# LEVELS OF INVENTION
# AND INTELLECTUAL PROPERTY STRATEGIES

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## ABSTRACT

The existence of levels of invention is a basic finding made by Genrich Altshuller in his initial TRIZ research. For decades this served primarily as a good illustration of the diversity of the innovation process. At the same time, any TRIZ specialist is familiar with the basic contradictions related to levels of invention, for example:

- Low-level inventions are usually easy to implement but cannot provide a competitive edge.
- High-level inventions can offer a competitive edge, but substantial and long-term effort is required before the invention starts to pay off.

This paper addresses the history of the subject and presents a number of strategies, along with examples from industry, that can help resolve the above contradictions.

## INTRODUCTION

Through the analysis of numerous inventions during the development of the Theory of Inventive Problem Solving (TRIZ), Genrich Altshuller discovered that different inventions involved different levels of creativity. It therefore seemed likely that different tools and techniques would be required to create a variety of inventions. (Clearly, the invention of a pencil with built-in eraser differed greatly from the invention of the steam engine.) In the late 1960s, Altshuller defined various levels for inventive problems related to[1]:

- The number of trial-and-error attempts required to guarantee a solution of a certain level.
- The scale of change imposed on the original system.

According to Altshuller, inventive problems can be divided into five levels, as follows:

[1] Genrich Altshuller, *The Innovation Algorithm*, 2d edition (Moscow Worker Publishing House, 1973), in Russian. Translated into English by Lev Shulyak (Worcester, MA: Technical Innovation Center, 1999).

## Levels of Invention

**LEVEL 1** – Apparent (no invention). *~1-10 solutions considered*

- Established solutions; well-known and readily accessible

**LEVEL 2** – Improvement. *~10-100 solutions considered*

- Existing system improved, usually with some compromise
  *(example: bifocals)*

**LEVEL 3** – Invention within paradigm. *~100-1,000 solutions considered*

- A concept for a new generation of an existing system
  *(example: automatic transmission)*

**LEVEL 4** – Invention outside paradigm. *~1,000-100,000 solutions considered*

- A new concept for performing the primary function of an existing system
  *(example: jet aircraft, integrated circuit)*

**LEVEL 5** – Discovery. *More than100,000 solutions considered*

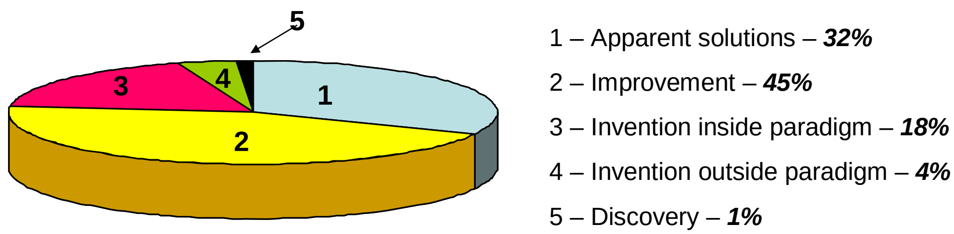
- Pioneering invention of an essentially new system
  *(example: laser, radio)*

It can be seen that the number of mental trials that must be entertained to guarantee a satisfactory solution grows dramatically as the level increases. In fact, for high-level inventions the number of trials is so high (in the thousands) that there is no guarantee that a solution can be found at all; in such cases we have no control over the innovation process. Example: Edison, who was known for his persistence (it took tens of thousands of trials to find a material suitable for use as a light bulb filament) was unable to build a nuclear motor using trial-and-error; inventions of this level are based on scientific discovery, and the necessary discovery (nuclear theory and neutron multiplication when a nucleus is divided) had not yet occurred.

In the course of his research, Altshuller conducted a statistical analysis of inventions granted between 1965 and 1969 over 14 patent classes[2]. The results showed the following distribution among the five levels:

[2] Russian patent classification.

## Altshuller's Research - Patent Distribution




For each stage in the typical problem-solving process, Altshuller identified specific criteria to help identify the level of a particular invention. According to Altshuller, the typical problem-solving stages included:

- Choosing the task
- Choosing the search concept
- Gathering data
- Searching for an idea
- Finding the idea
- Practical implementation

Altshuller regarded the discovery of levels of invention as a very important step in the development of TRIZ as a pure engineering science (i.e., a science based on the statistical research of patents and other sources of technical information). He also used his findings to emphasize the fact that high-level inventions were always the main focus of TRIZ, and that TRIZ was the only way to control the process of high-level innovation, as it reduced (and possibly eliminated) the number of blind trials required. At the same time, however, levels of invention were not used for practical problem-solving purposes.

