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Patterns of Evolution: Recent Findings on Structure and Origin[1]

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Abstract

The Patterns of Technological Evolution are the heart of the Theory of Inventive Problem Solving (TRIZ) and the driving force in the transformation of TRIZ into a science of technological evolution. Since the mid-1970s, when Genrich Altshuller published his first set of patterns, numerous TRIZ specialists have worked in this area, primarily in attempts to find the most advantageous structure and create a complete system of patterns. These attempts, however, have had limited success due to the patterns' empirical nature and a lack of understanding of their origin. In this paper the authors share their latest findings in the area related to the following:

- Linking technological evolution with the evolution of human needs (evolution of markets)
- Refining and deepening knowledge about existing patterns of evolution
- Formulating new patterns
- Developing the general structure of the patterns
- Developing analytical instruments for effective utilization of the patterns, not only for problem solving but for predicting future generations of systems and controlling their evolution.

[1] Edited by Vicki Roza

Introduction

History

The main efforts of Genrich Altshuller (the originator of the Theory of Inventive Problem Solving, or TRIZ) and his followers were directed toward a very practical and well-defined goal: the development of methods for finding inventive solutions to difficult technological problems. This approach was successful in that it provided effective results relatively quickly. But this same success somewhat overshadowed the fact that the most valuable outcome of Altshuller's endeavor was the discovery of patterns of technological evolution, which in turn provided a means of controlling the evolution of technological systems rather than merely solving ongoing problems.

Starting with Aristotle, the identification of a set of universal evolutionary patterns was a goal of philosophers, scientists, and many others; rather limited success was achieved, mostly by those who focused on the study and analysis of real-life systems[2] instead of abstract philosophical considerations.

Altshuller's search for basic patterns of technological evolution started when he began his work on TRIZ.[3] Consequently, in the late 1940s he formulated patterns that became fundamental to TRIZ, such as the evolution of technological systems toward increased ideality through the resolution of contradictions. But Altshuller's focus was a practical one and thus his main efforts were directed toward developing the Inventive (Innovation) Principles and the Algorithm of Inventive Problem Solving (ARIZ). The first seven principles were published in 1964[4]; by 1969 there were 35 principles, and finally in 1973[5] the 40 Inventive Principles were published (Altshuller had distributed the final list of principles among TRIZ followers and students around 1971).

The relatively wide practical application of the 40 Inventive Principles during the 1970s revealed the strengths and weaknesses of this first TRIZ knowledge-based tool.[6] The main problem was evident in the dramatic range of efficacy of the principles: while certain principles prompted fairly conventional solutions (such as principle 3, *local quality*), others yielded strong solutions with narrow application (32, *changing the color*) and some offered robust and widely-applicable solutions that could be further refined and strengthened. In time it became clear that the more powerful Inventive Principles represented strong, recurrent Patterns of Technological Evolution (such as 15,

[2] Scientists like Charles Darwin, Ludwig Von Bertalanffy, Norbert Wiener, Iliya Prigogin, etc.

[3] The authors did not participate in TRIZ development before 1975, therefore, their knowledge about certain events that had taken place prior to 1975 is based on numerous conversations and discussions with Altshuller after the fact, while working together on seminars and co-authoring books.

[4] Altshuller, Genrich. *Bases of the Inventive Process*. Voronezh: Tsentralnochernozemnyi Publishing House, 1964.

[5] Altshuller, Genrich. *Algorithm for Invention*. Moscow: Moskowskii Rabochii Publishing House, 1969 (first edition), 1973 (second edition).

[6] Altshuller, Genrich. *Creativity as an Exact Science*. Gordon and Breach Science Publishers, Inc., 1984. pp. 175-179. The Russian version of the book was published in 1977.

dynamicity) or supported them (25, *self-service as a way to increase the ideality of a system*).

In the spring of 1975 Altshuller distributed a manuscript with the first set of Patterns of Technological Evolution among TRIZ schools. These seven-pages became the most valuable component of TRIZ and established the foundation for TRIZ as a science.[7]

The set of patterns included three groups named after the laws of theoretical mechanics:

Group 1 – Statics – determines the beginning of a system's life cycle, including:

1. Completeness of an engineered system
2. Energy flow in an engineered system
3. Harmonization of the synchronization rhythms or parts in an engineered system

Group 2 – Kinematics – determines the general evolution of a system, including:

4. Increasing ideality of an engineered system
5. Non-uniform evolution of subsystems comprising an engineered system
6. Transition to the overall system

Group 3 – Dynamics – reflects evolution in contemporary conditions involving certain physical and technical factors, including:

7. Transition from macro- to micro-level in an engineered system
8. Increasing substance-field involvement

While continuing his work on the Patterns, Altshuller established a critical requirement: a formulated pattern must not only be ***informative*** (describing how systems evolve) but must be ***prognostic***, making it possible to predict the directions in which a given system would evolve; and ***instrumental***, helping to realize these directions and ultimately control the system's evolution.

In the fall of 1975, Boris Zlotin began teaching a course on the Patterns of Technological Evolution to second-year students at the St. Petersburg People's University for Technical Innovation (SPUTI). During this and subsequent courses, Altshuller's Patterns were presented in detail and illustrated with many examples, including military weaponry and even tactics and strategy.[8] The active participation of many of the students (among whom were a number of talented engineers) prompted new ideas on the subject.[9] At the same

[7] Eventually published in Altshuller, Genrich. *Creativity as an Exact Science*. Gordon and Breach Science Publishers, Inc., 1984. The Russian version of the book was published in 1979.

[8] In fact, applying the Patterns to the evolution of the structure of attacking troops (from no organization to the Macedonian phalange and Roman legions) was the first example of using Patterns for non-technical systems.

[9] For example, the discovery that selected patterns could be applied to the evolution of an art (such as painting or music) as well as to organizations.

time, it was noted that the suggested structure of statics-kinematics-dynamics was more confusing than beneficial.

In 1980 the first TRIZ conference was held in Petrozavodsk, Russia, and the Patterns of Technological Evolution were a topic of discussion. A leading TRIZ theoretician, Vladimir Petrov, suggested that the Patterns be combined with certain aspects of classical system analysis; Boris Zlotin suggested the addition of patterns describing the evolution of technological processes; Esther Zlotin reported her findings about patterns in the evolution of music.

In 1981, two full scale TRIZ seminars took place:

- A four-week seminar held in Moscow for Value Engineering specialists from the electrical industry
- A three-week seminar in Kishinev (Chisinau), Moldova for members of the local Society of Inventors

Both seminars were conducted by Genrich Altshuller, with Boris Zlotin serving as a second instructor. As was the custom, other TRIZ specialists and instructors attended these seminars to update their TRIZ knowledge and enhance their teaching skills; among them were Vladimir Gerasimov, Tatiana Kurashova, Valentin Bogach, Victor Fey, Isaac Bukhman, Valery Shteinberg, Igor Kondrakov, Boris Farber, Igot Kulikov, and others. Unrestricted communication and fruitful discussions led to significant contributions to the Patterns, and prompted Boris Zlotin to develop a hierarchical structure for the Patterns that included more detailed descriptions (sub-patterns) that were later called Lines of Evolution.[10] Although this structure was later criticized for its redundant complexity, the most important output of this attempt was the recognition that much room existed for enhancing and further developing the Patterns.

In late 1981, Alla Zusman, who had attended a TRIZ seminar in Kishinev, began teaching her own class on TRIZ in the organization where she worked. She gathered all available material on the Patterns and, in organizing it for teaching purposes, attempted to coordinate the Patterns with Hegel’s system of dialectics.

Since the summer of 1982 the authors have worked together in the field of TRIZ, often with other attendees from the Kishinev seminar (Vladimir Proseanic, Anatoly Ioysher, Bella Rykova, Valery Yanov) and students of Alla Zusman (Len Kaplan and Alex Chernobelsky). Gradually, the Kishinev TRIZ School was established and later included other TRIZ practitioners from Kishinev and elsewhere (Svetlana Visnepolschi, Zinovy Royzen, Vladimir Oleynikov, Vladimir Shapiro, Sergey Malkin, Lev Pevzner, Igor Kholkin, Valery Prushinskiy, and others).

[10] A line of evolution describes in detail the sub-steps within a particular Pattern.

The Patterns of Evolution have been the primary focus of the Kishinev TRIZ School since its inception.[11] Research efforts have included studies in biological evolution (advised by Vladimir Petrov and including non-Darwinian theories) as well as the evolution of science, art, language, social systems, etc. They were in continuous dialogue with Altshuller about their work, via correspondence and in person during numerous TRIZ seminars (12 seminars, from 2- to 4-weeks long between 1981 and 1986).[12]

Other TRIZ schools and independent TRIZ specialists have been actively working in this area. In 1982, Vladimir Petrov presented two important papers at the second TRIZ conference in Petrozavodsk, based on:

- Forecasting the evolution of electrical welding equipment (the first large-scale forecasting based on the Patterns of Technological Evolution)
- Introducing the concept of "excessiveness" in technological systems. According to this concept, every technological system possesses more capabilities than are necessary for normal functioning; these excessive capabilities can be revealed and utilized to increase the system's ideality. In addition, it is possible to identify new applications for underutilized substances, fields, information, etc. – the concept of redundancy in technological systems.

In 1985, Genrich Altshuller introduced a well-developed concept regarding the utilization of substance-field resources (in other words, excessive capabilities) in the Algorithm for Inventive Problem Solving (ARIZ), which became a very fruitful concept.[13]

At the TRIZ conference in Novosibirsk, Russia in 1984, several interesting works on the Patterns of Technological Evolution were presented, including:

- The "pulsing" model of evolution, by Yury Salamatov and Igor Kondrakov[14]
- The increasing complexity and simplification of technological systems in the process of evolution, by Igor Vertkin[15]
- Evolutionary patterns of methods and devices for curing broken extremities, by Nikolai Predein[16]
- Two ways of increasing ideality of technological systems, by Boris Zlotin and Alla Zusman.

