# Revolutionary Innovation Tools for the Ultimate R&D Organization

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Revolutionary Innovation Tools for the Ultimate R&D Organization

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Abstract

Leading experts in the areas of R&D organizational development and knowledge creation have correctly identified an innovation crisis in the majority of corporations. They suggest a reasonable organizational model for the next, fourth-generation R&D organization.

At the same time, the tools and processes offered by these experts are too limited to provide effective knowledge creation, because they are mostly derived from a limited number of success stories and thus lack long-term and/or representative proof.

While the organizational model for the fourth generation R&D organization can serve as a foundation, it must be complemented with powerful technology and tools capable of delivering innovation in a mass production fashion. The authors suggest that TRIZ (Russian Acronym for the Theory of Inventive Problem Solving) and Directed Evolution™ (DE) are well-suited for this purpose.

TRIZ and the DE™ approach have been used to develop a model of the Ultimate R&D organization. This model includes basic attributes, functions, structure, culture, and tools.
Introduction

The crisis in corporate innovation

Analyses by prominent academic and industrial analysts of corporate innovation activity over the last decade has revealed rather disappointing results: in spite of universal agreement as to the importance of innovation and R&D, and the vital role that both play in the growth, survival, and success of companies and nations, the existing process for creating innovation is ineffective.2 In particular:

- About 3,000 raw ideas are generated for a single commercial success
- Of four projects that enter the development stage, only one becomes commercially successful
- According to the U.S. Department of Commerce, 90% of all new products fail in the first four years
- Over the last ten years, fewer than 10% of American companies have attempted to develop a new product
- 80% of all innovations originate from customers rather than producers
- For every 150 patent applications, 112 patents are issued; 9 of these will be supported by the owners; one might be really successful.

While acknowledging that existing R&D divisions in leading companies are fairly successful in carrying out continuous innovation, Miller and Morris emphasize their failure to produce discontinuous innovation for the following reasons:3

- Lack of appropriate organizational models for the structure of R&D divisions
- Ineffective knowledge management
- Financial and accounting systems that hinder, rather than stimulate, innovation activity
- Cultural problems that result in strong resistance to change
- Lack of effective tools and processes to support and manage innovation activity
- Lack of effective interaction with potential consumers/customers/clients for the purpose of identifying their latent needs.

Attempts to improve the situation

A number of attempts have been made to overcome these obstacles. In particular:

- A new model of the R&D organization has been proposed (fourth generation R&D).
- Introduction of a spiral-based knowledge creation process that entails the sequential transformation of tacit and explicit knowledge.4

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3 Miller and Morris provide the following definitions: *continuous innovation* – innovation within an existing paradigm, targeting existing markets; *discontinuous innovation* or breakthrough – innovation outside the existing paradigm (i.e., associated with a paradigm shift), typically requiring the creation of a new market or market niche.
• Creation of exploratory groups, whose functions extend beyond the usual functions of existing R&D organizations, allocated to business units.

An analysis of the successes and failures of various exploratory groups (described above) shows that these groups require the presence of certain activities, including stronger creative efforts than those associated with regular R&D activities. For this reason, the results achieved by the exploratory groups were always highly dependent on the personalities of the scientists and leaders involved – i.e., dependent on their commitment, creative potential, knowledge, and other personal factors.

In general, certain patterns are seen with regard to institutionalizing new organizational models and methodologies in the areas of quality management, product development, innovation, etc. In particular:

• Correctly identifying the failure of existing practices to deliver desirable results (quality, innovation, competitive time-to-market, etc.).

• Various authors have suggested fairly reasonable organizational models.

• Somewhat useful recommendations for tools and processes have been derived from limited success stories, therefore, there is no long-term proof of the efficiency of these tools and processes.

• There is a varying degree of awareness of cultural problems and of the resistance to new methods and associated changes.

• There is a general unawareness of TRIZ-based tools and processes.

• New models/methodologies experience a “rise and fall” popularity (initial high expectations followed by disappointment when these expectations are not met).

Given the above, from an evolutionary point of view the “rise and fall” popularity associated with change seems natural and inevitable, for the following reasons: At the inception of a particular change, certain organizational actions (assigning responsibilities, organizing educational and pilot projects, etc.) combined with the natural enthusiasm of champions often brings about excellent results. However, every new process includes a phase during which certain creative (innovative) results must be generated; these results are usually rather inefficient due to the limitations of the “creativity tools” used. (See the figure below, which describes the traditional innovation process.)
Indeed, psychology-based creativity methods and tools typically used for idea generation cannot provide repeatable and reliable results in a normal working environment (i.e., after the initial enthusiasm has subsided). In our review of creative methods\textsuperscript{6} we have shown that TRIZ is the only methodology that has the following:

- Innovation knowledge base
- Evolutionary approach

Due to these advantages, TRIZ can provide added value to all phases of the innovation process, particularly the concept development stage (see the figure below):

TRIZ and science

The following scientific problems/situations require a creative approach:

- Discoveries of new events, effects and phenomena
- Integration and hybridization of knowledge and ideas from different areas
- Creation of a model or theory to explain a new event or phenomenon
- Planning and developing of experiments, effective measurement systems, methods for processing information, etc.
- Finding new applications for new effects

The utilization of a TRIZ approach to science has its own history. Since inventing TRIZ in 1946, Genrich Altshuller continuously sought to expand his new methodology to the scientific arena. In 1960 he distributed his paper entitled “How Scientific Discoveries Are Made,” in which he formulated the basic approaches to developing methods for solving scientific problems. In particular, he identified two classes of discoveries:

- Class 1 – The discovery of a new phenomenon or fact
- Class 2 – Finding an explanation for a new phenomenon or fact whose mechanism or nature is unclear.

Based on an analysis of a limited number of discoveries of both types, Altshuller formulated around ten useful recommendations to help with class 1 discoveries, and eight recommendations for class 2 discoveries. Later, the accomplished TRIZ specialist and educator Volyslav Mitrofanov suggested a method for utilizing the Patterns and Lines of Evolution to discover new physical, chemical, and other effects.

Since early 1980s, authors have been involved in a research that has produced important theoretical achievements and vast practical experience related to scientific and research problems/situations. These include:

- Refining the techniques related to the application of TRIZ tools to scientific problems
- Discovering and formulating evolutionary patterns of scientific systems (theories and hypotheses)
- Developing general methods for building new scientific concepts.

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9 Volyslav Mitrofanov, From Manufacturing Defect to Scientific Discovery (St. Petersburg: TRIZ Association of St. Petersburg, 1998).
10 The theoretical aspects and specifics of scientific activities have been addressed in Boris Zlotin and Alla Zusman, Searching for New Ideas in Science, Solving Scientific Problems (Kishinev: STC Progress in association with Kartya Moldovenyaska, 1991). This work is currently being translated into English.
Directed Evolution™ of R&D organizations

Directed Evolution (DE), an application of the Ideation/TRIZ methodology (also known as I-TRIZ), is used to identify a comprehensive set of potential evolutionary scenarios for products, services, processes, technologies, organizations, markets, etc. DE is based on an extended set of patterns/lines of evolution, as well as other tools and techniques developed by the Ideation Research Group.\(^{11}\)

In 2001, a DE project was carried out for an R&D organization within a large international company, resulting in the development of an ideal futuristic model for an R&D organization. Such an organization (referred to herein as the Ultimate R&D organization) would be capable of ensuring a sustained breakthrough innovation process, both for itself and its host entity.

**Basic model of R&D evolution**

We have studied the evolution of R&D organizations from various points of view, and submit the following definitions for the past and present generations of an R&D organization:\(^{12}\)

- **First generation.** Laboratories are managed by leading scientists. Examples: The first R&D chemical lab (BASF), 1867; Thomas Edison’s lab, a prototype for many industrial corporations, 1876. By 1946, approximately 2000 labs had been established world wide.

- **Second generation.** Business needs are the focus of an R&D organization; project management practices are applied to the management of R&D labs.

- **Third generation.** Technology management takes place within the context of financial risks, strategic planning, and technology road maps (early 1990s).

- **The next, fourth generation** R&D organization is on its way, and should overcome all the deficiencies inherent to the previous generations.\(^{13}\)

**Super-system and driving forces**

An analysis of current evolutionary trends and forces has shown that the driving factors in the evolution of an R&D organization are the requirements imposed on it by its super-system – that is, the organization responsible for financing and exploiting the results of R&D activity. A super-system for an R&D organization might therefore be a commercial company, government agency, university, association, etc. (See the figure below.)

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12 Miller and Morris, *Fourth Generation R&D*.
13 To complete the historical picture it might be useful to add the “0th generation,” where discoveries and innovations made by individuals or small informal groups slowly, via trial-and-error, improved existing systems and created new ones (weapons, boats, various processes, domestication of animals, etc.).
Sequential changes to the tools, organizational structure, and culture indicated in the above figure typically result in numerous contradictions:

A substantial reduction in the R&D “response time” to super-system requirements can be achieved by applying the DE approach based on foreseen upcoming changes, and by working in parallel on the tools, organizational development and culture that can meet the imposed requirements.
An additional benefit of this concurrent change scheme is that it allows little time for resistance to change to develop. (For more about resistance to change, see the section entitled Ultimate R&D organization culture.)

**Additional important trends**

Additional trends affecting the evolution of an R&D organization are:

- High efficiency of the host companies, based on free-market relationships.
- General changes in employment structure and private “links” between people, caused by the development of informational links. Development of global information and communication systems.
- The desire of people to work under more comfortable and convenient conditions. In the past, this was less important than earnings; today it is very important in the U.S. and Western Europe. Employees and employers – especially in high-tech arenas – want to refine their working conditions, as this can increase efficiency (especially for intellectual operations such as programming, design, research, etc.).
- The growth of the Internet, which has allowed many people to work at home or on a flexible schedule.
- An increase in the educational level of many workers.

**Evolution of the basic features of an R&D organization**

The authors have complemented the four-generation model discussed above with additional features important in an evolutionary point-of-view. In particular:

- Science, technology and production situations
- Market situation
- Main focus
• Return-on-investment (ROI) components
• Organizational structure
• Organization leader
• Personnel
• Organization of work
• Cultural specifics
• Applied theories, models and approaches
• Knowledge management
• Creativity methods
• Research techniques
• Research tools
• Main problems

Comparative descriptions of the above features for each generation are given in the table entitled *Evolution of R&D Organizations* (see Appendix 1). According to this table, the majority of R&D organizations in existence today belong to the second or third generation. While these organizations can be fairly efficient at producing continuous innovation, they fail when it comes to discontinuous innovation. Typically, such organizations suffer from bureaucracy, limited vision, non-productive specialization, duplication, and other undesired effects.

