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The Direction of Innovation - The Application of TRIZ Rule Based on the Industrial Life Cycle

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Abstract: Starting from the randomness of innovation in current investment, this article explores an innovation platform jointly built by universities and enterprises. Based on the technology system evolution law and industry life cycle theory in TRIZ theory, it hopes to seek guidance and direction for innovation in universities and enterprises, improve the efficiency of scientific research transformation, and reduce investment risks.

KEYWORDS: Industry lifecycle, Technology system, TRIZ rule

It cannot be denied that innovation is an important force driving the continuous progress and development of human society. The development of society needs innovation, and the development of innovation has become an important strategy for countries around the world. In fierce international competition, only innovation can win and only innovation can strengthen oneself. It is the same for enterprises. Only through continuous innovation can enterprises survive for a long time. Therefore, successful and effective innovation has become a decisive factor in career development.

The development of a company is like sailing in the ocean. Without clear direction and navigation tools, any wind is against the tide. So how can we have clear direction guidance? How can companies innovate to keep up with the pace of the market?

Soviet inventor and educator G S. Altshuller and his research team have developed a TRIZ theory by analyzing numerous patent and innovation cases. TRIZ is "invention problem solving theory".

Achille analyzed and refined existing technological innovation achievements (mainly patents), and summarized a methodology to guide people in invention, creation, and technological innovation. He found that any technological innovation and change, like biological systems, has an evolutionary cycle of birth, growth, maturity, and decline. The technological evolution cycle can be depicted as an industrial lifecycle. If we can clearly depict the industrial lifecycle of the technology system, we can determine its current position and provide effective product and development strategies for the enterprise.

From the classic TRIZ theory, we can determine the lifecycle of a technological system based on Main Parameter Value, patent quantity, invention level, and product profit, and divide it into infancy, growth, maturity, and decline periods as time goes by. However, the indicators of patent quantity and invention level do not quite match the actual situation. Since it takes a period of time, generally two years, for a patent to be granted from application, during these two years, the market environment and the technical system could undergo significant changes, so these two indicators have obvious lag effects.

Therefore, based on the market performance at different stages of the industry life cycle, the commonly used evolutionary laws at that stage, and the strategies of enterprises, this paper will focus on elaborating the different stages of the life cycle of products and technical systems in a phased manner. In classical TRIZ theory, there are 8 major evolutionary laws of technical systems, which are the law of technical system completeness, the law of energy transmission, the law of increasing ideality, the law of subsystem uneven evolution, the law of evolution towards super-systems, the law of evolution towards the micro-level, and the law of harmonious evolution.

These laws reflect the trends of improvement, development, and innovation of products and technical systems. Below, we will introduce the 8 major evolutionary laws of technical systems in detail.

Law 1: The Law of Completeness A complete technical system must have four parts: a power unit, a transmission unit, an executive unit, and a control unit. These four parts interact with each other and coordinate to achieve the system's functions. In the evolution of the technical system, these four parts will continuously improve and develop to enhance the overall performance and reliability of the system.

Law 2: The Law of Energy Transmission In a technical system, energy should be able to flow from the energy source to all components of the technical system, and the efficiency of this transmission process should evolve towards continuous improvement.

Law 3: The Law of Dynamism Evolution Technical systems will evolve towards increased structural flexibility, mobility, and controllability, thereby enhancing the system's adaptability to better adapt to the changing environment.

Law 4: The Law of Increasing Ideality The ideality of a technical system refers to the system achieving its functions with as few resources consumed and harmful effects produced as possible, that is, ideality = the sum of useful functions / (the sum of harmful functions + cost). The evolution of technical systems always moves towards increasing ideality, constantly adding useful functions and reducing harmful functions and costs. This is the most fundamental law of technical system evolution, and other laws are all developed around this law.

Law 5: The Law of Subsystem Uneven Evolution Technical systems consist of multiple subsystems, which do not evolve synchronously but exhibit unevenness. When the performance of a subsystem is rapidly improved, it may cause other subsystems to be mismatched, thus limiting the performance improvement of the entire technical system. This unevenness will prompt the system to continuously adjust and optimize to achieve coordinated development among the subsystems.

Law 6: The Law of Evolution towards Super-systems The evolution of technical systems towards super-systems refers to the integration of functions between different systems or the separation of a subsystem into a super-system.