By 1985, the authors had concluded, based on work and discussions, that the approach to the process of revealing and formulating Patterns of Technological Evolution should be changed. Altshuller had always insisted that the creation of TRIZ tools be based solely on

[11] The Kishinev TRIZ School existed between 1982 and 1992. The most typical activity included TRIZ education course for 25–40 industrial professionals (200-220 hours; one full day per week with a project involving finding a solution to a particular technological problem and/or theoretical research).
[12] After 1986 Altshuller stopped conducting seminars due to poor health.
[13] Zlotin, Boris and Alla Zusman. *The Concept of Resources in TRIZ.* Presented at TRIZCON 2005.
[14] Based on the evolution of heat pipes.
[15] Under Altshuller's guidance.
[16] Based on the work of the famous Doctor Elizarov.

high-level inventions documented in the patent library. This approach had been successful for the Inventive Principles despite a disregard for whether the patented solutions had been implemented. But such an approach to revealing patterns of technological evolution created several problems:

- Excluding certain steps from the evolutionary lines just because they look obvious today renders the lines incomplete and narrows their application area; for example, dynamization in mechanical systems looks almost trivial, while dynamization in a chemical molecule can yield quite extraordinary effects.
- Many patented inventions have never been implemented because they are not feasible; others were patented for the sole purpose of misleading competitors, etc.

Given the above, the authors changed the focus of their research from the patent library to the history of technology. The first results were published in[17] *The Profession of Searching for New Ideas.* Besides the new approach, other changes were introduced, in particular:

- Upgrading the pattern of *coordination of rhythms* to *matching-mismatching of all technological system parameters*[18]
- Introducing a new pattern: *reduction in human involvement*
- A new structure for the Patterns, including multiple Lines of Evolution

In addition, several of Altshuller's patterns were omitted from the new system for various reasons:

- Two patterns from the Statics group (*completeness* and *energy flow* in technological systems), as they represented the conditions for a system's existence more than its evolution. Moreover, certain cases were found that contradicted these patterns.
- The pattern *increasing substance-field involvement* related more to system models than to the evolution of actual technological systems. However, the essence of the pattern related to the actual utilized field evolution, which was included as a line of evolution within the pattern *transition to the micro-level*.

Until 1985, the majority of studies on the Patterns were in technology, although examples of non-technical applications were known and utilized in educational courses. In 1986, a TRIZ course on the Patterns conducted by the authors at the Kishinev School included numerous case studies and a comparative analysis on evolution in biology, society, military strategy, arts, entertainment, sports, etc. The main focus shifted from problem-solving to TRIZ forecasting. Eight final projects of the 1986 course attendees were devoted to this topic; others included certain elements within it. For example, Alex Chernobelsky and Yakov Grinberg conducted TRIZ forecasting on methods for raising

[17] Altshuller, Genrich, Boris Zlotin, and Vitalii Philatov. *The Profession of Searching for New Ideas*. Kishinev: Kartya Moldovenyaska Publishing House, 1985.

[18] Besides rhythms, matching/mismatching is applicable to materials, shapes, structure, longevity, etc.

calves; Sergey Malkin and Len Kaplan developed methods for forecasting the evolution of measurement and control systems. Earlier, Boris Zlotin and Svetlana Visnepolschi conducted a comparison of traditional forecasting and TRIZ forecasting for water pumps. Later, TRIZ forecasting projects were performed for lifting cranes, helicopters, banks, mercantile and stock exchanges, educational systems, certain social systems, etc.

The first course was recorded and transcribed by TRIZ specialists Victor Ladoshkin and Yury Bychkov, supplied with comments from the authors, and distributed among TRIZ professionals. Valuable feedback from this course led to further development; the results were published in *Searching for New Ideas: From Insight to Methodology; The Theory and Practice of Inventive Problem Solving*,[19] and included:

- Development of definitions and fundamental elements for Patterns of Evolution
- Development of requirements for the process of revealing and formulating Patterns in any area
- Revealing the links between patterns in technological evolution and laws of nature and human intuition.
- Constructing a new set of patterns, including:
  - Stages of evolution (infancy, growth, maturity and decline)
  - Evolution toward decreased human involvement
  - Non-uniform development of system elements
  - Evolution toward increased ideality[20]
  - Evolution toward increased complexity followed by simplification
  - Evolution toward increased dynamism and controllability
  - Evolution with matching and mismatching elements
  - Evolution toward micro-levels and the increased use of fields

In addition, the following topics were discussed in *Searching for New Ideas*:

- General patterns of evolution
- Methodology for TRIZ forecasting
- Patterns of organizational evolution
- TRIZ and patent science
- TRIZ and elements of creative education
- TRIZ education

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[19] Published first in the brochure by Boris Zlotin and Alla Zusman, Patterns of Technological Evolution. Kishinev: STC Progress in association with Kartya Moldovenyaska Publishing House, early spring of 1989; later included in the book by Altshuller, Zlotin, Zusman, and Philatov, Searching for New Ideas: From Insight to Methodology; The Theory and Practice of Inventive Problem Solving. Kishinev: Kartya Moldovenyaska Publishing House, 1989.
[20] The patterns included definition of global and local Ideality; utilization of various resources for the purpose of increasing Ideality.

- A structured system of typical resources enabling the evolution of technological systems
- Typical mistakes in the evolution of technological systems, and ways to avoid them
- Approximately 30 lines of technological evolution, with examples

By 1991, the authors had attempted to adapt general patterns of evolution to the evolution of scientific systems (hypotheses and theories) and to R&D organizations.[21]

Since 1993, the authors have been working on patterns of evolution within the framework of Directed Evolution™, an extension of TRIZ forecasting.

The main challenges

Given the above, it can be said that over the last 60 years TRIZ has grown from a problem-solving methodology to a ***science of technological evolution***, with the Patterns of Evolution at its core. At the same time, we know that all known Patterns are empirical in nature and therefore can describe the main direction ("what"*)* of a system and its actual evolution ("how") but lack the "why" – that is, an explanation of the origin and driving forces of technological evolution. Obviously, finding answers to these questions is critical for revealing and structuring the Patterns and for TRIZ becoming widely recognized as a science.

Another important aspect of converting knowledge about evolutionary patterns into a real science is consensus with regard to the main definitions and assumptions. To date, TRIZ literature refers to laws of evolution, patterns of evolution, trends of evolution, and lines of evolution. Different translations from Russian into English and other languages also contribute to the confusion.

Definitions and assumptions

Definitions

The first attempt to clarify definitions for English terms for the main TRIZ elements related to technological evolution was made in 1999,[22] as follows:

An ***evolutionary trend*** is a sequence of events directly and/or indirectly connected through cause-effect relationships. Each event in the chain (alone or together with the others) leads to the next one and thus increases the probability of its emergence. A trend may represent a limited (specific) model of an evolutionary process that describes its

[21] *Solving Scientific Problems*. Kishinev: STC Progress in association with Kartya Moldovenyaska Publishing House, 1991.

[22] *TRIZ in Progress; Transactions of the Ideation Research Group*. Ideation International Inc., 1999.

specific feature(s). Examples of trends in social life, technology, science, fashion, art, etc. are well known.

Examples:

- *Growth of "high-tech" technologies*
- *Increasing attention to the environment*
- *Increasing utilization of synthetic materials*

The ***Patterns of Evolution*** represent a compilation of trends that document strong, historically-recurring tendencies in the development of man-made or natural systems. (And as was noted earlier, an identified pattern has predictive power.)

Examples:

- *Evolution toward decreased human involvement*
- *Evolution toward increased dynamism and controllability*
- *Evolution toward micro-levels and the increased use of fields*

The Lines of Evolution reflect the historical sequence of changes that a technological system undergoes during its evolution.

Example:
A multi-step transition that includes the following steps:

1. *Use of a permanent field*
2. *Transition to a pulsed field*
3. *utilizing a pulsed field with matched frequency*

While a trend might be a short-lived event (certain styles in consumer products, for example) patterns and lines represent the strongest long-term (often permanent) trends. In other words, a pattern of evolution addresses *what* exactly will happen as a result of evolution (increasing dynamism, for example); a line of evolution shows *how* this goal will be accomplished (step-by-step).[23]

Assumptions

Below are 19 assumptions supported by an extensive study of the history of evolution of various systems of different scale.[24]

[23] See *TRIZ in Progress; Transactions of the Ideation Research Group*. Ideation International Inc., 1999.

[24] The first set of 11 assumptions with their derivatives was introduced in 1999 in *TRIZ in Progress; Transactions of the Ideation Research Group* (Ideation International Inc., 1999, pp. 175-180).

Patterns and trends of evolution

The majority of man-made systems evolve not randomly but according to the pre-determined patterns described below. These patterns can be revealed by studying the history of evolution of various systems and can then be used to accelerate system evolution instead of waiting for the system to evolve "naturally."

Patterns are hierarchical in structure and include multiple lines of evolution. The evolution of a system can be impacted by specific trends that occur at specific times. These trends are relatively short-lived and have their own lifecycle, including typical stages such as emergence, slow growth/impact, strong growth/impact, and weakening followed by disappearance and/or transformation into another trend.

The driving force of evolution

The majority of existing man-made systems evolve to satisfy customer requirements and needs (either spelled out or unrecognized). In general, customers want more functionality and quality at reduced cost and with fewer harmful effects.

Generation of change combined with selection

Any technological system evolves by the realization of various ideas that result in system change or in the creation of a new system; a selection process is then applied to choose the best system for satisfying the requirements (if they represent an increase in the system's ideality). The main selection factor is market response, which in turn provides the financing that is crucial to system development.[25]

Two types of selection – positive and negative – impact a system's evolution:

- Positive selection – works in healthy economic situations to favor systems capable of effectively capitalizing on available resources and that can be quickly spread throughout the industry or market
- Negative selection – works during times of economic depression to favor systems capable of surviving with minimum resource-consumption and which are well protected from the negative impacts of the environment.

Evolution at the expense of resources

A system's evolution proceeds via the consumption of resources existing in the system itself, its neighboring systems, and/or the system environment. Each evolutionary step generates new resources that can be used to further develop the given system as well as other systems. However, negative resources that can cause undesirable effects might also result from the evolutionary process.

[25] The process of idea generation and selection is mutually dependent and iterative: idea generation is typically governed by certain market demands while market selection is applied with consideration of technological feasibility.

Excessiveness of an existing system

The majority of existing technological systems have redundant resources, that is, they have more resources than are necessary to perform their intended function.

Co-evolution of different systems

Many technological systems are connected with one another; the strength of these connections increases with the process of evolution.

