ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20231212053424

Original scientific paper
Received: 2023-12-12, Accepted: 2024-06-07

A Study of Anticipatory Failure Determination (AFD) based on Scenario Analysis Methods

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Abstract: Theory of Inventive Problem Solving (TRIZ) is a methodological algorithm that helps solve complex problems by generating original ideas. The Anticipatory Failure Determination (AFD) method is one of the problem-solving methodologies within TRIZ. It is a creative way to solve problems when you cannot find the cause of a problem or observe the situation in which it occurs. This study aimed to investigate the effectiveness of the Anticipatory Failure Determination (AFD) method, which is one of the problem-solving methodologies within the Theory of Inventive Problem Solving (TRIZ). TRIZ is a methodological algorithm designed to address complex problems by stimulating the generation of original ideas. It involves a shift in thinking: instead of looking for the cause of a problem (i.e., "why does it happen?"), it looks for ideas to solve the problem (i.e., "how can I make it happen?") by formulating a hypothesis and testing the hypothesis. In doing so, they explore and leverage resources that exist within or adjacent to the system to support the failure hypothesis. A resource is anything that is used to fulfill the ideal final result. In this study, scenario analysis, a methodology synonymous with foresight, is integrated into the AFD framework to enhance problem-solving capabilities. By incorporating scenario analysis, the formulation of failure hypotheses crucial to the AFD process is facilitated. Additionally, a case study demonstrating the application of AFD augmented by scenario analysis is presented, showcasing its efficacy in resolving complex problems. This integration aims to proactively mitigate future risks and prevent potential damages. Through this research, a comprehensive understanding of how scenario analysis enriches the AFD methodology is provided, empowering practitioners to pre-emptively address emerging challenges. Ultimately, the goal is to fortify problem-solving capacities and foster resilience in the face of evolving complexities.

Keywords: Anticipatory Failure Determination (AFD); Inversion Analysis; Scenario Method; TRIZ

1 INTRODUCTION

The recent experience of the COVID-19 pandemic has made the world acutely aware of the need to prepare for changes resulting from uncertainty. A number of unexpected events, such as the territorial war between Russia and Ukraine and the bankruptcy of global financial firms, have led to a growing interest in predicting the future in various fields. It is impossible to predict the future with any accuracy. However, it can be said that forecasting is not a prophetic statement, but a process of clearly identifying the current situation and presenting a highly probable realisation. This simply means that future research is about predicting the future and preparing to respond flexibly, quickly and wisely to situations that are likely to arise from the current situation.

The future is full of possibilities and opportunities, but it is also full of uncertainties and vagaries, and it would be foolish to face it without countermeasures and preparations, because it always contains risks and failures. To manage future failures and risks, it is important to understand the current situation and examine possible scenarios, taking into account trends in change. Seeing what could happen in the future and preparing for failure is a great way to reduce risk. As a way of managing failure and risk, this study investigated a method of predictive failure assessment based on scenario analysis. Scenario analysis, a concept first used during the Second World War, is a methodology for predicting the future by forming hypotheses to estimate the development of different possible alternatives that may emerge in the future. It is characterised by the fact that it does not simply predict intuitively, but derives different situations by reflecting current situations and trends, rather than making a definitive prediction. In essence, anticipating failure is not just about avoiding negative outcomes; it's about fostering resilience, innovation, and continuous improvement, ultimately enabling organizations to thrive in dynamic and uncertain environments.

Anticipatory Failure Determination (AFD) is a TRIZ (Theory of Inventive Problem Solving) inversion analysis method. Inversion analysis is the redefinition of a problem into a creative problem. It generates new ideas or solutions by reversing the function of a system or component. Inversion analysis can be traced back to the psychological phenomenon of denial, where people refuse to think about unpleasant and negative things, thus rejecting the causes of problems and failures. However, approaching a problem through the lens of change analysis makes it easier to uncover possible causes of failure and unpleasantness that are not found by more conventional methods. Failure Analysis and Predictive Failure Detection share the ability to generate innovative solutions and improve design. Combining the concepts of both methods can help develop creative solutions, mitigate future risks and provide a broader approach to problem solving.

Inversion analysis in TRIZ is used as a methodology for product development or technical problem solving, but failure prediction based on the scenario analysis method can reduce potential risks and prepare countermeasures. Inversion analysis in TRIZ is a problem-solving methodology that aims to prevent problems from occurring by identifying the cause of failure in advance, or when it is difficult to identify the root cause of a particular problem. AFD aims to prevent or solve problems by predicting the situation in which failure will occur in advance, by establishing and verifying hypotheses about "how the normal process of the system will fail" through a change in thinking. In the process of generating hypotheses about possible failures, scenario analysis, one of the foresight methods, is used to facilitate the discovery of more accurate, rational and consistent failure hypotheses. In addition, to validate the hypothesis, the scenario analysis process should consider whether there are resources within the system that can cause the failure to occur, to ensure reasonableness and plausibility when using the scenario analysis method. AFD is not limited to technical issues but can be applied in many areas such as corporate business and strategic planning, politics, economics, international energy issues, international political forecasting and human resource management issues. In particular, it is suggested that the worst-case scenario setting method implemented in the scenario analysis method can be applied to the predictive failure decision method to prepare optimal responses to situations that would cause a lot of risk if they occurred in reality.