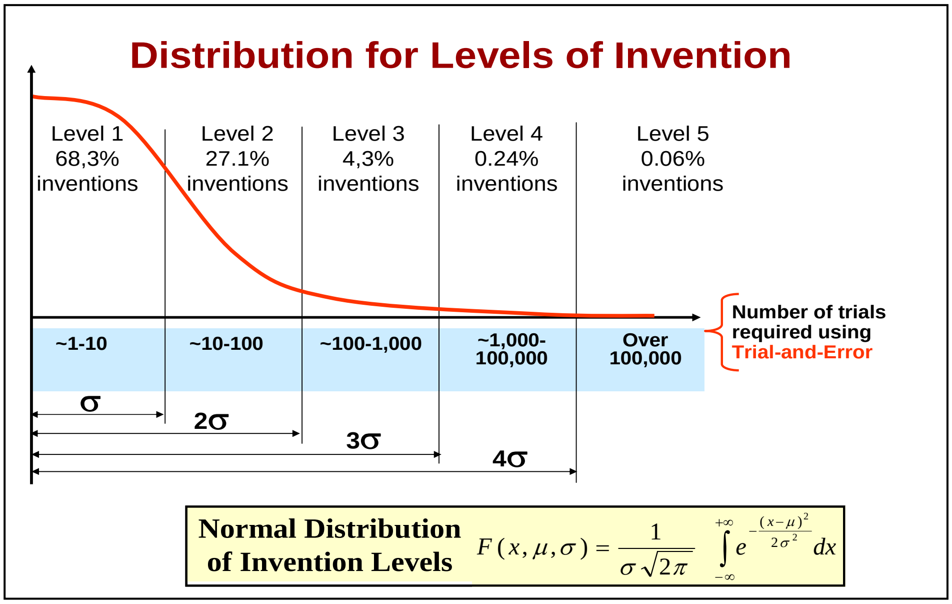
## FURTHER DEVELOPMENT AND PRACTICAL APPLICATION OF LEVELS OF INVENTION

Between 1982 and 1985, the Kishinev TRIZ School began utilizing the concept of levels of invention for practical purposes as part of the development of a workable process for

TRIZ forecasting[3]. These efforts have continued, resulting in the theoretical findings and practical recommendations addressed below.

**Distribution of inventions among the levels**

An analysis of inventions throughout various levels suggests that the distribution is close to the Gaussian (normal) distribution curve, as shown below.



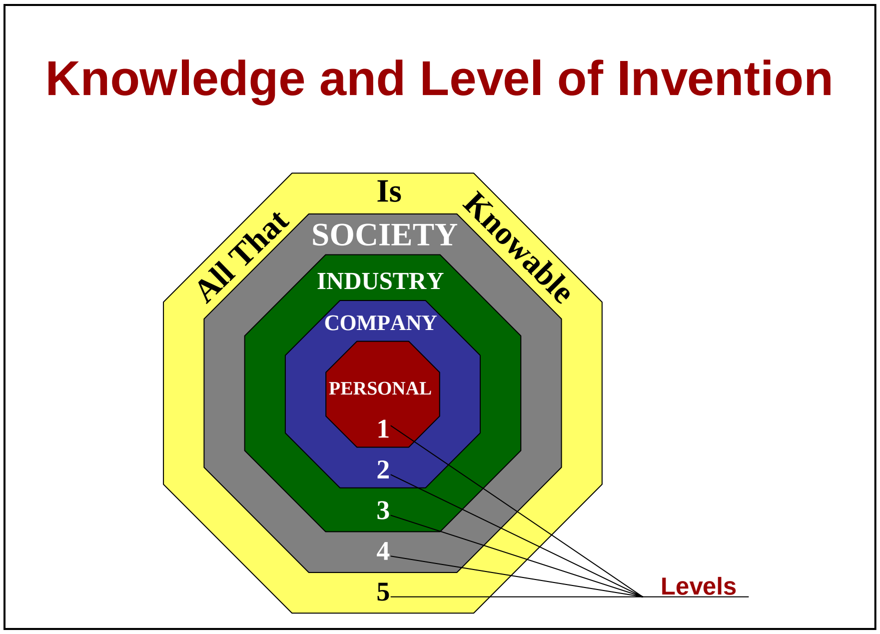

The difference between the Gaussian distribution and Altshuller's numbers (in Altshuller's research there were fewer inventions at level 1 than level 2, which does not comply with the normal distribution) can be explained as follows:

- Level 1 inventions often go unpatented, for various reasons that include:
  - Local importance and limited value of the invention
  - Unwillingness to disclose the invention to competitors
  - Preference for treating low-level inventions as useful suggestions
- It is often difficult to prove that a level 1 invention meets the criteria for patentability (patent law does not suggest an exact definition of the invention but rather offers a set of criteria to be met).