Co-evolution of systems belonging to different hierarchical levels

Systems belonging to different hierarchical levels (a system and its supersystem(s), or a system and its sub-systems) are tightly connected in their evolution and evolve with each other in a coordinated manner.

Short- versus long-term forecasting

A system's short-term evolution (improvement) depends primarily on the resources inherent in the system. Long-term development, including next-generation systems, breakthroughs, etc., depends on the evolution of the overall technology and/or market rather than on the particulars and resources of the given system.

Limited number of ways to perform a function

A function can be realized in a limited number of distinguishable ways based on the utilization of known resources. New types of resources might arrive as a result of a discovery.

Evolutionary alternatives

There is more than one (though still limited in number) fairly equal directions by which a given system can evolve from its current position to the next one, based on the involvement of different types of resources. The "winner" is usually the one that starts first and attracts the majority of financial and human resources.

Standard ways to solve problems

Common ways to solve problems or improve a system, based on the Patterns of Evolution, exist. These ways can be revealed through an analysis of the history of invention, allowing innovation knowledge to be collected and transferred.

Mechanisms behind the realization of trends or patterns

Each trend or pattern is supported by certain mechanisms (cause-effect relationships) which determine how they are realized. The same trend/pattern can be provided by several different mechanisms acting either separately or together; one mechanism can support more than one trend/pattern.

The weight of trends and patterns

Each trend/pattern has a weight (or power) that is determined by the number of people involved and the strength of this involvement. This weight can change over time and as conditions change.

Interaction between trends/patterns

Actual evolution is a product of the interaction of numerous trends with different weights and directions (including opposing directions). This product doesn't comply with the superposition principle but is a non-linear result of multiple factors.

Resistance to evolution

The realization of a trend/pattern produces system change that is not always welcomed. Moreover, system change creates various types of resistance. This might be a force toward maintaining the status-quo, a general response to any change. In other cases it might be an opposite trend. Given the above, the evolution of a particular system can be controlled by managing either the trend itself or the response to its enforcement.

Evolution as a specific ability of certain non-linear systems[26]

Practically all evolving systems are non-linear; their evolutionary history includes crisis zones in which their behavior is principally unpredictable and therefore often appears to violate cause-effect relationships. The evolution of a non-linear system is a combination of pre-determined and random events.

Inertia of trends/patterns of evolution

As a specific system evolves, if a certain trend, pattern or line has been realized, it is highly probable that this trend/pattern/line will continue to exert a strong influence for some time.

Change of system goals and functions over the evolutionary process

A system often emerges in a "foreign" market to perform a function and satisfy a need that can be articulated in the given evolutionary period. As the system develops, new

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[26] Systems whose properties change under the influence of processes taking place within them, either accelerating (positive feedback) or stabilizing (negative feedback) these processes. See more in Zlotin, Boris and Alla Zusman. *The Concept of Resources in TRIZ*. TRIZCON 2005.

features, possibilities and applications are invented and, as a result, the system creates its own market.

Formation of specialized lines of evolution

For a specific system or for systems of a certain type (for example, measurement and control systems, milling systems, software, etc.) a set of specialized lines of evolution can be developed that will reflect and take into consideration the main particulars of that system or system type.

General scenario of system evolution

Man-made systems follow certain steps as they evolve, including:

- Discovery of a new function and multiple attempts to realize it
- Screening of developed variants by the overall current level of technology
- Development of selected systems through further competition
- Hybridization of known variants
- Building a new generation of the system using known variants and new enabling technologies.[27]

Driving forces of technological evolution

Any TRIZ specialist practicing TRIZ forecasting or Directed Evolution for products and/or technologies would eventually realize that to make a reliable forecast for a particular subsystem (such as a car door or cleaning products) one must first understand where the higher-level system is headed (the automobile for the car door, the home for the cleaning products). Furthermore, the design of the car or home might be governed by certain environmental and/or social regulations. The reason for this is found in a derivative of the assumption *co-evolution of systems belonging to different hierarchical levels*, which states that requirements imposed by a higher-level system are always dominant and "force" the subordinate system (or sub-system) to evolve accordingly.[28] Indeed, technological evolution is not an isolated process but rather is an aspect of the more general evolution of society; moreover, the evolving world resembles a Russian nested doll (*matreshka*) with multiple evolution processes of different scale taking place both independently and interdependently. For our purposes, the following levels (from the top down) can be identified together with the main features, including certain fundamental specifics and patterns and trends.

[27] See more detail in the "general scenario…" section
[28] With the permission of technology, of course.

Evolutionary Level	Main Trends/Patterns and Non-Linear Effects
1. Universal	▪ Growth of complexity and variety ▪ Acting feedback mechanisms ▪ Self-organization ▪ Emergence of systemic effects ▪ Evolution through the emergence and resolution of crises
2. Biological evolution	▪ Directed toward unlimited growth and expansion; growing utilization of various resources ▪ Biological “products” as a combination of the “product” itself and the “production plant” (reproductive system) ▪ Evolution toward an increasing degree of survival of organisms based on haphazard mutation (trial and error) and natural selection ▪ Combination of evolutionary and revolutionary processes (gradual improvement of existing species and emergence of new species) ▪ Co-evolution within the biosphere as a whole, specific biological systems (biogeocenoses, ecosystems) and evolutionary “duos” such as prey and predator
3. Evolution of human civilization as a whole	▪ Gradual increase in the quality of life (personal ideality[29]) for an average individual in the society ▪ Increase in the role of technology and overall human intelligence ▪ Constant “tag war” between two opposing trends – integration and disintegration – with the gradual increasing of integration in the society ▪ Emergence of evolutionary waves in human civilization (primitive, agricultural, industrial, informational)
4. Evolution of man-made systems	▪ Separation of production plants from products, greatly simplifying and accelerating the evolution of both ▪ Utilization of resources unfavorable to biological evolution (high pressure and temperature, powerful energy sources, dangerous substances, etc.) ▪ General growth in the ideality of man-made systems by an increase in benefits and a reduction in associated costs ▪ Replacement of human labor with machines in situations ill-suited for humans ▪ General increase in the “intelligence” of man-made systems, providing improved performance and human interface

[29] Ideality in TRIZ is defined as a ratio, where the numerator represents all useful benefits provided by the system and the denominator represents all costs (including non-monetary) associated with providing these benefits.

5.	Micro-evolution steps – inventions and innovations	▪ Enhancement of the trial-and-error method as an evolutionary tool for man-made systems, based on the utilization of analytical and psychological stimulation approaches ▪ Transition from trial-and-error with purposeful utilization of evolutionary patterns and other instruments that have been developed, based on theoretical models of evolution ▪ Transition from innovations created by extraordinary individuals to mass innovation via education and utilization of innovation methodology and tools, including computerized processes of managing innovation activity

It is important to understand that the trends and effects inherent to a higher level can work on lower levels as well.[30] It can therefore be suggested that the evolutionary trends/patterns of the higher level serve as evolutionary driving forces of the lower levels. This suggestion can explain why the Patterns of Technological Evolution are so strong. For example, the pattern *increasing dynamism* is strong because increased dynamism means more flexibility – an important performance feature that in turn provides more convenience for the user and thus an increase in personal ideality (a feature of the level higher than the ideality of technological systems).

Orientation according to the main user benefits can help create a certain structure for evolutionary patterns. These main user benefits could be listed as follows (in no particular order):

- System performance (i.e., providing a certain positive function)
- Cost
- Quality (reliability, absence or limited number of drawbacks and side effects)
- Safety/security
- Fun associated with the owning and/or utilization of the given system

It seems reasonable to suggest that these main requirements serve as a natural selection mechanism for all man-made systems.

See Appendix 1 for selected groups of the general patterns of evolution.

General aspects of the evolution of man-made systems

The rate of evolution depends on both driving forces (positive impact) and impeding forces (negative impact).

[30] The opposite effect doesn't typically occur. For example, specific trends existing for musical CDs don't provide insights to the universe.

In general, the evolving human civilization is like a vehicle carrying us from our past to our future. At the same time, in an effort to achieve the best ride, we are continuously redesigning the vehicle, in particular:

- Increasing the engine power (driving forces)
- Removing various impediments that compromise higher speed (friction, air resistance, etc.), reliability and safety (impeding forces)
- Enhancing the vehicle's control systems

Using the above analogy, this group of patterns describes the following general aspects of evolution:

- Driving forces of evolution
- Impeding forces and limitations
- Means and methods to control the evolution of man-made systems

Evolution of driving forces

General description

The most powerful driving force of our evolution is the chain reaction[31] of the development of human civilization that started about 100,000 ago. In the process of this development, various participating elements and sub-systems directly and/or indirectly influence the evolution of one another to result in an overall evolutionary acceleration. This chain reaction generates local driving forces responsible for the evolution of various specific man-made systems.

Interestingly, the recent "dot.com" boom that occurred in the area of computer and Internet technologies was not the first burst of activity.

An earlier "explosion" took place at the end of the 17th century, when Europe began a rapid recovery after a devastating 30-year war. In England, Parliament ceased to be the main power, which opened the path for business development; in France, the financial genius Colbert built a system of governmental support for businesses. In 1697, Daniel Defoe, a successful businessman, writer, and one of the founders of the British Intelligent Service published *An Essay on Projects* in which he described in great detail (and with much criticism) the new passion of inventing and pursuing new and tricky ways to get rich. Although some projects targeted building a production plant to produce new goods, most of the projects were related to trades, speculations, changing laws and taxes. The burst of new projects spread all over Europe, with England and France leading the way. Surprisingly, many projects were successful, generating revenue and accelerating the overall business but often creating crises, business scandals, frauds, etc.

[31] A result of the non-linear nature of human civilization.