Law 7: The Law of Evolution towards the Micro-level The evolution of technical systems is usually from the macro to the micro, from large to small, and from complex to simple. With the continuous advancement of technology, people can achieve more complex functions at smaller scales, making technical systems more compact, efficient, and intelligent.

Law 8: The Law of Harmonious Evolution During the evolution of technical systems, the phenomena of matching and mismatching between subsystem components will alternate, so the evolution of the system will move in the direction of harmonious coordination among the subsystems, including structure, performance, and frequency.

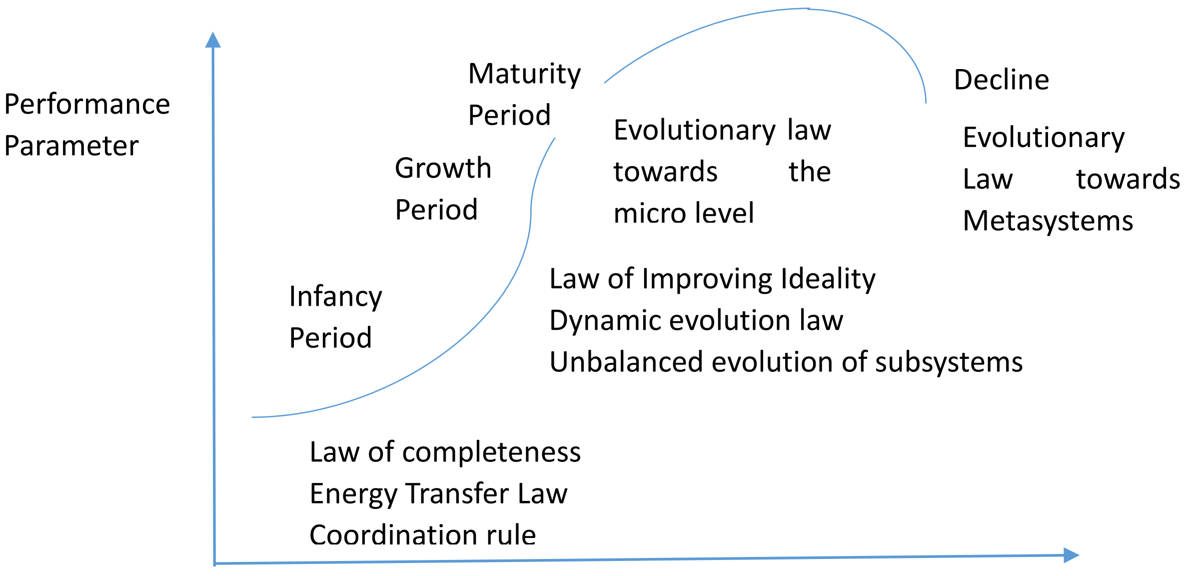

Figure 1 The relationship between the different stages of the industrial lifecycle and the commonly used evolutionary rules at that stage

It can be seen from Figure 1 that during the infancy stage, technical systems evolve towards greater completeness, higher energy transmission efficiency, and better coordination among subsystems. In the growth stage, technical systems evolve towards improving ideality, more flexible and controllable structures, and more balanced development of subsystems. In the maturity stage, technical systems tend to evolve towards a micro direction with smaller volume but stronger functions. In the decline stage, technical systems tend to evolve towards the continuous integration of system resources or the separation of a subsystem into a super-system.

Below, the paper will elaborate on the different stages of the life cycle of products and technical systems based on the market performance at different stages of the industry life cycle, the commonly used innovation evolution laws at that stage, and the response strategies of enterprises and universities.

(I) Infancy Stage

Market performance of infancy stage is the first stage of the industry life cycle, and the market characteristics of this stage are as follows:

(1) The technology is immature. In the first stage, the technical system can operate initially but is very unstable. There are many development obstacles and bottlenecks in the technology, and there are many technical challenges that need to be broken through urgently. Without sufficient resources to support the research and development of the system, the development of the system will remain at a low level for a long time.

(2) Weak investment willingness. Due to many technical bottlenecks, enterprises are not very active in investment. At this time, enterprises cannot see hope and it is difficult to make a decision to upgrade and improve the technical system, so the market prospect is not clear.

(3) Unclear market. Since the advantages of new technical systems in performance and cost-performance compared with other competitive products in the market are not seen, these new products are difficult to get market attention and corresponding investment.