**Levels of invention and knowledge – reducing the number of trials needed for high-level inventions**

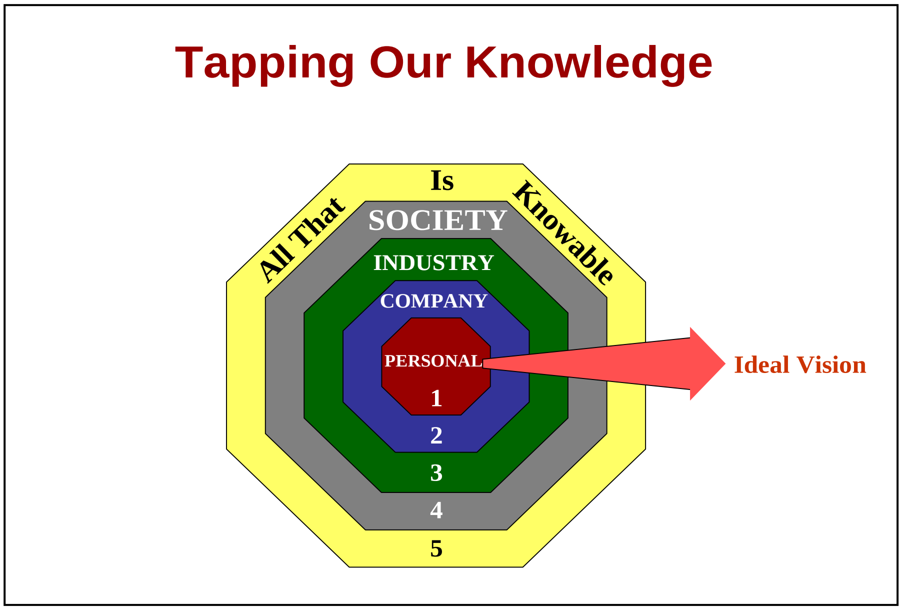
[3] Technological forecasting based on the utilization of TRIZ patterns and lines of evolution. See Zlotin and Zusman, *Directed Evolution: Philosophy, Theory and Practice* (Southfield, MI: Ideation International, 2001).

Every invention requires that certain knowledge be available. We can therefore suggest that the amount and type of knowledge that can guarantee the creation of an invention correlate with the invention's level, as shown below:




According to the above figure, the personal knowledge of a professional is usually enough to produce a level 1 invention. The number of necessary trials (from 1 to 10) is also manageable for an individual. A level 2 invention might require the knowledge and assistance of colleagues working in the same division or company. For a level 3 invention, knowledge within the industry should be available. For a level 4 invention – invention outside the paradigm – a wide range of knowledge (for example, knowledge available within a large community of professionals, such as the entire engineering community) should be considered. For a level 5 invention, any knowledge could be useful. It is as if the amount of knowledge increases by a power of three with each successive level.

The above model is another way to illustrate that traditional creativity techniques cannot provide control over the creation of higher-level inventions. At the same time, this model can be utilized to show how this control can be achieved (see figure, below).




In TRIZ, the "beacon" of the ideal vision for a solution reduces the number of necessary trials by limiting the search to the area in which the best (ideal) solutions reside.

**Solving a problem at different levels**

Many problems can be solved at different levels, depending on the available resources of the system and the imposed limitations to system change. The table below shows the results of a project aimed at reducing the vibration of an electrical generator for a specific transport scenario, and describes typical solutions found at different levels.

| Level of invention | Technical solution | Drawback |
|---|---|---|
| 0[4] | Install generator on rubber pads to absorb vibration. | Vibration at certain frequencies not effectively addressed. |
| 1 | Use multi-layer pads of different materials, with the thickness of each layer calculated to better reduce vibration in the given range. | Does not address haphazard impacts. |
| 2 | Introduce pneumatic cylinders with feedback-based control mechanisms to adjust cylinder pressure according to the magnitude and direction of haphazard impacts. | Space around generator is limited; solution is expensive. |
| 3 | Position the generator on strong permanent magnets with electromagnetic windings. | System has high inertia; strong electromagnetic field |

[4] Conventional, non-inventive solution.

| | | |
|---|---|---|
| | Winding current can be changed to dampen vibration. | dissipation. |
| 4 | Replace generator with a device that can generate electrical energy without rotating parts, which cause vibration (for example, by using isotopic elements[5]). | System is too new; costly research and testing required. |
| 5 | Not considered for this project. | |

Given the above, it is clear that levels should be attributed to the inventions (solutions) rather than the problems. For practical purposes, however, it is convenient to rank inventive problems as well. To resolve this issue, it was suggested that the level of a problem be determined according to the *acceptable* solution level. In the above case, a level 1 solution was satisfactory and the problem was ranked accordingly.