At the same time, certain elements of the fourth generation organization began to develop during the reign of the second and third generations. Moreover, some of the conditions necessary for the emergence of the next generation are in place – it is necessary to collect these “seeds” and to create an environment in which they can grow and prosper. The TRIZ approach holds that, in order to establish an effective system, an ideal (ultimate) system should be imagined. An analysis of the entire evolutionary picture has allowed us to identify the main features of the Ultimate R&D organization.
The Ultimate R&D organization as a center for innovation and knowledge creation

The main features of the Ultimate R&D organization include:

- Typical attributes
- Typical functions
- Organizational structure
- Organization culture
- Utilized tools and processes

Typical attributes of the Ultimate R&D organization

The Ultimate R&D organization should comply with the most prosperous evolutionary stage in the life cycle of an organization – Contrived Dynamic Prosperity (CDP). This stage, identified by the authors in their theory of organizations \(^{14}\), is an artificially created and artificially supported stage that differs from the “natural” evolutionary stages of an organization. (See the figures below.) \(^{15}\) CDP is in many ways similar to the second stage (“rapid growth”), but what was temporary during the second stage becomes a normal, continuous condition in CDP, where natural aging is prevented by a specific organizational business model and culture. \(^{16}\)

![](naturalLifecycle.png)

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14 This theory, whose development began in the mid-1980s, is based on extended analyses of the most successful companies.


16 For a detailed description of typical CDP features, including goals, management system, organizational structure, leadership, rules, behavior, morale, discipline, driving and impeding forces, and other features see Zlotin and Zusman, *Directed Evolution: Philosophy, Theory and Practice*, Appendix 8.
Desired lifecycle of an organization

Stage 0 - an organization does not yet exist but important conditions for its emergence are developing
Stage 1 - organization start-up
Stage 2 - fast growth
Stage 2D - contrived dynamic prosperity

In addition to its main features, the CDP stage, like all other stages in an organization’s lifecycle, is characterized by its own general business objectives, as well as typical mistakes (or traps) that must be avoided.\(^\text{17}\)

**Typical functions of the Ultimate R&D organization**

The typical functions of an R&D organization are defined by the requirements imposed by its super-system, that is, the organization responsible for financing and utilizing the results of R&D activities. The typical functions for the Ultimate R&D organization are addressed below.

*Navigation ensuring the effective evolution of an organization*

The Ultimate R&D organization conducts scientific, technological, and market research, and evolutionary screening (i.e., to determine the location of a product/process/service on its own evolutionary lifecycle, whether there are resources yet to be exploited, etc.). The results of these efforts are submitted to management to support strategic planning and decision-making related to the company’s growth, or as a response to important factors such as new discoveries, regulation changes, political changes or other disruptive events.

*Conducting exploratory projects*

The Ultimate R&D organization conducts exploratory (including pioneer) projects that target:

- Development of new intellectual property
- Development of new products/processes/services
- Enhancement of technologies/products/quality, etc.

Exploratory projects might include both internal research and acquisition of knowledge from various sources (publications, competitive intelligence, etc.).

**Forming and managing an intellectual property portfolio**

To ensure sustained growth, an effective structure must be established to continuously support an intellectual property portfolio, including the development and accumulation of property in the form of patents, patent fences, etc.

**Methodological projects**

The Ultimate R&D organization provides methodological supervision and support to R&D personnel from other divisions, including:

- Development and acquisition of new methods, software, etc. that will ensure the best innovation results (quality, speed, efficiency, etc.)
- Educating business unit specialists regarding effective innovation methods

**Establishing an innovation culture**

The establishment of an innovation culture includes the creation of an atmosphere where innovation and creativity is rewarded, where positive attitudes toward innovation prevail, and where creative cooperation and competition between people, divisions, etc. is fostered through TRIZ education and the presence of an innovation web site.

**Generating revenue**

The Ultimate R&D organization should entirely pay for itself as well as generate revenue for the company. Revenue generation might be provided via:

- Contributing to the growth of the company
- Developing valuable intellectual property (patents and licensing)
- Completing commercial projects for external organizations

**Structure of the Ultimate R&D organization**

**Basic model**

As mentioned earlier, in the process of evolution a new functional organization emerges in response to the emergence of new tools and working methods. According to the table entitled “Evolution of R&D Organizations” (see the Appendix 1), different generations of R&D organizations had different kinds of leadership and structure. In particular:

- The first generation had a simple structure: a creative leader with entrepreneurial skills (an Edison-type individual) and personnel (often lacking formal scientific or engineering education) working on his/her assignments.
- The second generation emerged when most major companies established large R&D departments. An R&D department typically had a more structured administrative scheme managed by an administrator (sometimes with a scientific background) rather than a scientific leader. Recruited scientific personnel had to meet specific requirements with regard to their education and scientific skills.
- The third generation was initiated by the marketing revolution, forcing R&D leaders to balance their portfolio of high- and low-risk projects. While the general structure of R&D
centers remained mostly unchanged, the leaders had to acquire entrepreneurial skills to deal with risks, ROI, etc.

- The upcoming fourth generation involves an increased initiative of all participants and the application of new tools. Thus it is vitally important that the new R&D organization be market driven, have a long-term vision, and be able to use incentives to motivate personnel. In other words, every participant must be market driven and have some entrepreneurial skills.

The transitions from one generation to another are illustrated in the figure below.

Based on the above model, the following aspects regarding the structure of the Ultimate R&D organization have been addressed:

- Commercialization
- Personnel management
- Researchers-individuals

**Commercialization of R&D activity**

The suggested model recommends treating each internal R&D project as an independent commercial venture. Once an R&D project has been approved by the host company, and when financial means have been allocated (in the form of investments, credit, etc.) this venture functions as an enterprise. The project manager then becomes responsible for the following:

- Building the project team (forming an agreement with each participant)
- Buying or renting the necessary equipment
- Issuing shares (at least internally) for the project, for the purpose of:
  - financing the project
− rewarding participants or other instrumental people
− trading options

On the other hand, when an employee is invited to participate in a project, he/she is able to negotiate the terms.

This commercial R&D scheme can provide a competitive advantage, however, a profit-oriented mentality might have a negative affect on long-term projects. To counter this, methods similar to government regulations can be employed. In particular:

• Allocation of funding according to the company’s long-term strategy, developed as a result of DE of the company business
• A special “tax” on implemented projects that will create funding for long-term and fundamental projects.

This scheme does not require that all project participants share the same facilities (see sections entitled “Personal workplace (home office)” and “Research machine”). People living in different cities can work on the same project. Face-to-face meetings (such as a three-day team conference, for example) could be held during critical stages of the project such as initial idea generation, discussion of results, etc.

**Personnel management**

With R&D projects organized as described above, each participant (from the leader or manager to the technical writer) should acquire entrepreneurial capabilities that will allow him/her to perform the following activities:

• Sell his/her services for monetary reward, including an equity position in the project
• Increase his/her “value” by obtaining additional education, participating in prestigious projects, providing useful initiative, making creative contributions, etc.
• Participate in a number of projects under different conditions
• Trade his/her shares on an internal “stock exchange,” etc.

Given the above, each project participant is highly motivated toward the project’s success, and is willing to come up with creative ideas (as would a scientist or entrepreneur).

**Researchers – individuals**

The history of science has clearly shown that during the 18th and 19th centuries most scientific discoveries were made by individuals who carried out their research as a personal mission or at the request of a private company, government agency, etc.

Individual researchers practically disappeared when technological advancements resulted in industry-level research capabilities on the one hand, and the growth of university-centered research on the other hand. The next cycle of the evolutionary spiral, supported by the development of new tools and possibilities (the Internet, research industrialization, home offices, etc.) will allow for the revival of the individual researcher, who can work under contract or with the intention of selling the fruits of his/her research.
**Personal work place (home office)**

Besides the important trend involving the increased independence and initiative of R&D participants, the following additional trends have been taken into consideration:

- Growing technical capabilities that allow people to work from their homes, and the increasing number of people desiring to set up home offices.
- Formation of “remote” working teams, where people from remote sites interact via telecommunication.
- Increasing percentage of projects completed with the help of computers.

We expect that these trends will generate the following changes in the working methods of R&D organizations:

- R&D personnel will work mostly from home offices which are equipped so as to allow effective full-scale communication and joint activity in real time.
- Simplifying (vs. complicating) of teamwork procedures; creation of various working groups.
- Decreased need for office space
- Reduction in commuting
- Working hours selected by employees according to what is most comfortable for their project activity.

Note: The efficiency of organization personnel working on various projects from their homes has been successfully demonstrated by TRIZ consulting teams working for Ideation International.

Given the above, a personal workplace becomes a computerized home/personal office, which includes:

- A high-performance computer with voice-recognition applications (for dictation), teleconferencing software, specialized professional software, etc. Such a system would likely be equipped with several monitors/screens.
- A large computer screen (probably wall-mounted) for teleconferencing
- High-speed access to the Internet
- Software that provides:
  - Creative and technical support
  - Project management
  - Efficient interaction with other project participants (team members) and with research equipment

**Ultimate R&D organizational culture**

The most effective tools and organizational structures might fail to deliver the best innovation results in the absence of a culture that supports their use.
The culture of a particular society or group consists of a set of paradigms (written or unwritten) that determine the “normal” reactions of an average member of the society in various situations. Typically included in a culture are the knowledge, opinions, goals, behaviors, etc. that determine the tolerance (or intolerance) to certain ideas, actions, changes, etc.

The main cultural components relevant to our research are as follows:

- People’s attitudes toward their own company, their commitment to its success, the degree of self-identification with the company (patriotism), including:
  - reaction to success
  - reaction to mistakes
  - reaction to unfairness (real or imaginary) directed at themselves and others
  - assessment of their own positions in the company

- Attitude toward the environment, including other social groups and other companies (including competitors).

- Attitude toward change and new ideas, including:
  - Changes initiated inside the company
  - Changes introduced outside the company by competitors, universities, other people, etc.

