Cognitive Reliability and Error Analysis based on Anticipatory Failure Determination

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Abstract. Market changes and diversity demands have brought great challenges for designers to build correct models and actively analyze and identify problems of a product in order to reduce probability of failures of the product. Product reliability and failure analysis is an important action to ensure that a product can work properly in its expected life time. Existing methods of the product reliability and failure analysis are mainly based on users' experience. Product failures are analyzed based on historical records but relationships of product interconnection faults. This paper proposes an effective method that integrates the anticipatory failure determination and cognitive reliability and error analysis to search causes of failure modes of a product. TRIZ tools are used to find solutions to avoid or reduce the failure causes. The proposed method improves the product reliability and failure analysis effectively. Feasibility of the proposed method is verified in a case study of the failure analysis and reliability improvement of a pneumatic nail gun product.

Keywords: Failure analysis, Anticipatory failure determination (AFD), Cognitive Reliability and Error Analysis Method (CREAM), Produce design, Reliability, TRIZ.
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1 INTRODUCTION

Market changes and diversity demands result in increasing complexity of product structures, which has brought great challenges for designers to build a correct model to actively analyze and identify problems of a product, and reduce probability of failures of the product. Therefore, the product reliability and failure analysis is an indispensable process in product design and quality assurance [17].

Traditional product reliability and failure analysis methods have been widely used in product design to determine the existence of potential failures of the product. One of the most widely used methods is Failure Modes and Effects Analysis (FMEA). This method analyzes product failures that have occurred in history but ignores relationships of product interconnection faults [4]. Hazard and Operability Analysis (HAZOP), Preliminary Hazards Analysis (PHA), Risk Assessment, Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) are also commonly used in the product failure analysis. These traditional methods usually use a forward thinking in the failure analysis. They start at happened failures for exploring failure causes according to different factors considered in the applied method. These methods usually perform the analysis based on the personal experience to search common failure causes. Therefore, obtained results of the failure analysis may be incomplete or limited as they just focus on explaining failures happened rather than exploring possible or potential failures to prevent them. Different methods have been proposed to improve the product reliability and failure analysis recently. Zlotin proposed an anticipatory failure determination (AFD) method based on the TRIZ invention solution to improve the failure analysis [25]. Chybowski analyzed the development and application of AFD for product quality assessment and combined it with other methods to improve the AFD method [4]. Silva found that advantages of AFD lie in the method innovation and freedom for exploration of the failure potential compared to the FMEA method. AFD encourages questioning 'how to fail', while other traditional failure analysis methods focus on 'what failures to occur'. AFD is better at discovering what has happened but not for unobvious and hidden failures. Although AFD is not yet widely used, it is a creative and alternative method for the product reliability and failure analysis. It can also combine with FMEA to analyze complex systems [25]. Christian combined FMEA and AFD for a new model of FMAAA to use the FMEA analysis framework as the main body to find potential failures through the AFD failure scenario construction. Multiple failures were combined to search the risk of failures and identify serious failure problems [22]. Steve compared two traditional failure analysis methods and hazard and operability analysis (HAZOP) with AFD. Even if inherent defects of these methods are not completely eliminated, the defects can be minimized by supplementing AFD [21].

Although the combination of AFD and traditional failure analysis methods can enhance the failure prediction and failure analysis of the product, there are still immature parts of the method. How to identify and use system resources and solve failure problems needs to be improved. In the step of creating a failure scenario in the early stage of the AFD analysis, Hiltmann introduced FLAGMORBUS series of parameters to describe a system. Using the AFD method to analyze the changed parameters can quickly identify system failures [5]. Jensen and Aven combined AFD and functional resonance analysis method (FRAM) to analyze correlations of fault events [9]. Yang introduced a substance-field model to AFD and used reverse thinking in the original model to predict failures of the product and improve the design solution [12]. Xu used the conflict resolution theory instead of the original resource method to solve and optimize failure problems, and constructed a failure analysis method and a failure prediction template based on the conflict resolution theory [13].

