identified, we can step by step build the cause effect chain based on routine Cause Effect Chain Analysis, and then we can continue to determine the key disadvantages to apply TRIZ tools to remove them.

It should be noted that the initial disadvantage hierarchy level should not too high and it should not be too low, either. If the selected initial disadvantages are too high, it will cause very serious deviation between the problems we are trying to solve and real project objectives. On the contrary, if the selected initial disadvantage is too low, the project scope will be very small, and we will lose a lot of opportunities which can help us to achieve the project goal. For example, in the example of “paint overflows”, if we continue to use the iterative method, we will find more consequences, such as “paint is wasted too much”. If we take “paint is wasted too much” as the

initial disadvantage, we will deviate from the goal of the project (because the project is not intended to save paint). For example, in the Triboelectrification problem, if we continue to use the step-by-step iteration method, we will find other disadvantages, such as “the mood is not good”. If we take this as the initial disadvantages, there will be big deviation from the goal of our project, because our project goal is not to please people).

#### **4. Precautions for determining initial disadvantages**

Application of the above iterative method can help us to effectively determine the initial disadvantages of the Cause Effect Chain, but still there are some items need to be paid attention to:

1. The determination of initial disadvantages and the Cause Effect Chain Analysis are team activities, not a job of a single person. The team members need to do intensive discussion and then make the final determination.
2. The initial disadvantage determined by iteration method above should get the agreement of all team members. It should be neither too high level, nor too low level.
3. Initial disadvantages identification and the Cause Effect Chain Analysis are not completely reversible. For example, we identified the disadvantages of N-1 as the initial disadvantages, but the disadvantages of N may not necessarily the immediate cause of the disadvantages of N-1. There may be some other disadvantages between Disadvantage N and Disadvantage N-1. We should follow rules and redo the Cause Effect Chain Analysis from the top to bottom.

#### **5. Conclusion**

This paper developed an iterative method which can help people to effectively determine the right initial disadvantages in the Cause Effect Chain Analysis, which is very critical for real problem solving.

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# INNOVATION FUNNEL OF MODERN TRIZ: EXPERIMENTAL STUDY TO SHOW THE EFFICACY OF THE TRIZ-ASSISTED STAGE-GATE PROCESS

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## Abstract

It is widely acknowledged that today's innovation processes are generally inefficient: various sources indicate that only one out of three-thousand, raw ideas yield a commercial product. Most of the ideas are quickly rejected before much time or money is spent on their development. Those that remain, some 300 raw ideas, are typically selected for further investigation and development, which results in launching around 125 small pilot projects and other time and money-consuming activities – all for the sake of a single commercially successful product. TRIZ-consultants claim a much higher efficacy with the TRIZ-based innovation process because TRIZ provides a more systematic basis for innovation and greatly speeds up the new product development (NPD) process. Unfortunately, so far, there is no solid quantitative data available to support this statement. In this paper, the authors have tried to evaluate the effectiveness of modern TRIZ in NPD by analyzing a pool of technical solutions for new products developed for different companies in actual TRIZ-consulting projects. For each solution, the authors have tried to identify whether the new product was ultimately launched. This analysis revealed (1) the number of solutions/ideas that TRIZ consultants developed in order to launch one new product and (2) the percentage of successful projects. The results show that using TRIZ indeed helps to improve the efficacy of the NPD process from 5 to 15 times, which confirms that TRIZ brings high value to NPD.

*Keywords:* innovation funnel, NPD, TRIZ

## 1. Introduction and problem statement

It is widely acknowledged that today's innovation process is not very efficient in terms of business impact. For example, Stevens and Burley in their extensively cited article [1] indicate that in order to obtain one commercially successful product about 3000 raw ideas are typically generated. Almost all of these ideas are then rejected in the new product development (NPD) process.

The innovation funnel described by Stevens and Burley [1] includes the following steps:

- About 3000 raw ideas are generated and internally screened,
- Approximately 300 of these ideas are then submitted to decision makers,
- About 125 ideas are further developed in small-scale projects,
- On average, only 1.7 of those ideas result in product launch,
- Just one of the launched products is commercially successful.

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Other authors indicate similar numbers characterizing the innovation funnel. For example, Staube in his post [2] indicates that 95 projects aimed at incremental innovations result in launching just one product (which is not necessarily commercially successful). Staube's figures are nearly comparable to Stevens and Burley's data that 125 small-scale projects yield 1.7 launched products.

In some industries, the efficacy of innovation is even lower than that indicated by Stevens and Burley. For instance, in the pharmaceutical industry the innovation funnel is especially inefficient: as Torjesen indicated in her article [3], "for every 25,000 compounds that start in the laboratory, 25 are tested in humans, 5 make it to market and just one recoups what was invested."

In order to improve the success rate of the innovation process, Yoram [4] suggested using a diversified team rather than a single purely technical inventor to generate, screen and present ideas to top management. This should lead to generating fewer bad ideas and rejecting fewer good ideas in an NPD process.

The common perception, though, is that in order to increase the probability of obtaining a commercially successful product it is necessary to generate more ideas, the more the better. For example:

- In Design Thinking, as indicated by Dam and Siang [5], "the goal is to generate a large number of ideas — ideas that potentially inspire newer, better ideas — that the team can then cut down into the best, most practical and innovative ones."
- The Systematic Inventive Thinking (SIT) approach by Boyd and Goldenberg [6] is based on generating a multitude of creative ideas 'inside the box' because "...the density of creative ideas is higher inside than outside."

TRIZ, being an efficient methodology for systematic problem solving, offers a different way to improve the efficacy of the NPD process: generate fewer ideas, but better and more targeted ideas as provided by the TRIZ-assisted Stage-Gate process [7]. The efficacy of TRIZ as problem solving and problem finding tools is confirmed in numerous papers, for example by Filmore and Thomond [8], Harlim and Belski [9], etc.

Many case studies illustrating TRIZ effectiveness have been published [10 -13]. The case studies, however, represent only anecdotal data that illustrate how useful TRIZ is in solving technical problems, but do not disclose whether the solutions obtained using TRIZ yielded commercially successful products. This leaves room for some skepticism and questions about the effectiveness of TRIZ in terms of business impact.

An example of such skepticism can be found in the report by Ilevbare, Phaal, Probert, et al. [14] who clearly expressed a common attitude toward TRIZ: "it appears to pay little attention to linking the inventive problems and their solutions to market needs and drivers. Therefore there exists the unpleasant possibility of TRIZ providing a solution to a problem which has little or no profitability or commercial benefit to an organization." It should be said that this statement seems to be relevant for the older, "classical" TRIZ that utilizes only Altshuller's Contradiction Matrix, SU-Field Analysis, ARIZ, etc.

On the other hand, modern TRIZ has tools such as Voice of the Product (VOP) [15] and Main Parameters of Value (MPV) Analysis [16,17] to address business needs better. Therefore, TRIZ developers and practitioners, including the authors of this paper, claim that modern TRIZ demonstrates very high efficacy in NPD, which is supported by case studies described in a few

conference papers [15,17,18]. However, there is no solid quantitative data to back up this anecdotal evidence.

In this paper, the authors try to fill this gap by deriving quantitative data on the effectiveness of the modern TRIZ innovation funnel and contrast it to that described by Stevens and Burley [1].

## **2. Method**

In order to determine the modern TRIZ innovation funnel, the authors statistically analyzed the outcomes of a wide range of actual TRIZ-consulting projects in which the authors were involved.

The analysis includes the following steps:

1. Out of a pool of completed projects, only those aimed at NPD or at developing/improving a new technology for manufacturing an existing product were selected for further analysis. Projects that were a continuation of some previous project and aimed at developing the same product were not counted.
2. The outcomes of each selected project were identified: (1) how many solutions/ideas were submitted to the client after the problem solving stage of the project; (2) how many solutions were further developed (e.g. substantiation, prototyping or patenting efforts); (3) whether any of these solutions eventually yielded a launched product; (4) whether any of these solutions were rejected by the client.
3. Percentages of “successful” solutions and projects (those that yielded launched products) were calculated.

The following comments regarding this procedure should be noted:

- The number of raw ideas generated in each project could not be identified because (1) the TRIZ-based methodology used in these projects does not assume using brainstorming, SIT or other techniques for generating raw ideas, and therefore (2) raw ideas that were randomly generated in the projects were not documented.
- Since all of the projects analyzed are small (typically 8-12 weeks), they can be considered equivalent to the ‘small projects’ in Stevens and Burley’s innovation funnel.
- It was not possible to identify just how many of the launched products were commercially successful because this is sensitive information that clients are not always willing to share.

## **3. Results**

In this research the authors analyzed a pool of 206 TRIZ-consulting projects in which they were engaged from 1994 through 2017. All of these projects were performed for different clients/companies representing a wide variety of industries. In all projects the TRIZ-assisted Stage-Gate process [7,18] was employed.

From this pool, 161 ideation projects where the objective was to solve a specific technical problem were extracted for further analysis. All other types of projects (e.g. IP landscaping, patent circum-ventions, and feasibility study projects) were excluded from consideration.

The projects analyzed have, in total, yielded 1082 feasible technical solutions that were delivered to the clients after the problem solving stage.

Only 180 of these solutions were selected by the clients and further developed at the substantiation stage of the projects, which means that some ‘small efforts’ were put into them (e.g. computer simulation, proof-of-principle prototyping, or patenting were done).

Of this number, the authors were only able to trace what happened with 64 solutions because often clients did not give feedback on whether the solutions delivered to them were actually implemented. Therefore, the authors analyzed only these 64 solutions, including:

- 48 solutions aimed at developing a new product; and 16 solutions aimed at improving a manufacturing technology or equipment;
- 31 successful solutions, i.e. they were actually implemented in launched products, and 33 unsuccessful solutions; that is, they were either abandoned by the clients or the clients tried to implement them but did not succeed.

Table 1

Modern TRIZ innovation funnel revealed in this research is compared to Stevens and Burley data [1]

Item	Data derived in this research	Stevens and Burley data
TRIZ-consulting projects	161	N/A
Submitted ideas	1082	300
Small efforts (e.g. prototyping) / patent submissions	180	125
Launched products	31	1.7

As can be seen from Table 1, the innovation funnel of modern TRIZ is much more efficient than the regular innovation funnel used in industry. This can be characterized by the success rate at different NPD stages, i.e. by the percentage of submitted ideas and solutions invested with some ‘small effort’ that resulted in launched products.

Fig. 1 shows the calculated success rate of different NPD steps and the success rate of TRIZ-consulting projects in general.

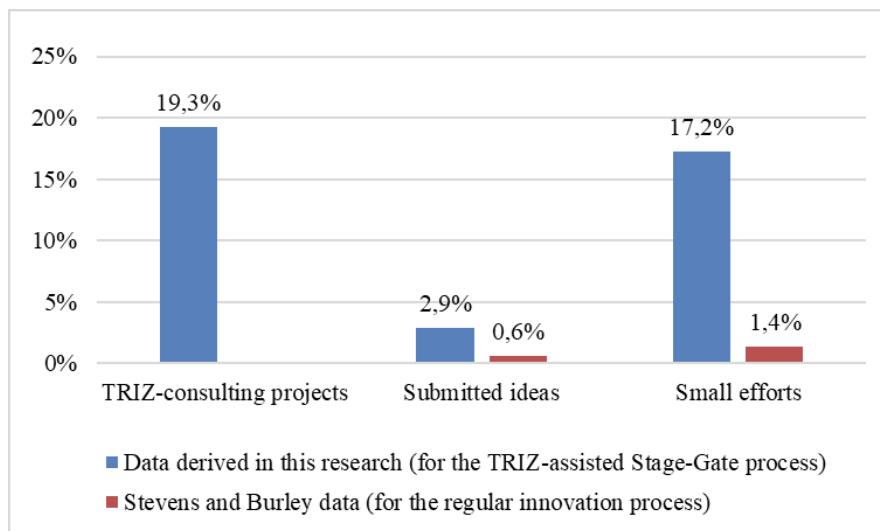


Fig. 1. Success rate at different NPD stages (calculated using the data from Table 1)

## **4. Discussion**

As can be seen from Fig.1, the modern TRIZ applied in the TRIZ-assisted Stage-Gate process provides, by an order of magnitude, a more efficient innovation funnel in terms of the number of small efforts that are needed in order to launch one product.

It should be noted, however, that the results of many projects analyzed in this research are not known to the authors. Therefore, there is a possibility that some solutions resulting from these projects have, in fact, been implemented by the clients or their implementation is still in progress, which may be quite likely for recent projects. This means that the number of successful solutions and successful projects may be higher than estimated in this paper. Therefore, the effectiveness of TRIZ indicated in this paper should be considered as a ‘pessimistic estimation’ while the actual effectiveness of modern TRIZ may be much higher.

In addition, it is important to note that all solutions, including those rejected by clients, were substantiated and proven technically feasible at the end of each analyzed project. The clients appreciated and accepted all of these solutions but later rejected some of them for non-technical reasons.

As shown by the authors in a recent paper [19], while clients rejected some solutions due to the ‘human factor’, most solutions were rejected because they were unpromising in terms of business impact. Such solutions could have been rejected early in the project by the TRIZ team if a new TRIZ tool ‘QEA-based screening’ [20] had been employed. Thus, the authors believe that using this tool may further increase the effectiveness of modern TRIZ.

## **5. Conclusions**

The results presented in this paper show that the effectiveness of modern TRIZ in the TRIZ-assisted Stage-Gate NPD process is by at least an order of magnitude higher than the regular innovation process, and about 20% of TRIZ-consulting projects result in a launched product (pessimistic estimation).

The new TRIZ tool ‘QEA-based screening’ may help to reduce the number of generated technical solutions that are unpromising businesswise, thus further increasing the effectiveness of modern TRIZ and the success rate of TRIZ-consulting projects.

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# NATURE AS A SOURCE OF FUNCTION-LEADING AREAS FOR FOS-DERIVED SOLUTIONS

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## Abstract

Rather than developing completely novel solutions, it is now common practice to identify and adapt technologies that already work in other, sometimes very remote, industries. Function-Oriented Search (FOS) is a tool in modern TRIZ that allows navigating between different industries, and consequently selecting the best available technologies to perform the desired function. One general recommendation suggested by FOS is to look at how the required function is performed in Nature. So far, however, no specific recommendation has been developed on how to identify the function-leading areas in Nature. To address this, we propose a soft algorithm: FOS in Nature. This algorithm helps identify the function-leading areas in Nature, not only at the macro-level (i.e. at the level of entire organisms or their organs), but at the micro-level as well (i.e. at the level of living cells, cell components and biomolecules). A few case studies are presented in this paper to demonstrate the proposed algorithm.

*Keywords:* Function-Oriented Search, Nature, algorithm, biomimetic design, biomimetics, biomimicry.

## 1. Introduction

Function-Oriented Search (FOS) is one of the most powerful problem-solving tools in TRIZ today. The main idea of FOS is to adapt existing technologies from remote areas of science and engineering to solve a specific problem in some area that needs innovation. A solution developed with FOS is easy to accept because, by definition, it is an existing technology that already works in a function-leading area, although there are adaptation problems to be addressed. Moreover, as FOS brings solutions from remote areas of science and engineering, it gives access to the scientific and technical knowledge of the entire world. So, FOS is a practical, efficient approach to open innovation.

One of the possible function-leading areas in FOS is Nature, which, however, is quite unlike other function-leading areas of the technosphere. This is, first, because engineers are generally not as comfortable navigating within subareas of Nature. Furthermore, despite the detailed character of the current FOS algorithm, there are still very few recommendations about how to identify the function-leading areas and corresponding technologies - which is even more problematic for engineers practicing FOS in Nature. And finally, in contrast to the technosphere, Nature does not usually provide ready, existing technologies to adapt, but offers only natural

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solutions for inspiration. These three issues may make the identification and adaptation of the most interesting natural solutions quite difficult for practitioners of FOS.

The present article covers a substantial part of a work-in-progress and suggests ways of tackling the aforementioned issues.

## **2. TRIZ-based biomimetic design approaches**

Nature has been a source of inspiration for inventors for eons, well before the advent of TRIZ, and certainly long before the word bionics (and later, biomimetics and biomimicry) was coined. One example of a biomimetic invention is the battering ram used in ancient Greece, inspired by the ram's forehead [1].

Altshuller once was surprised by the scarcity of bionic inventions and proposed in step 8 of ARIZ-71 the paleobionics approach, i.e. to look first at old Nature “patents”, for they are considered simpler and more effective [2], which may or may not be the case. Interestingly, the latest official version of ARIZ, ARIZ-85C, omits this recommendation.

A long time after Altshuller’s preliminary work, several authors have proposed TRIZ-based or TRIZ-related biomimetic design approaches. A modern TRIZ approach is to apply FOS [3] [4] and consider Nature as a possible function-leading area; however, no specific recommendation is given on how to identify function-leading areas within Nature.

Attempts were made to expand the Altshuller matrix into the so-called Matrix 2003 (and later into Matrix 2010), so as to integrate modern technology findings [5]. Initially it was aimed at building a new contradiction matrix based on identified biological solutions; however, this project was later abandoned when it turned out that the 48 parameters of Matrix 2003 were sufficient to describe biological strategies, and that 95% of the solutions developed by Nature matched the inventive principles suggested by the cells of Matrix 2003 [6].

Other authors proposed a new 6x6 matrix (the 6 considered parameters are: substance, structure, time, space, energy/field and information/regulation) based on biological solutions, but this new matrix keeps the 40 inventive principles unchanged. This so-called PRIZM matrix shows a correlation factor between the respective biological and technological solutions to contradictions of only 12%. Nevertheless, from a practical point of view this matrix suffers the same disadvantages as the Altshuller matrix, including its general and abstract aspects.

Later, Bogatyrev *et al.* [7] proposed new biology inspired trends for developing current technologies with the aim of making those technologies eco-friendly. This interesting approach still needs a detailed description backed up by biological and technological examples to make it fully instrumental.

A comparison between the Altshuller matrix and biomimetic design has been made by Currie *et al.* [8] based on a specific technological challenge, i.e. the design of a proton exchange membrane fuel cell. Although the authors considered only one example, they concluded that biomimetic design and TRIZ seem to yield comparable results.

Another work defines a network of relationships between bio-inspired geometrical structures and principles (symmetry, spirals, undulations, ramifications...), functions, eco-principles, and the Altshuller matrix parameters and inventive principles from TRIZ. Nevertheless, it is questionable whether this approach provides more benefit than the Altshuller matrix.

In their study, Baldossu *et al.* [10] have recommended improving the usability of biomimetic databases (those of the Biomimicry Institute [9] being the most famous), which show how different natural organisms tackle different challenges, by re-indexing them using an OTSM-TRIZ functional model (function carrier – action – function object). This approach could be instrumental, but such a complete, re-indexed biomimetic database does not yet exist.

Weaver *et al.* [11] propose to illustrate both principles for the resolution of physical contradictions and inventive principles with biological examples in addition to technological examples – for better inspiration.

In order to reduce the identification of biological strategies for a given technological challenge, Vandevenne *et al.* [12] have proposed an automatized biomimetic design process. Their process determines product features based on a patent database, and then matches those with organism features determined from a biological database, finally delivering biological solutions. The main drawback to this approach is that the product features do not necessarily relate to the key problems that have to be solved.

Hu [13] has made an attempt to combine biomimicry and TRIZ. He suggested finding all the contradictions linked to a specific problem and determining all the inventive principles that relate to them. Then, using these principles, the problem solver needs to find Nature's "solutions" to similar problems in a biomimetic database.

The most accomplished study so far, by Bogatyrev *et al.* [14], recognizes and explains the complex and empirical nature of biomimetic design; introduces four TRIZ-derived axioms (simplification, interpretation, ideal result and contradictions), and, finally, proposes a 6-stage biomimetic algorithm which attempts to overcome the issues mentioned in the introduction. This algorithm can help when no engineering prototype exists (e.g. for the artificial cilia project executed by Bogatyrev *et al.*). It is well structured and uses sound concepts, such as main function, environment, time and size scales. Some aspects of the algorithm, however, remain unclear (for example, which TRIZ tools should be used for the problem definition?), and too many TRIZ tools must be used, including contradictions, nine-windows tool and the inventive principles, which may make it very complex to apply.

Kamps *et al.* [15] have developed a TRIZ-based biomimetic part-design method for optimizing laser additive manufacturing (LAM) for a titanium alloy reamer. The technological feasibility of a biological solution is assessed to see whether this biological solution matches an inventive principle and the corresponding pair of conflicting parameters from the Altshuller matrix. This method of assessment seems rather constraining.