- Factors influencing an individual’s career within the company

An analysis of the existing R&D culture, and of upcoming changes stimulated by environmental trends, has allowed the authors to develop a vision of the Ultimate R&D organizational culture. One of the most important features of this culture is a so-called “winning mentality” based on a TRIZ way of thinking and handling problems, and on an evolutionary approach to any aspect of life.

A corporate culture cannot be abruptly changed (as is seen by the problems encountered during company transitions or mergers). Therefore, the creation of a desirable culture is a complicated task that entails the active use of the best components of the existing culture along with the addition of necessary elements, supported by various tools and management measures.

One of the most critical issues in introducing cultural change is dealing with resistance. As mentioned earlier, the introduction of something new always generates resistance. Resistance to change occurs on both a conscious and subconscious level, and includes (but is not limited to) the following components:

- Mechanisms of individual and group survival
- Psychological defense systems
- General negative attitude
- Fear of bad news
- Defense of one’s home territory
- Prejudice and the influence of accepted paradigms
- Age-related issues
• Loss of knowledge foundation
• Right- and left-brain thinking
• Brain deactivation during problem solving

To a certain extent, resistance can be useful because it supports the stability of an entity and ensures the effective selection of the best practices for implementation and utilization. But in most cases, resistance can be very harmful and can create serious obstacles to evolution.
TRIZ tools for a new R&D organization

Co-evolution of tools and organizations

In the late 1920s a high-ranking student in a military academy was assigned the following thesis: “The influence of the evolution of military strategies on artillery development.” Six months later he asked for permission to change the thesis to: “The influence of artillery development on the evolution of military strategies.” His research had shown that the evolution of artillery had influenced military strategies, rather than the other way around. Indeed, the emergence and evolution of guns, aiming devices and ammunition has forced the military to change its strategy.18

In any field of activity, the development of tools determines the structural development of the associated organization, and even, to a great extent, the culture. (People who use computers think, speak and live differently than people who use quill and ink or even ball-point pens.)

The typical developmental scheme of tools and organizations is as follows:

Step 1: New tools emerge within the framework of the old system, increasing efficiency and opening up new possibilities. In the beginning, however, these tools have only a weak influence on system organization and functioning. What’s more, the new tools are not very efficient within the limitations imposed by the existing old system and the old applications. (The influence of the first firearms on feudal warfare was rather limited, for example.)

Step 2: The new tools undergo qualitative improvement (which at this stage is fairly easy). The number of new tools grows while new applications are introduced based on these new tools; the tools are then improved based on feedback from the use of the associated applications, and so on. New resources, which were invisible earlier, are revealed in the new tools. At the same time, contradictions emerge and grow between old organizational and management policies and new requirements for efficient use of the new tools. Eventually, a significant transformation of the old system (revolution) occurs, bringing with it an organizational structure based on the capabilities of the new tools.

An analysis of the tools available for use by researchers over the last 5 to 10 years has shown that most of the tools suitable for the activities of the new R&D organization already exist. But the number of tools is increasing rapidly, making the selection of the appropriate tool for a specific purpose very difficult. Today, this problem can be solved through the integration and hybridization of different elements of various R&D activities, based on applying a new evolutionary approach – the DE approach – to the development of artificial (manmade) systems.

The following trends have been taken into consideration:
• The continuous emergence of new fields of knowledge, new information, rapid aging and changing of knowledge, etc.

18 This student later became the Soviet Union’s Chief Marshal of Artillery.
• “Breakthroughs” created on the boundaries of different sciences and fields of knowledge, and the development of a methodology for the purposeful hybridization of ideas and concepts.

• The enhancement of theoretical foundations in most scientific and engineering fields, along with the advent of computerized modeling and calculation programs.

• General computerization that results in the emergence of a new type of specialist – the “computer-driven specialist.”

• The new and enhanced ability to search and access information world-wide.

• The introduction of numerous tools and methods for improving quality and accelerating scientific and engineering work.

• The emergence of TRIZ as a proactive approach for developing and enhancing artificial systems (technical, informational, social, etc.) based on applicable evolutionary theories.

• The emergence of the DE methodology – the purposeful management of the evolution of various systems (technical, science, social, etc.)

• The introduction of techniques for fast and effective learning based on TRIZ knowledge (i.e., knowledge of general evolutionary patterns, utilization of TRIZ tools to model any type of situation, etc.)

• Integration of different sciences and methods for the purpose of enhancing creativity.

The changes associated with these trends should involve the development of an integrated computerized methodology, including:

• Utilization of computer and network capabilities

• Utilization of world-wide information

• An evolutionary and knowledge-base approach to idea generation; the transfer and exchange of ideas and technologies between different fields of activity.

• The control of systems evolution (DE process)

• A scientific problem-solving approach based on problem inversion, that is, converting scientific problems into engineering problems and applying effective tools originally developed to solve engineering problems.

• Continuous education extending throughout one’s professional career.

This integrated methodology will not substitute for professional knowledge in specific fields, but rather will create:

• A common language for communication and for the transfer and hybridization of ideas, knowledge, technologies, etc.

• General standardized approaches to typical problems, such as development control, generating and evaluating new ideas, building hypothesis, quality control, maintaining safety and security, etc.

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19 Problem inversion is a method for transforming a certain class of scientific problems into engineering problems, thus allowing for the utilization of most TRIZ tools for scientific problem solving. The essence of problem inversion is simple: instead of asking “How can a certain phenomenon be explained?” one asks “How can this phenomenon be produced under the existing conditions?” The problem therefore becomes a typical inventive problem and can be attacked using existing TRIZ tools such as the Innovation Principles, ARIZ, System of Operators, etc.
Given the above, we will address two of the most important and closely related R&D activities requiring an effective methodology and the tools and techniques to support it:

- Knowledge creation
- Knowledge management

Methodology and tools to support the knowledge creation process in an R&D organization

The new R&D organization has a strong emphasis on innovation. For this reason, in addition to conventional scientific and engineering activity, a methodology for stimulating creative activity should be utilized. TRIZ and its recent advancements (including Directed Evolution), along with the best practices of other innovation/creativity techniques, can serve in this regard offering special techniques and recommendations.

Integration and hybridization of knowledge and ideas

It is well known that integration is one of the most effective methods of producing new theories from existing ideas (sometimes even opposite ideas). An example is the complementary principle introduced by the physicist Niels Bohr. To ensure the effective integration of ideas, a special hybridization methodology has been developed in TRIZ.20

Hybridization is a specific process for combining different systems for the purpose of building a new one. It is an important means by which both biological and scientific/technological systems evolve. Regarding evolution as a permanent process of hybridization helps us to understand that evolution relates to a family of systems (the population of fighter planes, for example) rather than a specific system (the F-16 airplane). Very often this evolution presents itself as the exchange of features (solutions, designs, specific technologies and processes, etc.) between family members. The hybridization technique provides the following advantages:

- The possibility of advancing a system through incremental, easily-acceptable steps.
- The exchange of proven and readily-available solutions and subsystems between different systems, which accelerates evolution and increases the probability of successful implementation.

Besides the purely technological advantages, hybridization can be a strong psychological approach that provides:

- A new “big picture” of technology as a world of dynamic, flexible and prone-to-integration hybrids.
- The capability for easily (and without psychological pressure) “mentally disassembling” a complex system, then reassembling it in a different way.
- A reduction in psychological inertia that enables one to critically analyze his/her own system and compare it to competing systems, then attempting to hybridize.

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Creating a model or theory to explain a new event or phenomenon

Both the solving of scientific problems and the generation of new scientific concepts are based on the same approach: Problem Inversion. The essence of Problem Inversion is simple: instead of asking “How can a certain phenomenon be explained?” one asks “How can this phenomenon be produced under the existing conditions?” The problem therefore becomes a typical inventive problem and can be attacked using existing TRIZ tools.

Based on this approach, a method for building new scientific concepts has been developed. This method includes the following steps:

• Formulate the original problem
• Amplify the problem
• Invert the problem
• Search for creative “hints”
• Utilize resources
• Verify the obtained hypotheses

For a more detailed description, see Appendix 2.

Building new scientific concepts

In many situations, it is enough, for practical purposes, to obtain one or more explanatory mechanisms. At other times, a comprehensive new concept is needed. The following algorithm is recommended for developing concepts:

• Analyze an existing system
• Synthesize a new concept
• Verify the new hypothesis
• Further develop the new concept

This algorithm was applied by the authors to create concepts in the following areas:

• Organization theory
• A “brain” for evolution (a concept related to the theory of biological evolution)

For a more detailed description, see Appendix 3.

Creating experiments

Experiments designed for the purpose of verification are often costly and time consuming. For such cases, TRIZ offers a knowledge base related to creative measurement and detection. (This knowledge base is based on certain Innovation Principles and Standard Solutions developed by Genrich Altshuller in the early 1960s and mid-1980s, respectively.) Today, a special module

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22 To be published.
called *Developing and improving systems for measurement and control*, which contains over 50 Operators (recommendations) is available to support this type of activity.\(^{23}\)

For selected recommendations, see Appendix 4.

**Finding new applications for new events and effects and/or to prevent or eliminate harmful effects**

Once the mechanism of a phenomenon is clear, the following can be considered:

- Finding a useful application for the phenomenon
- Amplifying the phenomenon
- Preventing undesired effects or eliminating their harmful consequences
- Creating a method for early detection of the phenomenon

For more detail, see Appendix 5.

**Methodology and tools to support knowledge management in an R&D organization**

- The following tools, which can contribute to increasing the efficiency of R&D activities, are addressed below:
  - Idea bank
  - Research machine
  - Tools for externalizing knowledge

**Idea Bank**

It is clear that today, idea generation constitutes a huge bottleneck. Yet there are many examples of good ideas being forgotten and reinvented later, resulting in unnecessary expenditures and other losses – an invention made in one department but useful in another one has never been used, an important invention has not been protected, etc. An increase in the number of ideas, along with an expansion in their “geography” (the areas in which the ideas originate) will only amplify these problems. There are serious concerns that the ease with which numerous ideas are obtained with the help of TRIZ and innovation software might diminish the value of ideas in the eyes of people, thus damaging a company’s creative environment. To avoid these problems, a special system for revealing, registering, classifying, accumulating, evaluating, enhancing, exchanging, and sharing ideas must be created.