The discovery that a problem can have solutions at different levels was an important argument in the discussion of what the primary focus of TRIZ should be – providing a single, ideal (or closest to ideal) solution, or providing an array of solutions at different levels of ideality (and inventiveness) from which the one that best fits the particular situation and requirements can be selected. Apparently, low-level inventions are better suited to short-term goals (such as reducing the cost of an existing product) while high-level inventions are better suited to long-term strategies (ideas for next-generation products, for example).

**"Relativity principle" for levels of invention**

Estimating the level of an invention can be considerably influenced by the area, current state, and overall level of technology. For example, Archimedes' screw for the water supply in Ancient Greece can be classified as a level 5 invention for the time; about a thousand years ago, a screw attaching a visor to a knight's helmet would rank between levels 4 and 5; today, using a screw to fix two parts together is not considered an invention at all.

The opposite effect – where the level of invention increases over time – can have much more important consequences. This can be illustrated with the history of the following invention:

In 1840, a lamp that burned whale oil in a specially-shaped glass was invented. This remained a "small" invention until 1855, when kerosene was invented. Kerosene had the following benefits:

- It produced a pleasant, bright white light
- It burned without creating smoke
- It was safe (kerosene lamps were not explosive like other gas lamps).

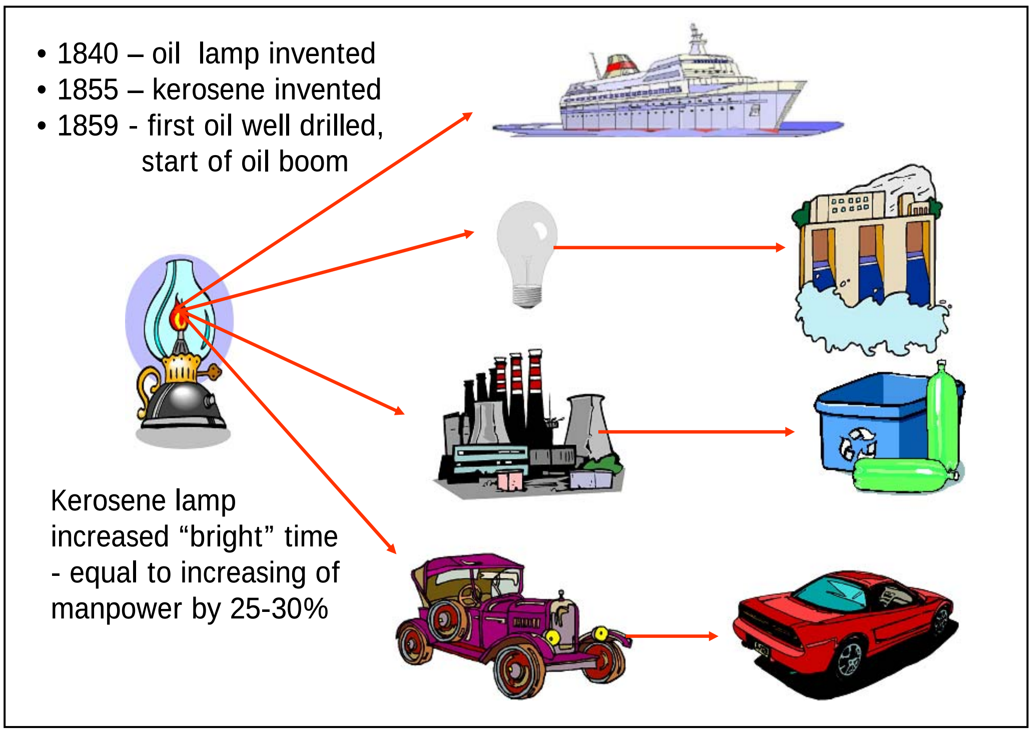
[5] At the time of the project, this was an entirely new direction based on a recent discovery.

The invention of the kerosene lamp abruptly increased the demand for oil which, at the time, was available only from oil pits. To satisfy the growing demand, exploration and new oil production methods were necessary; in 1859 the first successful oil drill launched the oil boom.