(4) No sales revenue. New products are relatively simple and have no market competitiveness, so it is difficult to open up the market, there is almost no sales revenue, and the profit is negative. Most products can only survive with government subsidies.

Innovation Evolution Laws in the Infancy Stage

In the first stage of the industry life cycle, which is the infancy stage, the main innovation evolution laws include the law of completeness evolution, the law of energy transmission evolution, and the law of coordination evolution.

（1）Law of Completeness Evolution

A complete technical system structure includes a power unit, a transmission unit, an executive unit, and a control unit. The entire technical system first obtains energy from the energy source, converts the energy into the form required by the system through the power unit, then transmits the energy to the executive unit through the transmission unit, and finally the executive unit works on the entire object.

For example, the energy source of a sailboat is wind energy, the power unit is the sail, the transmission unit is the mast, the executive unit is the hull, and the control unit is the rudder. Finally, a person controls the entire system to propel the hull forward.

The energy source of an electric fan is electrical energy, the power unit is the motor, the transmission unit is the drive shaft, the executive unit is the fan blades, and the control unit is the switch and adjustment buttons. Finally, electrical energy drives the fan to rotate.

In industrial robot technology, it may be found that the current control system has insufficient processing capacity for complex tasks and a lower level of intelligence, while the performance of the power unit and the executive unit is relatively high.

（2）Law of Energy Transmission Evolution

In addition to having complete subsystems, each part of the technical system also has the characteristic of energy transmission. The law of energy transmission evolution in the technical system is mainly manifested in A. Ensuring that energy flows from the energy source to all components of the technical system. B. Energy evolves in the direction of higher transmission efficiency and less loss.

A. Ensuring that energy flows from the energy source to all components of the technical system According to Figure 2, the energy from the energy source is sequentially transmitted to the power unit, transmission unit, executive unit, and control unit. This is like arranging dominoes in a certain interval, and gently knocking down the first domino, the rest will have a chain reaction and fall in order. If a component (domino) cannot receive energy, it cannot operate, which will affect the overall function of the technical system.

B. Energy evolves in the direction of higher transmission efficiency and less loss Because energy will continuously lose during the transmission process, it is an unchanging law that the technical system evolves in the direction of the shortest path or higher transmission efficiency.

For example, from steam locomotives to internal combustion locomotives, from internal combustion locomotives to electric locomotives, and then to high-speed trains, the development of trains is towards the direction of higher energy transmission efficiency. Steam locomotives convert chemical energy into thermal energy, then into pressure energy, and finally into mechanical energy. The energy utilization rate is 5%-10%. Internal combustion locomotives convert chemical energy into thermal energy, and then into mechanical energy. The energy utilization rate is increased to 30%-50%. Electric locomotives convert electrical energy into mechanical energy, and the energy utilization rate is increased to 65%-85%. High-speed trains mainly have two driving methods: wheel-rail method and maglev method. The wheel-rail method is to let the train wheels grip the rails tightly, and through the electric power traction transmission system, convert electrical energy into mechanical energy to generate power for the train. The maglev method is to levitate the train by magnetic force to avoid contact between the wheels and the track, thereby reducing friction resistance, and converting magnetic energy into mechanical energy to achieve higher-speed operation.

(3) Law of Coordination Evolution The development of the technical system evolves towards the coordination of various parameters of the subsystems and the coordination of system parameters with the super-system parameters. Each component fully exerts its function while maintaining coordination and integrity, achieving dynamic adjustment and cooperation. Improving coordination can be achieved through the coordinated evolution of shape, performance parameters, frequency, and materials.

A tennis racket is the coordination of power and dexterity. A lighter racket is more flexible, and a heavier racket can generate greater swing power, so it is necessary to consider the coordination of the two performance parameters. Designers choose lighter materials to reduce the overall weight of the racket, increasing flexibility; at the same time, they increase the weight of the head part to ensure the power of the racket.