Product application is a process of the integration of human, machine and environment. Human factors should be considered in the product failure analysis. There may be some deficiencies of solutions if only failure causes of the product itself are analyzed, and failures from human errors are ignored. For the failure prediction using AFD, most of the researchers combined AFD with other methods to improve the analysis accuracy, but they only considered the possible failure state of the product itself, the human factor was rarely discussed. Sunday analyzed shortcomings of the AFD method for identifying failures caused by man-made errors. An AFD3 template was proposed by combining the zigzag design process between different domains in the axiomatic design [19]. However, the AFD3 template requires a proficient application of relevant knowledge of the axiomatic design to clarify the input and output of the process, which undoubtedly increases designers' workload in finding causes of failures.

Although FMEA is a linear, well-applied and standardized method for the product failure analysis, AFD is better to predict hidden failures without obvious failure causes [25]. AFD uses the reverse thinking for a state of product success to search for all possible failure modes and causes, which actively creates failures to predict problems in the product application. Traditional failure analysis methods mainly focus on what failures occur, while AFD actively creates hidden failures that are not obvious and have not yet occurred but may occur. This reverse thinking can well turn the prediction problem into an inventive problem-solving process, called the cognitive reliability and error analysis method (CREAM). CREAM is a representative analysis method in the second-generation human reliability analysis (HRA) method, which can be simply used as a convenient way to organize categories of possible causes and effects in human actions.

This paper introduces an improved CREAM method. The method can track causes of failures based on failure modes to predict failures that may occur. Failure causes are found according to the classification method of CREAM, which improves the AFD method to determine the potential failure modes and causes using the human factor analysis. TRIZ tools are introduced to avoid failure causes in the product reliability and failure analysis.

2 PROPOSED METHOD

The proposed method is named as iACTC (Integration of AFD, CREAM and TRIZ) for the analysis of product failures in the product improvement. A flowchart of iACTC is shown in Figure 1.