The introduction of a bright, inexpensive and safe source of light allowed for a longer work day, night shifts, and more time for reading, education, entertainment, etc. The need for good illumination activated by the invention of the kerosene lamp stimulated the development of electrical power and of the electrical industry in general.

The mass production of kerosene created a problem, however: What could be done with the by-products, such as gasoline, that were unusable for illumination purposes because they were explosive, or heavy oil components with complex hydrocarbons? Ultimately these by-products offered inexpensive fuel for the growing automotive industry, as well as a rich source of raw material for the emerging chemical industry.

At the same time, the utilization of oil fuel instead of coal eliminated the most serious drawbacks to the expanding military and civil fleets (steam boat engines that burned coal required a lot of stoking).




The kerosene lamp serves as a good illustration for how a modest invention activated an avalanche ("invention tornado") of industrial evolution. Other illustrations are the invention of typography, gun powder, hay production, the cotton gin, etc.

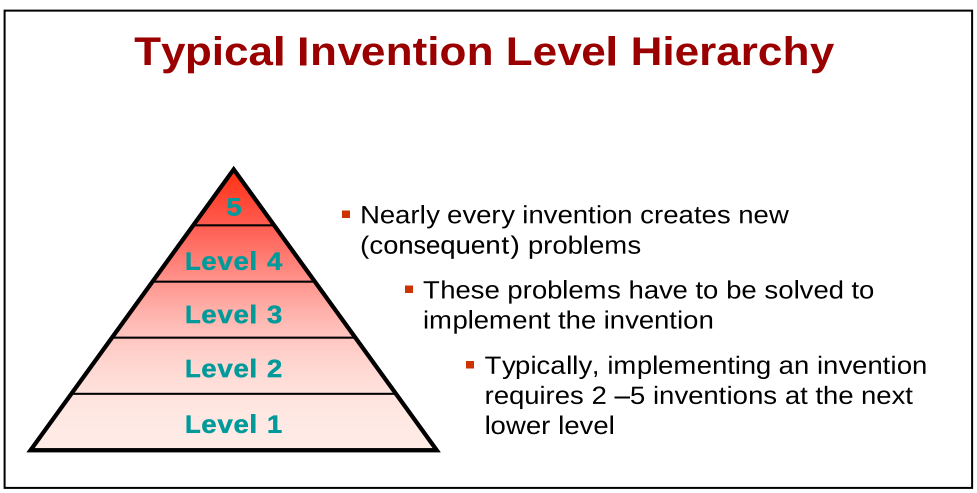
**Evolutionary resources**

Every invention arises from the utilization of certain evolutionary resources[6] and, in turn, gives birth to new evolutionary resources. The concept of evolutionary resources constitutes an expansion to the usual definition of resources in TRIZ. Evolutionary resources include (in addition to substances/materials, energy fields, functions, information, space, time, etc.) specific knowledge in various areas, general evolutionary knowledge, particular ideas, unutilized properties and capabilities of systems and their elements, market demand – anything that can be exploited to create next-generation systems and new products. The richer the evolutionary resources associated with a new invention, the higher its actual value (and overall level) over the long term.

**Levels of invention and implementation strategy**

The main concepts and approaches in TRIZ were developed on the basis of statistical research of patent literature, and thus always lacked details about how the inventions were implemented. Common sense tells us that the implementation time for high-level inventions is typically long, mainly due to the lack of necessary knowledge and the research required to gain that knowledge. Another reason is the high psychological barrier associated with a paradigm shift. At the same time, the analysis of information other than patents (including anecdotal knowledge about how particular inventions were implemented), shows that another important reason for delays in implementation is the number of problems that must be solved to ensure success.

Typically, the implementation of a level 4 invention cannot occur unless a number of level 3 inventions have been made (i.e., to solve secondary or so-called "consequent" problems). In turn, each level 3 invention might require a number of level 2 inventions, etc., ultimately entailing the solution of many conventional engineering problems to form a hierarchical pyramid, as shown below.




[6] The term "evolutionary resources" was introduced by Gafur Zainiev in the late 1990s.

Given the above, an effective implementation strategy should include the timely identification and resolution of consequent problems at all levels. Failure to do so can result in long delays in implementation.

It is important to note, however, that consequent problems *should not be more difficult to solve than the original problem*.

**Levels of invention in marketing**

The implementation of a technical invention is often unsuccessful unless accompanied by a high-level marketing invention.