Lithium-ion battery fires and spontaneous combustion were often seen in the news in previous years. Apart from mechanical failure caused by battery compression, unreasonable battery layout and problems after long-term use will also occur. In electric vehicles, overcharging and fast charging with large currents are the main culprits of electrochemical failure. When the battery is fully charged and continues to charge, more lithium ions will be stuffed into the negative electrode. When it exceeds the maximum bearing capacity of the negative electrode, it will collapse, causing the battery to bulge at best, and causing an internal short circuit at worst. In addition, inside the battery, charging too fast will cause lithium ions to form dendrites on the surface of the negative electrode, similar to tree branches. These dendrites are as thin and hard as needles. When the dendrites grow to a certain length, they will puncture the separator and induce an internal short circuit. Therefore, in the development of lithium-ion batteries, the first problem to be solved is the coordination problem of battery layout and internal short circuits caused by overcharging and fast charging of batteries.

How should we response in the infancy stage?

In response to the above market analysis and innovation evolution laws, we can deduce the main response strategies of enterprises in the infancy stage.

(1) Identify and eliminate bottlenecks and obstacles in the technical system to make the system more complete and coordinated, and continuously update and iterate.

(2) Continuously reduce the cost of the product through mass production, and then reduce the selling price of the product to make the product competitive in price.

(3) Research and develop or choose a technical route with higher energy transmission efficiency. In the early stage of the technical system, there may be multiple technical routes competing. The technical route that can stand out in the end must be the one with

higher energy transmission efficiency.

II. GROWTH STAGE

Market Performance of growth stage is the second stage of the industry life cycle, and the market characteristics of this stage are as follows:

(1) The main technical risks and bottlenecks have been eliminated. The main performance parameters (MPV) have been greatly improved and have shown a good market prospect. Moreover, the growth rate of MPV is faster than in the infancy stage.

(2) It has attracted a lot of attention and investment. Since the technical system has shown a good market prospect, the investment risk has been greatly reduced. Therefore, a large amount of investment has been directed to this field, and the competition has also intensified.

(3) It attracts support from the government level, such as tax reduction or subsidy policy support. When the product has not reached a certain quantity, the price is not competitive. At this time, in order to support the industry, the government will give corresponding tax reduction and subsidy policy support.

(4) Due to the breakthrough of the technical bottleneck of the product, MPV has been improved, and the application scenarios of the product have begun to expand continuously. For example, new energy vehicles had the characteristics of long charging time and short driving range in the early stage, and they did not have corresponding competitiveness compared with traditional fuel vehicles. However, new energy vehicles have begun to be used for scenic spot tourist vehicles, golf course vehicles, and buses, which do not require high driving range.

(5) Infrastructure will adapt to the technical system in reverse. In the first stage of the industry life cycle, the technical system must adapt to the infrastructure to obtain the corresponding resources of the infrastructure to the greatest extent. However, in the second stage of the industry life cycle, as the technical system is more and more widely promoted, it also promotes the infrastructure to change and adapt to the technical system in reverse. For example, with the popularization of electric vehicles, more and more places have begun to lay charging stations to facilitate the charging of electric vehicles.

(6) With the continuous development and rapid popularization of the technical system, providing related services and products becomes profitable. For example, as smartphones began to enter the later stage of the second stage, their sales volume increased significantly, and mobile phone screen protection services and smart APPs emerged like mushrooms after rain.

Innovation Evolution Laws in the Growth Stage

In the second stage of the industry life cycle, which is the growth stage, the main innovation evolution laws include the law of improving ideality, the law of dynamism evolution, and the law of subsystem uneven evolution.

(1) Law of Improving Ideality According to the ideality formula, ideality = (useful effects) / (harmful effects + cost), the effective means of improving ideality is to increase the useful effects of the technical system and reduce costs and harmful effects. Since every system inevitably has harmful effects when producing useful effects, every system has the possibility of continuously improving ideality, and only in this way can it better meet the needs of users.

The methods to improve ideality mainly include A. Integrating the functions of different systems, B. Increasing system functions, and C. Reducing harmful effects.

A. Integrating the functions of different systems Integrating originally independent system functions together is a common method to improve ideality. With the progress of science and technology, originally independent printers, copiers, and scanners have all been integrated into a multifunctional machine with the above functions, and the product functions are stronger, but the price is far lower than the sum of the prices of the previous three independent machines. In addition, smartphones have integrated the functions of PCs, feature phones, and digital cameras, and the performance is more stable, but the price is lower than the sum of the prices of the previous three independent machines.