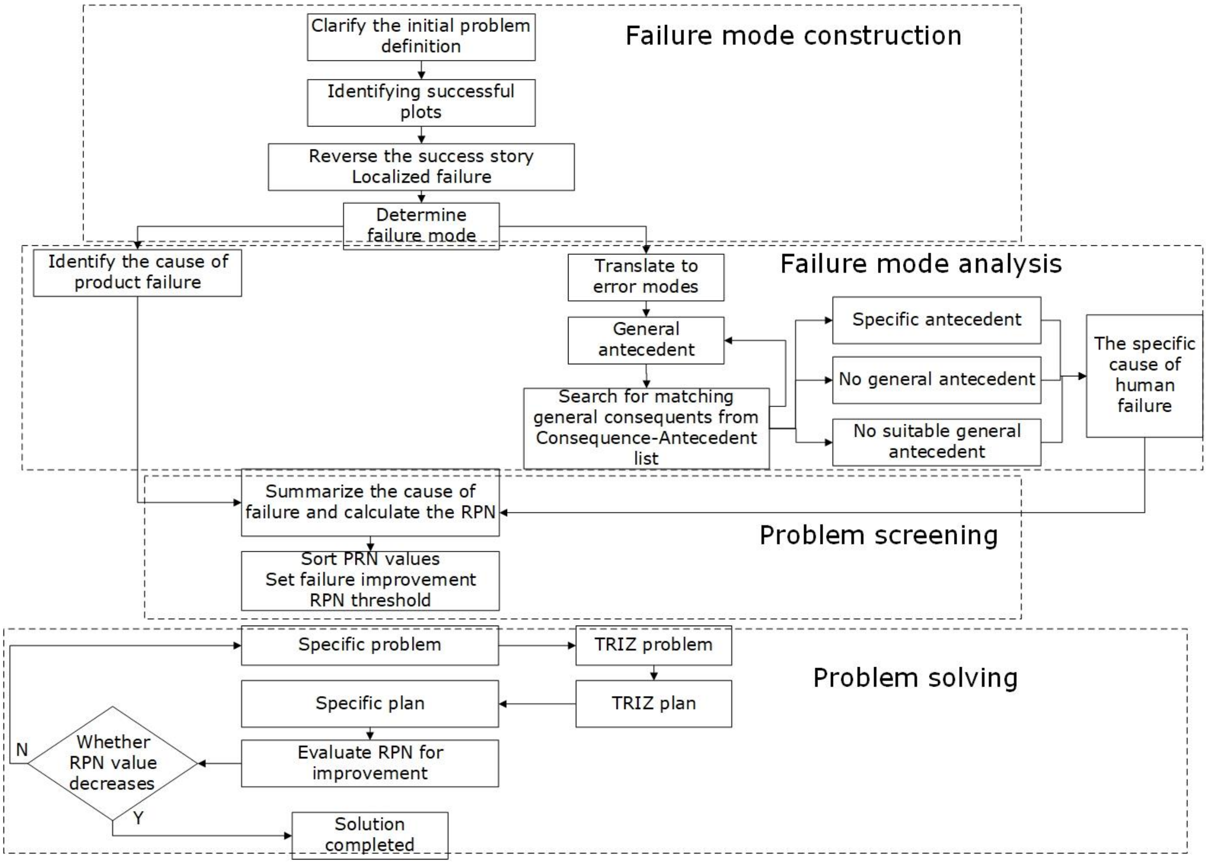

Figure 1: Flow chart of the proposed iACTC.

The method includes following four steps:

(1) Failure mode construction: Anticipatory failures are used to form failure modes from the problem definition to the initial problem identification in an existing product. It is required to collect additional related problems of the product, such as disadvantages or side effects of the product, and operation environments of the product. These additional problems will be

comprehensively and objectively understood to help identify product failure problems. Product functions and target effects are searched to find possible failures and modes. If a failure is not obvious, the mode will be aggravated and exaggerated to make it worse for the easy problem identification. For example, when a particular failure takes place at a point, or in some parts of the surface or volume, the amplified search of the problem should include the entire surface or volume. When the failure occurs rarely or from time to time, we should amplify possible failures and modes repeatedly or constantly. The problem formulation is then converted into a creation process to make the problem vivid and stimulate an inventive thinking [25]. The purpose of failure predictions is to find all possible failure modes as much as possible. In order to achieve this goal, we use the principles of "absolute" and "comprehensive" with a risk priority number to screen failures to eliminate those that are unlikely to occur.

(2) Failure mode analysis: This is to find causes of product failures. A cognitive reliability and error analysis method is used to analyze human factors based on eight types of failure modes including time, duration, force, speed, direction, distance, sequence and object. For example, force denotes the power or effort that is applied to an action. If too much force is used, equipment may malfunction or break. If insufficient power is used, the action may not have any effect [7]. An antecedent branch of causes is used as a consequence. The possible general antecedent and specific antecedent are selected in a consequence-antecedent chain list. There are three types of corresponding general antecedents including human-related causes, technology-related antecedents, and organization-related antecedents. When multiple antecedents are selected, a new branch is formed. If there is no reasonable antecedent available, the analysis of this branch is stopped. For the branch of a specific antecedent where the analysis cannot be continuous, a cause is selected again in the consequence-antecedent linked list to continue the analysis until all branches are analyzed. The analysis principle and stopping rules can be illustrated by the following example. If an observed failure mode is time, the time group lists six general antecedents including communication failure, faulty diagnosis, inadequate plan, inadequate procedure, inattention and observation missed [7]. The search is now switched to look for antecedents. For the case of “observation missed”, there are five general antecedents and four specific antecedents for a general consequence of observation missed in collective observations. If a specific antecedent (such as information overload) is selected as the most likely candidate, the search ends. The classification scheme is structured so that specific preconditions do not appear anywhere under normal circumstances as the influence of other factors. The analysis will be continuous until all branches are analyzed.

(3) Problem screening: Based on causes found by the AFD method, the severity of failure problems can be identified. A risk priority number (RPN) is introduced for influence degrees of the failure causes as follows.

$$RPN_i = S_i \times O_i \times Di \qquad (1)$$

where S_i, O_i and D_i represent factors of severity S, occurrence O, and difficulty detection D of the ith failure cause, respectively. S is determined through the analysis of degrees of the failure impact, O is decided by probability of the occurrence of the failure cause, and D is determined based on available existing failure detection methods and control measures. Their value ranges are from 1 to 10. RPN is used in ranking failures for actions. Table 1 shows severity, occurrence, and detectability scales to classify failure modes based on standard SAE-J 1739 [18].