In the most recent approach by Vincent [16], a database of biological examples has been built where the identified principles that solve any pair of engineering contradictions are sub-classes of the well-known 40 inventive principles. For example, the principle "conversion to dynamics" is further split into 5 sub-principles, including "reduce shock", and the sub-principles might be further split into sub-sub-principles. Interestingly, this database can also be filled with biomimetic case studies. This biomimetic design approach gives the designer a wide set of biological strategies. So, the instrumentality of this approach is higher than that of many others, but yet it is limited by the representative character of the examples studied.

In conclusion, most of the TRIZ-based or TRIZ-related biomimetic design approaches rely either on the Altshuller matrix and/or inventive principles, or on its simplified or refined versions. Also, biology inspired technological trends by Bogatyrev *et al.* [7] might have potential, but they are not yet instrumental.

None of the authors mentioned above, nor any others, have yet developed FOS in Nature. If, however, FOS in Nature can address the issues mentioned in the introduction, it would become an instrumental approach in state-of-the-art TRIZ.

### **3. Biomimetic design approaches and their partial convergence with TRIZ**

Today biomimetic design (or its equivalents) is an active field of science and a recognized design method. Usually two complementary sides of this discipline are considered: the problem-driven and the solution-driven approaches [17]. In the present paper we focus on the former approach.

The problem-driven approach has yielded numerous products, materials, manufacturing processes, robots, optimization methods and algorithms; its fields of applications has expanded to include sports, building, transport, software, etc. This can be seen from the growth in the number of biologically inspired design patents [17]. Nevertheless, the method should be improved to make it more systematic [18].

The power and limits of different problem-driven biomimetic design approaches introduced in papers [17 - 20] have been investigated by some authors, who observe the following similarities with some modern TRIZ tools:

- a functional definition of the problem [17];
- the identification of contradictory functions [17] [19] (e.g. moss should have a big surface area to collect sunlight, but moss should have a small surface area to retain water);
- the extraction of the biological principle [17] and the principle application or analogical transfer resembles TRIZ Feature Transfer tool;
- the search for variations [17] is equivalent to the search for different systems using different principles, i.e. TRIZ Benchmarking;
- broadening the search when reframing the initial engineering problem into biological terms [17], or the search for hypernyms [19], is similar to the function generalization in FOS;
- interviewing biology experts [19] is similar to interviewing function-leading area experts in FOS;
- the search for champion adapters [17], based on the assumption that “extreme habitats provide survival challenges that leverage innovative design solutions” [21], is similar to the identification of leading areas in FOS, for which the fulfilling of the generalized function is a matter of life and death.

Some aspects of biomimetic design not related to TRIZ should also be noted, e.g.:

- the similarity of environment between the initial engineering problem and potential biological solution (e.g., the lunar LIDAR at risk of failure because of fine regolith particles is similar to the environment of some marine bivalves) [19];
- the consideration of different size scales when searching for biological solutions [19].

These observations show that there are several elements of biomimetic design that are similar to classical or modern TRIZ concepts and tools, and a few that are not. Some of these elements, whether or not similar to TRIZ, can be used in the development of FOS in Nature, as will be shown below.

## **4. The algorithm of FOS in Nature**

The FOS algorithm was proposed by Simon Litvin [3] and consists of 11 consecutive steps:

1. Identify the target main parameter of value (MPV) to be improved.
2. Identify the target physical parameter to be improved in order to address the MPV.
3. Identify the key problem to be solved in order to improve MPV.
4. Articulate the specific function to be performed in order to solve the key problem.
5. Formulate the required parameters/conditions for performing the function.
6. Generalize the function by an object and action of function.
7. Identify the function-leading areas (FLA).
8. Identify most effective technologies within the FLA which perform the same or a similar function.
9. Select the technology that is most suitable to perform the desired function based on the requirements and constraints (primarily MPVs) of the initial innovation area.
10. Identify the initial level of similarity factor (SF) between the conditions of performing the function in the selected technology and the initial innovation situation.
11. Identify and solve the adaptation problems required to increase SF in order to ensure effective implementation of the selected technology.

Not all of the above steps need be employed in practice. For example:

1. If a set of target MPVs has already been defined at the beginning of the project, and a key problem has already been defined in functional terms, then the FOS algorithm starts at step 5.
2. If a set of target MPVs has not been defined, then the FOS algorithm starts from step 1; in that case, the output of FOS at the end of step 8 can be used for Benchmarking in the analytical stage of the project.

Whatever the case, steps 7 and 8 are clearly those that should always be used in TRIZ projects; however, they have to be adapted for FOS in Nature. We then propose the following modifications for these steps:

7. Identify in which natural environments the generalized object of the generalized function can be found, preferably at an extreme concentration level (either huge concentrations or minute concentrations), all the time, usually, or rarely. In fact, any relevant parameter (e.g., pressure, speed, contamination) of the generalized object should be considered at an extreme value. Optionally, any component, also generalized, that influences the generalized function can help identify the leading area in Nature; i.e. most promising natural environments where potential solutions can be found. It should be noted that these natural environments may even be living beings.

8.1. Identify which non-biological natural phenomena perform the same or similar generalized function within these natural environments. Possibly this function is critical for the survival of some living beings (threat or opportunity).

8.2. Identify which biocomponents or their products perform the same or similar generalized function within these natural environments. Biocomponents may be any type of life form: animals, plants, fungi, bacteria, or viruses. First of all, look at where this function is critical for

their survival (threat or opportunity). Consider biocomponents at any size, from molecule to biosphere.

8.3. If the key problem is expressed in the form of a contradiction, identify which biocomponents have apparently “faced” and “solved” the same or a similar contradiction, while performing the same or similar generalized function.

8.4. Extract the physical/ chemical/ geometrical feature(s) from the identified non-biological natural phenomena.

8.5. Extract the biological feature(s) from the identified biocomponents.

8.6. Transform the biological feature(s) into physical/ chemical/ geometrical/ information transfer/ organizational feature(s).

8.7. Transfer the extracted feature(s) onto the engineering system/ component at hand.

We denote biocomponents as any part of a living being (organ, cell, etc.), any entire living being or any group of living beings.

## **5. Test of the algorithm of FOS in Nature on some case studies**

### *5.1. Test of the algorithm on a macro-level case study: Mercedes biomimetic car*

Let us first consider the well-known case study of a Mercedes biomimetic car [22]. In a retrospective approach, let us see how the proposed algorithm could have been applied to come up with this concept, and maybe other concepts. In 1996, Mercedes engineers were trying to design a concept car with new aerodynamics. The application of FOS in Nature could have been as follows:

1. The MPV “energy/fuel consumption of a car” should be decreased.
2. The target physical parameter “air drag coefficient of a car” should be decreased.
3. Key problem: how to decrease the drag coefficient of a car?
4. Specific function: the car directs air.
5. Required parameter: the front of the car is short – e.g. so as to park easily in cities - and has a relatively high cross section – so as to transport a sufficient number of passengers.
6. Generalized function: to direct fluid.
7. Fluids that are available “in high concentration” (which may be interpreted in this specific case as high mass density per volume unit) in Nature are water, saltwater, blood or other fluids in animal bodies, plants, or biological cells. For example, fish and aquatic mammals, birds, reptiles, cephalopods can be selected as leading areas.
  - 8.1. This step suggests searching for rocks close to the sea surface that have been eroded by water resulting in a shape providing minimal drag.
  - 8.2. So as to match the required parameter, these animals should have a short front. We identify the female yellow boxfish, the bullhead shark, the beluga and the sea iguana (see Fig. 1).
  - 8.3. It is probable that in addition to the female yellow boxfish, all the identified animals have “faced” and “solved” the contradiction between large and high front and “direct water” with a

low drag coefficient, as they are all predators. The initial key problem could have been expressed as a contradiction.

8.7. In this particular case, the biological feature is easy to transfer to the front of the car because it is (or at least it seems to be) purely geometrical. In practice, one obtains several geometrical options for the targeted concept car. Note that the boxfish has a drag coefficient of a mere 0.06, while a good, aerodynamically designed car has about 0.26 [22].

Mercedes designers created a new vehicle concept based on the female yellow boxfish. The final design had a very unusual shape for a car (see Fig. 2). Tests proved that this shape provides one of the lowest drag coefficients ever tested. However, as was shown above, other prototypes from Nature are available for the biomimetic design of some air or even water transport vehicles.

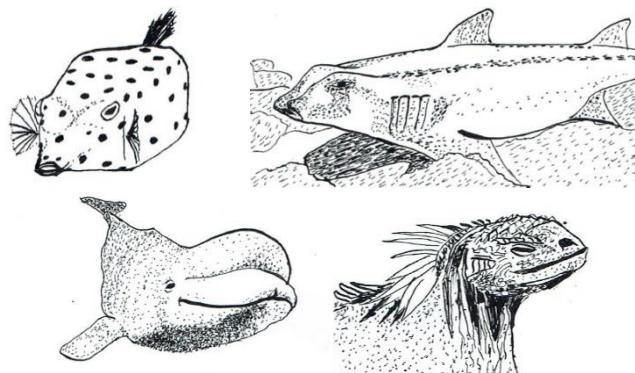


Fig. 1. Composite drawing of several aquatic animals with large and short front (female boxfish, bullhead shark, beluga, marine iguana)

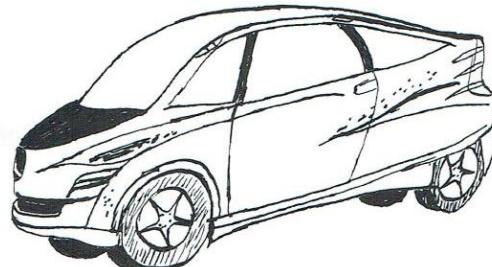


Fig. 2. Mercedes biomimetic concept vehicle based on the female yellow boxfish [22]

## 5.2. Test of the algorithm on a partial macro-level case study: dental mirror

The problem proposed for this case study is the usual dental mirror that gets contaminated quickly while the dentist drills a tooth. It is necessary to avoid any heat that is detrimental to the tooth pulp; therefore, the drill is cooled by a water jet. Drilling readily sprays water droplets and minute tooth residues onto the dental mirror. One efficient, commercial solution is a continuously rotating mirror [23]: the water droplets and residues are removed from the mirror by centrifugal forces. Applying the usual FOS [3] to this problem allows identifying some ideas based on hydrophobic coatings, on hydrophilic coatings, and on some other technologies. In this paper, a biomimetic, passive solution is considered. An application of the algorithm of FOS in Nature starting from Step 4 is as follows:

4. The external part of the dental mirror collects water droplets.

5. The mirror surface should retain its reflecting function, no contamination on the surface is allowed.

6. Generalized function: to collect fluid droplets.

7. A fluid that can be found in extremely fine “concentrations” is water/ fog in deserts, and in heavy “concentrations”, again water, during occasional strong rains, also in dry areas. For example, plants, reptiles and insects from the desert can be selected as leading areas.

8.2. Some animals and plants harvest water from occasional fog in deserts (see Fig. 3): a long-legged Namib beetle [24], the Namib dune bushman grass [25], and a cactus from the Chihuahua desert [26]. The Texas horned lizard collects water from occasional rain [27]. And the list goes on.

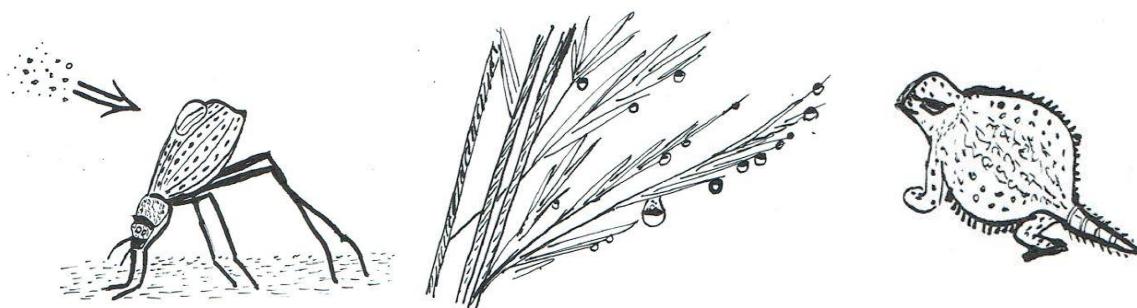


Fig. 3. Composite drawing of two animals and a plant harvesting water

8.5 and 8.6. A complete study of the different physical or chemical features exhibited by those natural prototypes that can direct fluid droplets is beyond the scope of the present article. Nevertheless, the following physical features can be identified: a combination of hydrophilic and hydrophobic zones; capillarity effects with open grooves; property gradients between water harvesting zone and consumption zone.

8.7. It would be necessary to adapt some of the identified features. For example, bumps and grooves and other three-dimensional arrangements are apparently not compatible with the two-dimensional structure of the dental mirror. The rest is left to the reader, who may possibly come up with some interesting solutions.

### *5.3. Test of the algorithm on a micro-level case study: micro- and nanomechanical systems*

This case study relates to reducing friction in micro- and nanomechanical systems (MEMS/NEMS). The problem is that regular lubricants cannot be used if the size of the lubricated parts is small because capillary, electrostatic, van der Waals and chemical forces make these lubricants adhere to the parts and fill all microgaps between the parts.

Therefore, in order to reduce friction in MEMS/NEMS it is necessary to create hydrophobic surfaces with a low friction coefficient and small contact area.

Since the MPV and key problem have already been identified, we will start with step 5 of the proposed algorithm.

5. Required parameters: high hydrophobicity, low friction coefficient, small contact area.

6. Generalized function that provides hydrophobicity: to direct (repel) fluid.

7. Fluids that are available “in high concentration” in Nature are water, saltwater, blood or other fluids in animal bodies, plants, or biological cells. For example, aquatic plants, animals and birds can be selected as leading areas.

8.1. This step suggests looking for natural, non-biological hydrophobic objects.

8.2. This could be aquatic plants, mammal skins and bird feathers that repel water. For example, duck and goose feathers as well as lotus leaves are hydrophobic.

8.3. In this case study we do not express the key problem as a contradiction.

8.5. The biological feature that allows lotus leaves to repel water is the specific microstructure on their surface that has tiny protuberances covered with waxy hydrophobic crystals. Additionally, this microstructure has a small contact area, which is needed to reduce friction in MEMS/NEMS.

8.7. This biological feature is easy to transfer to the surface of MEMS/NEMS parts because it is mostly of a geometrical feature (see Fig. 4).

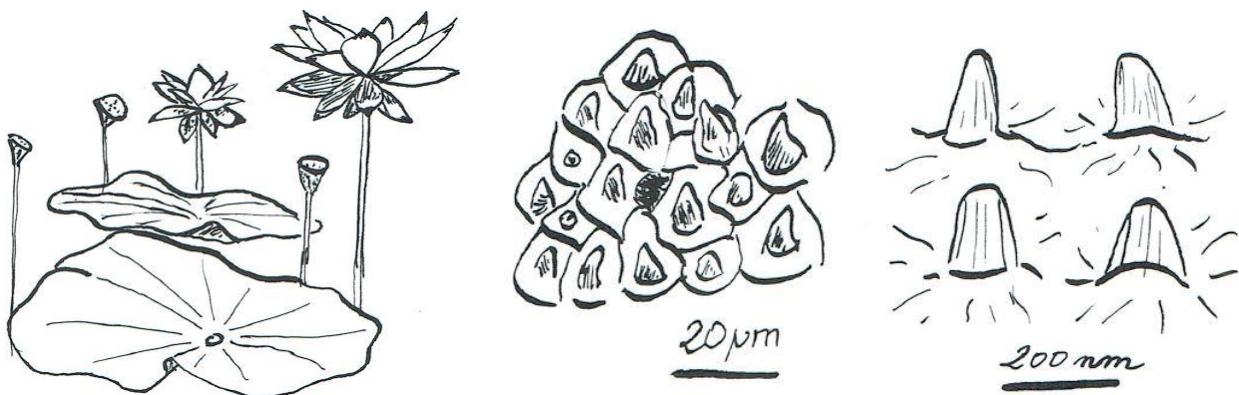


Fig. 4. Lotus leaves, microstructure of their surface and biomimetic nanopatterns suitable for use in MEMS/NEMS [28] [29]

This solution is described by Arvind Singh and Kahp-Yang Suh [29] and is claimed to be very efficient.

#### *5.4. Test of the algorithm on another micro-level case study: wet adhesive*

This case study relates to the development of wet adhesive. One possible application is the adhesion of small mosaic tiles in swimming pools and Turkish baths. Another potential application is the adhesion of structural parts of an aeronautical component in non-standard conditions, i.e. in oily or humid conditions. Usually the aforementioned mosaic tiles detach prematurely from their support due to the adhesive's poor durability, which is probably of a chemical and mechanical nature.

Since the MPV and key problem have already been identified, we will start with step 5 of the proposed algorithm.

5. Required parameters: long durability under water, the surface of the considered support is flat.

6. Generalized function that provides wet adhesion: to grasp a flat, solid surface.

7. Flat solids that are available “in high concentration” in Nature are bare mountains, and rocky lake, river or sea shores, and rocky surfaces in the ocean depths. For example, sea animals or plants that attach to rocks can be selected as leading areas, as well as animals that attach to other marine animals such as sharks and baleen whales.

8.1. This step suggests looking for natural non-biological objects that attach to flat rocks.

8.2. One may consider shellfish, whale barnacles, remora fish, encrusting marine algae, or sea anemone. For example, marine mussels adhere very well to hard surfaces despite the action of strong sea waves (often over 25 m/s) [30] and often contaminated by sand. To adhere to the solid surface, they use a byssus, which is a bundle of filaments whose extremities are tiny feet (plaques).

8.3. In this case study we do not express the key problem as a contradiction.

8.5. The global biological feature that allows for the adhesion of the mussel foot plaque on a flat surface is rather complex; intensive academic research has described it in detail as a specific spatial arrangement of seven different mussel foot proteins (mfps) of polyelectrolyte nature within the plaque (see Fig. 5). Indeed, mfp-3s, mfp-3f and mfp-5 are localized in the plaque-support interface [30].

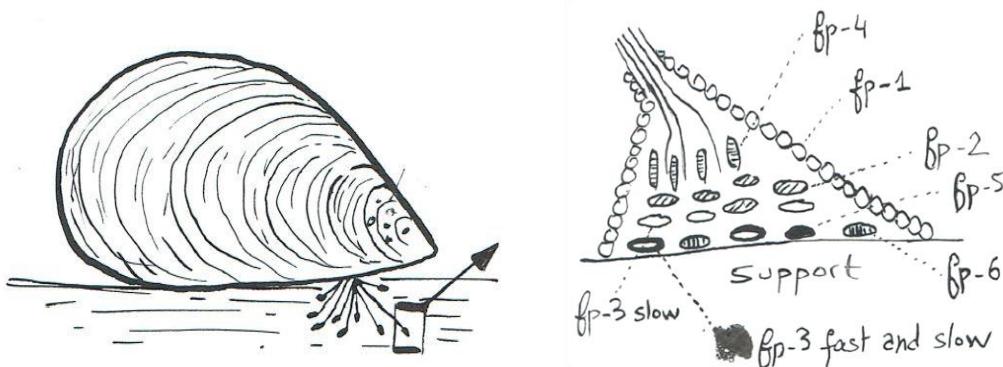


Fig. 5. Marine mussel attached by its byssus to a solid surface and schematic of the different types of mussel foot proteins and their respective locations in the mussel plaque [30]

8.6. Assuming the chemical structure of the three mfps at the place of contact is responsible for the wet adhesion of marine mussels, this biological feature seems as though it can be easily transformed into a chemical feature.

8.7. Unfortunately, transferring this chemical feature to the synthetic adhesive is not easy. First, the considered proteins have complex chemical structures and, therefore, cannot be easily synthetized. Second, there is a wide variety of proteins and their interactions are not well-known. Thus, some simplifications must be made. It turns out that Dopa (3,4-dihydroxyphenylalanine) is the main chemical responsible for the functionality of mfps. If the Dopa functionality is the only feature that is used in a synthetic adhesive, the wet adhesion fails because Dopa is very susceptible to oxidation. This simplification is clearly excessive. Actually, mussels have “solved” the Dopa oxidation problem at the micro-level. First, mussels use specific micro-environmental conditions of adhesive protein deposition which promote a complex coacervation [30], i.e. a unique type of electrostatically-driven liquid-liquid phase separation. Second, they have the following chemical features that provide the targeted wet adhesion, which have been transferred with success onto copolyampholytes [31]:

- high proportion of non-polar, hydrophobic amino acid residues in the flanking sequence around Dopa;
- dynamic pH control, from acidic to neutral;
- ionic strength less than 100 mM;
- catechol functionality;
- amphiphilic functionality;
- ionic functionality.