An *idea bank* can serve as this system. This bank will consist of a database built on a TRIZ “foundation” (classified and searchable in terms of contradictions, principles, operators, etc.) and will be capable of integrating and coordinating all activities related to the generation, evaluation, implementation, etc. of new ideas. An idea bank can provide for:

- The utilization of innovation software and specialized databases of inventive solutions

\(^{23}\) The module is incorporated in the Innovation Workbench (IWB)\(^{\text{®}}\) software.
• Information search
• The accumulation and storage of relevant inventions and innovations
• Support of teamwork
• Prioritization of directions for development

An idea bank will allow each individual to have his/her own “box” in the database for the purpose of entering ideas that will be registered and notary certified to ensure author’s rights for the individual and company. The author can grant or deny access to his/her ideas to others. The box can be accessed and evaluated by a supervisor (who can determine how many ideas have been developed, how creative and/or useful they are, etc.). Ideas can be sent to other specialists for discussion. Any additional suggestions and improvements can also be documented, providing a means by which author’s rights can be supported in the future.

The primary users of an idea bank will be R&D departments, departments concerned with strategic planning, patent departments, quality control departments, etc.

**Research machine**

A *research machine* should become a standard (industrial) facility capable of performing experiments in accordance with the following trends:

• Growing differentiation between theoreticians and experimenters.
• Standardization of experimental work, transition to the use of standard equipment, techniques, measuring and testing devices, etc.
• Creation of more efficient methods of obtaining, accumulating and storing information.
• Industrialization of research work and the use of mass-production methods. One can expect to see new industrial-type labs containing various equipment and operated by highly-skilled professionals who will conduct experiments requested by remotely-located scientists.
• Creation of highly efficient, automated (programmed) experimentation equipment.
• Transition toward the micro-level (labs on microchips, CDs, etc.). A “micro-chemical lab” is created on a layer of silicon or glass by methods used to manufacture microchips; “paths” within the lab are created with printed circuit board (PCB) technology. PCB methods can also be applied to feed and withdraw substances (micro-pipes, micro-pumps, micro-valves), to provide cooling and heating (micro-refrigerators, micro-heaters), to act as evaporators, condensers, etc. It is also possible to build a lab on a compact disk (CD). The rotating CD allows for the use of centrifugal forces to change electromagnetic fields, etc. for various experiments.

The above trends above can result in the following changes:

• The emergence of industrial-type standard research (experimental) facilities serviced by industrial personnel rather than researchers.
The possibility of requesting an experiment from any available facility in the world, from a remote site.\textsuperscript{24}

**Tools for the externalization of knowledge**

In the last decade, certain corporations have recognized the importance of knowledge management in achieving an effective innovation process. However, current available means for managing knowledge are limited to search engines and internal databases that are still far from satisfactory. Although these tools and processes could be substantially improved if a TRIZ approach were applied,\textsuperscript{25} emphasis has recently shifted to the knowledge creation processes and tools institutionalized within a company.\textsuperscript{26} Unfortunately, the situation with knowledge creation is even worse than with knowledge management, primarily because there are two types of knowledge that must be dealt with:

- **Explicit knowledge**, which can be articulated and documented in formal language (verbal statements, mathematical expressions, graphical figures, etc.)
- **Tacit knowledge**, which is fairly intuitive and exists in the form of personal (including emotional) experience. Such knowledge is difficult to present in formal language.

Knowledge creation is a process that involves the conversion of tacit and explicit knowledge according to the following matrix:

<table>
<thead>
<tr>
<th>From/To</th>
<th>Tacit</th>
<th>Explicit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tacit</td>
<td>Socialization</td>
<td>Externalization</td>
</tr>
<tr>
<td>Explicit</td>
<td>Internalization</td>
<td>Combination</td>
</tr>
</tbody>
</table>

Each of the above conversions requires its own processes and supporting tools. Particularly critical – and difficult – with regard to innovation is operating with tacit knowledge, because the process is mostly intuitive (although conscious).

TRIZ-based tools for externalizing knowledge are equally important both for knowledge creation and knowledge management, as they help formalize the process of knowledge creation and transform activities that require creativity into well-defined, organized and fairly routine processes. These tools include:

- Problem Formulator\textsuperscript{TM}
- Knowledge frames

\textsuperscript{24} This system is compatible with the idea of working from a home office. Also of note is that such a facility was described over 40 years ago by TRIZ founder Genrich Altshuller in his science fiction story “Discovery Machine.”


\textsuperscript{26} Ikujiro Nonaka et al., *The Knowledge Creating Company: How Japanese Companies Create the Dynamics of Innovation* (Oxford University press, 1995).
**Problem Formulator**

The Problem Formulator implements *problem formulation* – an analytical technique based on the TRIZ System Approach and rooted in Genrich Altshuller’s multi-screen model of creative thinking. Problem formulation allows for the transformation of complex and often net-like information about a system (pieces of which usually exist only in the minds of various individuals and thus are tacit rather than explicit) into a well-organized “map” reflecting the cause-and-effect relationships between system elements (as well as the system environment) in the form of a “knowledge diagram.”

Building a diagram starts with one element and continues with the sequential identification and mapping of other related elements, resulting in documented knowledge about the elements and their relationships (cause-effect, structural, functional, etc.). By following certain rules and answering a set of control questions, a reasonable effort can result in practically complete knowledge (including tacit knowledge) about a certain situation. Problem formulation can be completed manually or with the Problem Formulator™ software tool.

**Knowledge frames**

Knowledge can be stored within standard TRIZ *knowledge frames*. These knowledge frames are based on general evolutionary patterns exhibited by various systems (technical, social, arts, science, etc.). Typical TRIZ frames might be:

- Patterns, lines and trends of evolution
- Typical contradictions and typical ways of resolving them
- Typical models of evolution, etc.

In the case of patent classification, a new tree-like structure based on patterns and lines of technological evolution can be suggested for the following technological systems:

Asynchronous electrical machines

...increased degree of matching

... ...matched shapes and dimensions of elements

... ... ...via utilization of geometrical effects

... ... ... ...utilization of hyperbolic properties of surfaces

...increased degree of mismatching

... ...mismatched shapes and dimensions of elements

... ... ...via utilization of geometric effects

... ... ... ...utilization of hyperbolic properties of surfaces

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27 G. S. Altshuller, *Creativity as an Exact Science* (Gordon and Breach Science Publishers, 1984), 117-123.
29 The Problem Formulator™ is included in some TRIZSoft® products.
30 Suggested by Russian patent agents V. Berezina and P. Maltseva in their TRIZ educational project in 1986. Chelyabinsk, Russia.
Due to the general nature of the patterns of technological evolution, the same classification structure can be applied to hydraulic machines, endoscopic surgical instruments, the process of coating non-electroconductive parts, etc. An important point can be made here: such a classification structure has *predictive power*, as “missing” sections can prompt new inventions in these areas.

Typical knowledge frames facilitate the accumulation and structuring of knowledge and allow for the linking of knowledge from different areas, which in turn increases the effectiveness of knowledge utilization and transfer. Knowledge frames provide managers and/or consultants with an important advantage: the ability to quickly assess new areas of knowledge, to effectively facilitate idea generation sessions, and to generate new ideas and concepts together with Subject Matter Experts.
Conclusions

- Miller and Morris (in *Fourth Generation R&D*) and Nonaka and Hirotaka (in *The Knowledge Creating Company*) correctly describe the basic problems associated with the current situation in the evolution of R&D organizations. To date, three generations of R&D organizations are known. In general, the third (current) generation, adopted by leading corporations, has failed to deliver sustained breakthrough innovation business. Also emphasized is the importance of operating in accordance with the latent needs and tacit knowledge of customers and developers to introduce successful products and solve the associated problems. Based on theoretical research and selected success stories, Miller and Morris suggest a reasonable organizational model for the next, fourth generation R&D organization.

- The above notwithstanding, the tools and processes offered by Miller and Morris are too limited to provide effective knowledge creation, as they have been mostly derived from a limited number of success stories and thus have no long-term and/or representative proof.

- The organizational model of the fourth generation R&D organization can serve as a foundation, but must be complemented with powerful technology and tools – TRIZ and Directed Evolution (DE) – capable of delivering innovation in a mass production fashion.
References


Case studies

Case study 1. Production of microwire

This case study, based on a problem solved in 1984 by our student, Anatoly Yoisher, represents the first scientific problem solved using the technique called Create a model or theory to explain a new event or phenomenon (Appendix 2)\textsuperscript{31}. Mr. Yoisher applied the technique to a critical problem in the area of microwire production that had gone unresolved for more than 15 years.

Microwire consists of a metal core encased in glass insulation. The production of microwire entails the following operations:

- A portion of the metal is placed in a thin glass pipe, which is then heated using microwaves. In the process of heating, the metal melts and the glass softens.
- A glass rod is touched to the softened glass at the end of the pipe. The glass sticks to the rod, which then pulls the glass onto a rotating drum.
- The rotating drum continues pulling and winding the glass capillary with the metal inside.

This method had been successfully used to produce microwire from over 50 various metals and alloys.

For 15 years, however, the company was unable to produce microwire from an important alloy: indium-antimony (In-Sb). For unknown reasons, the pulled microwire ruptured into small (0.5 mm) pieces. Under a microscope, these pieces looked as if they contained thin metal needles that pierced through the insulation.

The In-Sb alloy differs from other metals in that its volume increases...
by 18% during solidification. It was suspected that this might be contributing to the problem, but it was unclear exactly how. By experimenting with various glass types and varying the microwave power and cooling modes, the length of the microwire pieces was increased to between 2.5 and 3 mm. But the minimum requirement was 250 mm (10”).

The problem was inverted: Instead of “What is causing the destruction of the microwire?” it became “How can we intentionally destroy the microwire?” And with that, Mr. Yoisher concluded that the best way to force the metal to pierce the glass was to plug the capillary and increase the internal pressure (using the plug as a piston, for example).

This seemed like a stupid idea, and Mr. Yoisher was about to give up. But he decided to take a look at the next step.

The next step recommended looking for analogies and creative “hints” in other areas of science, technology, or even everyday life. Mr. Yoisher quickly recalled a situation where he had left a sealed bottle on his balcony during the winter, and the bottle had ruptured.

This analogy helped overcome the psychological barrier associated with his “stupid” idea.
The list of available resources was rather limited, consisting of the alloy (liquid and solid) inside the glass capillary, and the properties of the alloy, which included a unique feature: In-Sb expands by 18% during solidification. The easiest way to create a plug would be to use the solidified alloy.

The next inverted problem then became: “How can the liquid metal be forced to solidify in at least two places, with liquid in between?” An experienced scientist, Mr. Yoisher quickly realized that a well-known effect associated with the behavior of supercooled liquids could be utilized.