Another explosion took place in the U.S. during the second half of the 19th century as the country recovered from the Civil War. Enormous business opportunities in the former Confederate states, the gold rush in California, and rapidly growing railroad transportation initiated avalanche-like business and industrial development associated with the burst of patents. Inventors were able to find investors and quickly implement their inventions, for example:

1869	The Hyatt brothers patent celluloid; production began in 1872.
1876	In February, Bell patented the telephone; the first working sample appeared in March; by August 800 units were in use. In 1877 the first central telephone station was created in New York…
1879	Edison began working on lighting; ten years later electric power stations, production of bulbs, fixtures, cables, etc. appeared
1884	Charles Parsons patented the steam turbine; in 1889 about 300 turbines were producing electrical power.
1884	Hiram Maxim designed his first machine gun. In 1887 it was accepted by British army. By the end of the century it was accepted worldwide.
1886	The first patent on aluminum production via electrolysis; in 1890, 40 tons of aluminum were produced; soon thereafter 450 tons were produced annually. The price of aluminum dropped by a factor of ten, stimulating wide implementation.
1888	Tesla and Ferraris discover the rotating magnetic field; in 1889 the mass production of a.c. motors began.
1892	Diesel files his first patent; in 1898 mass utilization of Diesel engines began.
1886	The first patents and automobiles of Daimler and Benz. By 1900, thousands of cars by numerous manufacturers existed in various countries.

Using the above examples we can summarize the typical reasons and conditions associated with a period of super-active evolution:

- Investors ready to invest are pressed by accumulating capital to put them to work
- Science is ready to support technology due to the accumulation of discoveries capable of launching numerous inventions.
- Technology is ready to provide the needed materials and processes, greatly increasing the feasibility of inventions.
- Industry is ready to quickly build production plants and equipment.

- The culture supports innovation (compared with countries having certain cultural and/or religious bans, government interference with businesses, etc.)[32]

Successful innovation is typically a result of the close cooperation of people and/or organizations, each of which play an important role[33]:

- Subject matter experts (an inventor, designer, researcher, etc.) provide a system that performs at a cost acceptable to the customer.
- Investor(s) finance the development and implementation of the invention
- Manager
- Sales and marketing personnel convince potential consumers to try the invention.
- Consumers support the invention by paying for it

Driving forces of evolution and the system's life cycle
The forces that drive the evolution of a particular system change with the system's life cycle, in particular:

Stage 0: Birth

- Personal motivation of certain individuals (enthusiasm, curiosity, ambitions, greed, creativity, etc.)
- Demand and/or pressure from a system at a higher level of hierarchy (super-system) that cannot further evolve without the particular function

Stage 1: Childhood

- Personal motivation of certain individuals – hope for success
- Motivation of the group(s) involved to sustain and grow
- Economic interests – the need to receive a return on investment; high potential of a large (although perhaps not yet existing) market
- Societal interests – satisfaction of a new and not yet widely recognized need
- Demand and/or pressure from a super-system

Stage 2: Rapid Growth

- Personal motivation of certain individuals – the quest for a career
- Group(s) interest – growth and expansion

[32] Interestingly, the main conditions did not necessarily include the presence of geniuses – other conditions were much more important. For example, if Alexander Bell was not interested in inventing the telephone, its invention would not have been much delayed: the second inventor, Elisha Grey, was less than an hour late with his invention.
[33] Role description suggested by Gafur Zainiev, Valery Prushinskiy, Vladimir Gerasimov of Ideation International.

- Economic interests –ensure high and sustainable profit, high potential of a large opening market, high ROI potential.
- Societal interests – satisfaction of a growing need
- Demand and/or pressure from a super- system

Stage 3: Maturity

- Personal motivation – the quest for a career
- Group(s) interests – growth and expansion of the bureaucratic part of the group
- Economic interests – ensure a sustainable and reasonable profit
- Societal interests – satisfaction of a stable need

Stage 4: Decline

- Personal motivation – attempt to survive an inevitable collapse
- Group(s) interests – self-preservation of the organization's top group
- Economic interests – reducing or possibly compensating for losses
- Societal interests – preventing the costly crash of the system to avoid a chain of undesirable events or even a depression.

Stage 5: Life after death

- Personal and group interests – the quiet existence of the system, which has practically exhausted its resources but can still provide a modest profit
- Search for new applications and new markets to return to stage 2.

The main components of the driving forces are:

- Human needs
- Evolutionary challenges
- Evolutionary opportunities

Evolution of human needs

In the process of evolution, various needs stimulate the evolution of the means for satisfying these needs, which in turn originate more sophisticated needs, resulting in a reinforcing loop. In other words, a need can stimulate technology (the invention of the telephone was stimulated by the need for communication) and technology causes greater need (using microwave technology for home cooking).

The first significant research in the area of human needs was conducted by Abraham Maslow[34] in the early 1940s, followed by numerous marketing studies.

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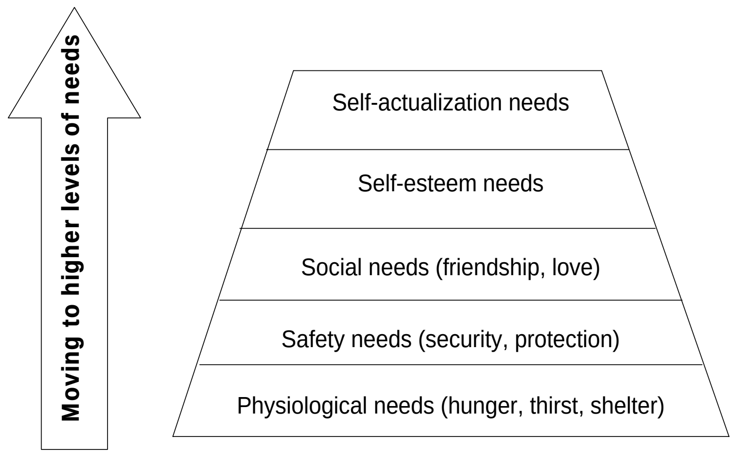
[34] Maslow, Abraham. *Motivation and Personality*. New York: Harper & Bros., 1954. (Rev. ed. 1970.)

According to Maslow, the typical hierarchy of basic human needs can be described as follows:



Typically, the satisfaction of needs starts from a basic level (elimination of hunger, thirst, obtaining shelter) then moves to higher levels (a starving person has little regard for prestige or image).

Practically all industrial technologies (with the exception of military technologies) targeted the satisfaction of basic human needs through the use of industrial methods. However, as basic needs were satisfied it appeared that, in addition to providing certain functions and satisfying certain needs, the consumption of products and/or services can be associated with certain emotional feelings (positive or negative) that can increase or reduce satisfaction respectively.[35] This new factor (we can call it the Enjoyment Factor or E-factor) is capable of increasing the value of products/services and thus increasing personal ideality.[36]

While realization of the main functions of products and services is rather standard and can be provided by mass production methods, the E-factor is much more personal and thus less defined and, as a result, difficult to predict. At the same time, it is a very important factor for mass customization. Moreover, when products/services from different producers or providers are practically the same, the E-factor can become the critical issue for customer product selection.

Five selected lines of evolution related to the evolution of human needs are presented below.

[35] Often it can be both – the pleasure of owning goods and the displeasure of having to pay for them.
[36] Similar to the concept of ideality in TRIZ, personal ideality can be defined as the ratio of positive emotions to negative emotions (see *TRIZ in Progress*, Ideational International, 199, p. 142). First introduced by Zlotin and Zusman in 1991.

Line: General evolution of basic human needs

According to Maslow, the needs of an individual evolve from pure physiological needs to safety, social, self-esteem and self-actualization needs. Satisfying a lower, more pre-potent need is a condition for seeking satisfaction of the needs at the next hierarchical level. Accordingly, human civilization is evolving toward the development of technological abilities and the accumulation of resources that allow its average members to move to the next level of basic need satisfaction, as follows:

1. Physiological needs, including:
   - Air, food and drink, physical activity, rest, sex, etc.
   - Clothes, healthy and comfortable shelter, etc.
   - Physical and psychological health
   - Need for new impressions, feelings, etc.

2. Existential (safety) needs, including:
   - Safety, freedom, ownership of one's life (business); being the object of someone's care.
   - Stability of life, confidence in the future, access to information, understanding of one's surroundings.
   - Absence of cognitive dissonances (irresolvable conflicts, contradictions)

3. Social needs, including:
   - Strong relationships with family and friends; communication
   - Being a member of a certain group(s); participation in joint activities
   - Desire for power, recognition, conformism, taking responsibility
   - Caring for others and seeking care from others

4. Spiritual needs, including
   - Self-confidence, self-expression
   - Moral obligations
   - Striving for pleasure
   - Curiosity; desire for knowledge
   - Need for playing (role playing)
   - Need for risk and self-improvement
   - Need for novelty, change

5. Need to care and serve, including:
   - Caring for children and other dependents
   - Being of service to a certain social and/or religious group
   - Being of service to humanity
   - Being of service to science, culture, arts

- Being of service to a certain cause
- Taking care of pets, the environment, etc.

<u>Line: Increasing role of spiritual needs</u>

1. People have time free from work that can be used for thinking and entertainment.
2. Emergence of certain spiritual needs that help with survival (curiosity, imagination, intelligence that enables one to learn and understand the connections between events, etc.)
3. Haphazard appearance of people with higher-level of spiritual needs
4. Emergence of certain demand for spiritual "products"; disciples and followers of the most successful storytellers, prophets, competition between spiritual leaders for disciples and followers. Emergence of positive feedback promoting the growth of spiritual needs.
5. Emergence of an individual's internal need for self-improvement and positive feedback for improvement.

<u>Line: Expanding base for enjoyment (E-factor)</u>

To have fun, an individual must be capable of emotion. As human civilization has evolved, people's attitudes toward fun, and the ways in which it is achieved, have constantly changed, as follows:

1. Enjoyment from satisfying the most basic needs – food, sex, relaxation. For example, the taste or presentation of food was not important.
2. Once basic needs have been satisfied, people enjoy a variety and quality of life.
3. Increasing fun (to fight boredom and counteract a reduction in fun associated with habitation) through the introduction of non-essential changes such as fashion.
4. Fun for individual tastes, often artificial.
5. Introduction of fun elements into any human activity, including work, business, etc.

<u>Line: Increasing the degree of work-fun conversion</u>

In the process of social enhancement, the relationship between an individual and his/her work changes, as follows:

1. Work as a curse (as in the Bible)
2. Work as a shameful occupation (a noble should only hunt and war)
3. Work for living (natural resentment toward work)
4. Work as an honest obligation (the Protestant work ethic, which began with the establishment of capitalism and the industrial revolution).
5. Work as a path toward a career and to establish a better position in life.