(4) Problem solving: Identified failure causes are then converted into standard TRIZ problems. TRIZ tools shown in Table 2 are used to find solutions to avoid or reduce causes. For example, a big sized umbrella can protect from rain, but it is too cumbersome to carry around. The protection and convenience present a physical contradiction. 40 inventive principles of TRIZ tools recommend methods of the problem transformation to find solutions [14]. Each specific problem can be solved in accordance with restrictions of the problem using interdisciplinary scientific knowledge [8]. According to results of the contradiction analysis of a problem, inventive principles can be applied to search solutions of the problem if there is a technical conflict of the system. The separation principle can be used if there is a physical conflict. At the same time, according to the substance-

field analysis of the system, substance-field models and standard solutions can be developed for related problems [20]. The RPN value of the improved solution is compared with the original RPN to evaluate the improvement. A decreased RPN indicates that the failure possibility is reduced. The above process is repeated until the failure problem is improved.

Severity (S)	*Occurrence (O)*	*Detection (D)*	*Rating*
Hazardous without warning	Very high failure is almost inevitable	Absolute uncertainty	10
Hazardous with warning	Very high failure is almost inevitable	Very remote	9
Very high	High repeated failures	Remote	8
High	High repeated failures	Very low	7
Moderate	Moderate occasional failures	Low	6
Low	Moderate occasional failures	Moderate	5
Very low	Moderate occasional failures	Moderately high	4
Minor	Low relatively few failures	High	3
Very minor	Low relatively few failures	Very high	2
None	Remote failure is unlikely	Almost certain	1

Table 1: Severity, occurrence, and detection rating scales.

Analytical tools	Function (and object) analysis Contradiction analysis Ideality solution analysis Resource analysis
Solving tools	Inventive principles Contradiction matrix (and inventive principles) Separation principles Substance field analysis Evolution analysis Effects database Standard solutions Trimming

Table 2: TRIZ tools.

In summary, the proposed method starts at the failure mode to find specific causes of failures according to different antecedents and consequences. The method integrates the product failure modeling and human factor analysis methods. A product can be comprehensively searched for causes of failures to improve the product reliability. The method actively creates failures, performs product failure analysis and human factor reliability analysis on the created failure modes. A risk priority number is introduced to screen failure causes for solutions. TIRZ tools are used to analyze the causes to reduce or avoid product failures. The method can not only analyze product failures that occurred before, but also identify unobvious and possible failures. The proposed method provides a structured and creative complete solution for the solution discovery of failure problems.

3 CASE STUDY

DC FF-F30B is a pneumatic nail gun product as shown in Figure 2. It is widely used in the operation of house building. We use this product as an example to verify the proposed iACTC method to find failure problems for the product improvement. The case study is conducted following the proposed methods in following four steps.

(1) Failure mode construction: Based on the working process of the pneumatic nail gun listed in Table 3, failures of the product were analyzed through inverting successful working stages into determining failure modes and locating failure areas. For the unobvious failure, the problem was enlarged. For example, the time of using the nail gun is exaggerated from a period of time to non-stop, or to make it worse that the nail hits the cavity to extend operations from several times to countless times.

(2) Failure mode analysis: Causes of product failures were searched based on failure modes identified in Table 4. After the failure mode was localized, the failure cause was analyzed by observing and analyzing parts involved in the failure and operations that caused the failure. The analysis results are shown in Table 5. For example, the failure mode of the spring-loaded gun clip cannot push the nail to the nozzle position. Parts involved in this failure mode are spring, nail clip, nails and nozzle position. To find possible effects of these parts on the failure mode to the specific cause of the failure, the CREAM analysis was performed to considering eight types of error modes of failure causes in different classification groups as listed in Table 6.