This example illustrates how tedious and complex the transfer of biological features can be.

Finally, as for the mosaic tiles in Turkish baths, which require a high temperature wet adhesion, a similar approach could be carried out. This may necessitate a study of the biological features involved in the wet adhesion of some animals living at high temperatures (up to 60°C) on hydrothermal vents in the deep ocean, namely “black smokers” and “white smokers”.

#### *5.5. Test of the algorithm on another micro-level case study: bacterial cement*

The problem considered in this case study relates to reducing power/heat consumption during the production of concrete and bricks that are used in the building construction industry. Cement production is one of the most power-consuming industries: it alone is responsible for about 5% of the global carbon dioxide emissions. High levels of CO<sub>2</sub> are emitted when raw materials are converted into Portland cement, and when bricks are hardened using the traditional method, because in both cases high-heat processes are involved.

Therefore, in order to reduce power/heat consumption in these areas it is necessary to develop processes for cement production that do not require heat at all.

Since the MPV and key problem are already identified, we will start with step 5 of the proposed algorithm.

5. Required parameters of the process: low heat consumption, i.e. low temperature.
6. Generalized function that we need to perform at low temperature: (1) to produce solid substance out of fluid; or (2) to hold solid particles together using fluid.
7. Fluids that are available “in high concentration” in Nature are water, saltwater, blood or other fluids in animal bodies, plants, or biological cells. For example, aquatic organisms (plants, animals, bacteria, etc.) can be selected as leading areas.
  - 8.1. This step suggests looking for natural non-biological solid objects that were created out of fluids. One example is stalactites and stalagmites that appear in caves.
  - 8.2. We could look at, for example, a termite mound, corals that create solid reefs, or molluscs that create their hard shells out of sea water. The formation of various stones in the human body can also be considered. Another promising area to look at is bacteria that make calcium precipitate, thus forming ‘bacterial cement’ [32].
  - 8.3. In this case study we do not express the key problem as a contradiction.
  - 8.5. The biological feature that allows calcium precipitating bacteria to form cement out of fluid is their ability to conduct/promote multiple chemical reactions that result in calcium precipitation under normal conditions.
  - 8.6. This biological feature is easy to use if you find or breed bacteria that produce cement fast enough.

Such a solution has been developed and commercialized by bioMASON Inc. [33], who has already built a pilot plant where bricks are “grown” using special bacteria.

## **6. Conclusions**

A specific algorithm named FOS in Nature has been proposed here. This algorithm is based on the eleven steps of FOS, a well-known, powerful solving tool in modern TRIZ. FOS in Nature differs from the original FOS in that it augments steps 7 and 8, so as to help identify the function-leading areas in Nature and natural solutions that can be found therein. It should be noted that the function-leading areas are non-biological phenomena or biocomponents found in natural environments linked to the object of the generalized function. The algorithm has been tested satisfactorily on five case-studies, two at macro-level and three at micro-level.

The present paper presents a work-in-progress. This research will continue in order to make the FOS in Nature more efficient. To do this, for example, a retrospective analysis of numerous biomimetic solutions should definitely help.

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# OPEN INNOVATION: TRIZ APPROACH VS. CROWDSOURCING

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## Abstract

The logic behind Open Innovation is compelling, but implementation can be difficult. In many cases, Open Innovation has failed to live up to its full potential. In our perspective, the problem lies not in the concept of looking externally for help, but in its execution. Unfortunately, the term “Open Innovation” in many cases, has become synonymous with Crowdsourcing. Crowdsourcing is a system, which relies on the probability that the right technology exists, and the right person will respond to the challenge. It ensures neither the right problems being addressed, nor does it filter out the bad ideas.

TRIZ provides a practical means for realizing the benefits of Open Innovation. Several cornerstones of TRIZ disciplined process of Open Innovation distinguish it from the Crowd Sourcing.

First, before searching for solutions, the underlying problems behind the challenge should first be understood. Open Innovation should focus on these key problems, instead of the initial ones.

Second, focus the external search on functions, instead of specific design components or technologies.

Third, search for solutions in functionally similar industries and areas of science and engineering where companies have already invested in R&D to develop the best possible solutions.

Fourth, focus on adapting the solutions to the application at hand, rather than inventing a solution from scratch.

*Keywords: Open Innovation, Crowdsourcing, Key Problems, Function-Oriented Search, Global Knowledge Network, Leading Areas.*

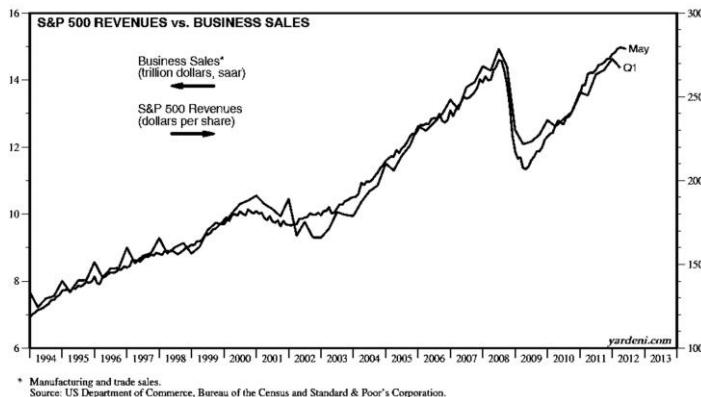
## 1. The Quest of Revenue Growth Acceleration

Top line (revenue) and bottom line (net profits) growth are basic business imperatives. Today's multinational corporations, however, are asked to deliver much more than their predecessors, in a much tougher global business climate. Consider the S&P 500 revenues (dollars per share) and business sales (trillion \$) over the past two decades for a moment. Their steep ascend reflects the intense pressures on businesses to maintain revenue growth. It also demonstrates, of course, their ability to continue doing so [1].

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“... Intellectual assets taken as a whole are rapidly becoming the key to value creation”

Fig. 1. S&P 500 Revenues

Yet, CEO confidence that revenues will always continue to grow as the graph seems to suggest is distinctly low – lower than one would expect listening to the CEOs’ quarterly report chats with investors and the press. PricewaterhouseCoopers International surveyed 1,258 CEOs in 60 countries and no less than 48% expected a decline in revenues, 34% anticipated stagnation, and no more than 15% assumed revenues to increase [2].

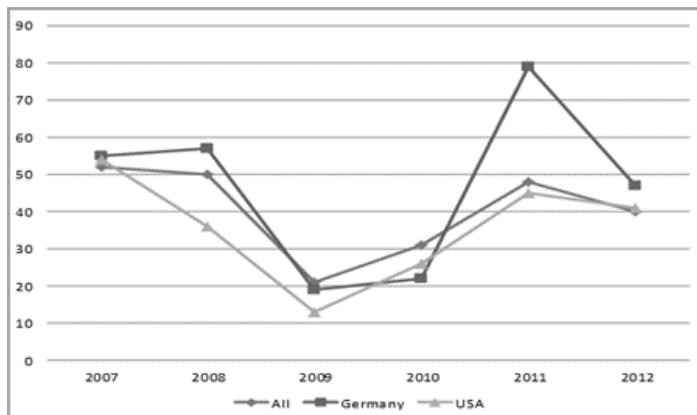


Fig. 2. CEO Confidence for Revenue Growth

Moreover, for many CEOs revenue growth alone is not sufficient. In a survey of 200 executives by Hackett Group (2012), 98% of CEOs stated that “accelerating revenue growth” – not just growing revenue but also accelerating the growth – was their top priority. By all accounts, they are fighting a tough battle as revenue growth figures have been showing continuing moderation [3].

## 2. The Key to Value Creation

Some economists regard revenue growth moderation as inevitable, a result of the natural limits of selling ever more products into relatively unchanged markets [4]. Others, however, argue that the markets’ fluidity and constantly changing consumer needs create a highly dynamic environment in which *transformational innovation* (more on this later) combined with the right business strategies can, indeed, achieve an increase in revenue growth rates.

“CEO confidence that revenues will continue to grow is distinctly low”

The OECD sees innovation as imperative for revenue growth. In an OECD report on innovation and growth, the authors stated “... intellectual assets taken as a whole — ... human capital, R&D and capacity to conduct it, patent valuations as well as intangible assets such as brand value or firm-specific knowledge — are rapidly becoming the key to value creation.” [5]

The Institute for Prospective Technological Studies concludes in “Profits, R&D and Innovation: A Model and a Test” that “the growth of industries’ profits is jointly driven by the ‘pull’ effect of expanding demand and value added, and by the ‘push’ effect of *the success of innovation performance.*” The authors further argue that this “pull” and “push” is supported by the parallel efforts of searching for technological competitiveness — through R&D — and for cost competitiveness — through the adoption of new technologies.” [6]

Most CEOs agree that increasing the success rate of innovation is a key means to driving growth. Automotive power train manufacturer BorgWarner, for example, was seeing declining cash flow when the U.S. economy deteriorated in 2009. The firm reduced wages, closed a plant, and laid off 5,000 employees. However, they did not cut R&D. “Innovation and new technology don’t happen overnight, so you have to fund them,” CEO Timothy Manganello told NYSE Magazine. “Spending money on R&D was the easiest decision I made all year.” In a survey, 40 percent of CEOs said they were increasing spending on research and development [7].

The “success of innovation performance” is a critical term here, but innovation success can be very difficult to measure — “demonstrating ROI” has been cited repeatedly as a key challenge across all industries [8]. Most innovation experts would agree, however, that ROI will typically be small because of an optimization effort and greater from more transformational innovation, reason why the latter is increasingly seen as an important strategic direction to achieve revenue growth acceleration.

### **3. The Difficulty with Different Knowledge**

There are various terms that partially or entirely overlap when it comes to transformational innovation, some with precise definitions, and others less so. For example, *Disruptive Innovation*, *Destructive Innovation*, *Radical Innovation*, and *Breakthrough Innovation*. This paper prefers the term *Disruptive Innovation*, albeit with a different definition than Clayton Christensen’s. We define Disruptive Innovation, as innovation that addresses a major unfulfilled user need and/or that “jumps” from one scientific action principle to the next (for example, from mechanical calculator to electronic digital computer).

Disruptive Innovation is rarely achieved with internal subject matter expertise alone — it often requires an interdisciplinary approach and depends therefore on identifying, accessing, adopting, and adapting *external knowledge*, another major challenge that many firms say they struggle with [9].

Ian Brinkley of The Work Foundation, a Lancaster university-based expert group on work and its future, argued in a presentation that: “Across all sectors, innovation depends critically on the ability of firms and organizations ... to exploit the constant flow of ideas, innovations and technologies through global networks.” These networks should include all stakeholders ... customers, suppliers, and even competitors [10].

“Despite — or, because of — the massive worldwide R&D expenditure (\$1.4 trillion in 2012), identifying the right slice of knowledge is increasingly difficult.”

It is a commonly heard theme, often repeated at conferences, in white papers, and in the press. In many ways, awareness of the “knowledge” requirement — be it internal or external — for success has been rising dramatically. Since the mid-1990s, investment in “knowledge” has grown more rapidly than investment in machinery and equipment and it has even surpassed the latter in the United States [11].

Yet, despite — or, as some argue, *because of* — the massive worldwide R&D expenditure (R&D efforts grew to \$1.4 trillion in 2012) [12] and the resulting knowledge explosion, identifying the right slice of knowledge for a specific problem has become increasingly difficult. As one innovation thinker put it: “How do we deal with knowledge in a world *filled* with knowledge?” By the way, the word “knowledge” is too general. It covers scientific expertise, information about products, technologies, institutions, etc. The problem of a right knowledge identification is even more challenging because of different types of knowledge sources — publications, patents, databases, registers, websites, experts’ brains, etc.

Harvard energy policy expert Matthew Bunn noted that knowledge growth makes innovation more difficult: “... it is true that as particular areas of science and technology become more complex and the “easy” discoveries get made, it becomes more difficult and requires more resources to push their frontiers further,” he writes [13]. Author Kevin Kelly goes even further. He makes a convincing point that as knowledge is growing exponentially, so is our ignorance. “The paradox of science is that every answer breeds at least two new questions. More answers, more questions. Telescopes and microscopes expanded not only what we knew, but also what we did not know. They allowed us to spy into our ignorance. New and better tools permit us new and better questions. All our knowledge about subatomic particles derived from the new questions generated after we invented an atom smasher.” [14]

#### **4. The Limited Interpretation of “Open Innovation”**

To navigate this knowledge explosion, innovators are confronted with having to find effective and efficient ways to bridge the gaps between their expertise and other fields of expertise. In practical terms, this means that they have to somehow request (*formulate the right problem*), *identify, adopt, adapt, and integrate unfamiliar knowledge* from unfamiliar areas of science and technology.

This identification process is a generally overlooked aspect of Open Innovation and a key reason why Open Innovation, since Henry William Chesbrough coined it, has been less successful than initially anticipated. Just take, for example, the impressive 179-page report titled “Understanding Knowledge Societies” published by The Department of Economic and Social Affairs of the United Nations Secretariat [15], which extensively investigates modern knowledge creation and its role in society. In it, no mention is made of methods for finding a specific piece of knowledge in the swelling ocean of global knowledge.

This lack of methods to identify precise pieces of external knowledge has contributed to limited applications of Open Innovation, as most firms prefer to stay well within their knowledge domain while sourcing knowledge outside the firm. For sure, day-to-day Open Innovation attempts are evident across most industries; rarely, however, do they extend significantly beyond an industry’s “comfort zone.” The Life Sciences, for example, are witnessing a convergence of public and private R&D toward open innovation and open source information. Recently, GlaxoSmithKline, Novartis, Pfizer, and Eli Lilly joined the Structural Genomics Consortium, a public-private partnership aimed at the discovery of new medicines through open access research

[16]. These pharmaceutical firms, of course, share or are intimately familiar with each other's' core competencies.

On the manufacturing side, an impressive 81% of U.S. companies said in the same survey that they are involved with some type of collaborative R&D. Not much of this collaboration crosses industry lines, though. A recent study based on 8,180 observations shows that the importance of internal sources for inventions is three times higher than that of external sources. It also indicates that the stakeholders in a firm's value chain, from suppliers to end users, serve as the most frequent sources of knowledge [17].

Enkel and Gassmann of the Swiss Institute of Technology Management lament in R&D Management (2010): "... innovation studies do not recognize the value of partners outside the value chain .... Drivers of innovation, such as technology fusion, shorter innovation cycles, the mobility of workers across industries, and the global availability of knowledge, make accessing external technologies imperative as well as easier." They conclude that: "The first studies on the optimal cognitive distance between alliance partners find that in industry or field of experience, distance is not counterproductive but can be a source of both *disruptive and incremental innovation* [18].

In the academic world, interdisciplinary translation and synthesis is increasingly deemed critical, as issues around a complex research effort require full involvement by more and more disciplines. "... this is not a deviant exception, but a common path for the modern academic. We need to learn how to understand, navigate and employ multiple and often contrary ways of knowing," writes Clinton Golding of the Centre for the Study of Higher Education [19].

## 5. A Tower of Babel?

While learning to navigate the ways of knowing sounds like a logical approach, the reality of hundreds of increasingly complex yet completely disconnected disciplines is stark. Basarab Nicolescu, the president and founder of the International Center for Transdisciplinary Research and Studies, asks darkly: "Is a modern tower of Babel inevitable?" He sees no simple solutions for one discipline relating effectively to another: "How can a theoretical particle physicist truly dialogue with a neurophysiologist, ... a biologist with an economist beyond mouthing more or less trivial generalities? ... Disciplinary language is an apparently insurmountable barrier for a neophyte, and each of us is a neophyte in some area." [20].

Nicolescu goes even further, arguing that if we are all ignorant of each other's' disciplines, then any attempt to find common ground would merely result in one generalized incompetence, "for the simple reason that the sum total of competencies is not competence: on the technical level, the intersection between different domains of knowledge is an empty ensemble." To solve this "dangerous" condition, as he sees it, Nicolescu goes on to dive into Interdisciplinarity, Multidisciplinarity, and Transdisciplinarity, none of which is very pragmatic tools for knowledge translation.

"Cognitive distance between partners is not counterproductive but can be a source of disruptive and incremental innovation."

One interesting attempt at overcoming Nicolescu's Tower of Babel is *cybernetics*, which proposes a formal language (with concepts and terminology) to build bridges between different disciplines based on the fact that many disciplines construct similar models, even if intended

for different applications. A well-known example of such a model is control by negative feedback, which is used across many areas of science and engineering. By identifying these shared concepts, cybernetics serves as a kind of translator between them. [21]

## 6. An Emerging Lingua Franca

We will take a closer look at another approach, one that goes a step further than cybernetics in that it strips the domain context of a product or process down to its bare functions; so bare that they exist in many domains. The approach allows an R&D team that is looking to find a new way to perform a certain function to “cut through” the unknown domain-specific substance of unfamiliar technologies and identify the way they perform the needed function. Called *Function-Oriented Search* and developed by one of the authors Dr. Simon S. Litvin, the method comes very close to representing a *lingua franca* for the multitude of science and technology fields.

How does this work? Systems can perform on each other hundreds of typical functions. For example, DIRECT, MOVE, STOP, HEAT, PRESS, INFORM, or HOLD. They are typically identified via a technique called Function Analysis, the results of which are charted in a Functional Diagram. The Functional Diagram shows all the components of a “system” (the product or process) and the functions they perform on each other.

To illustrate this, below are three greatly simplified Functional Diagrams for three completely different systems in three different knowledge domains. For example, the left diagram might be for a tooth brush, the middle for a jet engine, and the one on the right might represent a banana. Despite the fact that these are distinctly different systems, all three have two components that perform the same function on each other — HOLD — albeit in different ways.

The purpose of Function-Oriented Search is to find other systems that perform the same function and then decide whether they perform this function more effectively and/or efficiently. If so, a R&D team may be able, for example, to dramatically innovate the jet engine by adopting and adapting the banana’s way to perform the function HOLD.

Two components in three different products/processes within three completely different knowledge domains perform the same function albeit differently, using domain-specific technology (Fig. 3).

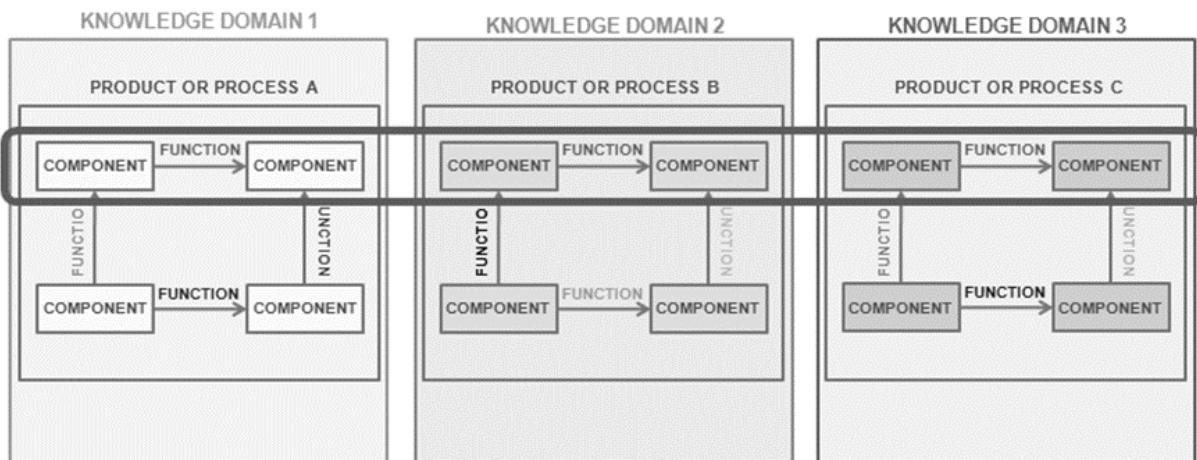


Fig. 3. Functions in Different Knowledge Domains

The technology with which the function is being performed in Knowledge Domain 3 could dramatically improve the product or process in Knowledge Domain 1. Since the function is the same for all domains, it can be found, and the technology can then be adopted.

## **7. The 11th Flattener**

An interesting parallel can be drawn with Thomas Friedman's *flatteners* in his best-selling book *The World Is Flat: A Brief History of the Twenty-First Century* (Picador, 2007) which analyzes globalization. As the title suggests, Friedman believes that geo-political boundaries no longer serve as barriers and that the world has flattened into a level playing field for all businesses regardless of where they are based. Cultural, legal, and lingual difficulties have been or can be overcome, he argues.