When a very pure liquid (i.e., lacking a crystallization seed) is slowly cooled, the liquid can remain in a liquid state under temperatures much lower than the usual crystallization temperature.

For example, when distilled water is cooled very slowly, it remains a liquid until 20°F (-10°C). At the same time, a supercooled liquid will instantly solidify when subjected to a very weak impact. Merely tapping a nail against a beaker of supercooled distilled water is enough to turn the water into ice.
The following hypothesis was offered as an explanation for the capillary rupture:

The liquid alloy in the capillary is supercooled to a temperature much lower than the crystallization point. At a certain moment the solidification starts in a certain zone. As the volume of the alloy increases, a pressure wave is created in the liquid metal. The compression wave creates a new crystallization zone at a certain distance from the first zone. The resulting crystallization fronts travel towards each other, compressing the liquid in between. Under this pressure the liquid metal pierces the glass, eventually breaking it as the two crystallization fronts converge.

A compression wave can create more than one crystallization zone. And it is important to note that additional zones always appear at a certain distance, as additional latent heat is released in the crystallization zones, heating the alloy.

The emergence of multiple crystallization zones causes the microwire to rupture into small pieces. This explains why many years of experimentation produced a limited increase of the length of the alloy pieces, but could not completely resolve the situation.
Mr. Yoisher was very interested in the newly-discovered mechanism, as supercooling was observed in other metals as well. It soon became clear how his hypothesis could be tested: according to specialists, crystallization creates a weak luminescent light. The first attempt to view the crystallization process under a microscope for different metals showed several such light spots.

However, metals (alloys) that did not significantly expand under solidification did not cause the capillary to rupture.

How could the knowledge of this newly-discovered mechanism be used to solve the problem with producing the In-Sb microwire?

Contrary to the existing practice, it seemed clear that the cooling stage should be carried out rapidly rather than gradually, in order to prevent the supercooled liquid effect. This idea seemed very strange, as it contradicted all existing production theories . . .
Mr. Yoisher spent several hours removing the complex device that provided gradual cooling, replacing it with two cold water streams directed onto the microwire. The first run with the new production method produced 15 meters of microwire (using all of the available alloy)!

But the main benefit of the solution (aside from a Ph.D. dissertation and the prospect for a new type of microwire) was that the revealed mechanism of supercooled liquids in a capillary provided a better understanding as to why microwires made from certain metals had unstable electrical and mechanical parameters. This new knowledge resulted in substantial increases in the quality of all types of microwire.
Case study 2. Solving scientific problems related to a water pump

General problem description

A water pump for transferring water from blowing wells consists of an electric motor, a rotating shaft, and several modules to increase pressure. Each module includes a body and certain working parts – a centrifugal wheel and water guide (see the figure below). The design of this pump is fairly typical: similar pumps have been in use world-wide for the last 100 years. The last major modifications were associated with the introduction of plastic parts in the 1950s.

About 60% of the pump failures were associated with washing the metal walls of the pump body. In this case, water moves inside the pump at a rate of up to several meters per second. The water often carries sand – it was no wonder that holes eventually developed in the walls.

The objective of the project was to increase the life of the pump. No specific problems were formulated up-front. Instead, the problem was to be defined and formulated in the process of working on the project. For this reason, the project started with an analysis of known failures that reduced pump life.

The project team started by refining the causes leading to the destruction of the pumps. We visited the repair facilities, paying close attention to the scrap heap containing hundreds of damaged pump bodies. Some had cone-shaped holes originating inside the body wall and extending through the wall to the outside. Since the flow of water occurred inside the wall, a typical washout scenario seemed impossible.
Subject Matter Experts speculated that the cause of the wear might be a material defect. But with so many holes, this seemed unlikely. What’s more, we soon found a pump body containing the familiar cone-shaped holes on each pump module but, amazingly, the holes were situated in a line (as if the body had been riddled by machine-gun fire). Material defects? It was hard to imagine that the casings had been assembled with the defects intentionally positioned in a line . . .

Our next guess was that the holes had been created by cavitation caused by the rapid movement of the water. However, this hypothesis could not explain the shape and position of the holes and therefore provided no clue as to how these defects could be prevented.

Further study of the damaged bodies showed that cavitation had nothing to do with the problem, since other pump bodies were found with holes in the outside that did not extend through to the inside – holes where, in other words, there was no moving water and thus no possibility of cavitation. When it became clear that the obvious guesses were not supportable, the team started working in accordance with the following technique:

**Step 1. Formulate the original problem**

The original problem was formulated as follows:

There is a system called “pump body.” An inexplicable occurrence of cone-shaped holes extending through the pump wall occurs under the following conditions:

- The pump is located deep inside a well, under water, for a substantial period of time
- The pump body is made of steel
- There is no fast moving water near the holes that could create cavitation

**Step 2. Amplify the problem**

The cone-shaped holes appear very quickly in the steel body of the pump while the pump is under water.

**Step 3. Invert the problem**

It is necessary to produce, very quickly, cone-shaped holes in the steel body of the pump under the given conditions: the pump is located deep in a well under water.

In the above statement, our problem sounds like an engineering problem that requires a creative solution: create holes of complex shape in a steel part in a zone that contains water and where no tools can be purposefully introduced.
**Step 4. Search for creative hints**

Some of the team members were familiar with certain technologies used in parts manufacturing, namely, impacting parts via electro-chemical and electro-discharge using electrodes with specific shapes. But these methods require an electrolytic medium and an electric current. As none seemed available, this idea was abandoned.

If no known method is available, we must invent one. Today we would apply the software-based System of Operators. At the time, however, no software was available so we had to use Substance-Field Analysis.32

The first step was to define an article – i.e., a substance that is impacted – and a tool, if any existed. In our case, we had an article (S1) – the pump body. The tool (S2) and the field (F) were as yet unknown.

![Diagram](image)

S2 and F often act as a couple, since the tool should be in contact with the field it uses to impact the article. To identify the S2-F couple we considered what resources were available.

**Step 5. Utilize resources**

What resources are necessary to produce, very quickly, the occurrence of cone-shaped holes in the steel body of the pump?

There are two substance resources in close proximity: water and the well casing pipe. What about fields? These were considered in the following order:

- **Mechanical.** There is moving water and a rotating centrifugal wheel, but these are on the opposite side of where the action takes place.
- **Thermal.** This field is obviously not useful due to the difficulty of creating, under water, a temperature high enough to destroy steel.
- **Chemical.** In theory, a chemical field could do the job. However, it would impact the pump body somewhat uniformly, while we need cone-shaped holes. Another reason to take this out of consideration is that the water in the wells is fairly clean (though it can be slightly salty).
- **Electrical.** We could create the holes we need using anode dissolution, but we would need a cone-shaped electrode and an electric current supply to the area.
- **Magnetic.** This is not capable of destroying the material.

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32 Substance-Field Analysis is an analytical tool for building simple models of inventive problems. A typical model includes three elements: two substances (objects), one of which is an article and the other a tool; and a field (energy) that allows the tool to impact the article. The basic TRIZ fields (so-called MeThChEM fields) are: mechanical (Me), thermal (Th), chemical (Ch), electrical (E), magnetic (M) and electromagnetic (EM). Each substance-field model has a graphical interpretation. For more detail, see *Tools of Classical TRIZ* (Ideation International Inc. 1999).
It looks as if, from a performance standpoint, the best candidate is an electric field. But we must find one . . .

New secondary problem: How can we create an electric field?

How can the existing resources be transformed to provide an electric field?

Two ideas popped into our heads:

- Utilize an electrical dissipation field from the electric motor
- Create an electric field using electrolization by friction

Using a dissipation field was rejected because of its alternating nature – for anode dissolution we would need a constant current.

To create electrolization by friction we need a moving object and a material in contact with the object. Our moving object is water. The material it is in contact with: the plastic centrifugal wheels and water guides. The speed of the water is high enough to produce an electrical charge. Water can also transfer the charge to the steel pump body. And electrical charges flowing from the pump body through the water can create the necessary electric current.

This solution is only partial, however. We must still explain the appearance of (i.e., we must still create) a cone-shaped electrode.

New secondary problem: How can we create a cone-shaped electrode?

\[
\begin{array}{c}
\text{Well casing} & \text{Electric current} & \text{Pump body} \\
\text{Water} & \text{Cone-shaped electrode we want to create} \\
\end{array}
\]

\textit{It is necessary to create} a cone-shaped electrode on the surface of the well casing \textit{under the given conditions}: the pump is near the well casing and an electric current passes between the pump and the casing.

The answer is shown in this and the next figure. The only resource for producing the electrode is the material of the pump body– steel – which can dissolve under the influence of an electric current (anode dissolution). The dissolved particles travel to the well casing and deposit there. A small protuberance starts to grow on the surface of the well casing. The electric field (which is always stronger around sharp edges or corners) becomes stronger around the protuberance, and thus the process is concentrated in this particular spot. The cone-shaped protuberance on the well casing – the electrode, in other words – and the cone-shaped hole across from it in the pump body grow simultaneously.
On a separate note, the electrode created by particles produced by anode dissolution is rather spongy and is not firmly attached to the casing. When the pump is lifted from the well, the electrode would easily break and fall off. This might explain why no one had ever found – or imagined – the existence of such an electrode.

There is still one unexplained fact left – why in some cases were the holes located along a line?

**Next inverted problem: How can we produce the holes along a line?**

It is necessary to produce the cone-shaped holes along a line under the given conditions: the pump is near the well casing and an electric current passes between the pump and the casing.

The answer is rather obvious: In order to create something in a particular place, one must provide this place with certain advantages. In our case, we need a stronger electric field. If the pump is placed closer to the well casing on one side, the holes will appear on this side and continue to grow. In other words, the pump must be placed off-center in the well.

**Step 6. Verify the obtained hypotheses**

The above explanations failed to convince the Subject Matter Experts. Even the TRIZ team members were unsure as to their validity. The idea of electrolization due to water friction seemed preposterous.

To test the idea, a simple experiment was conducted: A metal container filled with water was placed on a drilling machine table and fixed with a small shaft with one plastic centrifugal wheel. The drilling machine was turned on and the wheel started rotating. The team members were standing around wondering how they could measure the voltage, if any . . . But the problem disappeared when someone touched the container and received a fairly strong electrical shock.