6. Work as fun – free schedule, high level of satisfaction and enjoyment.
   Note: At first, work and fun were connected only for people of certain professions (actors, artists, scientists, professors, etc.). Gradually, this category grew to include more engineers, entrepreneurs, business people, etc.). People started looking for jobs that bring maximal "return" in terms of fun as well as monetary rewards).
7. Enjoyment of work is transformed from an important criteria in choosing a job or profession to the main criterion. Emotional attitudes (including love) toward work grow, increasing the probability of success.

<u>Line: Increasing the fun associated with product consumption</u>

1. Introduction of a product capable of performing a particular useful function
2. Improving a product's ability to perform a useful function
3. Introduction of auxiliary and/or additional functions that increase the product's real value
4. Introducing functions related to enjoyment (fun), such as:
   - Fun directly associated with performance, for example, enjoyment of working on a computer equipped with a large screen, driving a car with a powerful motor, etc.).
   - Fun associated with auxiliary functions (for example, attractive packaging).
   - Fun from additional functions not associated with the main performance (enjoying a good audio system in one's car).
5. Increasing amount of fun associated with products that utilize human senses and motives, in particular:
   - Vision – nice colors, beautiful forms
   - Hearing – pleasant sounds, reduction of annoying noise
   - Tactile – enjoyment of touching things
   - Olfactory – enjoying nice scents
   - Psychological and social positioning
6. Transformation of fun functions into the main criterion for product success
7. Product diversification on the basis of fun and the method by which it is created (such as products that perform the same main function but provide different types of fun).

Evolution of impeding forces and limitations

Impeding forces

Any fairly complex system resists change in one or another way. In social and man-made systems this resistance is primarily associated with the attitudes of people whose positions are somehow affected by imposed changes and the associated psychological inertia. At the same time, objective aspects of resistance also exist. In effect, when a system is transformed from one stable position (not necessarily a bad position) into to another, better position, the situation temporarily worsens before it improves (for example, it is inconvenient to live in a house during remodeling). The greater the change, the worse this effect can be.

Resistance generated by the temporary deterioration of a situation adds to the resistance caused by psychological inertia. Attempts to “push” the change only strengthen the resistance. After several cycles of pushing and repelling, the maximum resistance occurs – usually before the deterioration has stopped. Resistance then gradually decreases to zero (although the situation might still get worse) and the system becomes “attracted” to the new, better situation.

The scale of deterioration associated with the transition to a better state grows with the process of system improvement. A very poor system can make the transition with little temporary deterioration, while a well-developed system (which is typically very stable) can suffer dramatically over the short-term from overall positive change.

Limitations

The history of evolution offers numerous examples of systems that develop due to the removal of imposed limitations (technological, psychological, social, etc.). For example, contemporary navigation devices (GPS systems, for example) lifted the limitations associated with the special skills a sailboat captain must acquire in order to successfully convey a boat to its destination. The refined skills with which scientists in the late 19^{th} and early 20^{th} centuries conducted experiments with primitive, inaccurate equipment are no longer required, given the computerized and highly accurate tools available today. Clearly, at certain evolutionary steps man-made systems can be freed from natural limitations through the use of new resources, approaches and technologies. Another way to avoid limitations is to take advantage of the existence of alternative methods for achieving a particular a goal. The process of lifting limitations results in the following:

- Substantial simplification of the system and its operation
- Standardization of the system’s design, processes, technologies; transition to mass production methods.
- Increasing process efficiency
- Continuous system growth along its S-curve, avoiding the maturity stage

Another fundamental limitation to the evolution of man-made systems is the exhaustion of alternative ways to perform a function. As was stated earlier, the TRIZ assumption of *evolutionary alternatives* suggests that there is more than one way by which a given system can be evolved from its current position to the next one, based on the utilization of different types of resources. Certain long-standing areas of technology dealing with relatively simple systems produced in volumes, where a large number of specialists and competitive companies are involved, can be quite close to this type of exhaustion, which typically takes between 20 to 50 years. In younger, more complex systems we can expect that the next-generation transition will occur before all possible alternatives have been exhausted.

The most important limitations influencing system evolution are:

- Fundamental limitations for growth imposed by laws of nature (laws of energy conservation, the speed of light, the Heisenberg uncertainty principle, etc.)
- Exponential growth of certain parameters (such as the dramatic increase in the aerodynamic resistance of an airplane as it approaches the speed of sound).
- Systems that are radically different from their predecessors (such as systems with too many novelties or systems based on new ideas and/or discoveries), or which require new markets, perform new functions, etc. tend toward slow implementation until they become less novel.
- General technological limitations, in particular:
  - Increasing cost and life cycle of certain technological systems (airplanes, for example).
  - Increasing system complexity and infrastructure, causing unpredictable systemic effects.
  - Increasing cost and time required for testing new products
  - Achieving a certain level of customer satisfaction
  - The absence of systematic methods for problem solving and system improvement.
- Limitations imposed by the environment:
  - The presence of a natural environment that is not optimal for the majority of processes and systems.
  - Potential environmental damage due to technological progress.
- Limitations associated with other systems:
  - Systems that compete with one another in the same market
  - Systems that compete for the same resources
- Limitations associated with system parameters:
  - Functioning of the system
  - Operating principle
  - Components, processes, design
  - Energy sources
  - Scale effects that occur as the system expands
- Limitations associated with the end-users of a product:
  - Physiological limitations (force, reaction speed, ergonomic issues, etc.).
  - Psychological limitations (inertia, subconscious fear of new things, conscious resistance, etc.).

- Social limitations – certain general cultural aspects, societal groups and/or institutions (parties, religions, organizations) can induce passive or active resistance to progress in specific areas or even in general:
  - Unorganized resistance of a relatively large group
  - Organized resistance of certain groups and/or organizations
  - Legal regulations that hinder the implementation of innovations
  - Culture and education that do not encourage innovation
- Market limitations:
  - Possible market size and market share
  - Presence of competing systems on the market
  - Realistic size and time table associated with possible investments and expected return on investment (ROI).

Impeding forces and limitations and system life cycle

Impeding forces and limitations change as the system progresses through its life cycle. In particular:

Stage 0: Birth

- The absence of theoretical foundations, financing, knowledge about potential markets, high uncertainty and low predictability of results.
- Society doesn't recognize the importance of the problem (or invention) and does not support system development

Stage 1: Childhood

- General psychological and social inertia
- Absence of an appropriate market sector
- High competition for a limited preliminary market sector
- Resistance from areas of activity in which people are threatened by new competition.
- Technical problems associated with insufficient theoretical foundations, technology availabilities and the absence of methods for systematic and effective problem solving.

Stage 2: Rapid Growth

- Limited speed of obtaining necessary resources, organizing production, training people, etc.
- Limited speed in market growth
- Fierce competition for market share and investments

- Technical problems associated with increased scale, undesired long-term effects, etc.
- Resistance from certain social groups (religious, ecological, extremists, etc.)

Stage 3: Maturity

- Exhaustion of the resource base
- Exhaustion of market space; rigid and stable market share distribution
- Reaching certain fundamental limits imposed by nature or otherwise
- Continued resistance from certain social groups (religious, ecological, extremists, etc.)

Stage 4: Decline

- Market shrinks when a new system supplants a mature one
- The new system draws off resources, especially the best managers and specialists, which accelerates the old system’s decline (“brain drain”).
- Diminishing reputation of the old system, which compromises consumer and investor trust in the future (“capital drain”).

Stage 5: Life after death

- Limited demand and resources
- Loss of trust

Main components of psychological resistance

Psychological inertia was formed as a survival mechanism, deterring humans from new and possibly dangerous activities. Different cultures have different degrees of acceptance of new things; typically, older cultures have less tolerance for change. Despite the fact that in recent decades innovation has grown and produced more useful and pleasant changes than negative ones, long-term, deeply rooted fears remain. The main components of psychological inertia are:

- System of psychological protection (introduced by Freud). If an individual is afraid that a new idea might be dangerous or cause conflict with colleagues or supervisors, the idea will be “blocked” by the subconscious.
- Protection of territory common to many species. People have similar instincts; moreover, they greatly expand the definition of territory to include their professional knowledge and experience, scientific and business interests, etc. This factor causes the “not invented here” syndrome, rejection of ideas suggested by others, etc.
- Perceptions established in childhood by strong propaganda and/or strong authorities often become undisputable doctrines. Any threat (real or imagined) to

these doctrines produces a strong negative (and often subconscious) reaction to the suspicious ideas and their carriers.

- Fear of logical inconsistencies and contradictions thwart the reception of new ideas that look especially weak or strange.
- Negative feelings based on the intuitive belief that new ideas are dangerous and prone to failure.
- Asymmetrical reaction of gain and loss. People hate to lose what they already have; the addition of certain useful features often cannot compensate for the frustration caused by the loss of features to which customers have grown accustomed.
- Use of logical proofs to justify subconscious psychological resistance.

Lines associated with evolution of impeding forcers and limitations

Described below are two selected lines related to the evolution of impeding forces and limitations.

<u>Line: Violation of boundaries during the process of evolution</u>

1. Boundaries to a system's utilization that are established haphazardly
2. The creation of "record breaking" systems intended to violate established boundaries.
3. The creation of optimized systems that operate as close as possible to the boundaries.
4. Achieving record-breaking or optimal performance without changing the original operating principle.
5. Sharpening of contradictions associated with boundaries and limitations.
6. Creation of a system based on an operating principle that if free of old limitations but has its own limitations or boundaries.

<u>Line: Lifting limitations in the process of product development</u>

An enormous variety of products (clothing styles, shoe fashions, telephone designs, kitchen appliances, etc.) have resulted from recent technological and economic limitations. In fact, the form and style of most consumer products today are determined primarily by fashion and the designer's imagination rather than technological issues. Limitations are lifted in the following order:

1. Limitations established in a haphazard manner
2. Limitations that provide "insurance" against our possible lack of knowledge
3. Limitations caused by process optimization
4. Limitations caused by product simplification and cost reduction
5. Limitations imposed by mass production

Evolution of means and methods to control the evolution of man-made systems

As man-made systems evolve, their evolution depends more and more on the conscious actions of people that can potentially be quite dangerous. Enforcing the driving forces produces crises of excessive production; the opposite action produces stagnation and recession. In fact, only a controlled balance between driving and impeding forces can ensure a more-or-less smooth, crises-free evolution.