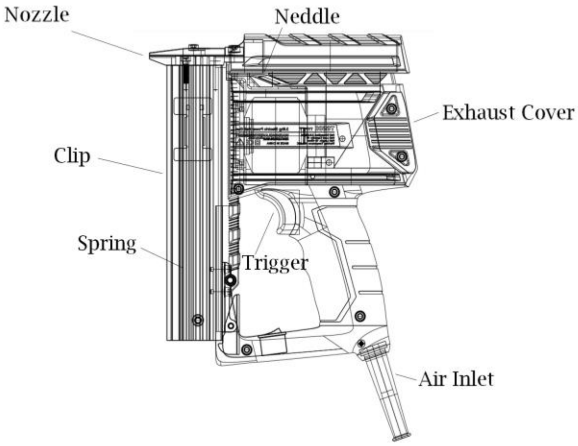

Figure 2: DC FF-F30B nail gun.

Work Stage	Working process

1.Gas storage stage	A spring-loaded gun clip pushes the nail to the nozzle position. The air compressor compresses the air and turns on the gas. The high-pressure gas fills the inner cavity of the handle.
2.Process stage	The high-pressure gas enters the cylinder by pressing the trigger. The high-pressure gas acts on the piston, the piston pushes the needle to the position of the nozzle, and the gun head shoots out a nail in the row of nails and nails the object.
3. Return stage	The switch is closed by releasing the trigger. Part of the air pushes the piston back, the remaining air is exhausted from the exhaust cover, and the next nail is pushed to the gun nozzle.

Table 3: Working process of the pneumatic nail gun.

Work Stage	Working process	Failure mode
1.Gas storage stage	A spring-loaded gun clip pushes the nail to the nozzle position.	A spring-loaded gun clip cannot push the nail to the nozzle position.
	The air compressor compresses the air and turns on the gas. The high-pressure gas fills the inner cavity of the handle.	The air compressor compresses the air and turns on the gas. The high-pressure gas cannot fill the inner cavity of the handle.
2.Process stage	The high-pressure gas enters the cylinder by pressing the trigger.	The high-pressure gas cannot enter the cylinder by pressing the trigger.
	The high-pressure gas acts on the piston.	The high-pressure gas cannot act on the piston.
	The piston pushes the needle to the position of the nozzle.	The piston cannot push the needle to the position of the nozzle.
	The gun head shoots out a nail in the row of nails and nails the object.	The gun head shoots out a nail in the row of nails but not nails the object.
3.Return stage	The switch is closed by releasing the trigger.	The switch is still opened by releasing the trigger.
	Part of the air pushes the piston back.	Part of the air cannot push the piston back.
	The remaining air is exhausted from the exhaust cover.	Remaining air cannot be exhausted from the exhaust cover.

Table 4: Failure modes of the nail gun.

Work Stages	Failure Modes	Failure Causes
1. Gas storage	Spring-loaded gun clip cannot push the nail to the nozzle position.	1. Low nail groove manufacturing accuracy 2. Dust and outside matter entered in the nail groove. 3. Weak spring in the nail groove and reduced force. 4. Low nail manufacturing accuracy. 5. More than one nail is ejected as multiple collisions of

		the nail and inner wall of the cavity result in a large gap of the cavity.
	High-pressure gas cannot fill inner cavity of the handle.	1. Air leaks as unbalanced valve, aged O-ring rubber, low manufacturing accuracy, or poor sealing effect. 2. Air leaks as holes or trachoma cracks caused by the poor casting body. 3. Air leaks in the air vent as low manufacturing accuracy of the air inlet. 4. Air leaks in the cavity as damage of rectangular seal at the cylinder head.
2. Process	High-pressure gas cannot enter the cylinder by pressing the trigger	1. Damaged structure of the trigger valve rod. 2. Damaged the nylon valve seat at the trigger results in the damage of the board machine.
	High-pressure gas cannot act on the piston	1. Worn piston results lost connect of the piston and inner cylinder. 2. Air leakage causes the pressure difference between two sides of the piston.
	Piston cannot push the needle to the position of the nozzle.	1. Air leakage from gun body results in reduced pressure of high-pressure gas. 2. The seal was worn and the piston moved ahead. 3. Foreign matter at the firing pin prevents the firing pin from moving. 4. Multiple strikes of the firing pin result in the head of the firing pin being abraded and deformed. 5. Nail and inner wall of the cavity multiple collisions result in a large gap of the cavity, and to eject more than one nail.
	Gun head shoots out a nail in the row of nails, not target object.	1. Air leakage in gun body with insufficient pressure gas power for nail impact force. 2. Worn gun head and insufficient hardness. 3. Gun tip processing issues lead to low gun tip hardness. 4. Nails are not standard and not rigid enough.
3. Return	Switch is still opened by releasing the trigger.	1. Debris in the switch and the switch failed to close. 2. Worn O-ring at the switch assembly and the switch failed to close.
	Part of the air cannot push the piston back.	1. Air leakage from the gun body results in high-pressure air to leak out of the outer cylinder, which reduces the pressure and cannot push the piston back into position. 2. Worn contact area between the piston and the inner cylinder, and pressure small difference between two sides of piston, which cannot push the piston back.
	Remaining air cannot be exhausted from the exhaust cover.	Exhaust cover was blocked, air cannot flow.