The ten things that *flattened* the world, according to Friedman, include: the collapse of the Berlin Wall; the introduction of Netscape; Outsourcing; Supply-chaining; Uploading; Wireless, Voice over Internet, and file sharing; etc. [22]

It appears that in many of Friedman's flatteners, *standards* and *protocols* have played a critical role, and as such, functions might be considered the 11th flattener. They represent a common language that breaks down the barriers between knowledge silos, levels global knowledge, and makes slices of unfamiliar knowledge identifiable without the need to master an entire body of knowledge. One might say that *the world is functionally flat*. It is interesting that Friedman is talking about geographical globalization. Effective functionally similar solution could be located in the same country, same city, and even the same company, but in a distant area of science and technology.

We strongly believe that Functional language is becoming the lingua franca of knowledge translation — a universal language that is effective, efficient, predictable and repeatable as a translator of knowledge from remote areas of science and practice to wherever such knowledge is needed.

Innovation providing companies like GEN3 Partners in the past and currently GEN TRIZ successfully apply Function-Oriented Search as a core tool in its overall innovation methodology. They have experienced first-hand how Function-Oriented Search often leads to the introduction of a new and more effective action principle for the product or process that's being innovated, which — as was argued above — is one of the main factors in successful Disruptive Innovation. An additional advantage is that less effort and resources are required to prove the effectiveness of the new solution as the technology already exists and is even routinely applied in a field where its effectiveness is critical [23].

Function Analysis is a cornerstone of a larger innovation approach, called GEN TRIZ Disciplined Innovation. GEN TRIZ Disciplined Innovation is a scientific approach to innovation execution that uses analytical tools to identify root causes of an innovation challenge and then finds functionally related practical solutions that can be adapted quickly, effectively, and with less risk.

We are commonly saying in our speeches at industry and innovation conferences: “Don’t always invent!” Our advice to R&D teams regardless of their industry is to do the analysis that allows them to reformulate problem statements into a language that is understood by the entire knowledge universe. That language is *functional* language [24, 25].

### **Example 1: “To stop solid particles”**

When finding solutions for an effective anti-allergenic nasal filter for trapping small particles, looking at other nasal filters would be a direct analogy, with little chance of a breakthrough solution. Function-Oriented Search (FOS) represents an indirect analogy based on the same or similar functions. In the nasal filter, the function is “to stop solid particles.” FOS asks in which leading areas of industry stopping solid particles is absolutely critical. In this case, the cement industry would be relevant, as it cannot allow solid particles to be released in the air. The next question is: how does the cement industry perform this function? They use a vortex action principle (industrial centrifuge). Based on this finding a nasal filter with a vortex interior was developed (Fig. 4).



Fig. 4. Vortex

“Functions represent a common language that breaks down the barriers and makes slices of unfamiliar knowledge identifiable.”

### **Example 2: “To remove a gas from a liquid”**

A major computer chips manufacturer had significant problems with a photo resist polymer that bubbled when applied to a wafer — losses amounted to \$1M/day (Fig. 5).



Fig. 5. Bubbles

The company first looked at every possible cause using a common “manufacturing language,” meaning that its engineers attempted to translate knowledge gained from solving problems in similar processes toward the issue. This approach did not identify the source of the problem.

Next, the firm tried to “translate” the knowledge of the best polymer scientists into new practice. This translation might have led to success, but was not practical since the polymer scientists required 2 years of research time and an investment of \$3M.

In its third approach, the firm applied Function Analysis and Function-Oriented Search, translating the problem from the object-based language (photoresist chemistry, polymer science) to a function-based language. The former yielded a highly generalized problem statement: “How

to control a gas in a liquid.” The latter leveraged this domain-neutral statement to identify multiple technology areas where management of gas in a liquid is critical, including: carbonated beverage filling equipment, blood transfusion equipment, scuba diving gear, and Champagne production.

A simple solution was quickly found in Champagne production. The way the champagne industry manages gas levels in Champagne is with special valves in the pipes that carry the liquid. An adaptation of these champagne valves removed the bubbles from the photoresist polymer and resolved the issue.

## **8. Conclusions**

In general, Open Innovation is a very promising concept compelling, but its implementation is challenging. The term “Open Innovation” in many cases, has become synonymous with Crowdsourcing. Crowdsourcing relies on the fact that the right technology exists somewhere, and the right person will respond to the challenge, which in many cases is not correct.

TRIZ provides exact practical tools for realizing the benefits of Open Innovation, making it an applied science. Several cornerstones of TRIZ Disciplined Open Innovation distinguish it from the Crowdsourcing.

First, before searching for solutions, Open Innovation should focus on key problems, instead of the initial ones.

Second, focus the external search on functions, instead of specific design components or technologies.

Third, search for solutions in functionally similar leading industries and areas of science and engineering where companies have already invested in R&D to develop the best possible solutions.

Fourth, focus on adapting the solutions to the application at hand, rather than inventing a solution from scratch.

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# SOLVING THE TONER ADHESION PROBLEM TO CYCLONE IN TONER MANUFACTURING PLANT

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## Abstract

In this study, TRIZ was used for solving the toner adhesion problem to cyclone in toner manufacturing plant. In the drying process during manufacturing polymer-toner, the cyclone blocking problem caused by cyclone attached toner was endemic trouble. The toner attached to the cyclone lead to the pipe pressure drop, cyclone jams, toner separation efficiency decreases, flowing backward symptoms (Bridge phenomena) and loss of the final production toner. According to the TRIZ problem analysis of RCA, function analysis, contradiction analysis, resource analysis and su-field modeling, it can be decided the direction of problem solving solution and can find concrete and simple practical solutions through heterogeneous field of technical analysis. Through the proposed solutions, it could be improved superior production efficiency minimizing changes of existing facilities. By TRIZ method that is simplifying the problem and searching solution in various fields, substantive solutions can be received within a few weeks starting project.

*Keywords:* TRIZ, cyclone blocking, production efficiency

## 1. Introduction

In digital era, we are facing severe competition and rapid change, and it is believed that prior occupation of core technologies is a key for surviving in business fields under these circumstances. The company without core technologies cannot lead the world and the bright future cannot be guaranteed in the 21<sup>st</sup> century. Thus, TRIZ can be a good methodology for the companies that need effective approach for innovation and invention.

Since TRIZ was introduced to Samsung Electronics in 1998, TRIZ methodology has contributed to various fields of Samsung products and manufacturing processes including mobile phones, semiconductors and home appliances (televisions, refrigerators, air-conditioners, printer, etc.)

This paper shows the application related to the toner manufacturing plant. Polymerized toner is made by complex chemical process.

In the drying process, the cyclone blocking problem caused by attached toner was endemic trouble. This problem brought about the loss of final production toner.

In this paper, the practical application of TRIZ for raising production efficiency is described.

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## 2. Initial Situation and Problem Statement

The polymerized toner is produced by adding a plurality of external additive for the printing properties to a fine particle diameter of  $6 \sim 7\mu\text{m}$ . The polymerized toner is preferred in the market because of excellent printing quality, high printing speed, eco-friendly characteristics compared to pulverized toner. But manufacturing process of polymerized toner is complicated, and the manufacturing costs is higher than the pulverized toner.

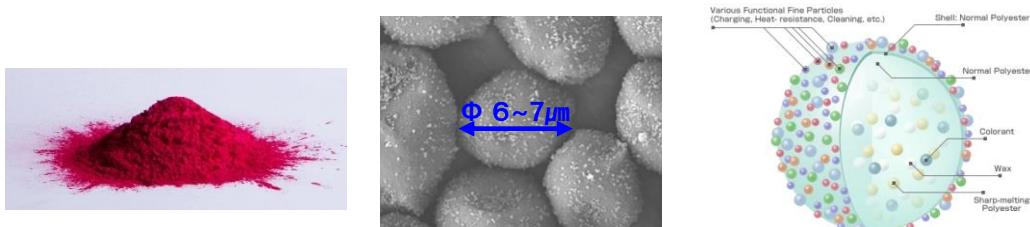


Fig. 1. Structure of toner

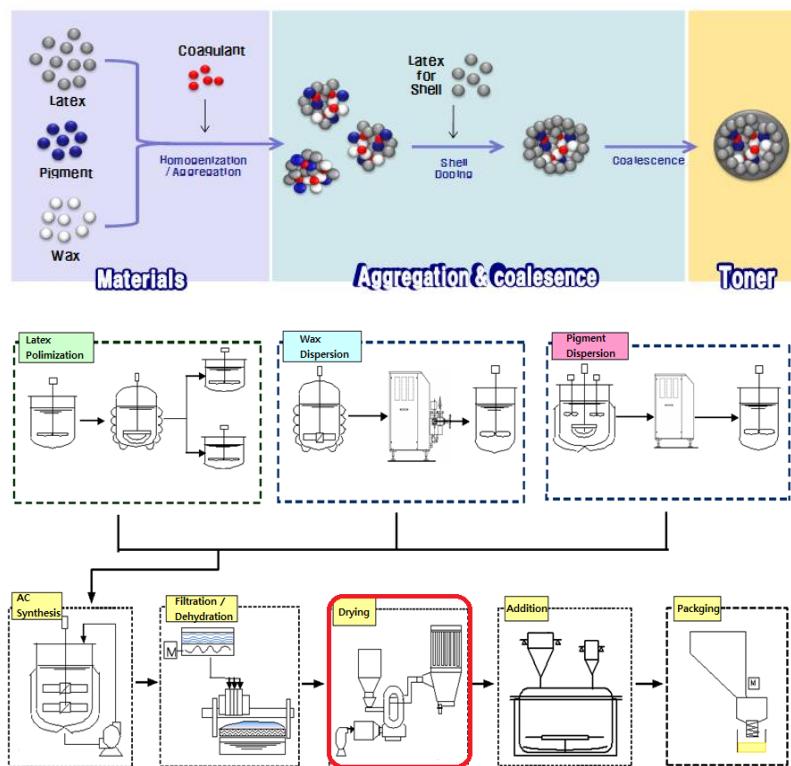


Fig. 2. The manufacturing process of the toner

The final step in the toner production process is a drying step. The toner having moisture is dried by hot air and the dried toner is collected by a centrifugal separator. The centrifugal separator is cyclone. Cyclone is a device which directly separates the particles using the centrifugal force. The inlet air flows into the cyclone is rotated spirally inside the conical cylinder. The toner particles are separated from the air in the cylinder inner wall by centrifugal force, they

flow down toward the bottom wall surface, and they are stored in the dust reservoir (tank). Since the conical central portion is maintained at a negative pressure, the air separated from the toner particles rises to the top of the apparatus and it is discharged. In this case, the problem that the toner is adhered to the pipe & cyclone surface occurs frequently. (This is ‘fouling phenomena’.) The toner attached to the pipe & cyclone lead to the pipe pressure drop, cyclone jams, toner separation efficiency decreases, flowing backward symptoms (this is bridge phenomena) and loss of the final production toner. Fouling phenomena have variations depending on seasonal characteristics, it occurs more frequently in high humidity on summer. In order to shake off the toner attached to the pipe & cyclone, electrical hammer was installed but the removing effect was so small and hammer caused a loud noise in the process. Through TRIZ, it was to improve the Fouling phenomena fundamentally, there was a requirement to minimize the modification of the current production equipment.



Fig. 3. Jet dry & pipe



Fig. 4. Cyclone for separation Toner

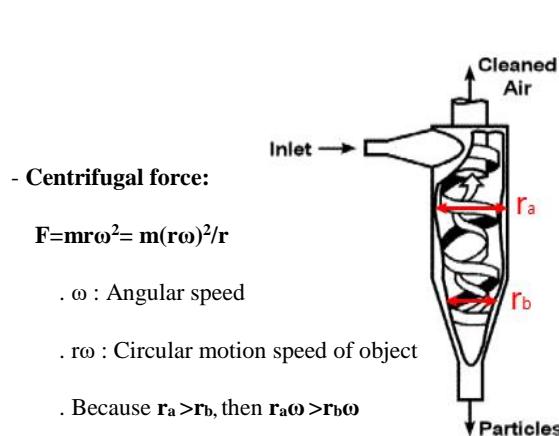


Fig. 5. The principle of Cyclone

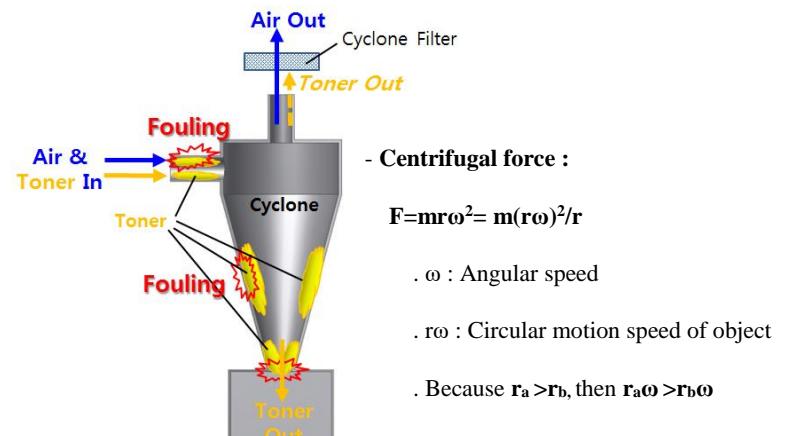


Fig. 6. Fouling phenomena in Cyclone

### 3. Approaches to Solve the Problem

#### 3.1. Definition of the problem

The goal of this project was to solve toner adhesion problem to pipe & cyclone in the drying process.

### 3.2. Root Cause Analysis

RCA was conducted to find out the primary cause of phenomena that toner attached to the inside pipe & cyclone and how to prevent the Fouling problems.

To reduce toner adhesion problem, simple solutions were derived. They are smooth surface processing of pipe, Teflon or hydrophilic property inner coating.

The pipe & cyclone insulation solution has been derived to reduce the temperature difference between inside and outside of the pipe.

In the drying process, the outside air is introduced in order to generate the hot air.

At this time, it was the underlying the solutions for removing moisture from the outside air that flows.

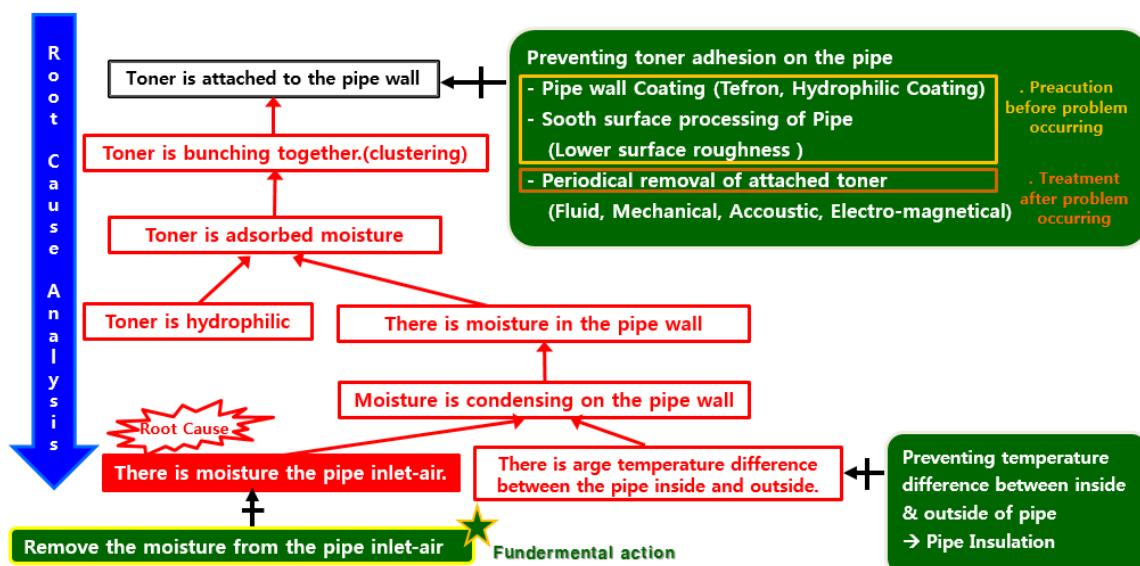


Fig. 7. Root Cause Analysis

Solutions for removing moisture of the external air flowing in the drying process was the general method used for milling, sugar, confectionery plant for preventing pipe clogging.

By RCA, it could be decided the direction of problem solving, heterogeneous field of patents and examples could get a concrete solution. Applications in other industries were a major basis to persuade process-engineer for concept implementation. That was useful to overcome the psychological inertia of a long period of time.

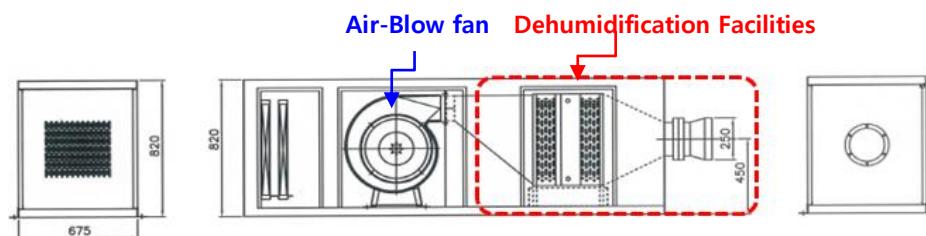


Fig. 8. Air-Blow Fan dehumidification facilities

### 3.3. Function Analysis & Contradiction Analysis

Functions were analyzed in cyclone system. There were useful function and harmful function between cyclone and toner at the same time. That was a point where the contradictory relationship occurs. Contradictions analysis was performed in order to derive a method for the periodic removal of the toner attached to a cyclone.

The end of the cyclone (neck point) gave the greatest effect on the dust separation performance of cyclone, and a main blockage occurred in the neck.

The technical contradiction was derived from this problem. If the diameter of neck( $\Phi$ ) is large, then flow is not blocked but toner separation efficiency is low. And if the diameter of neck( $\Phi$ ) is small, then toner separation efficiency is high, but flow is easy to be blocked.

To solve the technical contradiction, 39 technical parameters were defined, and 40 inventive principles were utilized by contradiction matrix.

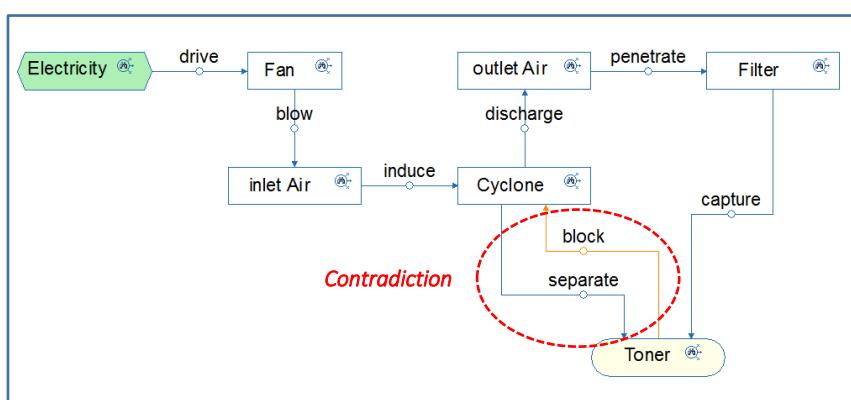


Fig. 9. Function Analysis

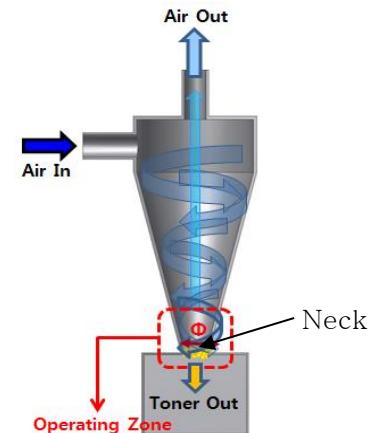


Fig. 10. Neck of Cyclone

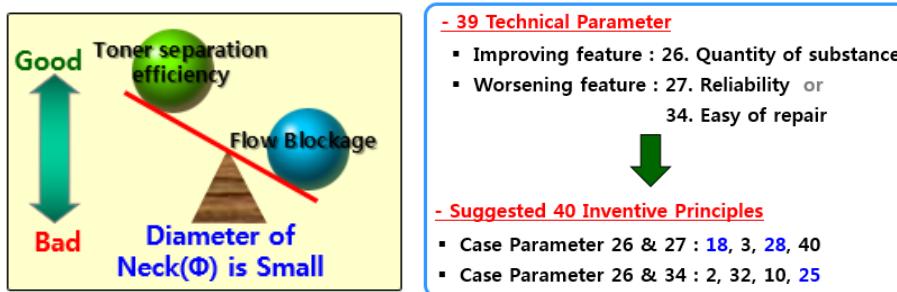


Fig. 11. Technical contradiction and Applying Inventive principles

The direction of improvement was taken by inventive principles No.18 (Mechanical vibration) & No.25 (Self-service) and more specific solutions were being found.