In the early stages, human evolution occurred no differently from the evolution of other inhabitants of the Earth – via mutation and natural selection (which is somewhat equivalent to generating ideas using trial and error). Invention and the spread of weaponry was the first big change toward humans controlling their own destiny, helping them avoid the natural selection imposed on them by predators. Thus a new and "internal" human evolution began, resulting in wars in which victory was claimed by those who had the best technology and organization rather than the greatest physical force. Winning technologies and other achievements were transferred to younger generations, improving along the way.

The most significant evolutionary step was the transition from physical trials to mental ones; instead of building numerous prototypes to find the best boat design, people started exploring possible designs by thinking about them and rejecting those that didn't seem feasible or useful.

These mental trial-and-error techniques have been enhanced; rules of logic followed by scientific methods have gradually allowed people to anticipate the results of potential change with higher predictability, capitalizing on the following achievements:

- Accumulation and structuring of knowledge, enabling the creation of many effective thinking models (hypotheses, theories, mathematical descriptions, etc.) which in turn streamlines the search for new designs.
- Creation of analytical methods (including mathematics) that help reduce new problems to known ones and thus exploit available knowledge and allow system optimization.

The emergence and development of science as a method for performing mental trial-and-error (or for creating simple models) has enormously accelerated the evolution of human civilization, making it less haphazard and more controllable, which in turn has significantly reduced the cost of design mistakes.

Creativity and innovation is the last area where trial-and-error still reigns (most creativity techniques developed in recent years still represent slightly modified versions of the trial-and-error method). The emergence of TRIZ in the middle of the 20th century launched a new era, converting the generation of new ideas into science. The Directed Evolution™ methodology, introduced in the early 1990s, is the next step toward controlling and managing the entire evolution of man-made systems.

Lines associated with the evolution of innovation activity

Selected lines associated with the evolution of innovation activity are described below.

Line: Increasing social acceptance of innovation

1. Society does not welcome innovation but prefers to follow tradition
2. Innovation occurs via slow, nearly unnoticeable changes in certain traditions (the “boiled frog” effect).
3. Society accepts innovation on a limited basis and as a “way out” of critical dilemmas
4. Innovation as a base for entrepreneurship. Establishment of legal protection for innovations.
5. Innovation as a weapon in competition.
6. Innovation as a means for building an organization’s intellectual property and ensuring successful long-term development.
7. Inventions and innovation become a mandatory part of daily engineering work.
8. Inventions and innovation become a part of everybody’s daily activity

Line: Increasing efficiency of tools for supporting innovation process

1. Individual innovation based on luck, intuition, haphazard events and trial and error.
2. Emergence of professional innovators who apply trial and error and their exceptional abilities.
3. Utilization of scientific knowledge (physical, chemical, psychological, etc. effects) to boost innovation.
4. Knowledge transfer and utilization, first between close areas and then between remote areas.
5. Establishment of teamwork and the use of multi-disciplinary experience (brainstorming).
6. Introduction of methods for the psychological activation of creativity (Synectics, De Bono techniques, etc.).
7. Introduction of the Theory of Inventive Problem Solving (TRIZ), a universal method based on the generalization of mankind’s innovation experience.
8. Development of specialized innovation technologies such as:
   - Directed Evolution™
   - Anticipatory Failure Determination (AFD®) for Failure Prediction
   - I-TRIZ (Ideation-TRIZ methodology) for solving scientific problems
   - I-TRIZ for solving business and management problems

- I-TRIZ to increase product quality while reducing cost

9. Development of specialized innovation technologies for specific tasks.

Line: Increasing cooperation and coordination in the process of product development

In the process of evolution, coordination takes place between the following:

1. Various requirements associated with the same product (social and economic parameters, safety, convenience, style, etc.)
2. Various subsystems of the same product (automobile motor, chassis, transmission, electronic systems, etc.)
3. Various services associated with a product (roads, gas stations, parking lots, traffic rules, vehicle services, etc.).
4. Various other subsystems such as vehicle audio systems, air conditioners, GPS, etc.).
5. Products related to the same product line
6. Overall system of related products and services (for example, the Christian Dior “empire” includes clothing, shoes, bags, cosmetics, accessories, etc.)

Line: Increasing efficiency in selecting innovations

Selecting among various innovations is the main method for managing evolution. During the early stages of human civilization this resembled Darwinian natural selection; since that time it has become more effective and reliable, in particular:

1. Innovation selection through genocide of tribes with weaker social and/or military technology.
2. Conquering of tribes and countries with weaker social and/or military technology.
3. Selection of innovations by people in possession of power and authority
4. Market selection
5. Selection based on forecasts of a given system and its market evolution
6. Selection based on knowledge about patterns and lines of evolution

Line: Increasing efficiency of financing innovation

1. Self-financing using the following funds:
   - Accumulated capital (sometimes from criminal or unethical activities)
   - Funds obtained from extreme exploitation of members of an organization (for example, Viking warriors), family members, etc.
   - Exploitation of slave or hired labor
   - Re-investment
2. Financing of innovations using private capital (interest loans, loans against property, investment in exchange for equity position, etc.), in particular:

- From ancient kings or other superiors
- From aristocratic or rich families (Barks family in Carthage, Medici family in Florence).
- Rich individuals (merchants, money-exchangers, etc.).

3. Community (ancient Athens) or government (from ancient Rome to recent governments).
4. Financing from special banks (Knights Templar in the 13th century).
5. Creation of a system for supporting innovation (Royal privileges and patents in England, Colbert system in France, Peter the Great of Russia, etc.)
6. Creation of corporations to finance innovation (East Indian Company)
7. Internal corporate financing in the following areas:
   - Core competency (for example, automotive companies invest in automotive research)
   - Adjacent areas (General Electric's past investment in the development of jet engines).
   - Unrelated areas (Ford Motor Company's investment during the 1920s in glass production)
8. Creation of a venture capital system involving banks, funds, etc.

Lines associated with general factors controlling the evolutionary process

Below are selected lines associated with the evolution of methods of controlling the evolutionary process.

<u>Line: Increasing degree of controllability of systems' evolution</u>

1. Haphazard evolution as the inevitable result of periodic crises (crises of self-organization).
2. Controlling evolution by reacting to challenges (responding to certain demands, dangers, competitive threats, etc.)
3. Managing production and/or marketing based on anticipating (predicting) possible near-term challenges and/or early detection of dangers. Anticipating challenges in order to prepare and respond in a timely manner.
4. Managing production and/or marketing based on comprehensive forecasts of market and technological evolution of a given system.
5. Managing production and/or marketing based on general patterns of market evolution, patterns of technological evolution and environment enabling full control and the ability to avoid undesired events.

Line: Life cycle and evolutionary speed of a system

Factors controlling the speed at which a particular system evolves change with the system's life cycle:

1. Latent development – theoretical research, experiments, collection of knowledge, building mock-ups and prototypes, etc.
2. Active development moving ahead of the overall technological level
3. Active development with the average speed of evolution of technology
4. Passive development – when the system itself is not improving but its features get better due to enabling technologies, better materials, etc.
5. "False" stabilization – development slows or even halts due to local unresolved problems.
6. Stabilization caused by resource exhaustion.
7. System degradation and displacement by new, more advanced systems.

Line: Factors influencing the speed of evolution

1. Pulsed selection, i.e., the periodic exchange of waves of positive and negative natural selection, as follows:
   - Positive selection – when resources are rich and/or there is no pressure, the species with the faster reproduction has the advantage
   - Negative selection – when resources are scarce and/or pressure is strong, only the fittest survive
2. Rich variety of system modifications, enabling highly effective hybridization
3. Existence of frontier-leading, rapidly-evolving systems
4. Strong competition (both technological and marketing)
5. Strategic planning and control

Bank of Evolutionary Alternatives™

The practical application of the patterns and lines described above has resulted in the development of potential scenarios of evolution (evolutionary alternatives) for various domains of human civilization, such as:

- Housing
- Retail business
- Community life
- Energy
- Food
- Consumer products

This bank of evolutionary alternatives is effectively applied in the process of conducting Directed Evolution for lower-ranking systems, for example, trends in the evolution of consumer products (see below) have been used to identify next-generation cleaning products. Appendix 2 presents a selected list of specialized groups of lines of evolution.

Evolution of consumer products

The main trends that influence the evolution of consumer products are divided into three groups:

- General evolution
- Market evolution
- Product evolution

General evolution

"Domestication" of the environment

"Domestication" of the environment manifests itself through the following:

- Elimination or reduction of various dangers, undesired or unpleasant factors, and environmental events
- Introducing into the environment numerous objects capable of performing useful and desired functions, including:
  - Objects of social infrastructure such as homes, buildings, roads, communication systems, etc.
  - Consumer products
  - Products of nature (plants, flowers, pets, etc.)

Utilization of resources – new level

All technological systems function and evolve due to the utilization of certain resources – materials, energy fields, information, space, etc. Evolution starts with the engagement of highly visible, easily accessible and readily available resources; when these "obvious" resources become exhausted in the process of evolution, less visible/accessible resources are utilized. This process is associated with the transition from the use of readily available resources to the use of derived, changeable, "smart," etc. resources that are revealed or created through human knowledge, intelligence and innovation activities.

Today, such resources often consist of the physical and chemical properties of materials, the application of various physical fields and effects, special geometric forms, inventive approaches, etc.

Evolution of technological processes

The following is a summary of the evolutionary patterns related to technological processes:

- General improvement of the design culture due to:

- Higher competition between designers
- Better informational services; conversion of many highly effective intuitive skills into knowledge available for everybody
- Utilization of computer aided technologies (CAD/CAM, ProEngineer, etc.)
- Utilization of improved design methods (DFMA, Concurrent Engineering, FMEA, etc.)
- Implementation of new, highly-effective problem solving technologies (TRIZ)
- Implementation of methods for directing the evolution of technology (DE™)

▪ General improvement in the area of manufacturing:
  - Higher competition between producers
  - Utilization of computerized production systems
  - Utilization of improved organizational methods (TQM, Value Engineering, etc.)

▪ Development of new technologies and production methods that provide:
  - Flexibility
  - Accuracy at low cost
  - Possibility of exerting local influence on process elements
  - Synthesis and utilization of materials with required properties
  - Effective safety and environmental procedures

Structural crisis

As societies evolve, various trends emerge and interact to generate certain changes to human philosophy and psychology that are difficult to predict. When they emerge, these changes are usually very small and thus cannot be identified through regular focused marketing research. Some of these changes then ignite positive feedback (reinforcing loop) that quickly generates a "structural crisis" – significant restructuring in certain industries such as product design, composition, production, sales, marketing, servicing, etc.