Table 5: Analysis of failures.

CREAM Failure Mode	General antecedent	Failure causes
Direction	User related causes	Forgot to regularly check wear of firing pin and replace firing pin in time.
Object	Interpretation	User action when the nail groove of the nail gun blocked, and missed check it.
Time	Observation	No screw drop out of the nail slot observed, the nail slot stuck.
Sequence	Procedure	No lubrication before operation each time, components were not maintained in good conditions.
Duration	Working condition	Long-time operations without maintenance of the nail gun, components were not in good conditions.
Time	Observation	Switch was not checked for foreign objects, preventing the switch functioning.
Force	Temporary user related causes	Tired users due to long-time operations. Deviation of directions of holding handle in operations causes the nail to shoot wrongly.

Table 6: CREAM analysis of the nail gun.

(3) Problem screening: The failure causes were summarized. RPN values were decided using Eqn. (1) and ranked for all failure causes in Table 7.

Problem	Severity	Occurrence	Detection	RPN
AFD analysis results				
1. Low nail groove manufacturing accuracy results in stuck when nail is pushed out.	3	2	3	18
2. Dust and outside matter entered in the nail groove result in the nail groove work improperly.	7	8	5	280
3. Low spring energy and push force for the nail not being properly ejected.	6	7	7	252
4. Low nail manufacturing accuracy results in the nail not coming out properly.	5	4	5	100
5. Nail and inner wall of the cavity multiple collisions result in a large gap of the cavity, and more than one nail ejected.	7	8	6	336
6. Air leaks as balanced valve, aged O-ring rubber or low manufacturing accuracy, resulting in poor sealing effect.	6	6	6	216
7. Air holes or trachoma cracks caused by casting of the gun body to leak air.	4	3	5	60

8. Low manufacturing accuracy of the air inlet leads to air leakage in the air vent.	6	4	5	120
9. Damaged rectangular seal at the cylinder head, insufficient air leakage in the cavity.	5	5	6	180
10. Damaged structure of the trigger valve rod, unresponsive trigger.	4	4	5	80
11. Worn piston, lost contact of the piston and inner cylinder, air leakage causes the pressure smaller difference between two sides of piston, which cannot push the piston	5	3	4	60
12. Bloacked exhaust cover, remaining air cannot flow.	5	5	3	75
13. Foreign matter at firing pin prevents the firing pin moving.	7	5	5	175
14. Multiple strikes of firing pin	6	7	6	252
CREAM analysis results				
1. Forgot to regularly check the wear of the firing pin and replace the firing pin in time.	5	5	3	75
2. User mistake to check blocked nail groove.	6	6	3	108
3. No screw drop out of the nail slot, the nail slot stuck.	7	3	3	63
4. Not lubricating before using each time, components cannot be maintained in good conditions.	6	9	5	270
5. Long-time operation without maintenance, components cannot be maintained in good conditions.	6	5	4	120
6. Switch is not checked for foreign objects, prevents the switch from functioning.	7	4	2	56
7. Tired user due to long-time operations. Deviation of directions of holding handle in operation causes the nail to shoot wrongly.	6	5	5	150

Table 7: RPN of the failure analysis.