Example: In 1903, Sir John Fleming invented the vacuum diode, on the basis of which Lee de Forest, in 1906, invented the vacuum triode and a system for signal amplification. (The first invention is based on one of Edison's discoveries and is estimated at level 4. The second invention is estimated at level 5, as it is associated with an entirely new principle for amplifying a weak signal using a local source of energy.) Soon thereafter, radio transmitters and receivers were invented that could adequately transmit voice and music, but this application prompted no interest because radio was regarded as nothing more than a wireless telegraph for transmitting Morse code. At the time, coded information could be received and printed, but a voice could not be recorded. According to legend, in 1910 the president of AT&T, upon entering a room filled with radio transmitters and receivers in which de Forest was working, remarked that there were enough radios in the room for the whole century…

In 1915 the United States was preparing to enter World War I, and the army needed an effective means of communication. It was easy enough to supply each squad with a radio, but there was no quick way to teach enough people to use Morse code. The alternative was to start using voice communication, and radio stations of different sizes (level 3 inventions, for the most part) were quickly developed to equip the army.

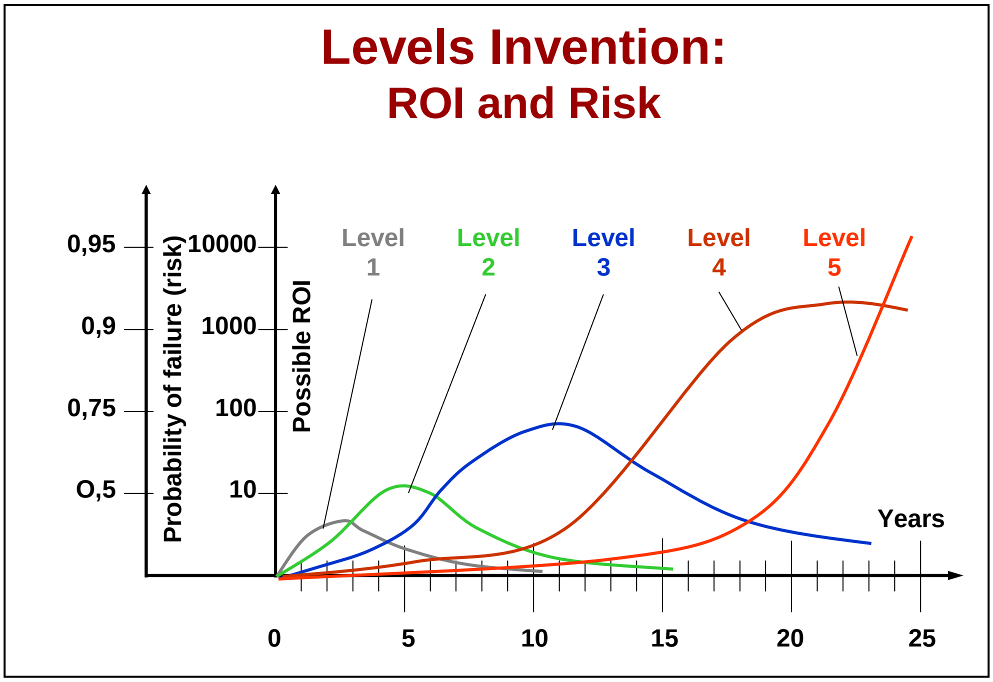
After the war, the U.S. government sold off its unused military equipment, including its radios. An entrepreneur bought a number of them, intending to extract the precious metals contained in the radio lamps. However, the plants capable of performing this work were booked for years in advance, and it was too expensive to put the radios in long-term storage. To avoid huge losses, the businessman came up with an idea that changed everything: he activated one of the more powerful radios, hired a girl to play records, and transmitted the music via radio. An advertisement informed people that for a reasonable price they could purchase a receiver and listen to the music; soon local housewives discovered how pleasant it could be to listen to music while working around the house. The girl changing the records started to include stories about the music and the composers, as she was knowledgeable in this area. Later she read the news as well. Radios were soon in short supply due to the unexpected demand, and the businessman was able to order new, more attractive models to sell. In parallel, powerful radio stations were being built, and the radio business "avalanche" had begun.

From this example it is clear that the implementation of a technological invention was enormously expedited by a very creative (high level) business idea.