B. Increasing system functions Continuously improving the functions of the system is an important method to improve ideality. In the 1940s, the United States developed the world's first computer, but its floor area reached 170 square meters, and the total weight was 30 tons, and its function was only calculation. With the development of science and technology to today's laptops, its functions have reached the ability to process a lot of complex information, but its area is only about the size of a 16-inch book, and the weight is within the range that an adult can carry with one hand. It can be predicted that future computers will be lighter and smarter.

C. Reducing harmful effects Reducing harmful effects is also an important method to improve ideality. A fan with blades may cause harm to people when rotating at high speed, especially to children who do not understand. Even with front and rear protective covers, there are still gaps that may cause harm to fingers. If the blades of the fan are cut off, this harmful effect can be reduced. In October 2009, the British James Dyson invented the first bladeless fan. The direction of its innovative invention is to cut off the harmful functions.

(2) Law of Dynamism Evolution

The evolution of the technical system is towards A. Structural flexibility, B. Mobility, and C. Adaptability, which is the law of dynamism evolution.

A. Structural flexibility From the home ruler to the folding ruler, and then to the rollable measuring tape. From the hard screen used by the TV in the past to the flexible screens used by smartwatches and smart TVs today. These trends all show the characteristics of products becoming more and more flexible.

B. Mobility The communication telephone has evolved from the immovable fixed telephone in the past to the partially mobile mother-child machine, and now to the freely movable mobile phone. Cleaning tools have evolved from the initial broom to the movable vacuum cleaner, and then to the controllable moving sweeping robot. These trends all show the characteristics of products becoming more and more mobile.

C. Adaptability The evolution of camera focusing has gone through manual focusing, button focusing, light focusing, and finally automatic focusing. The switch of the street lamp has evolved from the original direct button control to open and close, to control the street lamp to open and close through sensing light brightness, and then to sense light brightness and automatically open and close and adjust the brightness according to the environment. These trends all show the characteristics of products becoming more and more adaptable.

(3) Law of Subsystem Uneven Evolution

The law of subsystem uneven evolution means that the development of each subsystem contained in any technical system is not synchronous and balanced, and each subsystem will move forward along its own industry life cycle. This uneven development often leads to contradictions between subsystems. The evolution speed of the entire technical system depends on the evolution speed of the slowest subsystem. This means that improving and innovating the slowest subsystem at this time is the direction with the highest return on investment.

For example, the performance of smartphone processors has improved rapidly. From the early single-core processors to the current multi-core, high-performance processors, the computing power has increased significantly. For example, Apple's A series processors and Qualcomm's Snapdragon series processors have significant performance improvements every year, allowing them to run more and more complex software and games. However, the evolution of the battery subsystem is relatively lagging. Although the battery capacity has increased, due to the increased power consumption of other components such as processors, as well as the requirement for thin and light mobile phones, the improvement in battery endurance has not kept up with the improvement speed of processor performance, thus restricting the further improvement of smartphone performance. Solving the battery capacity problem will remove the obstacles to the development of smartphones and enter the next stage of development.

How should we response in the growth stage?

In response to the above market analysis and innovation evolution laws, we can deduce the main response strategies of enterprises in the growth stage.

(1) Continuously improve the ideality and cost-effectiveness of the technical system. In the growth stage, the MPV of the technical system grows very fast. Continuously improving the ideality and cost-effectiveness of the technical system is the foundation for enterprises to improve their competitiveness in the growth stage.

(2) Quickly put the product into the market, occupy the market, seize the opportunity, and continuously adjust the direction of improvement according to customer experience and feedback. Small steps and quick trials are effective means to seek and improve innovative methods in the growth stage.

(3) Find the slowest developing subsystem in the system and make a breakthrough. According to the barrel effect, the amount of water in the barrel is determined by the shortest board. Similarly, the overall performance of the system is determined by the slowest developing subsystem. Therefore, finding the slowest developing subsystem for a breakthrough is the direction with the highest return on investment and the direction with the greatest contribution to the industry.

III MATURITY STAGE

Market Performance of maturity stage is the third stage of the industry life cycle, and the market characteristics of this stage are as follows:

(1) The technical system itself has reached the physical limit and has encountered bottlenecks. It is quite difficult to improve the MPV of the system at this time.

(2) The cost is difficult to reduce. After the development of the growth stage, the system is relatively mature, and the cost is relatively low, and it is difficult to reduce further.