It is obvious that those who can predict a structural crisis and prepare for it ahead of time can benefit greatly. Those who ignore the situation and must face it unprepared can lose everything. Presently, many mass production industries are at the beginning of a serious structural crisis produced by the following events:

▪ Changes in customers needs and expectations
▪ Changes in technology
▪ Availability of vast amounts of investment capital
▪ New marketing opportunities and competition from post-Communist countries

The main sign of this upcoming crisis is decreasing market stability. As mentioned earlier, we have a new business situation today where the barriers to entering the business world are lowering and it is fairly easy to change a company's profile and production volume. In other words, the situation in various industries might evolve in a similar way to the computer or other high-tech industries, i.e., the rapid and unexpected emergence of new players, dramatic changes in the stock market, formation of strategic alliances, etc.

The most typical signs of an upcoming crisis are usually:

- Profit reduction for all (without exception) basic players
- Increased competition and spending on marketing and advertising
- Increased business activity (merger wave, rapid stock market changes, market share changes, etc.)
- Emergence of aggressive small companies offering certain process/equipment improvements.
- Certain signs of customer dissatisfaction
- New enabling technologies that introduce state-of-the-art electrical, electronics, informational and computerized breakthroughs that can reduce cost and complexity, increase reliability and add new useful functions to numerous products.

Over the next 5 to 10 years, the upcoming crisis can produce the following results:

- Substantial changes in the market position of the basic players
- Paradigm shift in the industry
- Diversification and integration process that targets the support of the complete product life cycle.

Market evolution

Business integration

An analysis of the evolution of business reveals two trends that periodically replace one another – *specialization*, which increases performance efficiency, and *diversification*, which improves coordination among various products. The most general trend, however, is the continuously increasing integration with the environment, resulting in greater cooperation and coordination between products and consumers with the aim of improving the environment (for example, with the emergence of convenience stores such as 7/11, people could purchase many urgently-needed goods in one place).

It appears that businesses targeting the satisfaction of mass human needs will continue to evolve in this direction. For example, instead of a number of different companies servicing various home utilities and appliances (water, sewer, lawn care, refrigerator, air conditioner, fireplace, cleaning, etc.), one company should service the entire home.

Similarly, in the evolution of, for example, shoe-related businesses, the following related businesses can be deeply integrated:

- Clothes production
- Clothes care (washing, drying, cleaning, storing, repairing, altering, etc.)
- Medical treatment
- Entertainment systems

Market expansion

With most consumer products, there is a strong trend whereby markets expand faster than demographic growth, due to the ever-increasing quality of life and consumption levels.

Changes in the system of purchasing consumer products

Upcoming radical changes in the marketing, purchasing and delivery of products are based on growing Internet and e-commerce technologies. This change is similar to the one that happened in the first part of the 20^{th} century with the introduction of purchasing via catalogs, which made it possible for people in rural areas to buy the same goods that had been available only to those residing in larger cities.

In the last decades, one of the most important trends in consumer product distribution is reducing the costs associated with distribution due to better organization and fewer mediators (the success of retailers like Wal-Mart, Sam's Club, etc. are a typical example). Today, the new way to reduce distribution costs is to purchase goods over the Internet; customer expectations will change accordingly, making them eager to use products that are more convenient to buy and deliver. Products that rely on traditional purchasing and distribution methods can significantly lose their customer appeal and thus influence market share.

Further evolution and introduction of new informational technologies will result in the following:

- Computer evolution that creates new ways to substantially increase the attractiveness of e-commerce. Even today we already have systems that allow customers to view 3D pictures of a product, learn about its features, read opinions from other users, etc. It is even possible to have "fittings" over the Internet so a potential customer can see how a particular item will look on him/her, determine if it matches accessories he/she already owns, or matches a companion's outfit, etc.
- Emergence of global delivery systems (FedEx, UPS, etc.) that can deliver goods economically in a timely manner.

The changes described above will lead to a situation where the majority of goods are delivered to customers directly from producers, eliminating the intermediate steps such as stores (Wal-Mart is an example). In turn, the following will result:

- Development of new distribution systems featuring substantially reduced costs (both of products and their distribution).
- Producers will depend less on distribution outlets and obtain more direct power over marketing their products.
- Increasing delivery speed and convenience.

Given the above, it is possible to foresee a serious crisis for the whole consumer product industry associated with the transition to direct delivery of goods to consumers. In turn, this crisis will lead to the following:

- Changes in market leadership, business models, advertisement, etc.
- Development of new products and technologies, new packaging systems, etc.

Increasing competition and changes in its content

In recent decades competition has become fierce, often changing in focus. In addition to the “classical” price and brand-name wars, contemporary informational wars have arisen, including:

- Intellectual property (IP) wars characterized by the use of the latest creative methods and the expansion and structuring of IP by way of patent fences[37] and patent blocks,[38] which can provide a relatively short-term monopoly or a financial benefit from IP licensing.
- Advertising attacks that target competitors (cable and dish TV ads are a typical example).
- Indirect attacks, including the sponsoring of political campaigns against certain products (for example, the well-organized, well-financed but not scientifically well-founded attack on Freon use). The most difficult issue here is to reveal the existence of informational aggression, its goals, and the sponsors who make it difficult to respond adequately.

The above issues will stimulate active growth and increase the importance of existing or new departments within companies that provide:

- Strategic planning of company growth by applying Directed Evolution methods and techniques.

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[37] Patent fences are a means of passive protection and consist of a set of patents that protects a product and/or technology, preventing or deterring attacks on a business by competitors.

[38] Patent blocks provide proactive protection and consist of a set of patents that protects a market, preventing attacks from competitors and/or allowing a company to profit from the success of its competitors (by licensing agreements, etc.)

- Prediction and prevention of potential negative effects, and diagnosis and elimination of existing negative effects.
- Effective IP control.
- Effective control of information flows, ensuring victory in various informational wars.

Changes to the stock market

E-commerce caused revolutionary changes to the stock market; the ability to invest online has added millions of new market players (over 20 million in the U.S.). Although most of these new investors operate with small capital, overall they control a huge amount of capital. Most importantly, many of them are not qualified to make adequate investment decisions.

The flood of new investors makes the stock market more homogeneous on the one hand, but also more prone to spontaneous action influenced by panic or fashion, decreasing the stability of the stock market and making it susceptible to investments in questionable projects that look fashionable and attractive to the public. We witnessed this phenomenon in the “dot.com” boom and collapse, which contributed greatly to the economic recession that followed.

Today, with the economy still in recovery, this “wild investor” factor again becomes important. Effective management of this process, based on PR methods, could become one of the most important financial instruments of evolution.

Customer/user individualization

The transition from paying for purchases with cash, to paying by check, then credit cards and, recently, Internet purchasing has created a growing opportunity for customer identification and monitoring of purchasing patterns. This trend will continue and strengthen due to contributions from RFID (Radio Frequency Identification Device) systems with which the flow of goods can be monitored.

This trend will allow for the monitoring of customer preferences, problems, previously purchased items, etc. It will also facilitate the creation of a system for blocking children from purchasing products that can be utilized inappropriately (for example, a card used to make purchases will contain an individual’s age and therefore disallow certain purchases just as today there are restrictions in some areas on buying liquor on Sundays or before a certain hour).

Changing criteria for product selection

The majority of recent users show little interest in the technical parameters of consumer products and usually do not compare these parameters between products of different producers. They believe that these parameters are generally the same and as a result are influenced by brand names, advertisements, or secondary issues such as packaging or color.

Today, the average consumer wants products that, in addition to the performing primary useful functions, provide other "pleasers" – these have to do with aesthetics for the most part, but there are others as well. For example, a product might be utilized as a toy while providing useful information that gains the attention and respect of others.

A reduction in price-sensitivity is occurring. Often in times of economic recovery there is an increase in luxury product purchases, as they are associated with better quality and personal success.

Evolution of fashion

In the early stages of human evolution, the majority of goods were manufactured in accordance with the limitations of existing technologies. Only with the emergence of new technological possibilities (new tools and methods for treating wood and animal skins; producing fabrics, threads, needles, etc.) did people begin to introduce various designs for goods, starting with clothing and jewelry. Later this trend included shelter, furniture, and dishes, which became an important social indication of position, wealth, etc. "Socially loaded" or signature elements were often associated with certain traditions or faiths, and thus were not easily changed, although they continued to evolve slowly.

Fashion as a cultural phenomenon emerged later, when the social limitations that had dictated the form and appearance of cultural artifacts started to soften, allowing for modifications to these artifacts; at the same time, the evolution of technology offered possibilities for creating modifications. Fashion often develops in a "snowball" manner, involving numerous people for a short period of time and then quickly disappearing, setting the stage for the next craze.

For several thousand years fashion produced changes in the style, type, form, color, etc. of furniture, clothes, shoes, jewelry, and other goods, exhausting nearly all technologically available possibilities for that time. Because the possibilities were limited, many of the same ideas (shoes with pointed or rounded toes, for example) have reappeared again and again. In many ways fashion evolves in a spiral manner; recently, however (i.e., in the informational era) we can identify the following new characteristics:

- The emergence of new materials and technologies capable of creating entirely new effects (radiating lights, changing form and color, flexible and highly absorbent materials, etc.).
- The appearance of "smart" features.
- The co-existence of styles that had previously been mutually exclusive (short and long skirts, pointed and rounded toes, etc.) has resulted in hybridization between different styles, which in turn gives people greater flexibility.

A main feature of contemporary informational society is an increase in the freedom and variety of consumer choices, which are supported by new technological possibilities. This leads to lower predictability and greater speed in market change, often resulting in a snowball (or tornado) effect. Similarly, fashion has become somewhat unpredictable while at the same time becoming capable of influencing various businesses.

Given the above, successful businesses in areas influenced by fashion require an effective system for fashion management based on existing industrial and informational technologies, including the development of methods that allow:

- Quick changes to design and production features to accommodate the latest trends.
- Mass customization, i.e., the ability to quickly adjust to individual or group requirements.
- Effective monitoring of current trends and early detection of upcoming trends.
- Fashion management, i.e., the ability to influence customers to accept certain fashion possibilities.