This study aimed to investigate the theoretical system of the predictive failure decision method based on the scenario analysis method for achieving ideality through resource utilisation as a problem-solving method that can be used in various fields, not only in product development or technical problem solving. In addition, the case of the anticipatory failure determination method based on scenario analysis was examined together with the theoretical previous studies.

2 LITERATURE REVIEW

2.1 Anticipatory Failure Determination of Theory of Inventive Problem Solving (TRIZ)

TRIZ is a problem-solving methodology based on logic and data. It is a powerful tool that provides repeatability, predictability and reliability in problem solving through a structured, algorithmic approach to problem solving [1, 2]. The Russian acronym for "theory of inventive problem solving", developed by the Soviet scientist G. S. Altshuller argues that anyone can develop creativity by thinking in terms of objective laws. TRIZ is a methodology based on the study of hundreds of thousands of patents to provide an objective method for problem-solving and has empirical objectivity as a tool for using knowledge.

Classical TRIZ was first introduced in the former Soviet Union, where an early system of problem solving methods was built and developed. Its tools include the ARIZ algorithm, the concept of resources based on matter field analysis, 40 principles of invention, contradiction, separation and eight evolutionary patterns, and many other methods. He also introduced the concept of ideality as a way of thinking that clarifies the purpose of problem solving. Classical TRIZ was further developed by interested scholars after the establishment of the Technical School in Kishinev. The more systematic development of TRIZ methodology during this period included the expansion and systematisation of the "resource" approach and the introduction of the concept of transition analysis in Anticipatory Failure Determination (AFD).

AFD is based on TRIZ, the Theory of Inventive Problem Solving developed by the Russian Altschuler [3], and on the concepts of Subversion Analysis or Sabotage Analysis in R&D problem solving methods developed by Voloslav Mitrofanov [4]. AFD is a problem-solving methodology proposed by Boris Zlotin, an inventor and scientist who was a student of Voloslav Mitrofanov. Boris Zlotin developed the methodology of TRIZ in the 1970s. In 1992, together with patent attorney Alla Zusman and experts from the United States, he founded Ideation International Inc. and ushered in the era of I-TRIZ. During this time, he developed Predictive Failure Determination (AFD), which is a reversal of the traditional TRIZ problem solving algorithm and is useful for failure analysis and prediction. Along with the development of the methodology, he also developed software as an analysis tool.

Predictive Failure Analysis can be used for problem solving when the root cause of a problem cannot be determined. Some problems are too difficult to analyse for their causes to use TRIZ or ARIZ troubleshooting algorithms. In these cases, inversion analysis can be used. In particular, it can be used when the nature of the problem makes it impossible to observe how the problem occurs. The current method of AFD is classified by I-TRIZ into the concepts of Failure Analysis and Failure Prediction and applied to problem solving.

Failure analysis is applied to identify causes and find solutions to problems that have already occurred. It is a systematic procedure for determining the root cause of a failure or undesired phenomenon in a system and correcting it. Failure Prediction is used to identify and prevent possible failures that have not yet occurred and to eliminate their causes. In particular, the idea process for Failure Prediction is a systematic procedure for proactively identifying and preventing all risks or harmful situations that may be associated with a system [5].

The process for Failure Analysis proposed by I- TRIZ consists of seven steps.

1) Formulate the problem, which includes naming the problem encountered and describing the failure.
2) Identify the success scenario of the original system by outlining the step-by-step outcome of the normal process.
3) Identify where the problem occurred in order to reduce the scope of the analysis by identifying where in the step-by-step process of the system the problem occurs.
4) Formulate the transformed problem and turn the problem into a creative problem by asking "How can we make it happen?" and formulate it by maximising or totalising the problem that has occurred.
5) Find solutions by using existing knowledge or using technology and knowledge through exploration. Also, identify the resources that exist in the system or in the environment. This is because there is a specific resource that causes the problem.
6) Formulate a hypothesis about the failure and design a test to validate the hypothesis.
7) Fix the failure. This step ensures that the failure will not occur again.

Next, the failure prediction process involves eight steps.

1) Formulate Problem by identifying and formulating all the important problems that may occur in the current system.
2) Identify the success scenarios of the original system, the same as in the Failure Analysis step, outlining the outcome of each step in the normal course.

3) Formulate an inverted problem using the scenario method to describe all possible failures of the problem.
4) Record the possible failures within the system and construct a scenario tree by assuming when the problem occurs, the harmful end state and the worst case scenario.
5) Investigate the resources in or around the system that enable the scenario to be realised. This may lead to new failure scenarios.
6) Use a checklist to generate more ideas for failure scenarios.
7) Identify the final harmful state, identify the failure scenarios for it, and suggest ways to maximise it.
8) Derive a solution to solve the problem.