Proceeding of resource analysis in current technical system described the resources that could be utilized in the cyclone. Air flow in cyclone could be used for energy resource realizing mechanical vibration & self-service concept.

Su-Field Model and Standard-Solutions help to reify concept direction.

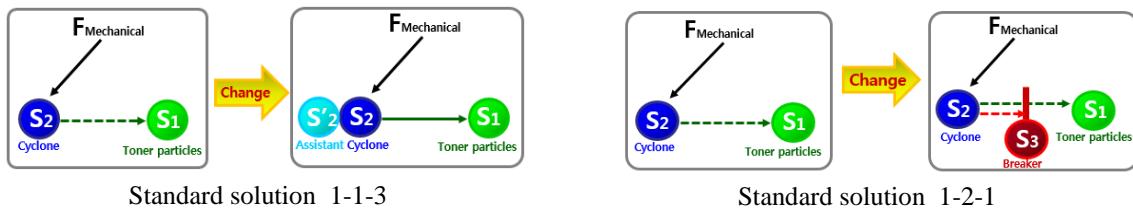


Fig. 12. Su-Field Model & Standard solutions

Position \ Property	Ready resource	Hidden & Derived resource
Inner system	- Tool : Cyclone	Shape of cyclone
	- Object : Toner	Toner additive
	- Field : Mechanical Field	
Upper system	Air	Air velocity, Centrifugal force, Turbulence, Tornado, Ascending current
Environment system	Moisture, Temperature	Condensation

Fig. 13. Resources Analysis

### 3.4 New Concept Solution

Function analysis, contradiction analysis, inventive principles, su-field model, resources analysis were used for laying down the solution direction in cyclone. And specific solutions were visualized by FOS in different-similar industries.

Finally, two solutions were materialized. They are vibrating flexible cone concept and self-vibration bar concept. A detailed description of the concept is shown in the figure below. The proposed solutions could be applied to cyclone vacuum cleaner, similar solution was realized.

This meant that its performance is proven effective in the field and market. This fact could be logical and convincing evidence enough for the applying concept to the huge and expensive chemical plant.

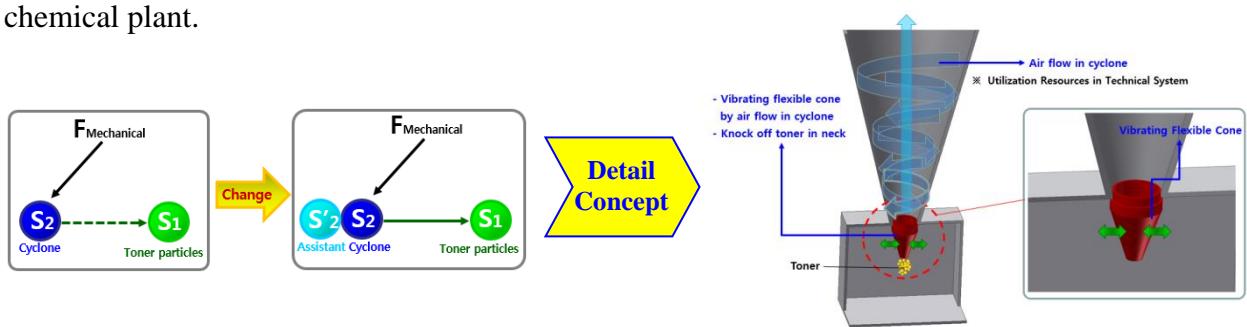


Fig. 14. Vibrating flexible cone Concept

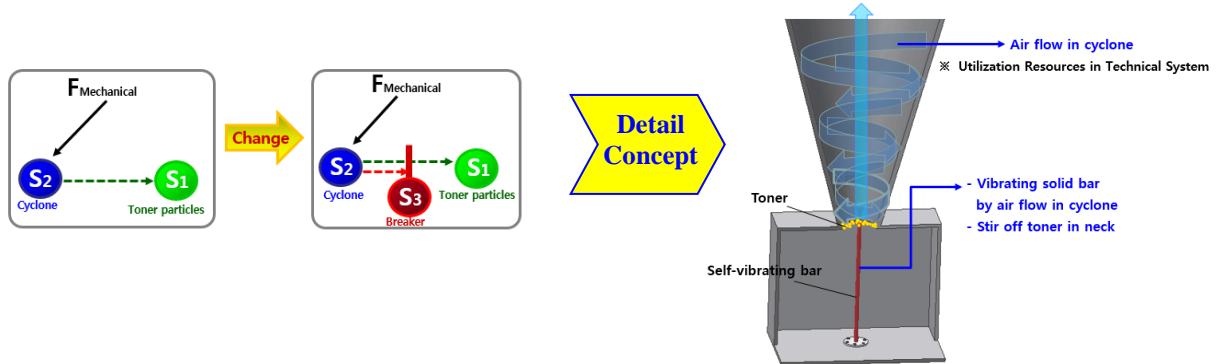


Fig. 15. Self-vibration bar Concept



Fig. 16. Self-vibration bar concept proto in vacuum machine

### 3.5 Implementation of Solutions. Final Results

Solutions to prevent toner adhesion and to remove toner in cyclone were drawn up by TRIZ.

The solutions are summarized as follows.

- Glary surface processing of pipe or Teflon or hydrophilic property coating
- Pipe & cyclone insulation for preventing temperature difference
- Removing moisture from the outside air
- Vibrating flexible cone concept
- Self-vibration bar concept

In particular, self-vibration bar concept design was made possible by minimizing the equipment changes and took effect immediately.

The results of applying the proposed concepts in the field went up to the production efficiency significantly.

## **4. Conclusions**

This paper shows the TRIZ application related to toner manufacturing plant. In the drying process during manufacturing polymer-toner, the cyclone blocking problem caused by cyclone attached toner was endemic trouble.

The toner attached to the cyclone lead to the pipe pressure drop, cyclone jams, toner separation efficiency decreases, flowing backward symptoms (bridge phenomena) and loss of the final production toner.

According to the TRIZ problem analysis of RCA, function analysis, contradiction analysis, resource analysis and su-field modeling, it can be decided the direction of problem solving solution and can find concrete and simple practical solutions through heterogeneous field of technical analysis.

Through the proposed solutions, it could be improved superior production efficiency minimizing changes of existing facilities.

By TRIZ method that is simplifying the problem and searching solution in various field, substantive solutions can be received within a few weeks starting project.

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# STATISTICS OF "ELEMENTARY FUNCTIONS"

Yury I. Fedosov<sup>1</sup>

## Abstract

One of the challenges that can be encountered while performing Function Analysis is how to correctly formulate functions of components while building a function model of a technical (engineering) system. In the paper, the author introduces an approach to compiling and completing a Directory of "elementary functions" to decrease the probability of the appearance of incorrectly formulated functions in function models, thus providing a higher quality and validity of function models.

*Keywords:* *Function Analysis, Elementary Function*

## Introduction

This article represents an attempt to involve young and active developers working in the fields of TRIZ and Function Analysis to solving the pressing methodological problem that would enable to significantly raise the efficiency of work during construction of function models for complex engineering systems (ES). Besides, the author hopes to get critical comments and constructive responses from experienced experts constantly working with function models and running into difficulties when trying to perfectly formulate the functions.

At the present, Function Analysis is one of the most effective tools for identifying the disadvantages inherent to complex ES. During relatively small expenditures of time and creative capabilities it allows to obtain a profound insight in the essence of ES being analyzed and to estimate and rank the interaction of its internal and external components. The methodology for the construction of function models characterized by high degree of algorithmizing [1, 2] makes the application of Function Analysis quite widespread.

At the same time, the existing methodology is not free from disadvantages. Many attempts were made to improve it. However, most of these attempts were unsuccessful and failed to find wide application. The main reason for this failure was that, as a rule, proposed improvements made the application of the methodology much more complicated, without giving significant improvements of outcomes. But this contradicts the main merit of the Function Analysis methodology - namely, its high effectiveness at minimal expenditures. Because of this, the primary and most important task consists in making the Function Analysis methodology easier to use, while keeping its effectiveness on the same level or even upgrading it.

## Problem statement

Formulation of functions represents the most labor-consuming and subjective procedure in the course of construction of function model for any ES. This procedure is described in the methodology quite clearly and precisely - so it doesn't raise any questions in people trying to master

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the methodology. However, in practical work users of the methodology immediately encounter significant problems when trying to formulate the functions correctly (not to mention perfect formulation of functions). And, since complex ES usually include a large number of components and each of these components performs a number of functions, time expenditures on thinking over and formulation of each function appear to be unjustifiably high.

Hence, making the function formulation procedure simpler (or formalization of this procedure) can reduce the expenditures on ES function model construction quite considerably. The availability of a list of "correct" functions and features, according to which they are used in function models, can facilitate such simplification of the function formulation procedure. Such a list could be named a Directory of "elementary functions". In addition to simplification of the function formulation procedure, the use of such Directory would possibly decrease the probability of the appearance of incorrectly formulated functions in function models leading to higher quality of the said models.

## **Approach to the stated problem solving**

Consecutive inclusion of all functions appearing in models in the list represents the simplest and most obvious way of compiling the Directory of "elementary functions". With this approach, a changeable parameter of the subject of function (i.e. target parameter) and parameter of the function proper should be indicated for each function in the list - for example, as shown in Table 1. However, in this case the list may become too exhaustive and inconvenient for use. Besides, a considerable amount of time would be spent on drawing of this list and it would be impossible to determine the degree of list completeness.

Table 1

Exemplary List of "elementary functions"

Function	Target parameter	SI	Parameter of function	SI	Convertible terms of function
To move	Position data	m	Motion rate	m/s	To remove, to shift, to drive, ...
To accelerate \ slow down	Motion rate	m/s	Motion acceleration	m/s^2	To raise, to brake, to stop, ...
To heat \ cool	Temperature	K	Temperature change rate	K/s	To heat, to chill, to quench, ...
...	...	...	...	...	...

At the same time, one can easily see that certain functions appear much more often in the models than the others. It is just these functions that would be of utmost interest during construction of function models for ES. They should be described first, and this should be done most thoroughly and precisely.

A statistical approach was used to identify such functions. 32 function models of various actual complex engineering systems (see Table 2) have been analyzed. In total these ES included 256 components performing 2132 functions.

## Preliminary results

Obtained results (subjected to front-end processing) are shown in Table 3.

It appeared, that among over two thousand functions performed by components of over 30 ES:

- there are only 40 names of functions;
- over half of them are represented only four (4!) functions: to move, to heat/cool, to accelerate/brake and to hold (to support); and
- only 16 names of functions are used in 90% of cases.

Table 2  
List of used function models

ES	Number of ES models	Number of ES components	Number of functions
<b>Devices:</b>			
- Special-purpose drying drum	1	16	53
- Controlled oil pump	3	15	95
- Diaper	1	9	37
- Hygienic pad	2	13	39
- Packing machine	1	13	45
- Anti-allergic product	1	14	67
- Fuel briquette	2	12	193
- Hydraulic press	1	8	115
- Mixing faucet	1	9	61
- Window	1	3	13
- Garage door	1	8	74
- Current limiter	1	13	36
- Golf car	1	7	44
<b>Technological processes:</b>			
- Paper-making process (at a generalized level)	1	4	22
- Production of roll-embossed film	1	12	43
- Production of potato chips	1	17	63
- Production of diaper components	2	13	117
- Production of fiber-glass chips	1	12	117
- Rubberizing of metal band	1	7	255
- Manufacturing of treated casts	1	6	141
- Pressing	2	15	139
- Mechanical processing (machining)	1	5	58
- Polishing	1	3	32
- Production of glass bottles	1	7	38
- Production of dry toasts	1	8	130
- Unloading of tropical oils	1	7	106
<b>TOTAL</b>	<b>32</b>	<b>256</b>	<b>2132</b>

Table 3

## Frequency (in %) of use of function names in models

Nº	Functions	% 55,15% 89,98%		Convertible terms of functions
1	To move	18.31%		To remove, to shift, to drive, to throw out
2	To heat \ cool	16.28%		
	including: To heat	12.19%		
	To cool	4.09%		
3	To accelerate \ brake	10.54%		
	including: To brake	10.54%		
4	To hold	10.02%		Including: to support
5	To wear out	4.85%		
6	To fill, to accumulate	4.38%		To collect, to gather; ...
7	To form	4.00%		Including: to deform
8	To measure, to check	3.53%		
9	To press \ stretch	2.97%		To squeeze, ...
	including: To press	2.31%		
	To stretch	0.66%		
10	To destroy	2.96%		To damage; to injure, to spoil, ...
11	To direct	2.73%		
12		2.64%		To detach to break off, to cut off, to snip off, to chop off, ...
13	To oxidize	2.16%		Including: to burn down
14	To join, to bind	1.88%		To unite, to connect, ...
15	To evaporate	1.60%		To exhale, ...
16	To grate	1.13%		To mill, to crash, to dismember, to subdivide, to split up, ...
17	To keep, contain	1.08%		
18	To bend\ unbend	1.08%		To curve, to crook, to straighten, including: to wind\ unwind
19	To confine	0.94%		To limit, to restrict, ...
20	To measure out	0.80%		
21	To separate (insulate)	0.80%		To part, ...
22	To generate, to create	0.66%		
23	To modify	0.66%		
24	To wet	0.56%		To moisten, to damp
25	To distribute	0.52%		To redistribute, to allot, to arrange, to classify
26	To mix	0.42%		To intermix, to intermingle, to shuffle, ...
27	To dilute	0.42%		Including: to melt (down), to found, to fuse
28	To turn	0.38%		To swing, ...
29	To inform	0.38%		
30	To measure off	0.24%		
31	To beat, to hit	0.24%		
32	To strengthen	0.19%		
33	To squash	0.14%		
34	To rub	0.14%		
35	To load	0.09%		
36	To paint	0.09%		
37	To choke	0.05%		
38	To weigh	0.05%		
39	To dilute	0.05%		
40	To record, to fix	0.05%		To write down, to note (down), ...

## Conclusions

1. The author sights but does not take responsibility for doubtful correctness of formulation of some functions included in Table 3. These formulations were taken from source documents (without changes). Without doubt, they should be and will be corrected in the nearest future.
2. Table 3 represents a preliminary material for the thorough work on drawing up a Directory of "elementary functions", which would considerably simplify and raise the effectiveness and efficiency of function modeling. The work is going on. Co-authors are required.

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# SYSTEMATIC BUSINESS INNOVATION: A ROADMAP

Valeri Souchkov<sup>1</sup>

*Original paper was published in the Proceedings of the TRIZfest 2015 International Conference, September 10-12, 2015. Seoul, South Korea*

## Abstract

Since 1956, TRIZ has been gradually evolving to bridge all sorts of gaps between a systematic approach and seemingly random creative innovation: from solving specific problems to systems analysis and forecast of future generations of technical products and technologies. In the early 1990s, the first attempts were made to use the core paradigm of TRIZ to explore if a systematic approach can be used to innovate within the areas of business and management [1]. Although the overall number of such attempts have been considerably lower than within technology and engineering, the experience gained during past dozen of years of applying TRIZ to business and management helps with drawing conclusions which parts of TRIZ can be directly used in the areas of business and management; which parts still have to be adapted; and what kind of new knowledge is needed to enable a systematic approach to business and management innovation. The paper attempts to structure business innovation tasks and summarizes the author's experience.

*Keywords:* TRIZ, business innovation, systematic innovation.

## 1. Value Business Innovation

### 1.1. Types of Technology and Business Innovation

The first question which has to be clarified is what is business innovation? In technology, the word “innovation” means a *new* solution which has proven its feasibility and has been successfully implemented. One of the key criteria of distinguishing a technology innovation from other types of solutions is that an idea which forms a basis of an innovative solution is new and it can be confirmed by the fact that the solution was patented. Usually patentability of a solution proves its novelty, even despite the fact that the idea could have failed its successful implementation or even failed to work at all.

There are no patents in the business world; and therefore, the word “innovation” can be understood with a much a broader meaning than in technology and engineering. Nevertheless, just like in the technology and engineering, one might assume that a business innovation is a solution which has never been used within a certain specific context: either it is a new business value proposition, or a new business model, or a new way of organizing a specific business process or activity. In fact, a certain solution could have been known for years within one market niche but its adaptation to a different market niche creates innovation. For example, Coca Cola was invented as a medicine but later was introduced as an innovation for the non-alcoholic

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refreshment drinks market. Selling the same product within a different context thus became innovation.

In general, a scope of business and management innovation is broader than within the technology. Business innovation belongs to a supersystem while both technical and non-technical products are systems or subsystems. Classical TRIZ presents two main categories of technology-related innovations:

1. *Innovation of a technical product* (also known as a “technical” or “engineering” system). It can result from disruptive change of product’s quality, performance, composition, as well as from drastic cost reduction or replacement of a basic physical principle (underlying technology) which makes it possible to deliver the functionality required. Innovation of a technical product can also address adaptation of already existing product to a new market (e.g. technology diversification).
2. *Innovation of a process* which results in the development and production of a technical product: in other words, innovation of production or manufacturing. As obvious, such a process includes a range of other technical products to enable its key operations.

A more detailed classification of innovative tasks for technology and engineering is provided in [2]. In the business and management environments, innovation can apply first, to how a business is organized, and second, how the same business is managed. Although there are known attempts to classify business innovation tasks, for example in [3,4] we believe that such classifications are still non-exact and overlapping because they are not based on a system approach.

An approach to business innovation structuring and roadmapping presented below is based on over 60 practical cases performed by the author since 2003 and studies of over 1000 cases of business innovation in diverse fields. These studies resulted in a better understanding how TRIZ can be used for business innovation [5].

First, one can distinguish between the following six large areas of business and management innovation:

1. *Innovation of value proposition*. This type of innovation is the same as innovation within technology and engineering since we deal with a value proposition which always includes at least one main ingredient: a tangible (physical) or an intangible product (e.g. service), or a combination of tangible and intangible products. For example, the value proposition of an automotive company can be based on the combination of delivery of a car, its service and insurance. A value proposition of a training company can be based on the combination of delivering a training course and its follow-up support.
2. *Innovation of a business process*. A typical business process consists of a sequence of more specific actions and activities. In a modern business organization, their structure is usually rather well defined. A business process can be considered similar to a production processes in the technology domain.
3. *Innovation of a business system*. A business system consists of a number of critical components which support business processes and create value which is then brought and maintained at either B2B or B2C markets. The components of a business system include tangible and intangible assets, which belong to the system and directly contribute to the shareholder value of the system.
4. *Innovation of a value network*. Due to broad expansion of businesses to supersystem, value networks have become increasingly popular. While in the past almost any business

could be represented by a value chain (both within the organization as well as on a broader scale), where each step adds value from a supplier towards a customer within the chain-like structure, today value creation can be represented through network structures and might involve non-commercial components: customers, social and government bodies, etc.

5. *Innovation of a business model.* Business model innovation becomes very popular today and affects all other types of business innovation [6]. However, it is important to recognize the difference between a business system, value network, and a business model. Recently, a number of different approaches have emerged to identify a business model: some only focus on the ways specifying how revenue is generated and distributed but other approaches might include all the components of a business system, value proposition, and supplier/partner/customer relationships as well. In other words, when we consider business system/network innovation we focus on the components change while when we focus on business model innovation we primarily change the relationships between the components of a business system and its supersystem. Thus, there can be two situations: a) a business model is encapsulated within a particular single business system (organization) and matches the business system architecture, and b) a business model expands beyond the business system.
6. *Management innovation.* This particular category covers those innovative solutions which deal with management and control of systems and processes to create and deliver value in the most effective and efficient ways. Those can be business systems, business models, value chains and value networks.

In the rest of the paper we will focus on the first 5 categories of value business innovation since as follows from the author's experience management innovation requires separate consideration. We will identify specific tasks which can be distinguished within each category of business innovation and show how these tasks can be supported with relevant TRIZ tools.

## **2. Typical Tasks of Value Business Innovation**

When triggering an innovation activity, a business organization usually faces two types of initial situations:

- 1) A specific challenge is known and is expressed in terms of a specific problem (challenge) which cannot be solved by known methods. For example, a company is willing to expand its products portfolio, or drastically cut costs of a specific business process but the existing methods do not help with reaching the targets desired.
- 2) A specific challenge is not defined yet, a company just wants “to innovate” to grow or to create competitive advantage. Such goals are too general and need to be decomposed to clear sub-goals.