Shift to professional services

With the growing complexity of home equipment and an increase in overall wealth, the trend toward the transfer of certain home-care functions to professional services strengthens. Starting from equipment repair, professional services move to maintenance and other convenient services. This trend should lead to the increasing complexity of certain products, transition to larger size packaging, and more professional equipment for product utilization appropriate for even a small service company rather than the individual user.

Product evolution

For most of human civilization, little attention was given to the convenience of product use. This is easily seen by a visit to a museum of culture or ethnography to view antique clothes, furniture, and the general home environments displayed there. Inventions targeting more convenient living conditions (soft furniture, for example) appeared during the Renaissance; mass production of various products of this kind started in the 19th century with the industrial revolution.

Increasing the convenience of consumer products involves these considerations:

- Improving a product's adaptation to human anatomy, physiology and aesthetics.
- Reducing the harmful effects associated with product use (such as stresses, traumas, accumulation of dirt and waste, etc.).
- The possibility for plug-and-play (utilization without the need for special installation, training, or other preparations).

Consumer products become "smarter"

Over the last 15 years, one of the basic evolutionary patterns for consumer products involves making products "smarter." Increasing public awareness of the possibilities of informational technologies, a number of publications about computerized homes, "smart" machines, etc., has created expectations (sometimes unrealistic) of "electronic miracles" in almost any area. As a result, only companies that can keep up with these expectations can succeed in today's market.

For the majority of consumer products, "smarter" means capable of adjusting to meet specific user needs, conditions, etc. For example:

- Receiving information from consumers in various formats, such as:
  - Instructions (programs, orders, etc.).
  - Selections made by voice, gesture, pressing a button, etc.
  - Information from certain sensors that monitor pulse, body temperature, etc.
- Processing the obtained information and reacting accordingly.
- Utilizing the obtained information and/or transmitting it to other devices.

One of the most important directions in the evolution of the human environment is the continuous monitoring of an individual's health for early identification of critical health changes. To comply with this trend, many consumer products are already equipped with sensors capable of collecting information and transmitting it to authorized destinations.

This trend manifests through the use of the following technologies:

- "Smart" materials that can perform special functions.
- Various micro-electronic devices (sensors, microchips, etc.).
- Communication and self-adjustment between various products and systems via local networks and the Internet.

In general, this trend leads to increased product complexity and cost; customer expectations usually adjust accordingly, although not necessarily reasonably.

Increasing safety requirements

For some time, safety requirements have been increasing even as the notion of safety is redefined. With the elimination/reduction of mortal dangers (wars, famine, infectious diseases, etc.) consumer attention has shifted to issues that represent less danger, such as the influence of a product on health, mood, etc. In addition, increasingly rigorous scientific research can reveal dangers that were previously undetectable.

The expansion of this trend to consumer products started with the 1965 publication of Ralph Nader's book *Unsafe at Any Speed: The Designed-In Dangers of the American Automobile*, along with the first campaigns against smoking and the use of Freon. Today, growing attacks on certain types of food and food companies are evident. Successful lawsuits against tobacco companies have prompted similar action in other areas, leading to growing numbers of lawsuits and compensatory awards for injuries, damage, and other inconveniences produced by various products, which in turn results in higher insurance premiums. This trend has strengthened with the increase in informational “transparency” that allows customers to obtain and exchange more information, revealing correlations between product use and harmful or undesired effects.

It seems clear that after the tobacco and food industries, the next litigation target will be the consumer product industry. Cleaning products, furniture, clothes, electronic items, home building materials – almost any consumer product could be potentially dangerous under certain conditions.

Based on the above, it is possible to predict the following two interconnected events:

- Increase in lawsuits against manufacturers and distributors.
- Government regulation of the introduction of new types of products, including the establishment of FDA-like organizations that analyze potential dangers associated with products and consider whether certain products should be banned.

Recently, the typical behavior of consumer product manufacturers has been passive and has included new product testing (without appropriate testing methods, however, it is practically impossible to reveal all potentially serious dangers) and reactions to specific customer complaints and/or desires when products enter the market. In the future, market success will depend on a company’s ability to effectively employ methods such as Ideation’s Failure Prediction and product development process, designed to identify and prevent potential dangers. Jointly, these methods can provide protection against:

- Harm to customers from consumer products
- Becoming the subject of lawsuits and/or unwarranted claims

Environmental regulations

Tightening of environmental and health requirements can produce:

- Increased suspicion of artificial materials, negatively impacting their image.
- Increased criticism of production located in wealthy countries, and the introduction of regulations that result in higher production costs.
- Transitions to more environmentally-friendly production, with reduced waste and utilization of artificial materials.

Expanding product functions

The value of any consumer product can be increased by increasing the number and quality of the product’s functions. This can be achieved by:

- Capturing the functions of adjacent products – functions performed by other products and systems in the same environment, or that interact with the given product during different stages of its lifecycle.
- Absorbing functions that had previously been performed by humans, using automation and "smart" technologies.
- Segmenting the functions of existing products to introduce sub-operations and/or sub-functions; in certain situations this is associated with product specialization (the performance of specific functions).

Increasing variety of products

An increase in the variety of products is a response to increased customer demands and preferences ("pickiness"), accelerated changes in fashion, and the growing volume and speed of informational exchange. The resulting effects include:

- Reduced volumes of any particular product.
- Spikes (often unpredictable) in the demand for certain products.
- Expansion of product lines to include an assortment in price and quality, from high-priced luxury products to inexpensive versions. In general, customers become increasingly more tolerant to higher prices.
- Customers become more conscious of other issues regarding product manufacturers such as a company's position on the environment, preservation of jobs within a community or country, etc.
- Acceleration of new product development and introduction to the market.
- Availability of agile manufacturing technologies.

An increase in product variety is possible by using the concept of mass customization – that is, developing technologies that support the production of base products that can be easily modified during the final stages of production or even at the consumer site.

Increasing product integration

As products evolve they tend to become integrated into a system correlated with other elements in the same super-system, creating "families" to some degree. Integration can take place on a functional level or on a more superficial level (in style, color, etc.).

Reducing human effort

A strong trend exists toward reducing the amount of work required for satisfying immediate human needs and servicing home equipment. This trend reveals itself in the "plug-and-play" requirement (no special effort needed for installation and servicing). In particular, the following procedures may become standard:

- Utilization of fully- or partially-automated "smart" systems

- Utilization of systems capable of communicating with the user.
- Online support for complex consumer products.

Emergence of packaging with useful functions

As a product evolves, packaging starts to be utilized to perform certain useful functions. Typical examples include cookie containers that can be used after the original product has been consumed.

Conclusions

1. Over the last 60 years TRIZ has grown from a problem-solving methodology into the ***science of technological evolution***, with the Patterns of Evolution as its core. At the same time, we know that all known Patterns are empirical in nature and therefore can describe the main direction ("what") of a system and its actual evolution ("how") but lack the "why" – that is, an explanation of the origin and driving forces of technological evolution.
2. Technological evolution is not an isolated process but rather is an aspect of the more general evolution of society; moreover, the evolving world resembles a Russian nested doll (*matreshka*) with multiple evolution processes of different scale taking place both independently and interdependently.
3. The main evolutionary levels under consideration include:
    - Universal evolution
    - Biological evolution
    - Evolution of human civilization
    - Evolution of man-made systems
    - Micro-evolution (inventions and innovations)

    Based on the above, 7 groups of general patterns have been formulated (19 patterns altogether) and 14 groups of specialized patterns/lines. Three high-level patterns with associated 15 lines are described in detail.
4. Higher-level evolutionary trends/patterns serve as the driving force for evolution at the lower level. This explains why the Patterns of Technological Evolution are so strong – because they are enforced by the general demand and expectation of customers.
5. Understanding evolutionary trends occurring on a higher level significantly increases the reliability of predictions regarding the development and marketing of next-generation products.
6. An example of the practical application of general Patterns of Evolution to the evolution of consumer products is described.
7. Using knowledge of the Patterns of Evolution in conjunction with analytical methods and other instruments provides the following benefits:

- Obtaining a substantial advantage over competition
- Forming a strongly-protected portfolio of intellectual property
- Avoid costly and often irreparable strategic mistakes in product development and marketing.

Appendix 1
Selected General Patterns of Evolution of Man-Made Systems

Group 1: General aspects of the evolution of man-made systems

Pattern: Evolution of driving forces (15 lines)

Pattern: Evolution of impeding forces (2 lines)

Pattern: Evolution of the means and methods to control the evolution of man-made systems (8 lines)

Pattern: Emergence and resolution of contradictions

Group 2: Evolution of the man-made environment

Pattern: Increase in the role of man-made systems (10 lines)

Pattern: Reduced human involvement in man-made systems (5 lines)

Pattern: Adaptation to the environment (6 lines)

Group 3: Evolution of the application and marketing of man-made systems

Pattern: Evolution of products for marketing (5 lines)

Pattern: Evolution of markets (9 lines)

Group 4: Increasing ideality of man-made systems

Pattern: Increasing a system's usefulness (14 lines)

Pattern: Reducing overall cost (10 lines)

Pattern: Increasing a system's usefulness in the process of reducing cost (5 lines)

Group 5: Evolution of resources

Pattern: Intensification of resources utilization (12 lines)

Pattern: Effects as resources (15 lines)

Group 6: Evolution towards increasing system adaptability

Pattern: Increasing dynamization (15 lines)

Pattern: Increasing controllability (9 lines)

Pattern: Matching-mismatching (18 lines)

Group 7: Evolution of system structure

Increasing system complexity (15 lines)

System simplification (7 lines)

Appendix 2
Selected Groups of Specific Lines of Evolution

Group 1: Evolution of substance utilization

Group 2: Evolution of chemical technologies

Group 3: Evolution of materials for chemical technologies

Group 4: Evolution of simple parts

Group 5: Evolution of standardization

Group 6: Evolution of the production and consumption of energy

Group 7: Evolution of systems for measurement and control

Group 8: Evolution of models

Group 9: Evolution of safety methods and equipment

Group 10: Increasing convenience

Group 11: Evolution of tools

Group 12: Evolution of technological process

Group 13: Evolution of flows

Group 14: Evolution of consumer products

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