The process of driving failure analysis and failure prediction is shown in Fig. 1 [5].

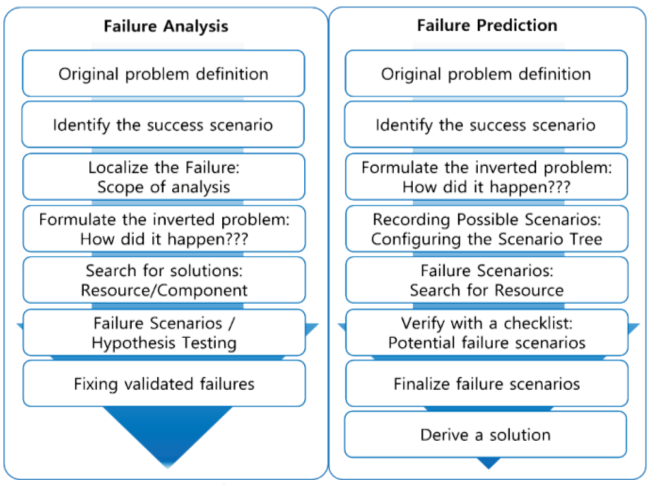

Figure 1 Anticipatory failure determination process [5], rewrite by quoting

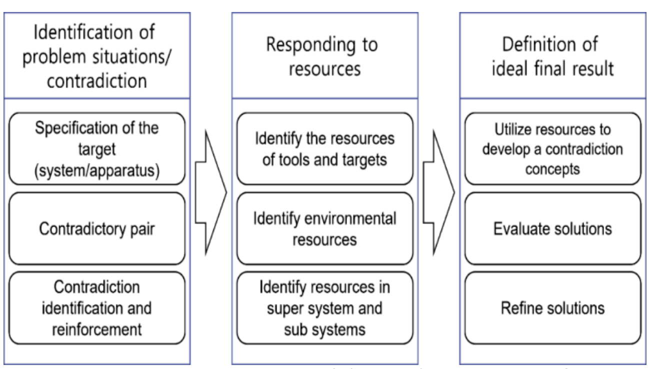

Figure 2 Invention problem solving process [6] (Theory of Inventive Problem Solving and Case Study – TRIZ Level 1 pp 52)

In this study, exploration of resources was essential in the process of problem solving through AFD. Furthermore, in order to realise the ideal in problem solving, it was essential to use the resources that exist in the system, and it can be said that problem solving ability is directly related to the ability to explore and use resources. The use of resources to realise the ideal of problem solving is, first, the use of resources that are generally available without cost within the system. In particular, it is most desirable to use casual or discarded resources. Second, to use resources available in the external environment. When an infinite amount of resources from the external environment is used to solve the problem, it is not limited by the difficulty of obtaining or the cost due to the scarcity of the resources. Common examples of resources from the external environment are air, water, temperature, sun and wind. Third, use tools to minimise costs. In this way, the use of resources takes into account the ideality of the problem to be solved, and the resources with the lowest cost and continuous procurement are selected and used to solve the problem. In addition, since there are always resources that cause failure when troubleshooting through AFD, eliminating resources that cause problems in the system can also be a way to realise the ideal. Fig. 2 shows the process of creative problem solving by using resources [6].

3 SCENARIO ANALYSIS METHOD

Scenario analysis is one of the methods for forecasting the future. It is a skilled and professional methodology that allows us to imagining of possible futures [7] and to presenting different situations that may occur in the future, based on consistency and logic [8]. The scenario analysis technique is a method of reasoning that starts from the present and logically derives different situations in order to know "what will happen" and develop a response to the facts that have occurred.

Scenario analysis was originally developed in the military field to analyse the relationship between military developments and strategy, and is said to have originated at the RAND Institute under the leadership of Herman Kahn, who served in the United States Air Force. It has since been popularised in the private sector and used as a management strategy by companies. Scenario analysis is a strategic tool that helps decision-makers in organisations to be prepared by examining possible outcomes and influencing factors and considering multiple alternatives [7, 9-14].

A classic example of the use of scenarios in business management is the case of Royal Dutch Shell. Pierre Wack, who worked as a scenario planner in the London office, used scenario analysis to predict the rise in oil prices caused by the fourth Middle East war, and responded quickly to the oil shock by reducing capital investment and improving the quality of refined oil products, greatly improving profit margins and growing the company to become the second largest oil company in the world. The company also used scenario planning to anticipate the collapse of the Soviet Union, securing the right to develop resources in Russia and growing into the global company it is today. There are countless other examples of company's successfully managing environmental change through scenario analysis.

In his study, Schoemaker [7] identified two common errors in scenario planning. The first is underestimation of environmental change and the second is overestimation. He argued that most people make the error of underestimation by imagining the future without considering the rate of change. He presented the steps to develop a scenario analysis as a 10-step process.