Our experience shows is that both situations occur very regularly at all types of business organizations. While in the first case TRIZ can be directly used in a structured way to approach a clearly defined challenge and establish a process of moving from a problem to generating and evaluating solution ideas, the second situation requires definition and clarification of both final and intermediate goals. Therefore, it would be of help to any organization to have a map of all possible opportunities for business innovation.

In this chapter we will introduce typical tasks of value business innovation with respect to each category presented in the previous chapter and illustrate these tasks with the examples drawn

from business innovation within a company delivering training services. It is important to note that a) only most significant tasks from our perspective were included and b) some tasks can overlap since they might belong to several categories.

## *2.1. Typical tasks: Value Proposition*

Value proposition is a sum of benefits a prospect is believed to obtain after purchasing a product, either tangible or intangible one or their combination. Therefore, the value proposition is based on the properties, parameters and features of a product itself. Table 1 shows typical tasks with examples which result in innovative solutions applied to a product. Note that this approach is valid for products that have functional meaning within the context of the functional use of the product. The vast majority of products are intended to be used within the context of their functional use. Exceptions are products created for a non-functional use, for example works of art.

Table 1. Typical innovative tasks for value proposition innovation

	Typical Task	Example
1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Eliminating misinterpretation of the course content.
2	Increase performance: increase value of key parameters.	Adding new content of a particular course without losing quality and creating demand for extra learning time.
3	Reduce “dimensions” of a product: physical volume, information volume, time taken by processes.	Making a training course considerably shorter without losing content and quality.
4	Improve user experience.	Making working with practical examples more engaging by using their own cases.
	Create new user experience.	Move training outside a class room to the real-world domain.
5	Radically change shape (for physical products) or reorganize structure (for intangible products)	Segmenting the course modules to make learning more effective.
6	Add new functions and features.	Adding “walk-through” case-based training experience.
7	Radically decrease cost: purchasing price, total cost of ownership.	Drastically cutting cost of training per person.
8	Transfer the existing product principle (technology) to a new market.	Using the existing training model for training new subjects for new markets.
9	Create a radically new product, a new product generation, or a new product line (including forecast).	Launching distant training.

## 2.2. Typical tasks: Business process

Table 2 identifies a set of typical tasks for innovative change of business processes.

Table 2. Typical innovative tasks for business process innovation

	Typical Task	Example
1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Eliminating miscommunication between a training company and a prospect within the customer acquisition process.
2	Increase performance: increase values of key performance parameters.	Serving increased number of prospects without extra cost and time.
3	Reduce a number of activities in a process.	Reducing ordering process to a “one-click” purchase of the courses.
4	Reduce a number of processes.	Merging processes of acquisition and introductory training.
5	Add new functions and features to the existing process.	Providing prospects with extra information in time on demand.
6	Radically decrease cost of a process.	Drastically decreasing cost of acquiring a new customer.

## 2.3. Typical tasks: Business System

Table 3 represents typical tasks for business system innovation.

Table 3. Typical innovative tasks for business system innovation

	Typical Task	Example
1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Decrease risks by leasing training rooms rather than purchasing new property.
2	Increase performance: increase values of key performance parameters.	Increasing rate of business development to search for new business partners.
	Radically decrease cost of a business system.	Decreasing cost of operating a specific business unit.
3	Reorganize for a new market or a new value proposition	Transformation of management structure from hierarchical to matrix
6	Merge two or more business systems.	Acquiring a company which provides complementary training.
8	Generate a spin-off business.	Starting a spin-off company to distribute products in addition to training.

## 2.4. Typical tasks: Value Network

If a business model focuses primarily on the functional relationships, a value network is a system of interrelated components which together create value, generate and maintain revenue streams. Often it is not easy to separate between a value network innovation and business model innovation. The primary goal of value network innovation is to identify how new value can be obtained from the existing members of the value network or how to discover new members to produce added value.

Table 4. Typical innovative tasks for value network innovation

	Typical Task	Example
	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Synchronizing similar types of training curricula to avoid confusion.
	Increase performance: increase values of key performance parameters.	Use trainers on different continents to handle time zone differences.
	Discover new value partners	Turning customers to licensed trainers.
	Innovatively optimize the existing network	Reducing travel costs by widely using videoconferencing.
	Reduce bottlenecks in the existing network	Lowering entering barrier for new customers through value-adding collaborations with partners
	Create a new value network	Launching a virtual aggregated training facility based on the network of independent vendors.

## 2.5. Typical tasks: Business Model Innovation

The table below presents only those tasks which do not directly relate to value proposition and business system itself.

Table 5. Typical innovative tasks for business model innovation

	Typical Task	Example
1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Asking a community to provide feedback on the training material (for bonuses)
2	Increase performance: increase values of key performance parameters.	Introducing “full immersion” training.
3	Increase scalability.	Introducing a franchising model.
4	Increasing market size/share.	Localizing the courseware and attracting local native speakers as trainers.
5	Restructure “system-supersystem” relationships	Outsourcing courseware development to a third party.
6	Introduce new revenue streams	Reselling related products from third parties

7	Introduce new offerings.	Creating and distributing new low-cost video tutorials
8	Radically decrease cost.	Licensing new material from third parties rather than developing own materials
9	Introduce a radically new business model.	Introducing a new model of payment through royalties based on future customer's revenue.

## 2.6. Evolution of business systems

By studying a process of business models evolution it becomes obvious that in general the process of evolution matches the S-curve model of technical systems evolution and the other TRIZ trends (Fig. 2). Two parallel trends have been especially observed: 1) Transition to supersystem and 2) The growth of the degree of segmentation of business systems and components.

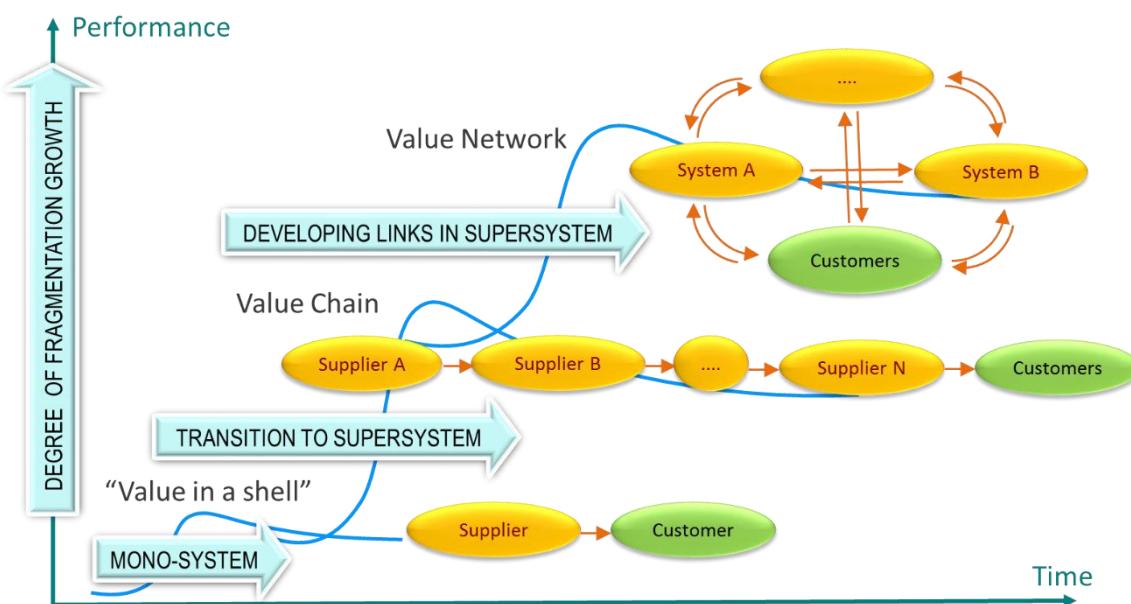


Fig. 2. Typical evolution of a business system: from a mono-system creating value and delivering it directly to customers towards network poly-systems with developed links and growing degree of segmentation

A deeper understanding of details of such an evolution model will help to make better decisions by business innovators regarding next steps of evolving their business systems.

## 3. A Systematic Roadmap

### 3.1. TRIZ Process to Support Business Innovation

As follows from an overview of typical innovative tasks shown above, there are three large conceptual groups of innovative tasks in each category:

- a) tasks dealing with solving specific innovative problems,
- b) tasks related to the overall system / value network innovative redesign, and

c) tasks related to extracting new market opportunities for innovation.

TRIZ proposes a systematic approach to deal with each group of tasks. A typical stage-gate process is shown in Fig. 1. This process does not depend on what conceptual group is involved.

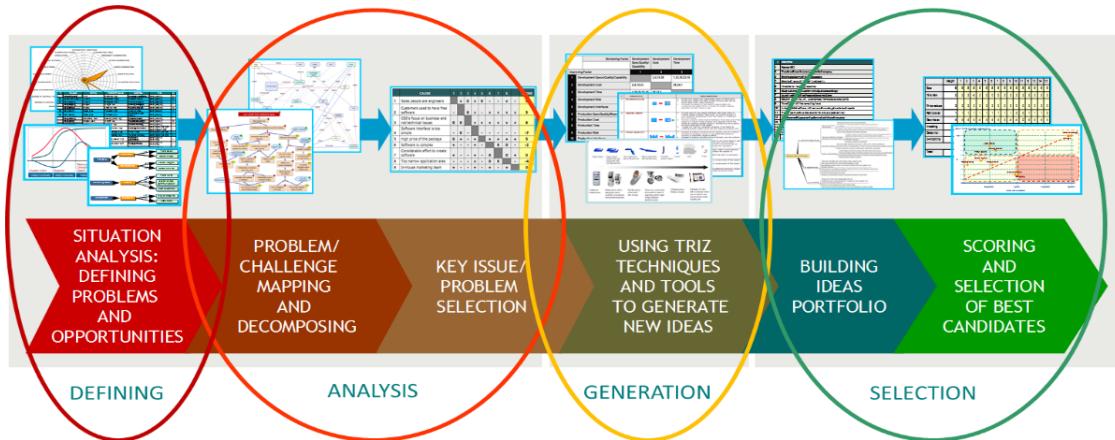


Fig. 1. A typical stage-gate process with TRIZ

A process of dealing with every type of innovation tasks includes four main steps where each step is supported with specific TRIZ tools adapted for business innovation [7, 8]:

1. Defining, where goals are identified and revision of demands and constraints is performed.
2. Analysis, where analytical tools are used to structure a situation, build its model, decompose a challenge identified and extract key problems/ specific challenges.
3. Ideas generation (including problem solving), where a list of new innovative ideas are generated.
4. Evaluation, where the most promising solution candidates are ranked and selected.

An example of such a process with the use of modern TRIZ tools to help with systematic business model innovation based on the Business Model Canvas approach [9] can be found in [10].

### 3.2. Tasks, Stages, and Tools

The size of this paper is too limited to present a process for each task mentioned in section 2, therefore some types of tasks were grouped. Table 6 shows a summary of the tools which are most relevant for different groups of tasks. This classification is based on the experience of the author and his network being engaged to assisting customer business innovation since 2003. The table only includes analytical and ideas generation stages, since evaluation stage uses almost the same tools to select most promising candidate solutions and roadmap them: Multi-Criteria Decision Matrix, Ideality Criteria, Ideas Landscape Chart.

Table 6. Summary of the TRIZ and Systematic Innovation tools supporting analytical and creative stages of different tasks of business innovation.

Generic task	Where to apply	Analytical Stage	Ideas Generation
Increase quality and reliability (reduce negative effects).	Value Proposition; Business System; Business Process; Business Model; Value Network	Problem perception network mapping; Root-Conflict Analysis (RCA+); Function Product /Process Analysis	40 Inventive Principles; ARIZ (+Knowledge bank); Trends of Business Systems Evolution
Increase performance (improve positive effects).	Value Proposition; Business System; Business Process; Business Model; Value Network	Problem perception network mapping; Root-Conflict Analysis (RCA+); Function Product /Process Analysis	40 Inventive Principles; ARIZ (+Knowledge bank); Trends of Business Systems Evolution
Radically decrease cost.	Value Proposition; Business System; Business Process; Business Model; Value Network	Function Product /Process Analysis	Trimming; Trends of Business Systems Evolution.
Reduce “dimensions”: (physical volume, information volume, time).	Value Proposition; Business System; Business Process; Business Model	Function Product /Process Analysis	Trimming; Trends of Business Systems Evolution.
Transfer the existing principle to a new area.	Value Proposition; Business Model	“ZIRT”: inverse TRIZ	Inverse Function-Oriented Search; Catalogue of business models
Reduce bottlenecks	Business Process; Business System; Business Model	Flow Analysis	40 Inventive Principles; ARIZ (+Knowledge bank);
Increase scalability.	Business Model		Trends of Business Systems Evolution; Catalogue of business models
Create a radically new system.	Value Proposition; Business System; Business Process; Business Model;	Value-Conflict Mapping; Multi-Screen Analysis;	Trends of Business Systems Evolution; Catalogue of business models

	Value Network	Technology and Business Roadmapping; Main Parameters of Value	ARIZ (+Knowledge bank)
Improve or create user experience	Value Proposition; Business Model.	Functional Needs Assessment; Value-Conflict Mapping; Main Parameters of Value	Trends of Needs and Demands Evolution
Introduce new revenue streams	Business Model.	Value-Conflict Mapping;	Trends of Business Systems Evolution
Reorganize for a new market or a new value proposition	Business System; Business Process; Value Network.	Value-Conflict Mapping;	Trends of Business Systems Evolution

## Conclusions

At this moment, applications of TRIZ in the areas of business and management are rather limited. Partly it is due to the fact that TRIZ and Systematic Innovation have been developed within an engineering community and their applications outside technology are not very well known. On the other hand, direct application of TRIZ tools developed for technology innovation is not always well received by the business audience due to a different language, and therefore adaptations are needed.

Nevertheless, there is already some positive experience with adapting TRIZ tools to business needs (such as reformulation of inventive principles, inventive standards, ARIZ), structuring innovative business tasks, and using the tools of TRIZ to support the process of business innovation. Still, a broader research and development activities are needed to bridge the gaps between various innovative tasks mentioned above and supporting systematic tools.

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# TRIZ AND VALUE ENGINEERING: DEEPER INTEGRATION AS INNOVATION ENHANCER

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## Abstract

TRIZ and VA/VE (Value Analysis/Value Engineering) are well known and widely adopted value improving methodologies promoted by professional organizations and communities with education and certification programs. Both offer a complete cycle of problem identification/ problem solving/ solution implementation; VAVE is a structured problem solving tool with a deep focus on cost and value offered to the customer, while TRIZ core has proved its strength for the idea generation process. VA/VE foresees a creativity phase but proposes no structure for it, introducing it in its standard agenda as a classical free brainstorming. On the other hand, TRIZ core consists of a structured innovation philosophy, so they represent already a natural fit. VAVE is adopted with the goal to identify and remove cost, while TRIZ focuses on the technological aspects and the evolution of the engineering system, in an effort to drive development of more out of the box solutions. In this paper, the experience with a mixed approach for a NPI (New Product Introduction) project at GE is described, delineating and leveraging proven integration pathways. Commonalities and complements between VA/VE and TRIZ will be outlined, with two application examples of workshops at GE Oil & Gas Florence, with special regard on how function analysis is implemented in the two methods.

*Keywords:* TRIZ, VA/VE, Value Engineering, Function Analysis, Creativity.

## 1. Introduction: VA/VE, Function Modeling, TRIZ and Innovation

The Value Methodology was introduced in the 1940s at General Electric by Lawrence D. Miles [1], as an answer to a raw material supply scarcity; the approach was formalized into a method in 1946, and later was carried on by the SSAVE society. Miles started analysing engineering systems in terms of functions that delivered value for customers. The process was refined into the so-called value analysis, with the goals of minimizing the total product life cost and eliminating unnecessary costs. Over the years it evolved as a systematic process to implement cost-out, based on a multidisciplinary team, with a formalized Job Plan as shown in Figure 1:

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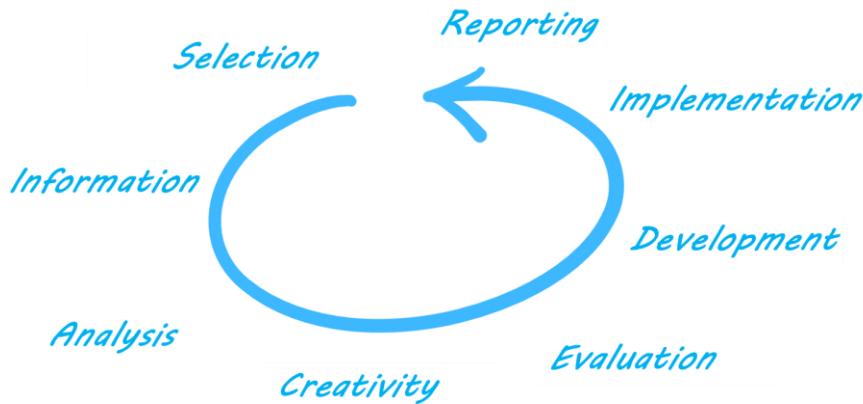


Fig.1. VA/VE Standard Job Plan as a Cycle

This methodology became mandatory for every US federal agency since the National Defence Authorization Act for the fiscal year 1996 [2], defined as “analysis of the functions of a program, project, system, product, item of equipment, building, facility, service, or supply of an executive agency, performed by qualified agency or contractor personnel, directed at improving performance, reliability, quality, safety, and life cycle costs.”

So it became an established paradigm for a process largely adopted by industry and US federal institutions as a means to leverage their activity and foster innovation, based on definition on the improvement of the value of a project by means of analysis of its functions. One of its more impactful effects was the introduction of Functional Analysis, which also emerged as TRIZ problem definition technique and is used for both engineering system and processes and business modelling [3]. The function model approach also fits very well with the new Design To Value philosophy introduced by McKinsey [4]. Nowadays, both VA/VE and TRIZ are widely used wherever a big effort on innovation is in place. They have been combined with other approaches and occasionally applied together. The combination of two or more value improving methodologies like lean, Six Sigma, DFMA, TRIZ and VAVE is often applied by current practitioners in order to get the maximum out of each toolset. A detailed description of literature contributions as well as direct hands-on experiences to understand how to better take advantage and optimize the joint use of both methodologies is captured in Paragraph 2.

## 2. Proven TRIZ and VA/VE combined pathways

The combination of TRIZ with several other product management and innovation methods has been already documented by many industry practitioners, business consultants and TRIZ Masters. Extensive activity on TRIZ-assisted Value Engineering Analysis has been reported among the Russian community in the 1980s and 1990s. Gerasimov and Litvin [5] showed how to reach VEA goals deploying all TRIZ tools, using Function Analysis to reformulate the key problem. Terninko et al. [6] explain how to use TRIZ in synergy with Quality Function deployment and Taguchi methods. Bukhman [7] recommends a Roadmap to optimize TRIZ effectiveness when used in conjunction with other methods for problem formulation and solving. Bolton [8] proposed to use TRIZ with Design for Manufacture and Assembly (DFMA) in order to maximize value and in [9] he claims TRIZ as one of the Value enhancing tools, using the functional approach to identify contradictions, with a cross- functional team as in VA/VE. Just like documented in Six Sigma [10], Bolton stated that when the target cost cannot be achieved, TRIZ can help to develop new solutions.

The described integration approach foresees a TRIZ expert who leads a team through the whole TRIZ inventive process and eventually identifies TRIZ as a powerful tool in conjunction with DFMA to be used at the early stages of product management. He also described how processes like Six Sigma, VA/VE and DFMA identify the actual problem to solve, but not how to solve it; in other words, they can be excellent problem identification tools but they need to be enhanced for the problem solving phase. Henschel and Czinki [11] introduce TRIZ mediated by Design Thinking to smooth the learning curve and raise acceptance.