**Return on investment and risk associated with inventions of different levels**

Implementation time and actual return on investment (ROI) are significantly dependent on the level of the invention. The first idea for an invention often emerges when there is no practical means to realize it. For example, the first theoretically possible laser was described by Einstein in 1913. In 1948, the Russian scientist V. Fabricant patented the idea of a coherent light source (the term "laser" came later), but couldn't get enough financing to build a working device. In the early 1950s, Towns in the United States and Basov and Prochorov in Russia almost simultaneously built the first maser (a gas device operating in the radio frequency range)[7]. At that time, however, there was no practical application for the new invention. Not until 1959, when R. Gould (a disciple of Towns) successfully built the first solid laser based on a ruby crystal, did the practical application of lasers actually begin. Still, it took another 20 years until lasers were widely applied in consumer electronics and significant profit was generated.

In recent times the acceleration of scientific and technological progress has significantly reduced the implementation time required for large inventions – but not enough. The typical correlation between implementation time, ROI and risk for inventions of different levels is shown in the figure below.




Apparently, none of the levels is optimal; each has its advantages and disadvantages:

[7] Later, all three shared the Nobel Prize for their achievements.

- Low-level inventions are typically fast and easy to implement and the risk is low; however, they do not provide a competitive edge or significant ROI.
- High-level inventions can provide a competitive edge and high ROI but require substantial and long-term effort before beginning to pay off, making them very risky.

Below we will address a number of strategies that can help "harmonize" the invention output.

## STRATEGIES FOR INCREASING THE VALUE OF INVENTIONS OF ALL LEVELS

### Strategies for low-level inventions

As mentioned earlier, low-level inventions were never the primary focus of TRIZ, yet their importance and value can grow enormously. The rich evolutionary resources that arose with the invention of the kerosene lamp eventually resulted in a "tornado" that went unnoticed for a long time, delaying the recognition of the invention's value. Our studies of U.S. and European patents show that underestimating an invention's value often results in patents that cover no more than 10-15% of the newly-created evolutionary resources. Such patents provide limited protection and can disclose more than they protect, serving as invitations for potential competitors to capitalize on strong, original ideas. For this reason, many patents are like houses with locked doors and open windows!

To avoid this situation, it is crucial to unveil, in a timely fashion, new evolutionary resources by conducting Directed Evolution (DE), paying special attention to the following:

- Assessing the evolutionary potential of an invention using patterns and lines of evolution.
- Identifying and analyzing the properties and capabilities of an invention that can provide new features and new applications[8].
- Analyzing typical human needs and searching for ways to satisfy these needs using the new invention.
- Analyzing existing trends already producing or capable of producing a demand "tornado," and finding ways to link the new invention to these trends in order to capitalize on them.

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[8] This is closely related to the concept of the "super effect" introduced by Vladimir Gerasimov and Simon Litvin. A super effect is defined as an additional feature or benefit resulting from changes brought about by a new invention that were not the initial purpose of the invention.

Example: The evaluation of an optical film intended for use in packaging resulted in the identification of a new area of application – home interior (following the recent boom in housing).

Given the above, new possibilities discovered for a low-level invention can increase its overall value (and ROI) while maintaining advantages such as short implementation time (at least for the first area of application), low initial investment, and relatively low risk.

**Strategies for high-level inventions**

The main problems associated with implementing high-level inventions are long implementation time, expensive R&D, and high risk.

In 1996, we conducted a Directed Evolution project in which we evaluated the current state of voice recognition technology (estimated at level 4). A large telecommunications company had spent nearly two decades and millions of dollars developing the technology, however the invention was still far from starting to pay off. The main problems were:

- Existing microphones were of low quality and thus required precise positioning, yet could not produce a clear enough signal to allow different accents to be recognized.
- The high cost of the devices (a system designed for automated directory assistance could cost 4-5 million dollars) scared off potential buyers; companies such as AT&T or MCI were in no hurry to make an investment of this size.

To resolve these issues, Ideation's project team suggested that the focus be shifted to short-term directions, including:

- Finding applications impervious to the primary technological deficiencies, such as situations where people are already equipped with headsets with fixed-position microphones.
- Reducing the cost of the system by employing a limited vocabulary (e.g., providing assistance for people searching for the best pizza in town rather than full directory assistance), making it affordable for small businesses and thus reducing dependence on large phone companies. This suggestion was based in part on early indications of a new trend – the emergence of small telephone companies (primarily long distance companies at the time), which would end the era of domination by large telephone companies.
- Identifying existing, emerging or potential demand "tornados" on which voice recognition could ride. Working along this direction, the Ideation team predicted the emergence of e-commerce[9], and suggested ways in which simplified voice recognition devices could be utilized for this purpose and thus benefit the manufacturer.

[9] In this case, the team applied a continually growing collection of forecasts made by Ideation in certain basic areas. In fact, the prediction of e-commerce was even more valuable than the other project results.