In the scenario construction process, step 1 is setting the time horizon of the issue to be analysed and the scope of the scenario analysis. Step 2 is identifying the key stakeholders in the issue to be analysed, and step three is identifying the underlying trends in the issue to be analysed, which he said is helpful to list in a chart or diagram and categorise the impact on current strategy as positive, negative or uncertain. Step 4 is recognising the key uncertainties that could have a significant impact on the issue, taking into account a range of factors including political, economic, social, technological and legal, and it is important to understand the relationships between the uncertainties.

Step 5 synthesises the information from steps one to four to form an initial scenario. A simple approach is to place all positive factors in one scenario and all negative factors in the other, creating an extreme initial scenario.

Step 6 is analysing of the scenarios created in step five to see if they are internally consistent or plausible. The internal consistency test should examine whether the scenarios are valid for the time period analysed. It should examine whether the outcomes caused by the uncertain factors can realistically occur in the real world. It is also important to ensure that the outcome of the uncertainty is one that key stakeholders are likely to choose. Step 7 is identifying some common themes, refined by the consistency and persuasiveness check in Step 6. This process identifies strategically relevant themes and organises the possible outcomes and situations.

Step 8 is reviewing the revised scenario for any overlooked or missing elements. This may require further research. Step 9 is developing a quantitative model, i.e., after further research, internal consistency is checked and a quantified scenario model is produced. Step 10 is finally developing the scenarios into decision scenarios. Through an iterative review of the process, the scenarios are finalised to confirm the strategy and generate new ideas.

The scenario building process is shown in Fig. 3.

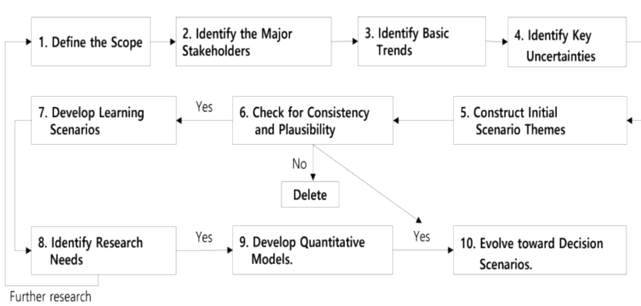

Figure 3 Constructing Scenarios Process [7]

In recent years, this process has been streamlined and often involves six steps. Identifying key issues are done in step one and key trends in step two. Selecting the driving uncertainties are done in step three and creating initial scenarios in step four. In step five, each scenario is given a title, and in step six, a response strategy for each scenario is developed.

When presenting scenarios using the scenario analysis method, it is common to present three to four scenarios. In practice, you can create many scenarios, but each scenario requires implications and explanations that can hinder decision-making. For this reason, scenarios should be limited and alternative scenarios should be developed [15].

3.1 Research Resources

A resource is anything that can be used to solve the problem that has occurred and create the desired situation [16]. In AFD analysis, when a scenario analysis method is used to formulate a failure hypothesis, there must be a resource within or adjacent to the system to support the hypothesis. In other words, a problem situation must have a cause (resource).

The concept of resources in TRIZ is very broad. From a detailed point of view, resources can be divided into basic resources, which can be classified as time, space, matter, field, energy and information, and induced resources, which are generated by the combination of basic resources. A function can be seen as an induced resource that combines matter, energy and information, and a person can be seen as an induced resource that combines matter, energy and information [16]. In addition, super-effects can also be seen as exploitable resources. Through systems thinking, available resources are not limited to the working system, but are explored through the nine windows such as the super system and sub-system that make up the system [2]. In addition, super effect is a new changed resource that occurs after problem solving, which suggests the best use of resources to solve the problem [17].

AFD aims to identify existing resources to reveal the occurrence of harmful or undesirable situations that threaten to disrupt the normal functioning of the system.

Fig. 4 shows the range of resources in terms of types and locations where they can be used.

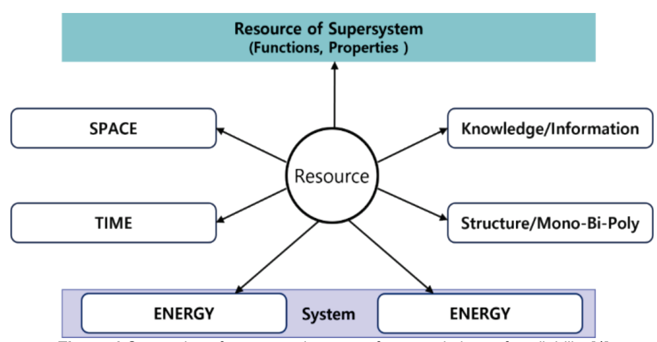

Figure 4 Categories of resources in terms of type and place of availability [4]