(3) After the development of the growth stage, users have a deep understanding of the product and technical system. In addition, with the continuous influx of competitive products, demand is quickly met, and the increase in users will tend to stagnate.

Innovation Evolution Laws in the Maturity Stage

In the third stage of the industry life cycle, which is the maturity stage, the main innovation evolution law is the law of evolution towards the micro-level. The evolution of the technical system is in the direction of reducing the size of its components while ensuring the same functionality.

For example, the chip size in modern smartphones and computers continues to shrink, but the processing speed and power consumption ratio are continuously optimized. After the technical system evolves towards the micro-level, it will increase its mobility and can increase more application scenarios.

How should we response in the maturity stage?

(1) Actively expand peripheral products of the technical system. For example, when PCs developed to the maturity stage, keyboards, mice, USB flash drives, and mobile hard disks sold very well. Similarly, when smartphones entered thousands of households, shared charging treasures, mobile phone bags, telescopic triangular mobile phone homes, and power strips with USB interfaces also sold very well. This kind of innovation direction is not complex, but it has become a classic innovation direction in the maturity stage.

(2) According to the industry life cycle, after the product or technical system passes the maturity stage, it will inevitably enter the decline stage. So, allocating R&D resources to fields with development prospects in the future is a wise choice. For example, autonomous driving technology is still in its early stage, and since this technology has not yet entered the market on a large scale, it belongs to the first stage of the industry life cycle and has great development potential. At this time, enterprises turn to research and develop autonomous driving technology, and improving intelligence will be a good innovation direction.

(IV) Decline Stage

Market performance of decline stage is the fourth stage of the industry life cycle, and the market characteristics of this stage are as follows:

(1) With the entry of a new generation of technical systems and products into the market, the development space of the old generation of technical systems and products is squeezed, and it immediately enters the fourth stage of the industry life cycle, that is, the decline stage. The MPV of this stage has significantly decreased, and the selling price has also significantly reduced. The revenue, profit, and market share of enterprises are continuously shrinking.

(2) The main functions of the product and technical system lose practicality and only retain entertainment, decorative, or become luxury goods. For example, candles used for lighting in ancient times have exited the historical stage with the emergence of electric lights and are now mainly used to create an atmosphere for birthdays or other festivals and occasions. For example, brushes played an important role in ancient Chinese writing, and with the popularity of pens, ballpoint pens, and pencils, brushes have gradually been eliminated. However, brushes still have a significant position in the calligraphy world.

Innovation Evolution Laws in the Decline Stage

Any advanced technical system will move towards the stage where different systems are integrated. In the process of system evolution, multiple systems can be integrated, combined with resources of the super-system, or the original system's subsystems can be separated into the super-system, where the functions of the subsystem are enhanced while simplifying the original technical system. For example, the Swiss Army knife integrates a variety of tools on a folding knife, including a rich array of tools such as the usual knife, scissors, pliers, and tweezers, in addition to ballpoint pens, flashlights, USB drives, and medical kits that are continuously added.

For example, the frequency of use of mobile phones and tablet computers is increasing, and the power consumption is also increasing. If only the battery capacity is increased, it will occupy the original small system space. Mobile phone charging has evolved from wired plugging to wireless charging, which can solve this problem. Separating the battery from the mobile phone and making it a mobile power source can resolve this contradiction.

How should we response in the decline stage?

In the decline stage, it is best for enterprises and universities to withdraw R&D resources from this field and look for products and technical systems in the infancy and growth stages. If you still want to continue operating this product and technical system, consider integrating more resources into this product or technical system. In addition, it is also possible to consider grafting new technologies or new materials onto the original product or technical system. For example, watches have entered the decline stage. However, with the birth of flexible screens, the miniaturization of batteries and chips, and the application of artificial intelligence technology, the development of these technologies has given birth to watches, allowing this ancient technical system to regain new vitality.

IV. CONCLUSION

In summary, mastering the laws of technological evolution and industry lifecycle can effectively improve the efficiency of solving invention and innovation problems, as well as determine the current and future development goals of products, and form strategic goals for product or technology system research and development. Although TRIZ often provides general and abstract solutions in practical applications, it cannot directly provide the final solution to the problem and requires further refinement and concretization. However, TRIZ helps reduce the number of trials and error attempts during the solution process, thereby lowering costs and time consumption.

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