Given the above, it is critical when dealing with high-level inventions to review the entire technology and its evolutionary resources, paying special attention to:

- Identifying low-level inventions and applications associated with the given high-level technology, especially those that can be quickly and inexpensively implemented.
- Identifying secondary (consequent) problems at lower levels, which must be solved to ensure successful implementation.
- Conduct Anticipatory Failure Determination (AFD) to reveal and resolve potential problems that could delay or complicate the implementation.

Some of the recommendations suggested for increasing the value of low-level inventions, such as searching for new applications or linking to "tornados," are applicable for high-level inventions as well.

## TECHNIQUE FOR IDENTIFYING THE LEVEL OF AN INVENTION

For the purpose of accurately identifying the level of an invention, we have modified and extended Altshuller's above-mentioned criteria to include the following:

- Problem type
- Direction type
- Information utilized
- Solution type
- Changes to the system
- Changes to system functions
- Transforming an idea into a design
- Counteraction against psychological inertia
- Application/market value
- Application of resources
- Generation of evolutionary resources

For each of the above criteria, descriptions and illustrations have been created for all five levels, making it easy to determine the level of an invention. See the example below.

**Criterion: Problem type**

The problem-solving process begins by recognizing and formulating the problem. The level of an invention can depend on the type of problem selected.

| Level | Description | Example |
|---|---|---|
| **1** | Previously | Many people tried to make an inexpensive and reliable portable |

| | | |
|---|---|---|
| | formulated problem is addressed | umbrella. Finally, one inventor succeeded. |
| **2** | One problem is selected from several problems | Providing safe bike riding is associated with the solving of multiple problems, including reducing the risk of falling, reducing damage in case of a fall, reducing the risk of being hit by an automobile, solving the trade-off between speed (or cargo-carrying capability) and safety, training, etc. Selecting the most promising problem can ensure success. For example, the invention of training wheels for children's bicycles made learning how to ride safer. |
| **3** | Initial problem is critically changed | Sometimes the problem must be changed in the process of solving it. For example, the difficult problem of reducing noise in a rice drying machine was changed when it was discovered that the main reason for reducing noise was the long operating cycle, which necessitated the use of the dryer at night when the noise disturbed the neighbors. Instead of trying to reduce the noise, a different problem was formulated and solved: reducing the length of the operating cycle. |
| **4** | New problem is identified | The first space flights revealed the phenomenon of diffusion welding of metallic surfaces due to high temperature and vacuum conditions. A new problem was formulated: preventing this undesired effect. |
| **5** | New, important problem is discovered | The discovery of a new problem is rare. For example, it was assumed that cloning would produce an identical organism. But an unexpected discovery occurred: in certain situations a clone can differ from the original organism (a cloned cat can have a different color, body build and character that its predecessor). This discovery yields a set of entirely new problems for genetic engineering. |

The level of an invention can be determined based on all the criteria mentioned above, along with the use of software. Software can also be used to develop new inventions that extend and expand a given invention.

## CONCLUSIONS

1. Aside from its theoretical importance, the concept of levels of invention is valuable in terms of practical application. For different levels, different intellectual property strategies can be recommended.

2. For low-level inventions (levels 1 and 2), the following can be suggested:
   - Identify possible ways to increase the value of the invention, and thus its ROI, by finding new applications, ways to enlarge the market, links to existing and

emerging "tornados," etc. while maintaining the invention's main advantages (including low risk and short implementation time).

- Identify possible ways to increase the invention's level, should it yield rich evolutionary resources that can result in a "tornado."

3. For high-level inventions (levels 4 and 5), the following can be suggested:
   - Identify possible limited-scale applications that can succeed even if the technology is still far from perfect.
   - Identify possible ways to reduce the cost of the technology to lower the initial barrier to implementation.
   - Lower risk by ensuring that all secondary problems and potential undesired effects are identified and addressed in a timely fashion in order to expedite implementation.

4. In general, for intermediate-level inventions (2, 3, and 4), the above suggestions for low- and high-level inventions can be combined to lower the risk and implementation time while increasing ROI.

5. The level of an invention can be identified using a set of 11 criteria, detailed descriptions and illustrations of which are embedded in software.

## References


1. Altshuller, Genrich. *The Innovation Algorithm*, 2d edition. Moscow Worker Publishing House, 1973 (in Russian). Translated into English by Lev Shulyak. Worcester, MA: Technical Innovation Center, 1999.

2. Zlotin, Boris and Alla Zusman. *Directed Evolution: Philosophy, Theory and Practice*. Southfield, MI: Ideation International, 2001.