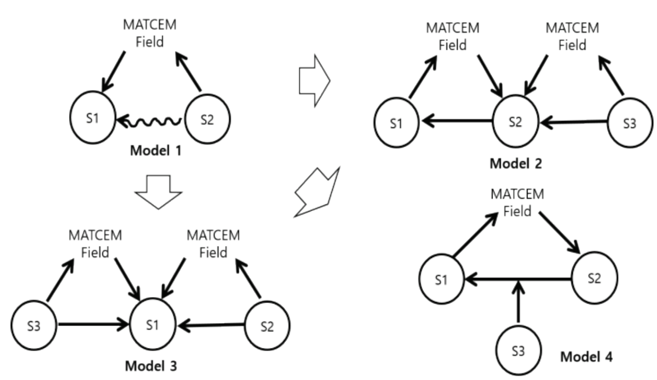

Figure 5 Standard Solution of Ideal Final Result

During the AFD process, it is necessary to identify the existence of resources that support the hypotheses generated by the scenario analysis, and subsequently to identify scenarios in which the resources are the cause of failure during the hypothesis validation process. It is important to note that resources may change in form or nature over time. They can also be combined with other resources to create new types of resources [16]. In TRIZ, the ideal solution is derived by using the standard solution to solve the problem by using other resources to solve the problem. Fig. 5 shows an example of how a standard solution becomes an ideal solution.

Model 1 represents a problem with a substance-field acting on the relationship between substance S1 and substance S2 [18]. As a standard solution to model 1, model 2 solves the problem by adding a new substance S3 and substance-field S2. Model 3 solves the problem by adding a new substance S3 and a field to substance S1. Model 4 solves the problem by adding a new substance S3 to the process of interaction between substance S1 and substance S2. The solution ideas of all models are sequentially considered and applied to implement the appropriate problem-solving model solution by applying the eight fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological) [19]. Thus, it can be said that in the AFD process, resources are an important factor affecting the cause and solution of the problem.

4 CASE STUDY FOR AFD

4.1 Case Study for Failure Analysis

4.1.1 Problem Cases of Mortar Shell Explosion Anomalies

The usefulness of the Inversion Analysis method is illustrated by solving the problem of anomalous explosions of mortar shells during the Second World War. The case is taken from the book "Theory of Inventive Problem Solving and Case Study - TRIZ Level 3".

Problem situation: During the Second World War, mortar shells were designed to fly unexploded after being fired, hitting enemy trenches where the impact would cause the projectile to hit the fuse and explode. As designed, the bombs fell into enemy territory, detonated and were used effectively, but towards the end of the war a problem arose where the bombs would explode in mid-air seconds after being fired. This was not a one-off mistake, but an ongoing problem, and the urgency of the fighting meant that the cause had to be identified and dealt with quickly. However, it was not possible to conduct experiments in the field and it was difficult to identify the cause. Inversion analysis can be used for problems like this where root cause analysis is difficult. Inversion Analysis can be done as follows:

Step 1, formulate the problem, name the problem, and describe the failure.

The problem is that mortar rounds are exploding in the air instead of reaching enemy territory and detonating, and this problem is called "Anomalous Mortar Shell Explosion". Because of this problem, friendly forces are damaged by the explosion and are unable to hit the enemy.

Step 2, create your first success scenario.

Decide to fire → Prepare mortar and shells → Fire mortar → Flight of shells → Reach target → Firing pin hits fuse → Explosion.

Step 3, identify the location of the problem. During the step-by-step process, identify the problem area.

The area where the problem occurs after the bombardment decision is made is identified as the area where the problem occurs during the process from mortar launch to shell flight, since the mortar launch proceeds normally without any problem. Set the analysis domain of the problem to Mortar Launch to Target.

Step 4, set the problem to Transitioned. The cause of the problem is that it is difficult to analyze the cause or observe the shell after it is fired, so it is difficult to analyze the cause with RCA (Root Cause Analysis) or CECA (Cause Effect Chain Analysis). Therefore, Inversion Analysis is used to turn the creative problem into "How can we make the shell explode in flight after being fired? The goal is to maximize the problem so that the mortar shells explode continuously and constantly during flight, rather than intermittently during flight.

Step 5, explore resources and use existing knowledge and skills to derive a solution.

From a TRIZ problem solving perspective, the resources that can be used for the explosion inside the system or in the adjacent environment during the flight after the mortar shell is fired are time, space, substance, field, energy, and information. Since the scope of the problem is the physical phenomenon of a mortar shell exploding, the substance-field should be given focus. The available resources include the outer casing of the mortar shell, the inner lining, the firing pin, the spring, and the metal plate that prevents the firing pin from escaping. According to the MATCEM analysis, there are various environmental resources such as air resistance, inertia, heat of friction with air, chemical reactions of the charge, sparks, and magnetic generation.

Step 6, develop a hypothesis for the failure (the shell always explodes in flight) and conduct a test to verify the hypothesis. In this case, the process of hypothesizing a situation where mortar shells can always explode in flight is determined by the scenario analysis method.