Direct proof was obtained when a small amount of soil was excavated from the bottom of an experimental well that had, for many years, been used to test the pumps. In the soil were many pieces of cone-shaped electrodes. Later, more rigorous research was undertaken to study the process of anode dissolution and the influence on it by various factors such as water speed, pressure, additives in the water, etc.

One question remained: Why hadn’t this effect been discovered earlier? The reasons are as follows: First of all, designers were misled by the “classical” schema of pump wear due to the abrasive action of water that contained sand. This classical effect was present as well, and in
certain cases was prevalent (depending on the amount of salt in the water). But another reason is that research of water-related wear mechanisms had taken place long ago, before the advent of plastic parts. Since then, the conclusions obtained by the research had been transferred from one textbook to another, and when plastics were introduced in the 1970s nobody thought to reevaluate how this new technology might change the process of pump wear.

The work was not yet complete – the effect still needed to be prevented. After the hypothesis was proven, it was not a difficult matter to prevent the effect from occurring. Several solutions were suggested, including electrically linking each working module with the well casing via flexible electroconductive blades. Another solution proposed was to produce the pump body and water guide modules from one piece of plastic. The latter suggestion, however, required that additional inventive problems be solved and implemented.

Altogether, the pump project included about 20 different scientific problems, and several new pump-wear failure mechanisms were revealed in the process of developing recommendations for preventing these failures in the future.
Case study 3. Solution to one biological problem

Between 1982 and 1984 we worked concurrently in the following three areas, as we pursued the possibility of expanding TRIZ beyond the technological arena.33

- Developing methods for solving scientific problems
- Studying biological evolution (for the purpose of further developing the Patterns of Evolution)
- Applying TRIZ to the evolution of social systems

As a result of our studies, a substantial amount of information was accumulated and a number of unsolved scientific problems were identified. It therefore seemed reasonable to test the new methods and techniques by applying them to newly-revealed problems. We found a substantial number of intricacies, paradoxes and contradictions in the theory of biological evolution (these things have not been emphasized by evolutionary biologists), particularly in the Synthetic Theory of Evolution within the framework of contemporary Darwinism.

For example, unusually cold weather can kill warm-water fish species, while foxes and monkeys learn to avoid the cold by hiding in ground holes, building shelters from fallen leaves, etc.

The development of mental (intellectual) capabilities helps animals survive because it allows them to better care for their young, gather in groups, share responsibilities, etc., thus reducing the “pressure” of natural selection. This means that as brain mass grows the rate of evolution should slow down.

The higher an animal is on the evolutionary ladder, the more

Intricacies and Paradoxes in the Theory of Biological Evolution

Cephalization Paradox

Cephalization – growth of brain complexity, reflecting the evolution of mental and psychological capabilities.

- It seems logical that with cephalization the pressure of natural selection should weaken, because organisms that are more psychologically developed can compensate for negative impacts of the environment by changing their behavior or adapting.
- However, paleontological research reveals the opposite: evolution speeds up along with cephalization.
- There is no satisfactory explanation for this phenomenon.

Cephalization

Speed of Evolution

There have been several more or less satisfactory attempts to explain this phenomena, but no agreed-upon opinion exists.

\[ F(x, \mu, \sigma) = \frac{1}{\sigma \sqrt{2 \pi}} \int_{-\infty}^{\infty} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \, dx \]
complex its structure and behavior; therefore, more mutations and selections are required to reveal and establish useful mutations (trials).

The longer an animal lives, the slower the rate at which changes occur over a generation.
The larger an animal, the smaller its population size and the fewer the number of possible mutations (trials).

As organisms increase in complexity the number of required trials grows geometrically, reducing to zero the chance that the required number of trials will occur at the normal pace of biological evolution.

In the process of evolution, positive feedback (a reinforcing loop) emerges between an organ and its function – the organ’s usefulness leads to its enhancement which, in turn, improves the organ’s performance, and so on, until the function enhancement is no longer useful or produces harmful side effects.

At the same time, the electric organ of an electric ray was not useful until its power reached 100 volts. This means that the organ began its evolution as a small, weak and thus useless organ. How could this organ evolve if it was not useful in the beginning?

Evolution of Certain Features and Organs Paradox

Darwinism cannot satisfactorily explain the evolution of certain features and organs:

• Features and organs that cannot be useful in infancy, but continue to evolve (the electric organ of an electric ray, for example).
• The development of advanced features before the actual need arises (seen in mammal skulls).
• Features that are useful for the species as a whole but harmful for an individual specimen (the rattle organ of rattlesnakes).
A better brain can improve an individual’s survivability, but it isn’t necessarily better for the population as a whole. In any event, there is no proof that “smarter” animals possess any evolutionary advantages over those that are not as smart. Both “smart” dolphins and “not so smart” sharks are fairly successful species. Similarly, “smart” parrots do not exhibit any advantages over other tropical birds, except perhaps in zoos or in people’s homes.

Numerous experiments have shown that if a child born into a primitive tribe is removed from his family and properly educated, his IQ will be no less than that of children born and raised in the Western world.

This means that the brain of a primitive person possesses an intellectual power that, under normal conditions, is unusable.
Paradoxes of Dispersion of Brain Characteristics

Most human physical parameters (height, weight, strength, blood pressure, reaction speed, etc.) are distributed in accordance with the normal distribution curve and do not differ above a factor of ten (and typically differ even less).

At the same time the intellect, memory, computational ability, imagination, creativity, and artistic capabilities of an average individual and a genius can differ by a factor of one thousand.

Archeological research has revealed no structural skeletal differences between early human cave-dwellers and contemporary humans. (Actually, some of us look even worse than these ancient individuals due to overeating and the lack of physical activity.)

A giant basketball player and a midget differ from the average human height by ± 50%.

A normal person might struggle to memorize a dozen phone numbers, while some people can memorize thousands of numbers at first attempt and remember them for years. Others can remember details of everything they have encountered throughout their lives. A normal individual can mentally process certain calculations, but there are also people who can compete with computers.

Paradoxes of Human Evolution

As mentioned earlier, the rate of evolution has grown continuously with the growth of cephalization. But since Cro-Magnon man appeared (40 to 50 thousand years ago) with a brain nearly equal to ours, human biological evolution has practically stopped.

Archeological research has revealed no structural skeletal differences between early human cave-dwellers and contemporary humans.
The notion of the existence of an “evolution governor” is associated with a serious problem: paleontology has shown that the process of evolution was not smooth and involved massive extinctions, numerous unsuccessful species, etc. In other words, this hypothetical governor made many mistakes.

In recent years the idea of an evolution governor was revived within various finalistic theories that suggest that evolution has a particular goal. Different theories address various notions about what this goal is and how and by whom it is pursued.

Attempts to Resolve the Paradoxes

The simplest way to resolve these paradoxes is by postulating a Creator (God, a cosmic intellect, a mental “field,” extraterrestrial, etc.) who controls the evolution of life.

But perhaps evolution can be explained without this mystique.

The Inventor’s Paradox

To explain the development of useful mutations, several hypotheses related to the natural inventiveness of a live organism have been suggested.

Originally, this was referred to as “embryo inventiveness.” Then (following the evolution of biology) this inventiveness was attributed to:

• a cell
• a gene
• a DNA molecule, etc.

In effect, the targeted “subject” responsible for biological invention has moved deeper and deeper into the micro-level. But where is the end point?

Another set of attempts to explain the evolution paradoxes is based on the hypothetical existence of an “evolution inventor” who invents the “right” mutations. One such idea involved an “inventive” embryo that manages its self-creation from a single cell, genome, molecule, etc.
In general, the inverted problem looks fairly ordinary: develop an automated control system. We have encountered several projects of this type in our professional practice.

---

**I-TRIZ Problem Inversion**

Imagine that we are assigned the task of designing a mechanism that can manage evolution – i.e., enhance a biological organism in the direction of greatest ideality in the most straightforward and expeditious way.

Let’s summarize the “requirement specifications” for such a mechanism. It must seemingly be capable of:

- Considering available models of the environment and the given organism, then choosing and testing (mentally) variants of possible changes to the organism in a particular environment.
- Accumulating information about variants considered in the past (to avoid repeating unsuccessful attempts).
- Establishing certain rules, with preferential directions that will exclude wrong variants and limit the number of trials – i.e., it must possess knowledge of certain patterns of evolution.
- Influencing the genetic mechanisms to allow for practical testing of the results of mental selection.

Obviously, a sufficiently powerful computer could satisfy these requirements. A live brain could do so as well.

---

**Defining Resources and Formulating Hypotheses**

If one sets aside “mystique” theories, the only real resources left are the brains of evolving live creatures.

---

*Given the above, the following hypothesis can be formulated:*

The evolution of a live organism can be guided by its own brain and nervous system. These possess practically all the capabilities necessary to perform this function since the brains of even relatively simple organisms can formulate and resolve problems based on an adequate model of the environment and the organism itself, along with certain computational capabilities. The brain is also capable of accumulating both operational and genetic information (complex instincts of animals).

---

*Concept verification*

Once the hypothesis of the “evolutionary brain” was formulated, it looked so surprisingly obvious that we became concerned that someone else had already come up with a similar idea.
Subsequent research proved this wasn’t so, however, although the English biologist Richard Dawkins has come very close in his book *The Selfish Gene*.

The evolutionary brain hypothesis clarifies many things that have remained unclear for a long time, in particular:

- Yes, an “evolution governor“ could exist, however, it is not a magical or all-powerful figure. It can make mistakes and select wrong directions, leading to dead ends and causing the species to become extinct.
- Yes, an “evolution inventor” could exist, but there is no need to look for it inside an embryo or in smart molecules or atoms. A live brain programmed to enhance the species by improving the next generation can perform the function of an evolution inventor. This program could be linked to the organism genome and genetically transferred to offspring. At the same time, each generation can introduce certain (limited) modifications to the program.

This hypothesis resolves all of the paradoxes mentioned above.