Threshold values were decided according to severity of product problems. Details of the problem screening are as follows. ① The dust and outside matter entered in the nail groove result in the nail groove not coming out properly. ② The cause of the spring in the nail groove for a long time is that the elastic potential energy is low, and the elastic force is reduced for the nail not being properly ejected. ③ Cavity multiple collisions of the nail and inner wall result in a large gap of the cavity, and more than one nail ejected. ④ Multiple strikes of the firing pin result in head of the firing pin being abraded and deformed, and the nail groove not coming out properly. ⑤ Not lubricating before operation each time results in that gun components cannot be maintained in good conditions.

(4) Problem solving: Conflicts were first identified to solve causes of failures using the contradiction analysis. For example, in order for the nail slot to eject a nail smoothly, the spring force needs to be large enough, but the impact of the ejected nail and inner wall of the cavity leads to a large gap, and more than one nail is ejected. As a result, the striker hits two nails at the same time, and the nails are stuck. At this time, the spring force needs to be reduced. That is, the spring force in the nail groove must be adjustable for "large" and "small". The type of conflict is a physical conflict. In TRIZ theory, the resolution of physical conflicts is based on the separation principle [23]. Through the contradiction analysis of failure causes, the separation principle of TRIZ was selected for the solution to avoid the cause. Similarly, all causes of the failure modes were analyzed to search solutions.

According to the conditional separation principle, solution 1 uses the mechanical energy of dynamic gear transmission to replace the static spring elastic potential energy. The gear transmission is the maximum elastic force when the nail is squeezed out, and the elastic force is small under other conditions. The improved partial structure diagram of the nail gun is shown in Figures 3 and 4.

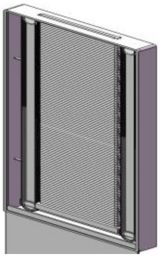

Figure 3: Partial structure of the nail groove.

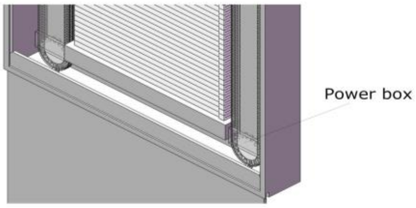

Figure 4: Detail structure of the nail groove.

According to the spatial separation principle, solution 2 is that the nail shooting track is separated from the vertical nail row cavity, and the improved partial structure diagram of the nail gun is shown in Figures 5, 6, and 7.

Comparing with solutions 1 and 2, solution 1 is complicated with the additional transmission power. The gear system needs a new motor to provide power. It requires the frequent start and shutdown, a large motor, and large energy consumption compared to the spring system, and it is also inconvenient to carry. In addition, in solution 1, the gear chain may be blocked by entering foreign objects during use. In solution 2, the nail groove and nail exit channel are separated to avoid foreign objects from being blocked. Therefore, solution 2 was selected for the nail slot to eject nail smoothly.

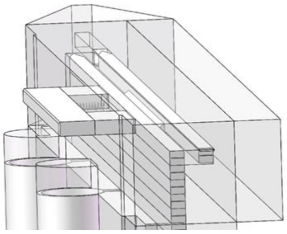

Figure 5: Partial structure of the nail gun.

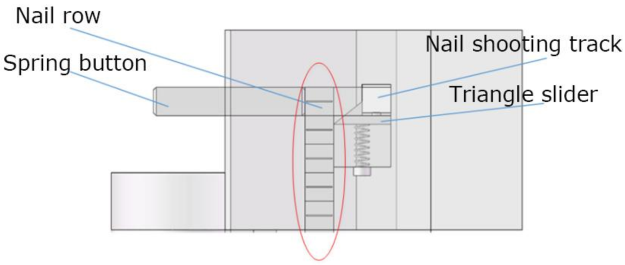

Figure 6: Side view of the nail gun.

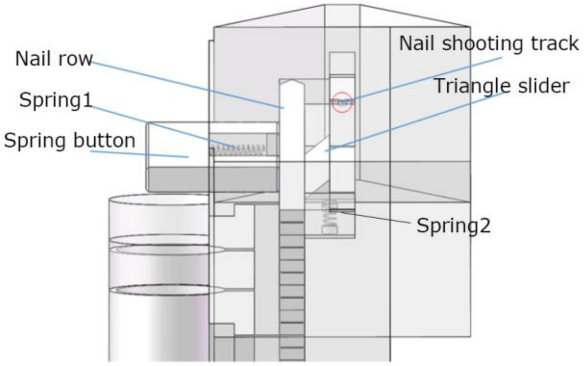

Figure 7: Perspective view of the nail gun.