The first step of the scenario analysis is to determine the scope of the analysis, and the analysis is focused on shells in flight after firing. The fourth step of the analysis is to use resources to apply factors that may affect the object of analysis. In particular, focus on factors that change from before launch. The step five of the scenario analysis is where an initial hypothesized scenario is created. The chosen initial hypotheses were:

Hypothesis 1. An enemy spy was present and planted the timer.

Hypothesis 2. A chemical reaction of the internal charge occurred during the flight of the mortar shell.

Hypothesis 3. The mortar shell's firing pin ejector metal plate lost or malfunctioned during flight, causing the firing pin to strike the detonator.

Hypothesis 4. Mortar shells detonate during flight due to the heat of friction with air.

In Scenario Analysis step six, hypotheses that are plausible and consistent are selected. In step seven, the selected hypothesis is refined by testing its feasibility. In step eight, overlooked aspects are revisited, and in steps nine and 10, the final scenario is determined. The final hypothesis is also summarized after this process.

In this case, Hypothesis 3 was selected which states that "The metal plate that prevents the firing pin from dislodging during the flight of the mortar shell lost its function or failed and the firing pin struck the detonator." Hypothesis 3 was chosen the most likely because it is the most likely change that could have occurred during flight compared to before the mortar was fired, and also because it is the most likely change compared to before the initial explosion.

Based on the selected hypothesis, "How can a mortar shell be made to explode in flight?" was analyzed. The analysis showed that the metal plate to prevent firing pin disengagement was designed to perform two functions: to keep the firing pin from being disengaged by the acceleration generated when the mortar shell is fired, and to absorb energy to prevent the accelerated firing pin from hitting the detonator. And when the mortar shell flies and hits the target, the firing pin hits the detonator by inertia, causing it to explode normally. Therefore, to perform this function, in the early days of mortar shell production, mortar shell designers made a copper metal plate to prevent the firing pin from disengaging.

However, as the war progressed and copper plates became scarce, factory engineers substituted readily available steel plates for copper. Unlike copper, steel plates are elastic, and while inertia does not affect the firing pin in the early stages of a mortar shell's firing, elasticity occurs when inertia is lost. By changing the material of the metal plate to prevent the firing pin from disengaging compared to before the first explosion, it was found that the firing pin performed the function of preventing the firing pin from disengaging, but an unnecessary function, elasticity, occurred, causing the firing pin to hit the detonator a few seconds after firing. Thus, the hypothesis was verified.

In step 7, the cause of the abnormal explosion of the mortar shell was confirmed to be a malfunction (elasticity) of the "metal plate to prevent firing pin disengagement". To improve this, the problem can be solved creatively by changing the "firing pin disengagement prevention metal plate" to a ductile copper material that does not produce elasticity.

4.2 Case Study for Failure Prediction

4.2.1 Problem Case that Causes "Company S" to Fail

We will present the case of Failure Prediction using the example of Company S, which has grown into a global company. The case is based on Daeje, Jin "Manage Your Passion" [20], as well as interviews and press releases from related parties.

In November 1994, a strategy meeting was organized by the head of the memory division of S Company. Executives from the strategic planning department were invited to the strategy meeting, and the topic was "Company S (semiconductor business) is in danger of going out of business.

The problematic situation was to select a possible scenario that could lead to the failure of Company S (semiconductor business) in 1997, three years later. In addition, countermeasures for the situation in which the continued business promotion fails need to be prepared. In other words, the anticipatory failure determination method and scenario analysis method to the situation that predicts the failure of the business should be applied. The analysis steps were as follows:

Step 1, formulate the problem, name the problem that occurred, and explain the failure.

Three years later, Company S (a semiconductor company) is facing a difficult business situation that may lead to its failure. This situation can be attributed to a number of environmental changes, but there are a number of uncertain situations that can be considered. Define the problem by considering the most likely trends within the industry. Industry trends include integration between companies, technology development, and exploration of new business areas.

Step 2, Company S wants to increase its market share by developing new technologies while expanding its reach to similar businesses. Create a scenario of successful business development that Company S wants.

Maintain market share → Develop new high-performance semiconductors → Create new customers and increase existing supply → Increase market share → Expand non-memory business.

Step 3, formalize the problem using a scenario analysis method by listing all the possible failures that could lead to the problem through inversion analysis. Formulate the problem by listing the ways in which the problem could occur.

In other words, hypothetically create a situation that causes a problem in driving the normal success scenario. For example, a strong new competitor enters the industry that is not an existing competitor. Or a new technology is developed that produces a product that is incomparable to what is currently being produced. Depending on the geographical environment, there are various geographical environmental changes, such as earthquakes, floods, and droughts. Assume that changes occur, such as a change in the political situation in a country that leads to increased regulation, or a change in consumer needs that leads to a decrease in demand for existing products.

Step 4, record possible failure scenarios within the system, and construct an initial scenario by synthesizing the time of problem occurrence, harmful end state, and extreme situation.