<table>
<thead>
<tr>
<th>Paradox</th>
<th>Paradox Resolution</th>
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</thead>
<tbody>
<tr>
<td>Cephalization Paradox</td>
<td>Cephalization (enlargement and increasing complexity of the brain) should naturally increase the rate of evolution and make it more controllable; a more complex and powerful brain increases survival capabilities and reduces the probability of species extinction as documented by paleontologists.</td>
</tr>
<tr>
<td>Probabilistic Paradox</td>
<td>This paradox now disappears, as the majority of trials could be made mentally rather than in actuality; a better brain can conduct more trials and provide faster evolution.</td>
</tr>
<tr>
<td>Evolution of Certain Features and Organs Paradox</td>
<td>“Advanced” development of certain organs can be explained as the result of the brain’s “strategic planning.” Now the situation with rattlesnakes can be easily explained: While the rattle organ is not useful for an individual snake, the brain is taking care of generations of snakes, as the rattle organ will help scare off other creatures competing for the same food-source area.</td>
</tr>
<tr>
<td>Individual Brain Paradox</td>
<td>When the brain of an individual serves more than just that individual alone, it no longer seems excessive.</td>
</tr>
<tr>
<td>Paradoxes of Brain Redundancy</td>
<td>The fast formation of intelligence and obviously excessive brain power can be explained as follows: under special conditions a portion of the evolution brain’s “computational power” can be re-directed to the activities of everyday life.</td>
</tr>
<tr>
<td>Paradox</td>
<td>Paradox Resolution</td>
</tr>
<tr>
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</tr>
<tr>
<td>Paradoxes of Dispersion of Brain Characteristics</td>
<td>The extremely wide range of mental capabilities in humans and the existence of geniuses can be explained as follows: Re-direction of brain power could be different for different individuals. An individual’s dedication to intellectual activities can stimulate the brain to allocate additional resources for these activities.</td>
</tr>
<tr>
<td>Paradoxes of Human Evolution</td>
<td>The abrupt deceleration of human evolution can be associated with the re-direction of brain power to everyday life rather than “working” on evolution.</td>
</tr>
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</table>

In general, the Evolution Brain hypothesis is fairly compatible with the Synthetic Theory of Evolution, with the assumption that both mutation mechanisms (haphazard and purposeful) take place. It is also possible that evolution began based on a haphazard process, resulting in the emergence of the first “brain computer” prototype. Later, the evolution brain became enhanced and more powerful, supplanting the haphazard process of evolution.

What objections to this hypothesis can be expected? For one thing, it seems unable to explain the evolution of plants because they do not have brains. However, it is possible that the role of brains could be performed by certain nerve knots (like the ganglia of insects). Also, we cannot exclude the possibility of the existence of certain cells that can perform the necessary functions (today we read about cellular or molecular computers). Actually, the question of how plants evolve and whether they have a brain-like power capable of guiding their own evolution could become an *experimentum crucis* that could confirm or reject the Evolution Brain hypothesis.

The real verification of a hypothesis of this type usually requires substantial work, including studying the whole complex of known facts, phenomena and mechanisms and determining if and how they comply with the hypothesis. In addition, special experiments should be designed to prove (or disprove) the conclusions. Obviously, this work can be completed only by Subject Matter Experts in the area. It is also understandable that, in the process of verification, the hypothesis will undergo clarification, corrections and other enhancements.

**Further development of the obtained concept**

The main point of the obtained concept is that the organism’s brain is utilized as a (functional) resource. It is assumed that, aside from its well-known function of ensuring the organism’s survival over its individual life cycle, it can perform the additional – and no less important – function of guiding the process of evolving the organism. This line of resource utilization can be extended with the assumption that the brain can perform some other useful functions as well.

Further development of the above ideas can lead to the ability to purposefully manage the process of biological evolution, involving a substantial increase in human brain power, “waking up” the brains of certain animals, improving health and other vital aspects (including “inventing” new as-yet-unknown capabilities), etc.
Obviously, our work on the Evolution Brain hypotheses is closely related to our general work on Directed Evolution – a process that allows people to purposefully manage their own lives, environment and destinies.

This publication, which represents a fragment of the subject, is presented with the sole purpose of illustrating the method of solving scientific problems. More details will be available soon at www.ideationtriz.com.
## Appendices

### Appendix 1. Evolution of R&D Organizations

<table>
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<tr>
<th>Aspect</th>
<th>R&amp;D Generation</th>
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<tr>
<td><strong>1. Basic features according to Miller and Morris</strong>&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Labs managed by leading scientists.</td>
</tr>
<tr>
<td><strong>2. Stage of science, technology and production evolution</strong></td>
<td>“Scientific” approach to technological revolution. Creation of a large number of new products, materials, services, etc.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Market situation</th>
<th>Unsaturated producer’s market: Demand is higher than supply. Producer is a king.</th>
<th>Market is saturated with products. Random marketing (random attempts to better understand customer needs).</th>
<th>Beginning of customer’s market and active marketing based on explicit customer’s needs.</th>
<th>Saturated customer’s market. Unveiling and utilization of latent customer’s needs and tacit knowledge. Marketing through the Internet</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. ROI components (in the order of importance)</td>
<td>Selling new or improved products by the company</td>
<td>• Selling new or improved products by the company • Selling licenses.</td>
<td>• Selling new or improved products be the company • Cost reduction • Selling information and intellectual property.</td>
<td>• Selling information and intellectual property • Creating new marketing opportunities • Selling new or improved products to the company.</td>
</tr>
<tr>
<td>6. R&amp;D organization structure</td>
<td>“Flat” – small groups and/or individuals working under supervision of one leader.</td>
<td>Hierarchical – specialized units with its own scientific leaders responsible for different scientific or applied directions.</td>
<td>Mainly hierarchical with elements of matrix structure (task force).</td>
<td>Netlike, dynamic, self-forming in response to market demand.</td>
</tr>
<tr>
<td>7. Leader</td>
<td>Creative leader – author of basic ideas, an inventor rather than a scientist</td>
<td>Manager – administrator</td>
<td>Businessman – administrator</td>
<td>Businessman – manager</td>
</tr>
<tr>
<td>8. Management</td>
<td>Creative leaders perform as managers of units and directions.</td>
<td>Administrators take care of large divisions, creative leaders take care of relatively small units and directions.</td>
<td>Managers and administrators – businessmen with high level of initiative and decision making power.</td>
<td></td>
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</tr>
<tr>
<td>9. Personnel</td>
<td>People working on assignments, often without serious scientific or engineering education</td>
<td>Basically people working on assignments, without room for initiative; education on the level of BS or MS.</td>
<td>Basically people following instructions with limited initiative allowed; education is highly specialized, MS or Ph.D. level.</td>
<td>Scientists or engineers with entrepreneurial skills – highly initiative and with substantial freedom in selecting direction of work. Broader education is welcome.</td>
</tr>
<tr>
<td>10. Work organization</td>
<td>Individual plans according to assignments</td>
<td>Formal assignments, strict schedule and subordination</td>
<td>Rather soft planning, allowing people to manage their workload</td>
<td>Self-planning; coordination with work of associates.</td>
</tr>
<tr>
<td>12. Utilized theories, models and approaches</td>
<td>Common sense, limited theoretical knowledge (qualitative models) brought from outside.</td>
<td>Development and utilization of phenomenological and empirical theories and various methods of calculations. Utilization of statistic and simple mathematical models.</td>
<td>Utilization of complex non-linear mathematical models for numeric methods of solving equations, etc. Building and utilizing various models (mechanical, electric, etc.)</td>
<td>Evolutionary approach, poly-model system approach</td>
</tr>
<tr>
<td>13. Knowledge management</td>
<td>Occasional knowledge, individual selection of people with knowledge</td>
<td>General and specific professional knowledge on paper carriers, simple methods of knowledge organization (card files, reference books). Purposeful selection of people with required knowledge</td>
<td>Fusion of knowledge. Accumulation of knowledge in electronic format. Utilization of more or less “smart” search engines. People are purposefully trained and educated with required knowledge.</td>
<td>Management of knowledge obtained is various sources. Integration of explicit and verbalized tacit knowledge.</td>
</tr>
<tr>
<td>14. Creative methods</td>
<td>Based on personality (talent, knowledge, intuition, initiative, energy, etc.). Trial and error method as basic tool for solving problems or discoveries.</td>
<td>Based on logic, information, organization, division of labor, large amount of researchers. Ignoring the role of intuition and creativity.</td>
<td>Recognizing the role of intuition and creativity. Attempts to integrate researchers and inventors; search for effective methods for systematic innovation.</td>
<td>New innovation process based on I-TRIZ</td>
</tr>
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Appendix 2. Creating a model or theory to explain a new event or phenomenon

Step 1. Formulate the original problem

Formulate the original problem as follows:

There is a system called \textit{(system name)}. An inexplicable effect or phenomenon (either useful, harmful or neutral) \textit{(description of effect/phenomenon)} occurs under the conditions \textit{(description of conditions)}.

Localize the existing phenomenon: define the area in which it occurs, describe other effects related to the phenomenon, and identify the last events that occur prior to the phenomenon.

Step 2. Amplify the problem

Try to amplify the effect by replacing the given phenomenon with an amplified one.

For example, if a certain phenomenon we are trying to understand is observed only occasionally or partially, amplifying it would entail imagining that it exists constantly, under any conditions, and on a full scale.

Step 3. Invert the problem

Replace the initial problem description as follows:

\textit{It is necessary to produce (description of effect) under the given conditions (description of conditions)}.

The main purpose of Problem Inversion is to change the way we think about the phenomena whose nature is unclear. Merely looking for an explanation is a fairly passive approach. TRIZ-based Scientific Problem Solving replaces this with a pro-active approach: instead of looking for explanations, look for ways to purposefully create (invent) the phenomenon. This transforms the problem into an inventive one, and all TRIZ tools and approaches for generating creative ideas can be applied.

This inventive approach also works in situations that seem clear, but where in fact the available understanding is incomplete or simply wrong. Typically, one’s understudying of a situation is incomplete if:

- The phenomenon cannot be reproduced.
- The mechanism of the phenomenon cannot be explained (without using complex mathematics or special terminology) to a teenager or to an adult working in a different profession.
When dealing with an undesired phenomenon, it is very helpful to think about it as an effect that is required for some useful purpose. Such “positive thinking” is always constructive and can increase one’s understanding.

**Step 4. Search for creative hints**

Consider areas of science, engineering, or even everyday life where this same phenomenon is intentionally created. Where and in what way is this most easily realized? Consider if this way is available for solving the inverted problem.

*If necessary, apply Inventive Problem Solving to find a way to produce the amplified phenomenon.*

It is very difficult to find an event or phenomenon for which there are no past analogies. Indeed, very often an effect we are trying to produce (by solving the inverted problem) is widely used in some area. If we can find this area and determine exactly how the effect is produced, we automatically have all the necessary explanation we need and can check to see if it applies to our situation.