More specifically, many works focus on TRIZ and VA/VE workshop integration. Gaikwad [12] points out the limitations of Osborne classical brainstorming and describes how he used TRIZ as a creativity tool of choice for VE workshop with a team of 14 people, aiming for quality improvement ideas, reporting 120 ideas generated, out of which 9 business cases were developed. No more information is given about the used TRIZ tools, TRIZ literacy among participants and time allocated for each session. Also Hanik and Kaufman [13] report bridging VAVE and TRIZ through the FAST model and confirm that the weakness of VAVE resides in the creativity phase. On the other hand it is described how TRIZ can bring the results out of the boundaries of capacity of the team members, though no other tools apart from the functional model and the inventive principles are used. Clarke [14] also leverages TRIZ for the idea generation process starting from the Innovation Situation questionnaire. Borza [15] describes the two methodologies to see how to take advantage of their complementary aspects rather than seeing them as competing approaches. He underlines their similarities in structure and the effectiveness of TRIZ for the creativity phase for VE, since it can enable people to hitchhike on ideas going beyond the limits of skills, knowledge and experience of the people in the session. He states that VAVE facilitators received training in structured innovation and gave good feedback, but no quantitative statistics are provided and no differences between the two functional analysis approaches are given. In [16] the integration of TRIZ and Value Engineering focused on the concepts of Ideal Final Result and Ideality. The FAST diagram of VAVE has the essence of The Function Analysis of TRIZ. VE is used to rank components regrouping the relative functions to which a value is attributed with a procedure borrowed by classic VE. The function value evaluation chart identifies the components to be improved cost-wise.

As a summary, all contributions confirm the power and flexibility of TRIZ, which as a methodology lends itself very effectively to be employed as a creativity enhancer in conjunction with several complementary methodologies and VA/VE in particular; in this case TRIZ application is confined to the creativity phase only and no precise roadmap on how to merge the different approaches is given, nor the detailed description on which TRIZ tools to employ. The report of the experience at GE will try to answer those questions.

### **3. TRIZ for VA/VE Online**

In this section, the experience gathered during two projects is described; one project utilized a four-day workshop merging the two methodologies “online”, that is, using VA/VE and TRIZ during the same workshop; the other project combined them offline, having a TRIZ three-day session after four VA/VE workshops on just as many subsystems. This latter experience will be described more deeply in Paragraph 5.

The first workout was meant to apply Design To Value and VA/VE methodologies, enhanced by means of TRIZ tools, to an NTI (New Technology Introduction) Program for Oil & Gas. The team was composed of a multidisciplinary team of seven people, recruited from the engineering, service and sourcing departments, plus the VA/VE facilitator assisted by two TRIZ

Practitioners, certified respectively Level 2 and 3. The VA/VE process is well known and structured and had previously already been applied in its standard form to a variety of project throughout GE Businesses and in particular for Oil & Gas at Florence Nuovo Pignone premises. The standardized VA/VE work plan includes a Creativity Phase, but not a systematic method to generate new ideas, so usually a classical free brainstorming is suggested and adopted at this stage. As explained in the paragraph before, TRIZ has been already described as a suitable tool to be inserted as a plug-in into this phase, but no examples of applications had been reported in GE Oil & Gas at the time, with only one case of application at GRC Bangalore, India. So the described workout was originally intended as a pilot for GE according to two novel aspects:

- Application of VA/VE to a NTI Program
- Plug-in of TRIZ tools to boost the Creativity Phase

The next paragraphs will offer a detailed description of this workout and synergy between the different tools. The workout was planned to follow the classic VA/VE structure, as shown in Figure 1, and was offered to two different teams, working on two separate projects. The teams gathered for a pre-workshop the week before the workout to define the project to be developed. One group followed the classic VA/VE agenda for a cost-out project with 20% cost cut goal, with a classical free brainstorming session, while the other followed the VA/VE integrated with TRIZ pathway, since the focus was on a NPI activity, with the goal to find novel solution and to meet a specific target cost threshold. The VA/VE session was common to the two groups until the creative phase when they were split and continued with a different schedule. Two TRIZ facilitators were engaged, and the selection of the TRIZ tools to be used in these sessions was left to their choice. As per their request, a brief TRIZ Introduction Session of about one hour was held for interested team at the end of day 1 in addition to the standard program, since only one person from this group had some TRIZ literacy. The goal was to have the team familiarized with the methodology and the TRIZ concepts and wording to be used during the subsequent phase. The time allocated for the TRIZ guided Creativity Phase was four total hours, split between Day 2 and Day 3. During the workshop though, more TRIZ concepts than originally planned were employed; a detailed description will be provided.

### *3.1. Problem Identification Stage: Function Analysis and S-Curve*

At the beginning of the first day a general introduction of VA/VE was presented, focusing on the concepts of ideality, functionality and cost. The goal was to complete the project goal definition, random function identification and FAST diagram steps as per standard VA/VE Job Plan, so as to define the boundaries for the creativity phase. The Function Analysis in VA/VE framework is defined as active verb and measurable noun. The measurable noun makes it more general and increases the scope of coming out with new cost-effective ways of doing the same function. But this does not exactly coincide with the Function Analysis according to the TRIZ approach, because functions are not identified between two components but from a single component. Functions are so listed object by object regardless of the target of the function. Moreover, in the VA/VE Function analysis the cost is included, while in TRIZ it can only be captured indirectly by means of the harmful functions. The main differences between the two approaches collected during the session are listed in Table 1:

Table 1. Function Analysis in VA/VE and TRIZ

VA/VE	TRIZ
Component analysis by cost	Component analysis for subsequent FA
System only	System and supersystem identified
Component: object (rest mass)	Component: substance (rest mass) or field
Function acts upon measurable noun	Function acts upon Component
Main Function: function for which the component is sold	Main Function: function for which the engineering system is designed
Ideality: ratio Functionality/Cost	Ideality: ratio of weighted sum for F,C
Functions: selected from a predefined list of active verbs	Functions not predefined (suggested list)
FA for products and processes (different lists)	FA for products and processes (different function categorization)
Functions: required/ aesthetic/ unwanted	FA products: useful (basic, auxiliary, additional)/harmful, normal, insufficient, excessive
	FA processes: useful (productive, providing, corrective)/harmful, normal, insufficient, excessive
Excel template	Innovation Navigator™ or other software packages

The initial intention of the TRIZ facilitators was to leverage the FAST model to find harmful functions or useful function with insufficient performance, in order to identify contradictions; however, this was not as efficient because in VA/VE usually not many unwanted functions are found. The translation into the classical TRIZ function analysis is thus not straightforward, so it was chosen not to pursue this effort building a TRIZ function model to map the FAST diagram, but to identify during the FAST modeling phase the already recognizable contradictions, to be used as examples during the TRIZ introductory session.

During the first day other important observations were made: during the VA/VE introduction many options of improving value are available, so that the quality of intervention upon the system can be recalibrated in different ways, choosing whether to act more on the functionality or on the cost: VA/VE does not offer a systematic way to select one alternative in particular, whereas the S-Curve recommendations do. In fact, the S-Curve theory can help at first to assess the phase where the project is and the recommendations can help decide what to follow. From this observation derived the decision to assess the system under analysis by means of the Innovation Navigator™ Express S-Curve tool: it resulted to be in the transitional stage, consistent with the existence of a prototype but not of marketable product. This assessment offered a more solid foundation to organize the creativity session.

### *3.2. Short TRIZ Introduction: project-focused examples*

The TRIZ Introduction was organized as a short session according to previous experience gathered at GE Global Research Munich, described in [16], Paragraph 5, customizing a standard procedure used for similar short brainstorming introductions. The goal was to convey to the team short introductory notions about the methodology and its history and to propose upfront the definitions of the Inventive Principles, Engineering and Physical contradictions; in this way the team was able to take advantage of classical TRIZ tools in a pre-prepared form. The participants became familiar with the concepts on project related examples with immediate applications, in a learning-by-doing fashion. Also, Su-Field models were used. The choice of the employed TRIZ tools reflected the experience gathered for short session described in [17] and the results of the S-Curve Analysis. The specific examples were prepared during Day 1 by the TRIZ facilitators while the team worked on the component list and the functional analysis according to the VA/VE approach; the whole team could then elaborate upon the presented contradictions. In this one-hour session some ideas were already emerging and were promptly documented for subsequent discussion. This phase reflected respectively already considered and discarded ideas or concepts already generated by the individuals (stage referred to as Idea Parking Lot in [17]).

### *3.3. Systematic Enhanced Creativity: different zoom levels*

The Creativity Phase took place during Day 2 and Day3, with two hours each day. Table 2 depicts the TRIZ tools used for each day and the number of ideas resulting from the guided brainstorming. The first session during Day 2 started with a short Idea Parking Lot [17], not longer than 20 minutes, when the ideas start to diminish in number. Then, for a smoother start with TRIZ, Substance- Field models of solutions were proposed, and the number of ideas started to increase again. This was done for several reasons: during the analysis phase, it emerged that the project could be considered in a pivoting phase. The Substance-Field modelling opened two ways: a zoomed out approach, going back to the basic physics: this allowed to having one class of model of problems defined as more radical, where no principle of action was assumed (stepping back to S-Curve Stage 1) and an harmful interaction was identified, and one where the initial principle of action was maintained, solving an insufficient interaction. It was evident how Substance-Field analysis enabled people to distinguish between concepts that could remove the harmful effects and ideas that in turn could remove the cause, solving the problem from different points of view, identifying at the same time opportunities to push the technology limits. This also emerged after a Multiscreen Analysis based on reflection of the system. In addition to that, the visual nature of the presented Su-Field models helped the team get started with the creativity phase in a more natural way. On Day 3 the team zoomed back in to the existing system, focusing on the results of the FAST diagram where five functions were identified as responsible for the bigger cost contribution. Engineering and Physical Contradictions were then written around the parameters affected by those functions, resulting in the more impactful contributions in terms of number of ideas. Some further insights were given mapping the Trend of Increasing Dynamization to the existing system.

Table 2. TRIZ Tools and Results. In *italic* non-TRIZ tools

Day	Time [hrs]	Tools	Ideas
1	1	<i>Idea Parking Lot</i> <sup>[17]</sup>	13
2	2	Substance-Field Models 1.1.3,1.1.4, 1.2.1	13
		Substance-Field Models -F 1.2.4	10
		Multiscreen	
3	2	Engineering Contradictions	5
		Physical Contradictions- Separation in Time	5
		Physical Contradictions - Separation in Space	5
		Physical Contradictions - Separation at System Level	3
		Physical Contradictions - Other	23

### 3.4. Down selection, Function Oriented Search, Feature Transfer

The Job Plan for day 4 was the Evaluation Phase, that is, the idea down selection process. According to the VA/VE pathway, the different concepts need to be regrouped according to certain labels. The team agreed on five different labelling tags and decided to scale them according to the Technology Readiness Levels (TRLs) defined for the Oil & Gas Industry by the Norm API 17N. For each of the five tag groups, one or two ideas were selected, for a total of seven concepts, all below TRL3. During this phase other TRIZ tools were employed to help formulate solid decisions about different concepts: the most useful ones were the feature transfer and the function-oriented search tools, implemented by means of a semantic search engine on a patent database. This helped identify physical effects used to solve analogous problems.

## 4. Workout Outcomes

The workout with a merged VAVE and TRIZ approach was quite successful in terms of number of identified possible solutions, which at the end were around 70 in total, accounting for repetitions that occurred during the different sessions (see Table 2). The participants acknowledged that TRIZ boosted the VA/VE creativity phase, noticing that also non-technologists were able to strongly contribute to the formulation of technical ideas. With respect to already documented experiences, new TRIZ tools were employed and an optimized approach for short TRIZ sessions was adopted. The most appreciated new introductions were the S-Curve Analysis at the very beginning, that offered a strong tool to support the decision on how to shape the following TRIZ sessions, and the adoption of the TRL scale and the function oriented- semantic search for the idea evaluation phase. The parallel team who applied classical VA/VE with free brainstorming worked on a different technology, so a direct comparison can be misleading; anyway it can be noticed that the team could formulate a similar quantity of ideas, but they were perceived as much less disruptive, leading to the proposal of small and incremental modification of the existing systems, with no big innovative content. The original Workshop Plan foresaw

the adoption of TRIZ concentrated to the creativity phase. This experience showed that distributing TRIZ tools along the Information, Analysis, Creativity and Evaluation (see Fig. 2) phases can strengthen a lot the VA/VE process both from for the number of generated ideas and from the level of system insight and zoom level at which the ideation process should take place.

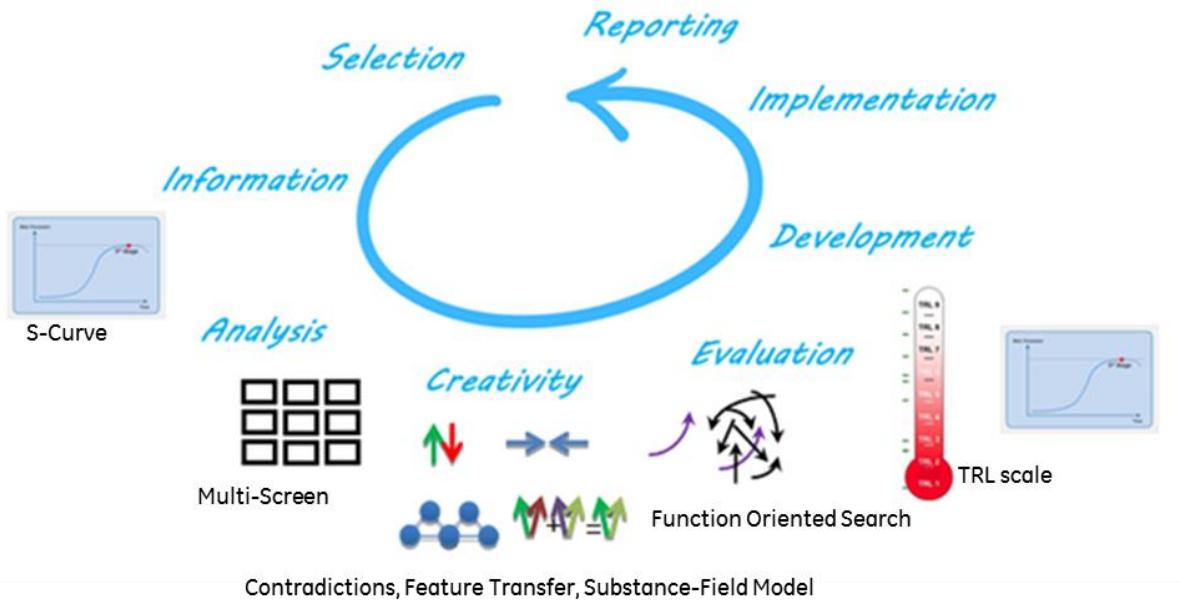


Fig.2. VA/VE + TRIZ Workout

Other takeaways include how to modulate the content of the workshop between VA/VE and TRIZ tools: the effectiveness of their combination is enhanced if the project phase is taken into account. Since the chosen level of focus can either offer the opportunity to pivot and drastically change the concept, or to zoom into the system to identify cost-out opportunities changing as little as possible, it is advisable to enhance the stress on TRIZ and Creativity at the early stages of the projects. A new session with more of a zoom-in approach can be added at the later stage with a bigger attention to the detailed emerging contradictions where the biggest costs are found. This is useful when the NPI is more advanced and the focus is on system optimization. This was experimented and confirmed by a three-day TRIZ session on a different project, described in Paragraph 5.

The participants appreciated TRIZ as a powerful tool: their perception on the pilot workshop was captured by a survey, results of which are reported in Table 3:

Table 3. Answers to a Participants Survey

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I understood how to effectively apply VAVE + TRIZ to my processes	67%	33%			
TRIZ adds value to VAVE	67%	33%			
The Day 1 introduction was enough to be able to have a working understanding on how to use the tools	33%	67%			
TRIZ enabled the team to developed more ideas.	67%	33%			
Some ideas were unlikely thought of without TRIZ	33%	33%	33%		

## 5. TRIZ for VA/VE offline

TRIZ was later applied during a dedicated workshop for a new NPI project. The goal was to formulate innovative concepts, leveraging on the functional analysis and cost structure previously identified during four classical VA/VE workouts on separate subsystems. The TRIZ facilitators met the team during a one-day pre-work session aimed to define the workout structure, elaborating at first on the S-Curve and Multiscreen analysis. VA/VE results were very helpful to the phases of problem definition and component analysis, guiding also a preliminary Cause Effect Chain Analysis. In this way the subsequent 3-day workshop was organized alternating common introductory sessions at the beginning of each half day, followed by workouts during which the team was split into 3 different groups, two of which working on incremental concepts and one chasing more disruptive ideas. The introductory sessions were designed to last less than one hour to allow the teams to get familiar with the proposed TRIZ tools on project-related examples and proceed with the creative phase. This allowed a more dynamic modulation of the creativity sessions, stressing the incremental and disruptive innovation efforts introducing the most suitable tools at the right time, with more than 100 generated ideas. Throughout the workshop the focus was on TRIZ tools, thus VA/VE idea down-selecting approach was very useful for concept post-processing, enriched with S-Curve and TRL concepts for idea regrouping and labelling.

## 6. Conclusions: more than Creativity Brainstorming

The experience gathered during the described workshops at GE Oil & Gas in Florence showed that the TRIZ methodology can enhance VA/VE and Design To Value activities far beyond the standard four hours scheduled for the VA/VE Creativity Phase. Moreover, it offered further insights on how to merge the two approaches more smoothly beyond the VA/VE Creativity Phase, suggesting the choice of the proper TRIZ tools according to the desired Technology Readiness Levels for the solutions and the integration of further TRIZ concepts. In particular S-Curve Analysis and Function Oriented Search can fit very well with other VA/VE stages,

such as FAST and Idea down-selection. Conversely, VA/VE concepts can strengthen the TRIZ Innovation Process, since TRIZ is very strong for idea generation, but lacks a structured approach to help a robust concept selection. Detailed description of the structure of the different workout days are given respectively in Table 4 for the *TRIZ for VA/VE Online* session and Table 5 for the *TRIZ for VA/VE Offline* workshop:

Table 4. TRIZ for VA/VE Online

Workshop Day	Activities
Day 1 AM	Introduction: VM Overview – The Power of VA/VE – Value concept Information: Project Selection – Goals - Scope – <b>S-Curve, MultiScreen</b> Random Function Identification
Day 1 PM	Function Analysis: FAST Diagram <b>TRIZ Intro: Brief History, Contradictions, Su-Field Examples</b>
Day 2 AM	FAST Diagram, Cost/Function Lecture and Matrix, <b>Choice of F/C</b>
Day 2 PM	<b>Creativity: TRIZ Engineering and Physical Contradictions</b>
Day 3 AM	<b>Creativity: Su-Field Models, MultiScreen</b>
Day 3 PM	Evaluation: Categorize – Rank – Combine T-Chart , <b>S-Curve, TRL</b> , Idea Selection Matrix, <b>Function Oriented Search</b>
Day 4 AM	Development: Concept Proposal Worksheet
Day 4 PM	Preparation and Team Presentation

Table 5. TRIZ for VA/VE Offline

Workshop Day	Activities
Prework AM	Introduction Idea Parking Lot, TRIZ Problem Definition, S-Curve Analysis,
Prework PM	Component List from 4 different VA/VEs on subsystems CECA Introduction, first Engineering Contradictions identification
Day 1 AM	TRIZ Intro, IFR, Root Cause Analysis, Multiscreen
Day 1 PM	Split into 3 Groups, Engineering and Physical Contradictions
Day 2 AM	Engineering and Physical Contradictions, Trends
Day 2 PM	Trimming
Day 3 AM	Idea Down-selection

Day 3 PM	Idea Down-selection, Team presentation
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So, we can outline the learnt lessons in the following list:

- TRIZ has already been successfully applied as VA/VE and other methodologies creativity enhancer, as shown by many literature papers and conference contributions; its use in the VA/VE process has been so far restricted to the creativity phase only, and there are few reports on which specific tools have been adopted: Contradictions, Ideal Final Results and Innovation Situation Questionnaire
- Adding a S-Curve Analysis as early as possible to the VA/VE process can represent a powerful tool to assess the technology status and the resulting recommendations could help significantly shape the creativity phase when deciding whether the desired level of innovation should be incremental or disruptive
- Ideally the S-Curve Analysis, along with a preliminary Cause/Effect Chain Analysis to identify key problems, should be done so that additional technologists may be included in the following workshop, and the TRIZ facilitator(s) should be involved
- Substance-field Models (TRIZ for VA/VE online) and Trends (TRIZ for VA/VE online) proved to be very powerful tools for generating disruptive concepts, while Engineering and Physical Contradictions were very effective for more conservative approaches where the Engineering System needed not to be changed radically
- Adding TRIZ tools such as feature transfer and function-oriented search to the Evaluation phase can offer solid decision support; also the system assessment, both in terms of S-Curve and/or TRL can be of great help in categorizing the ideas
- VA/VE offer a quite strong method for the idea evaluation phase, while TRIZ lacks a structured approach to the post-processing phase and can profit from VA/VE approach
- It is advisable to enhance VA/VE workshops for low TRL and NPI projects, whenever a strong innovative pivot is needed; higher TRL systems can better profit from classic VA/VE cost structure identification process
- GE saw value in recommending to merge the two approaches further and launched new pilots to assess the effectiveness at different TRL levels, in order to increase product and project sustainability
- GE experience underlined the value offered by repeating similar workshops for the same project at different TRL levels, modulating the TRIZ/VA/VE content, so as to shift smoothly the focus between radical innovation and cost-out intervention

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# UNIVERSAL UNSOLVABLE PROBLEM AND PROCESS OF RESOLVING IT.