Hypothesis 1. The emergence of a strong competitor in the industry or the expansion of the business leads to a decline in market share, which leads to a decline in the productivity of the company and the failure of Company S.

Hypothesis 2. The development of new technologies leads to the mass production of substitutes for existing semiconductors and the semiconductor industry enters a period of decline, causing Company S to fail.

Hypothesis 3. Due to changes in the geographical environment (earthquake, water damage, lack of industrial water, etc.), the semiconductor infrastructure collapses, making it difficult for Company S to produce products.

Hypothesis 4. Due to the deterioration of the international situation, import restrictions on production materials, materials, parts, and production equipment occur, making it difficult to produce products and causing Company S to fail due to a decrease in production rate and sales.

Step 5, explore the resources that exist in or around the system in which the initial scenario could be realized.

Looking at the various resources that could cause problems, there are established companies that could be strong competitors. These include Intel, Toshiba, Hitachi, and Texas Instruments. There are not many resources that can cause geographic change, but there are many new competitors, and there is a high probability of mergers among semiconductor companies, so there are many resources for developing new technologies. In addition, South Korea, where S Company is located, has a complex and delicate international relationship with the United States, China, Japan, and North Korea, so there is a lot of volatility in international affairs.

Step 6, use the checklist to get more ideas for failure scenarios.

In a strategy meeting, the memory division of Company S reviewed the various possible scenarios and resources that could cause problems, and finally settles on two failure scenarios. The finalized scenarios were,

Hypothetical Scenario 1.

The current chairman of Company I, Mr. Grove, retires and a new chairman is appointed. After taking office, the new chairman announces a business policy to focus on the memory semiconductor business as well as the current CPU production. Company I, a powerhouse in the memory semiconductor industry that integrates semiconductor devices that control memory, declares that it will determine the specifications of memory semiconductors based on its patents and technologies and will not allow other companies to use its technology. Company S, whose main business is memory semiconductors, is facing a serious crisis in its business due to the emergence of strong competitors and technological threats.

Hypothetical Scenario 2.

Due to the delicate international situation in Northeast Asia, Japan enacts a law to prevent the export of semiconductor manufacturing equipment to South Korea, such as exposure equipment needed to produce D-RAM, in order to punish South Korea economically.

This means that Company S will not be able to procure the materials, components and equipment needed to produce semiconductors, causing a significant disruption in the production of its main product, D-RAM.

Step 7, check the final harmful state, assuming the worst-case scenario.

If the scenario is realized, in the worst case, Company S may go bankrupt and the country's core business, the semiconductor industry, may collapse. In particular, if the two hypothetical scenarios occur simultaneously, the situation will be so serious that both Company S and the country will have no countermeasures.

Step 8, derive a solution to resolve the problem.

Company S did not disclose a clear plan for countermeasures based on scenario management. However, through scenario management, Company S anticipated a scenario in which the company might fail, so it prepared a medium- to long-term preparedness plan internally.

Subsequently, the failure scenario was realized. However, it can be judged that it was able to adequately prepare for the failure scenario. Company S has now become a world-class company in the semiconductor industry. Here is an example of a real failure scenario,

Fact 1. In 1997, Mr. Grove, Chairman of Company I, retired and Mr. Barrett, Senior Vice Chairman, took over. Company I then entered the memory semiconductor industry and introduced a memory product called "iRAM" to the market. In fact, the failure scenarios predicted by scenarios and predictive failure decision methods were realized. However, unlike the failure scenario that expected the worst, Company S cleverly solved the problem through thorough preparation. First, it was able to maintain price competitiveness due to its production cost advantage through technology development. In addition, it maintained product quality through the superiority of D-RAM's heat control technology. By reducing the defect rate through product quality control, the company was able to maintain the trust of its customers. In this way, the company was able to overcome the crisis wisely.

Fact 2. On July 4, 2019, Japan's Ministry of Economy, Trade, and Industry imposed export restrictions on fluorine polyimide, photoresist, and hydrogen fluoride, which are key materials for semiconductors and displays, to South Korea due to deteriorating diplomatic relations. This is the situation predicted in Failure Scenario 2, which means that it is difficult to substitute by regulating items corresponding to materials and components. Company S is in an urgent situation to produce products on time to deliver the contracted products to its customers. In addition, the company does not have much inventory and urgently needs to procure parts.

However, Company S has been trying to locate photoresist, which is the most difficult to replace, for more than 20 years. Hydrogen fluoride has also been localized, and the company has supported technology development by domestic companies. On the one hand, the company put pressure on the Japanese government, pointing out that the Japanese company could go bankrupt if it failed to deliver its products. On the other hand, Company S worked with other domestic S-corporations to localize their supply chains. By preparing for the worst-case failure scenario through scenario management and contingency planning, they were able to overcome the risk. In the end, a major Japanese company invested more than 100 billion yen to build a photoresist plant in Korea. This outcome is the result of the failure scenario that highlighted the superiority of Company S.