It is usually much easier to find analogous areas if we describe our effect in general terms rather than specific.

**Step 5. Utilize resources**

Consider the resources available in the system and its surroundings that are necessary for reproducing the given phenomenon (effect). In particular, ask the following questions:

*What resources are necessary to provide the amplified phenomenon?*

*What resources required for the amplified phenomenon exist in:*

- The system defined by *(system name)*?
- Its subsystems?
- Its environment?

*How can the existing resources be transformed in order to provide the amplified phenomenon?*

An event or phenomenon occurs when all necessary components (such as energy, time, materials, and other things that in TRIZ are regarded as resources) are in place. Once a hypothesis has been built, it must be verified — i.e., one must make sure that all necessary components (resources) are available or can be easily obtained. Even the most creative hypothesis will remain a hypothesis if the resources are not in place.

To further verify a hypothesis we must consider the resources of the system and its surroundings, both in their readily-available forms and as they could be used after some kind of transformation has taken place.
Looking for typical resources

Start by considering typical resources and their combinations, including:

- Available materials or substances
- Produced or supplied energy
- Free moments or periods of time
- Vacant space within an object
- The structure of an object
- Functioning of the system
- Information about the system

Non-specific resources

Non-specific resources are the things that, for all practical purposes, are always present – gravity, air, humidity, ambient temperature, the Earth’s magnetic field, vibration from various transport methods, etc.

Accumulating resources

Some resources are not capable of producing any effects unless they are present in some accumulated form. Such resources can accumulate slowly and not reveal themselves until a certain threshold is reached. Once the critical amount is reached, a certain event can trigger. In other situations, resources accumulate naturally (as a result of aging of materials, chemical reactions, etc.).

Resources for change

Another type of resource capable of producing new (including harmful) phenomena concerns various changes that occur in a system. For this reason, if a new phenomenon appears it is very important to track down all changes that have taken place in the system, and try to link these changes to the event under question.

Effects

When one is attempting to explain an unexplainable event, the knowledge gained in school or other studies – especially with regard to physical, chemical geometrical and other effects – can be very helpful. Even simple effects such as thermal expansion or water freezing can produce quite remarkable events.

Step 6. Verify the obtained hypotheses

Consider all obtained hypotheses and select the one that best fits the actual situation.

Verifying a hypothesis is a typical scientific activity requiring the collection and analysis of information and, often, special experiments to confirm the idea. It is critically important to make sure that all resources necessary for realizing the given phenomenon are available in the system or its environment. If something is missing, it is necessary to
determine how it can make its way into the system to produce the phenomenon (this is analogous to solving a secondary scientific problem).

In other situations, a creative approach is required to plan and run the verification experiments. TRIZ tools can be used for this purpose – in particular, methods of synthesizing and/or enhancing measurement or detection systems can help one invent verification experiments.
Appendix 3. Building new scientific concepts

Stage 1. Analyze an existing system

Step 1.1. System analysis

Learn about:
- Subsystems
- Super-systems
- Structure
- Functioning
- Basic postulates and original facts
- Basic patterns and known mechanisms
- History and dynamics of system evolution, basic trends and stages of evolution

Step 1.2. Other related systems

Learn about other systems related to the given system (analogies based on similar phenomena, approaches, etc.)

Step 1.3. Build and analyze a model of the system

Build and analyze a model of the given system. In particular:
- Build a simple model
- Identify basic subsystems of the model
- Identify known limitations
- Try to use typical and “universal” models

Step 1.4. Reveal and analyze the model’s drawbacks

Analyze the shortcomings of the model. In particular:
- Reveal facts inconsistent with general patterns of evolution, including:
  - facts based on poorly-founded postulates
  - facts that violate accepted boundaries
  - facts that contain internal contradictions
  - facts based on “ad hoc” hypotheses35
  - facts related to unsolved problems

35 An ad hoc hypothesis is a hypothesis introduced solely for the purpose of explaining a new fact, and which is not related to or correlated with other theories. (Translator’s note.)
• Reveal drawbacks (such as stagnation, for example) associated with the current stage of system evolution
• Formulate problems

Stage 2. Synthesize a new concept

Step 2.1. Solve the formulated problems

Solve the formulated problems using scientific problem-solving techniques: the Problem Inversion approach, application of typical and universal explanatory mechanisms, etc.

Step 2.2. Integration

Combine all results into a new, integrated model-concept that can complement or replace the original one. Structure the new concept and define its boundaries and limitations.

Stage 3. Verify the new hypothesis

Step 3.1. Check for compliance with known facts

Determine how the new concept fits the whole complex of existing facts and patterns in the area of concern.

Step 3.2. Check for compliance with other related theories

Determine how the new concept relates to other theories (i.e., comply with the Principle of Coordination).36

Step 3.3. Predict new facts

Reveal new facts and patterns predicted by the new concept; solve problems related to the verification of these facts (using TRIZ if necessary); conduct necessary verification experiments.

Step 3.4. Test for the possibility of falsification

Test the new concept for the possibility of falsification.37 If at least one of steps 3.1 through 3.3 produces negative results, return to Stage 2 and formulate new problems related to the search for mechanisms that can explain the deviations.

36 The Principle of Coordination, introduced by physicist Niels Bohr, states that any new, more general concept must include the old theory as a particular case. (Translator’s note.)
37 The famous scientist Karl Popper showed that a scientific theory or hypothesis is valid only if an experiment capable of invalidating (falsifying) it can be imagined. Otherwise we are dealing with faith rather than science. Unfortunately, Popper did not offer any tools for this process, thus his brilliant idea is rarely utilized. TRIZ offers such a tool: Problem Inversion. (The process of “falsification” is similar to the application of Failure Analysis.)
Step 3.5. New cycle

If at least one of steps 3.1 through 3.4 produces negative results, return to Stage 2 and formulate new problems related to the search for mechanisms that can explain the deviations.

Stage 4. Further develop the new concept

Step 4.1. Utilize patterns of evolution

Apply patterns of evolution to the new concept. In particular:

- Formulate the opposite concept. Try to find conditions under which this “anti-concept” might become valid. Find a way to combine the concepts in accordance with the pattern of integration of alternative systems and the Complementary Principle.38
- Consider applying other patterns of evolution

Step 4.2. Expansion

Describe the new explanatory mechanisms you have obtained. Consider the possibility of expanding them to other areas.

---

38 The Complementary Principle, another principle introduced by Niels Bohr, states that two contradictory theories can be both valid and complement one another.
Appendix 4. Selected recommendations for building measurement and detection systems

When a creative approach is required to plan and run verification experiments, the following recommendations can be utilized:39

- Check the availability of informational resources, in particular:
  - Fields of dissipation
  - Substance properties
  - Substance flows from a system
  - Transient substances or field currents
  - Alterable properties of substances

- Consider performing measurements on a model or copy of the object being processed.

- Consider replacing a measuring process with a detection or dual-detection process that indicates whether or not a parameter is within limits.

- If it is difficult to control a process, consider introducing an opposing process that can be easily controlled, and can be used to adjust or correct the results.

- Consider obtaining information about an object or system by subjecting it to some field (force, effect, or action), then measuring the resulting effect.

- If it is impossible to obtain information about the condition of an object or system, consider obtaining the information by introducing:
  - A field (force, effect, or action) that the object or system will transform into an easily measured or detected field (a tactile, olfactory, auditory, optical (visual) field, etc.)
  - One or more additives that can become a source of an easily-detected field:
    - A marker that will detect the needed events
    - A witness that will produce the needed information
    - A sensor or transducer that can present the desired information in the form of an easily-detected field

- If it is impossible to introduce additives into the system, try to introduce the additives into the environment.

- If it is impossible to implement additives into the system or environment, try to obtain them from the environment itself, for example, by destroying or changing its phase state. Among other things, gas or vapor bubbles obtained by electrolysis, cavitation or other methods can often be applied.

- If the desired information is present in a weak form or is not detectable against a background of other objects or information, consider separating out or highlighting the desired information.

39 For more detail, see the Innovation WorkBench® software.
• Consider giving the object/system/process special properties that will amplify the desired information, or will suppress undesired interference with the recognition of the desired information.

• If it is impossible to directly detect or measure changes in the system, and it is also impossible to pass a field through the system, the problem can be solved by creating oscillations of either the whole system or part of it. Variations in frequency can provide information about changes in the system.

• If it is impossible to create oscillations in either the whole system or part of it, information about the state of the system can be obtained from oscillations of an external object (or the environment) linked with the system.

• The effectiveness of measuring or detection processes can be improved either by substituting a substance with ferromagnetic particles, or by introducing ferromagnetic particles into the system. Information about changes in the system can be obtained by detecting or measuring the resultant magnetic field.

• The effectiveness of a measuring system can be improved by applying one or more (of many) physical phenomena such as phase transformation, thermal expansion, thermocoupling, piezoelectricity, magnetostriction, luminescence, chemical indicators, etc.

• The effectiveness of a measuring system on any stage of evolution can be improved by creating a bi- or poly-system.

• The effectiveness of a measuring system on any stage of evolution can be improved by transitioning from measuring the function to measuring the first and/or second derivatives of the function.
Appendix 5. Finding new applications for new events and effects and/or to prevent or eliminate harmful effects

Once the mechanism of a phenomenon is clear, one can:

- Find a useful application for the phenomenon
- Amplify the phenomenon
- Prevent undesired effects or eliminate their harmful consequences
- Create a method for early detection of the phenomenon

**Find a useful application for a phenomenon**

We can try to find a useful application for new events (either useful or harmful) by following these steps:

- Identify all possible resources associated with the effect
- Identify other systems in which these resources could be useful. Utilize lines of technical and market evolution, if necessary.

**Amplify the phenomenon**

Understanding the mechanism of a useful phenomenon often allows one to amplify or enhance it to make it stronger, more controllable, etc. For this purpose various TRIZ tools, including patterns and lines of evolution, can be utilized.

**Prevent undesired effects or eliminate their harmful consequences**

In certain situations harmful effects can be eliminated even when the mechanisms responsible for them are unknown. However, eliminating and (especially) preventing harmful effects is much more effective when these mechanisms are clear.

**Create a method for early detection of the phenomenon**

Understanding the mechanisms responsible for a phenomenon often allows for the development of a method for early detection of the phenomenon, and thus timely and appropriate reaction to it. For more about detection, see the recommendations in the section entitled “Creating experiments.”