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## Abstract

What problems should we solve with TRIZ? The problems unsolvable with use of professional knowledge and expertise. Why problem becomes “unsolvable”? Due to incorrect formulation.

These understandings facilitated discovery of universal structure of unsolvable problem. Availability of such structure, in its turn, facilitated discovery of universal process of resolving the unsolvable problems. This process involves four problem-solving stages having same structure; each stage has its specific task. Shift from previous stage to the next one happens only if the previous stage could not produce the satisfactory solution.

Every problem-solving stage includes the following steps: collecting the information; analysis and formulation of Opportunities; idea generation; combining the ideas into Solutions; evaluation and selection of Solutions. Each stage requires minimum information about problem situation and minimum analytical work.

This process is successfully tested at Samsung TechWin and in a Manufacturing 4.0 innovation contest organized by TRIZ France/INSA CVL France & MDBA.

*Keywords:* TRIZ, problem-solving, unsolvable problem, problem-solving process, analysis, idea generation, solution, evaluation.

## 1. State of the Art

To solve a problem in any area of human activities, one should perform the same actions: collect the information, develop the model of problem, analyze this model, select the appropriate problem-solving tools, apply these tools to the model of problem, form the model of solution, and evaluate the solution. Accordingly, the ideal goal of any problem-solving approach is reducing the variety of problem models and, accordingly, the variety of algorithms for selection and use of problem-solving tools, without reducing the variety of real-world problems this approach can solve.

TRIZ is not any different. Entire history of evolution of TRIZ problem-solving shows the relentless attempts of finding the universal model of problems TRIZ could solve, as well as the universal algorithms for problem-solving [1]. However, each model and each algorithm had their own limitations. Since Classical TRIZ times, the situation in this area has not changed too much. This fact is based on extant understanding of problems that could be solved with TRIZ ([3], [4], [5]). Accordingly, the fundamental model of “inventive problem” remains the same:

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*The peculiarity of such problems consists in the presence of a strong contradiction which is impossible to solve by traditional engineering methods [3].*

Recent research reported in this paper revealed the universal model of “unsolvable” problems; this discovery resulted in development of universal algorithm of problem-solving.

## **2. How Does the Unsolvable Problem Occur?**

**Unsolvable problem** could be defined as a real-world problem that could not be solved by experts in the area where this problem occurred.

Despite of seeming fuzziness, this definition is substantially strict from pragmatic viewpoint, because it provides the clear criteria for separation of “problems that should be solved with TRIZ” from other problems. Moreover, this definition facilitates development of universal model of unsolvable problem, which is shown below.

“Could not be solved” means that all solutions suggested by experts were accompanied by substantial drawbacks. Now, what does “substantial drawback” mean? It means that this drawback represents an insurmountable obstacle to process of performing some job or satisfying some need.

Where did the problem occur? It occurred in some situation. This situation was intended to produce a useful result needed for performing some job or satisfying some need. Then, what is the problem? The problem is that some result of this situation became, for some reason, intolerable. Why? Because it turned into insurmountable obstacle to the process of performing some job or satisfying some need.

Then, why did the problem occur? When the situation was purposefully created, it did not involve any problem. Moreover, the experts who created this situation tried to avoid any side effects or problems. However, the problem occurred. But why?

Presumably, the reason for problem occurrence was some alteration that happened in this world. Something changed, and situation that worked before without any unsolvable problem went wrong. Where had this alteration happened? If it had happened inside the situation, the experts could’ve revealed and eliminated it. Since they could not eliminate it, the alteration had happened outside the situation, far out of experts’ reach.

Experts, then, had to compensate for influence of this alteration. For this purpose, they tried to modify something within their reach, i.e. within the situation or its close environment. However, every suggested solution had the substantial drawback...

This is the way the unsolvable problem occurred.

## **3. Universal Description of Unsolvable Problem**

This mechanism of occurrence of unsolvable problem provides us with opportunity to describe this problem in some universal format:

The *Initial Situation* was purposefully created to produce the *Useful Result* needed for performing the *Job-1*.

Somewhere outside the *Situation* some *External Alteration* happened. As a consequence of this *Alteration*, some output of *Situation* is now perceived intolerable. As a result, the *Initial Problem* occurred. This *Problem* creates an insurmountable obstacle to performing the *Job-2*.

The experts tried to correct the *Situation* and eliminate the *Initial Problem*. However, the suggested *Preliminary Solution* is accompanied with substantial *Drawback* creating the insurmountable obstacle to performing the *Job-3*.

What could be done?

This description could be represented by the following visual model (flowchart) [2]:

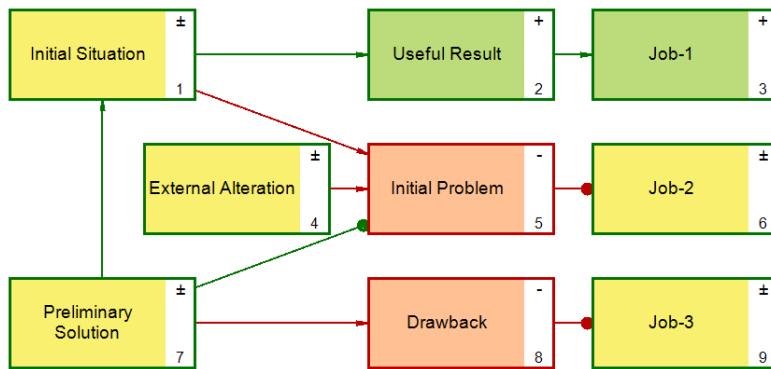


Fig. 1. Model of Unsolvable Problem

This model is so general that it could be applied to any unsolvable problem, including interpersonal and business ones. On the other hand, this model comprises a handful of basic components that are easily related to the actual problem situation; as a result, this model could be easily “translated” to the specific language of real-world problem.

#### 4. Solving the Unsolvable Problem

Altshuller, in course of analyzing many hundreds and thousands patents, found out that all problems could be divided into two categories [2]: problems that could be solved by direct use of already known Patterns of Evolution of Technological Systems or their consequences, and problems that are not yet completely formalized. Hence, he divided problems to two classes: typical and non-typical and said that “problems that are today non-typical, tomorrow, when we reveal the yet unknown patterns, would become the typical ones.”

Here, we see the main purpose of search for typical problems: the typical problem assumes the typical process of problem-solving. The Universal unsolvable problem could be solved in the standardized process including four stages:

- I. Generate all possible Preliminary Solutions, select the most promising one, and find out its Drawback;
- II. Improve the most promising Preliminary Solution by counteracting the Drawback;
- III. Improve the Initial Situation;
- IV. Make processes of getting Jobs done independent on the problem situation.

This process overtly resembles the Stage-Gate® process. Every problem-solving stage includes the following steps: collecting the information; analysis and formulation of Opportunities; idea generation; combining the ideas into Solutions; evaluation and selection of Solutions. Each stage requires minimum information about problem situation and minimum analytical work.

At the gates between stages, the following decisions could be made: **go**, e.g. proceed to implementation; **no go**, e.g. satisfactory solution is not found, and the project team should proceed to the next stage of problem-solving; **return**, e.g. satisfactory solution is not found, the project team should return to the previous stage and consider other opportunities; and **postpone**, e.g. temporary stop the problem-solving activities.

The detailed description of universal problem-solving process could be found in [6] and [7]. Here, authors are going to explain this process through the case study.

### Case Study: Rice Dryer

*Rice should be dried to be stored. Rice is dried in opposing airflow: rice falls down; hot airflow goes upward and removes moisture and dust from rice. Exhaust hot air goes to atmosphere through the long pipe. Exhaust hot air creates a lot of noise, and neighbors complain. However, silencer increases price of rice dryer, and farmers cannot afford it.*

The following flowchart models this problem:

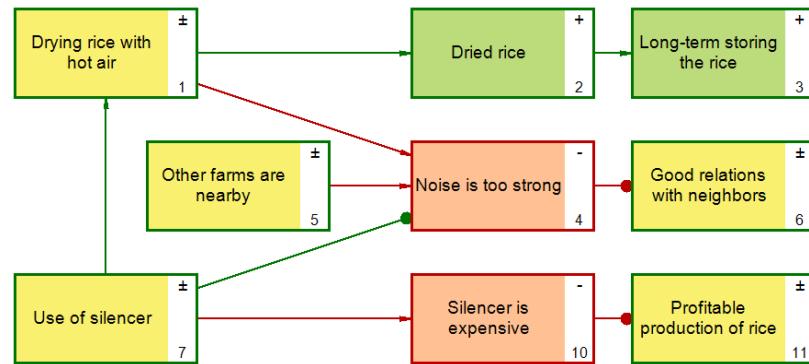


Fig. 2. Model of Case Study

#### 4.1.Stage I. Generate Preliminary Solutions

The Goal of this stage is finding the practically exhaustive set of possible preliminary solutions. At this stage, the model of problem looks like this:

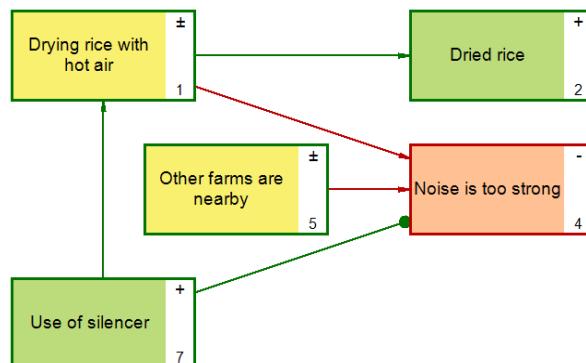


Fig. 3. Model for Stage I

As you could see, the information that should be collected before starting work at this stage is limited to both the information needed to fill the boxes of the problem model and criteria for solution evaluation.

At this stage, one opportunity was formulated: Counteract *Noise is too strong*.

Accordingly, all suggested Preliminary Solutions were aimed at noise reduction. Unfortunately, none of them satisfied the client. Anyway, the most promising and realistic Preliminary Solution still was *Use of silencer*.

In the Universal Problem-Solving Process, all preliminary solutions are assumed as failures; each preliminary solution has severe drawbacks that occur if we try to implement it. Hence, the project team should reveal the drawbacks of selected preliminary solution.

In this case, the major drawback of *Use of silencer* still was its unaffordable cost.

If selected preliminary solution does not have any severe drawback, it is a sin not to take advantage of such luck. In this case, the preliminary solution should become the final solution. If evaluation of this solution is satisfactory, project team should start planning its implementation.

#### 4.2. Stage II. Improve Preliminary Solution

If selected preliminary solution is accompanied with severe drawbacks, it should be improved rather than rejected. The Goal of this stage is to correct the selected preliminary solution, to eliminate its drawbacks. At this stage, the model looks like this:

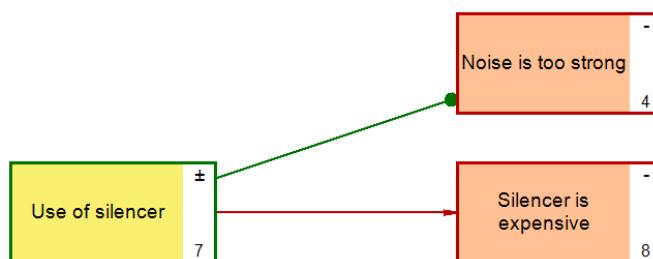


Fig. 4. Model for Stage II

The opportunity formulated at this stage was Counteract *Silencer is expensive*. Accordingly, the suggested solutions were aimed at cost reduction of known design of silencer (some time ago, client's engineers designed silencer to the rice dryer, but market did not accept it due to high cost). The main limitation to cost reduction effort was silencer's efficiency: any simplification of design or manufacturing process should not affect the noise reduction. Unfortunately, this direction did not provide the project team with sufficient cost reduction.

#### 4.3. Stage III. Improve the Situation

If none final solution produced at Stage II is OK for implementation, project team should move to improvement of initial situation. This situation should become insensitive to influence of external alteration that already caused the initial problem. The Goal of this stage is to modify the situation so that, under condition of external alteration, the initial problem could not occur. At this stage, this general model should be used:

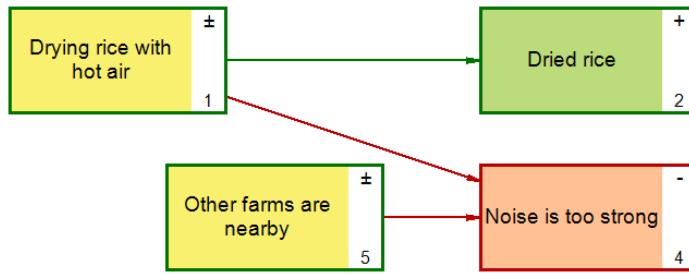


Fig. 5. Model for Stage III

This stage incurs some analytical work. The facilitator should develop the models of situation “as it was intended” and “as it happened in reality.” These models should be developed in form of flowcharts that represent events (functions) and links between them.

At the end of analytical work, facilitator should formulate the specific opportunities.

Analysis of problem situation *Drying rice with hot air* revealed several reasons for noise occurrence. However, any changes in rice drying process were prohibited by client: the process was successfully used for many years, and any changes would take too much time for testing. Other changes in aerodynamics of hot air flow inside the rice dryer, as well as in the exhaust pipe, have not provided for any successful solution.

As a result, the project team decided to proceed to the Stage IV, because “technological” problem-solving has not produced the solution worth the implementation effort.

#### 4.4. Stage IV. Improve Jobs

If none final solution produces at previous stages is OK for implementation, the project team should stop solving the “problem as it is” and start providing for performance of jobs affected by problem situation. The Goal of this stage is to find the ways to perform the jobs so that they cannot be affected by problem situation.

Here is the model for this stage of work:

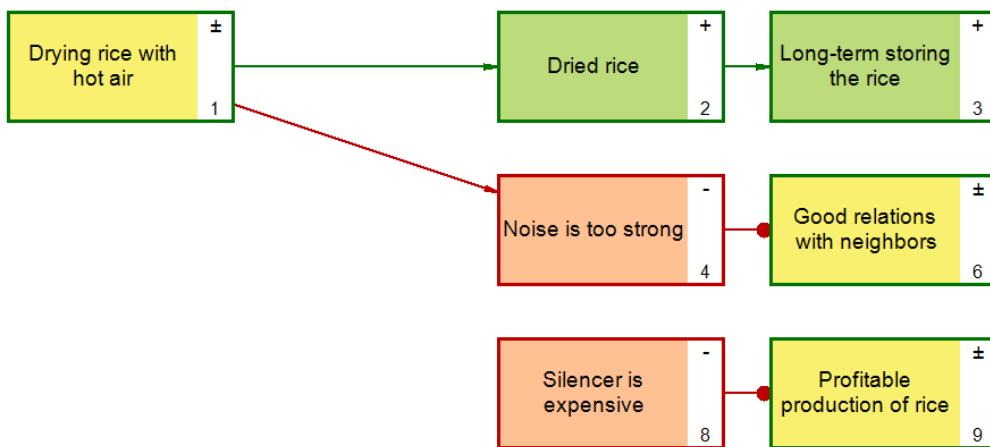


Fig. 6. Model for Stage IV

At this stage, the following analytical work is needed: develop the flowcharts of processes of performing the jobs-1, 2 and 3; model the processes of performing the jobs-1, 2 and 3; reveal which operations of these processes are affected by problem situation; reveal the problems in alternative ways to produce the useful result; and formulate the specific opportunities.

If project team manages to perform the job-3 *Profitable production of rice* so that drawback of preliminary solution *Silencer is expensive* does not affect it, project team should start implementing this preliminary solution *Use of silencer* to eliminate the initial problem *Noise is too strong*.

If project team manages to perform the job-2 *Good relations with neighbors* so that initial problem *Noise is too strong* does not affect it, there is no need to solve the problem as it was stated; project team could keep the situation *Drying rice with hot air* as it is.

If project team manages to perform the job-1 *Long-term storing the rice* without use of useful result *Dried rice* produced by initial situation *Drying rice with hot air* or manages to get this useful result *Dried rice* in alternative way, without initial situation *Drying rice with hot air*, project team could stop performing this situation and forget about initial problem *Noise is too strong*.

Project team started working with Job-3: *Silencer is expensive* counteracts *Profitable production of rice*. Two ideas looked attractive: *Silencer should pay for itself* and *Silencer is combined with rice dryer*. The first idea suggested the following solution: *Hot exhaust air preheats intake air and kerosene (fuel), thus reducing fuel consumption; heat exchange is provided by silencer*. Second idea suggested another solution: *Silencer is embedded in the rice dryer design*. Combination of these two solutions produced the solution for implementation: *Heat exchanger for preheating of intake air and kerosene is embedded in the top portion of rice dryer (thus recycling both heat of exhaust airflow and convection heat of rice dryer); this heat exchanger is designed as silencer*. As a result, noise was reduced to the tolerable level, and fuel consumption was reduced by 15%, thus compensating the cost of silencer.

## **5. Solution Development**

Facilitated project team performs the solution development process in the same way regardless the stage of problem-solving. The solution development scenario comprises five steps: idea generation, idea discussing, development of Idea List, combination of ideas into solutions, and solution discussing.

Project team generates ideas in course of guided, facilitated brainstorming. The project team members, experts in the problem-at-hand and related areas, on their own solve their own problem under TRIZ specialist's facilitation. They generate ideas using TRIZ recommendations that direct their thinking toward the most probable solution areas. Project team members generate ideas either individually or in pairs; the latter is the most efficient way. Facilitator provides each project team member or pair with specific opportunity aimed at solution.

The goal of idea generation is to formulate and document as many as possible thoughts on purposeful modification of resources participating in the problem situation and relationships between them. None of these thoughts should solve the problem. However, various combinations of these thoughts would produce solutions; this job would be done later.

The “guided brainstorming” process driven by simple, but exact TRIZ recommendations was proven as the most efficient way to extract and use the relevant knowledge from brains of subject matter experts. Hence, in this case “brainstorming” does not mean “trial-and-error,” rather “knowledge extraction and use.”

The goal of combining the ideas (thoughts) into solution is to produce the conceptual solutions resolving the problem-at-hand.

## **6. Recommended Technique and Tools**

The suggested universal problem-solving process is convenient for facilitated work under guidance of TRIZ expert [6]. Facilitator (TRIZ expert) collects needed information, analyzes the problem-at-hand, and formulates the Opportunities (tasks). Then, the project team uses TRIZ recommendations and generates the “raw” ideas (thoughts). The project team could use for this purpose, for example, System of Inventive Principles [8] or other idea-generation tools ([9], [10]). Later, the project team combines these “raw” ideas into Solutions, evaluates these Solutions and selects one worth implementing. If evaluation shows that no Solution meets all criteria, the project team should proceed to the next stage of problem-solving process.

Since the suggested problem-solving process is common-sense based, its structure is similar to other processes of similar purpose, for instance, the Design Thinking process. It means that suggested process and/or its tools could be naturally integrated into other problem-solving approaches.

From TRIZ standpoint, the universal problem-solving process should be compared to ARIZ, due to similarity of purposes. This comparison [11] shows that suggested process is more focused on overtly defined specific directions, and provides for more directions for problem-solving.

This process has been successfully tested in multiple TRIZ projects at Samsung TechWin and in a Manufacturing 4.0 innovation contest organized by TRIZ France/INSA CVL France & MDBA.

## **7. Results And Discussion**

The suggested Universal model reflects the process of occurrence of unsolvable problem: first, the Useful Result is produced by Initial Situation; then, something changes in the world, and Initial Problem occurs; experts try to resolve it, but every time fail. Hence, this model could be applied to any unsolvable problem that should be resolved with help of TRIZ. Since we have the universal model of problem, we can develop and use the universal problem-solving process presented in this paper.

The major benefits of suggested universal problem-solving process are overtly determined directions for finding the solutions, as well as Stage-Gate® process determining the pragmatic sequence of addressing these directions. In this way, suggested process substantially reduces trials and errors inherent to other TRIZ problem-solving processes.

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