5 DISCUSSIONS

The integration of scenario analysis into the Anticipatory Failure Determination (AFD) methodology has yielded promising results in enhancing problem-solving efficacy. The study demonstrates that by employing scenario analysis, organizations can systematically formulate and test failure hypotheses, thereby preemptively addressing potential risks and vulnerabilities. This aligns with previous research by Chybowski, Leszek & Gawdzińska, K. & Souchkov, Valeri

[4], which emphasizes the importance of early-stage application of AFD in system development for risk mitigation and performance optimization.

Furthermore, the findings underscore the broader implications of leveraging anticipatory approaches in problem-solving. By anticipating and proactively addressing failures, organizations can not only minimize costs associated with downtime and repairs but also safeguard their reputation and maintain customer trust. Moreover, the integration of scenario analysis into the AFD framework fosters a culture of continuous improvement and innovation. By systematically exploring potential failure scenarios, organizations can uncover new insights, identify areas for enhancement, and drive iterative innovation. Several studies emphasize the role of anticipatory approaches in stimulating creativity and innovation within organizations. Additionally, the study underscores the importance of interdisciplinary collaboration in addressing complex challenges. By bridging the domains of future prediction and problem-solving methodologies, researchers and practitioners can leverage diverse perspectives and expertise to develop holistic and robust solutions.

Furthermore, the research highlights the need for organizations to embrace a proactive mindset in navigating uncertainty and change. By embracing anticipatory approaches like AFD, organizations can position themselves to effectively adapt to evolving circumstances and seize emerging opportunities. The study underscores the transformative potential of integrating scenario analysis into the AFD methodology for enhancing problem-solving efficacy. By anticipating and proactively addressing failures, organizations can mitigate risks, foster innovation, and drive continuous improvement. This research contributes to the growing body of literature on anticipatory problem-solving approaches and underscores the importance of proactive strategies in navigating complex and uncertain environments. The study has achieved its objectives by effectively integrating scenario analysis into the Anticipatory Failure Determination (AFD) method within the Theory of Inventive Problem Solving (TRIZ), thereby enhancing the understanding of predictive failure analysis and problem-solving methodologies. This integration has provided insights into proactive approaches for identifying and addressing potential failures, ultimately contributing to more robust problem-solving strategies.

6 CONCLUSIONS

Foresight is the process of trying to predict what will happen in the future by taking the current situation and adding the changes that are expected to occur in the future. There are many ways to predict the future, and there is no right answer. However, the reason for this difficulty is that there are many risks and damages that can be caused by an unprepared future. In other words, the purpose of forecasting is to prepare for the risks that will come in the future. One of the different methods of foresight is scenario analysis, which is a method of preparing different possibilities of what might happen in the future. Scenario analysis does not determine the future. It assumes all possible scenarios and prepares for the worst, based on the most likely to happen scenario.

The TRIZ perspective on foresight defines a situation where risk and harm occur as a problem situation and uses creative problem reversal to solve problems, where the cause of the problem is difficult to identify or the process of the problem is difficult to observe. By switching the problem, it solves the problem by switching to "How can I cause failure?" instead of worrying about "Why does failure happen? This is how predictive failure analysis works. It is a method of creating a hypothesis that causes a problem and validating it. In this process, there are resources that cause failure.

This study applied a method based on the scenario analysis method in the process of using the anticipatory failure determination method and examined cases. In the process of using the anticipatory failure determination method to turn the problem into a creative method and solve it, the scenario analysis method is applied at the stage of setting the failure hypothesis. In other words, the failure hypothesis is analyzed using the scenario analysis method to determine the situation that will cause the failure by examining the hypothesis that is likely to be realized and is consistent.

In addition, in the process of establishing failure hypotheses through the scenario analysis method, it is easy to derive failure hypotheses for problem solving by exploring and applying resources that cause problems that exist in the system or resources that allow ideal problem solving among the troubleshooting methods. In other words, as a way to solve problems that are difficult to identify and observe, it is easy to solve problems by setting hypotheses for the anticipatory failure determination method based on the scenario analysis method using the exploration of system resources. TRIZ's anticipatory failure determination method, which solves problems by shifting thinking, is a creative problem-solving method, and it is necessary to actively conduct research in this area in the future. Creativity is learned, not born. The convergence of research on future prediction and problem-solving methods underscores the growing recognition of the interconnectedness between anticipation and effective resolution of challenges. As organizations navigate increasingly complex and uncertain environments, the need to anticipate future scenarios becomes imperative for informed decision-making and risk mitigation. By integrating predictive techniques with robust problem-solving methodologies like AFD, researchers and practitioners can not only identify potential failures in advance but also develop proactive strategies to address them, ultimately enhancing organizational resilience and adaptability in the face of dynamic change. This synthesis of future prediction and problem-solving methodologies represents a pivotal advancement in addressing the intricacies of modern-day challenges and fostering sustainable success.

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