Working steps of the nail gun are as follows: connection of the air source - pressing the spring button - pushing a nail out of the nail row - squeezing out the triangle slider - entering the nail shooting track - resetting the spring button - moving the nail row up under the action of the vertical spring - pushing the second nail to the top - repeat the previous steps.

This solution improves that the nail slot cannot smoothly release the nail as follows: ① The nail shooting track is separated from the vertical nail row cavity for reducing the wear of the shooting nail track top. ② It effectively reduces dust entering the magazine and probability of blocking the nail shooting. ③ The pressure switch is triggered after the nail is driven, and the spring switch is controlled to push the next nail into the nail track, ensuring continuous operations of the nail gun.

For the gun lubrication before operations, a technical conflict was identified through the contradiction analysis. The solution of technical conflicts is searched using TRIZ inventive principles. By applying No.10 inventive principle, preliminary action, the use of the step type can prevent the oil leakage in advance during the oil discharge process. The air inlet is changed into a hollow to store oil. An oil injection hole is added at the bottom and an oil switch is added to the side as shown in the air inlet in Figure 8. When the air pipe is connected, the air pipe squeezes out the oil switch to push it down. A small amount of oil is pushed out by a large baffle and into the inner wall of the air inlet. The large baffle closed to the pipe wall can block the oil outlet hole to ensure that the oil will not leak. When the air pipe is removed at the end of an operation, the oil outlet switch is reset under the spring action to ensure the normal sealing of the internal lubricating oil. A process of the automatic lubrication is shown in Figure 9. RPN values of the solutions are significantly reduced compared to the original RPN as shown in Table 8, which proves that the proposed method is feasible and effective.

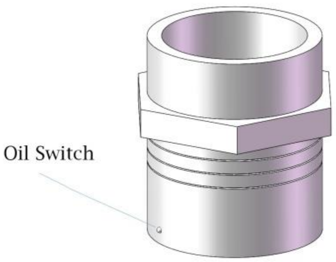

Figure 8: Nail gun air inlet.

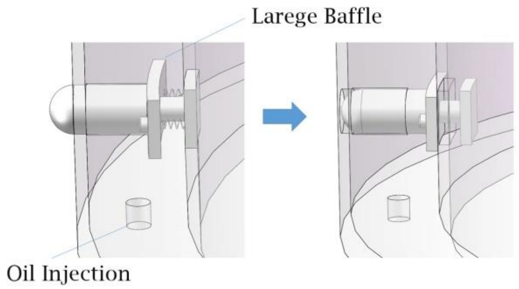

Figure 9: Process of automatic lubrication.

Product problem	Improved Severity	Improved Occurrence	Improved Detection	Improve dRPN	Original RPN
1. Nail groove cannot work properly as dust entered in the nail groove.	5	4	3	60	280
2. Nail cannot be properly ejected as low spring force.	6	5	4	120	252
3. More than one nail is ejected as the large gap of the nail and inner wall of the cavity.	5	3	4	60	336
4. Head of the firing pin is deformed and nail groove cannot work properly as multiple strikes of the firing pin.	7	6	5	210	252
5. Components are not maintained in good conditions as the lack of lubrication before operations.	3	1	4	12	270

Table 8: Evaluation of solutions.

4 CONCLUSIONS

This paper introduced as iACTC method by integrating AFD, CREAM and TRIZ for the product reliability and failure analysis. A risk priority assessment scheme was proposed to rank failure problems. TRIZ tools were applied to reduce causes of identified failures. The construction of the proposed failure analysis model is a step-by-step process of the complete product failure analysis. The combination of product failure analysis and human factors enables the comprehensive and complete analysis. The generated solutions have improved the product reliability to reduce failure problems. The feasibility of the method was verified by the failure analysis and design improvement of the pneumatic nail gun. The current solutions are only proposed in the concept design. Real applications of the concepts for the product improvement will be implemented to validate the solution.

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