Title:
Cognitive Reliability and Error Analysis based on Anticipatory Failure Determination

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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 analyze and identify problems in product design, and reduce failures of the product. Therefore, the failure analysis is indispensable in product development to ensure the product quality and reliability. Traditional methods of the failure analysis are usually based on designers' experience [1]. An anticipatory failure determination (AFD) method was commonly suggested to improve the failure analysis [2]. Advantages of AFD include the innovative process and freedom for exploration of the failure potential compared to the traditional failure mode and effects analysis (FMEA) method [3]. It can greatly enhance the failure prediction and failure analysis of product. Combined AFD and functional resonance analysis methods (FRAM) can analyze correlations of fault events effectively.

Product application is a process of the integration of human, machine and environment. Human factors should be considered in the product failure analysis. For the failure prediction using AFD, most of the researchers used AFD and other methods to improve the analysis accuracy, but they only considered possible failures of the product itself, human factors were rarely discussed. An AFD3 template was proposed using a zigzag process in different domains of product design [4]. However, the AFD3 template requires proficient design knowledge to clarify the input and output of the product, which undoubtedly increases designers' workload to search causes of failures. This paper introduces a cognitive reliability and error analysis method (CREAM) based on the AFD method. CREAM is a representative analysis method of the second-generation human reliability analysis (HRA) method. It can be simply used in a convenient way to organize categories that describe possible causes and effects of human actions. The method can track causes of failures based on failure modes to predict failures. The failure causes are found according to the classification method of CREAM, which improves the AFD method to find potential failure modes and causes by considering human factors. TRIZ tools are introduced to avoid the failure causes. A CREAM model is built for the failure analysis of a pneumatic nail gun product.

Main Idea:
Method: AFD uses the reverse thinking for a state of product success to search all possible failure modes and causes, which actively creates failures to predict problems in the product application. CREAM 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. A product is comprehensively searched for causes of failures to improve the product reliability. The

TRIZ tool is used to take actions for the failure cause. The proposed method is named as iACTC (Integration of AFD, CREAM and TRIZ) to be applied in the analysis of product failures for the product improvement. The method includes following four steps:

(1) Failure mode construction: AFD is used to build failure modes from the problem definition to the initial problem identification in an existing product. Product functions and target effects are searched to find possible failures and modes. If the failure is not obvious, the mode will be aggravated and exaggerated to make it worse for the easy problem identification.

(2) Failure mode analysis: The failure mode is analyzed to find failure causes of the product. CREAM is used to analyze human factors based on 8 types of failure modes including time, history, power, speed, direction, distance, sequence and target. Corresponding causes are searched for human-related, technology-related, and organization-related problems.

(3) Problem screening: After finding causes of failures, a risk priority number (RPN) is introduced for influence degrees of the failure causes as follows.

$$RPN_i = S_i \times O_i \times D_i \quad (1)$$

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. Their value ranges are from 1 to 10. RPN is used for ranking failures for actions.

(4) Problem solving: Identified failure causes are then converted into standard TRIZ problems. The TRIZ tool is used to find solutions to avoid or reduce the causes. The RPN value of the improved solution is compared to 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. A flow chart of iACTC is shown in Figure 1.

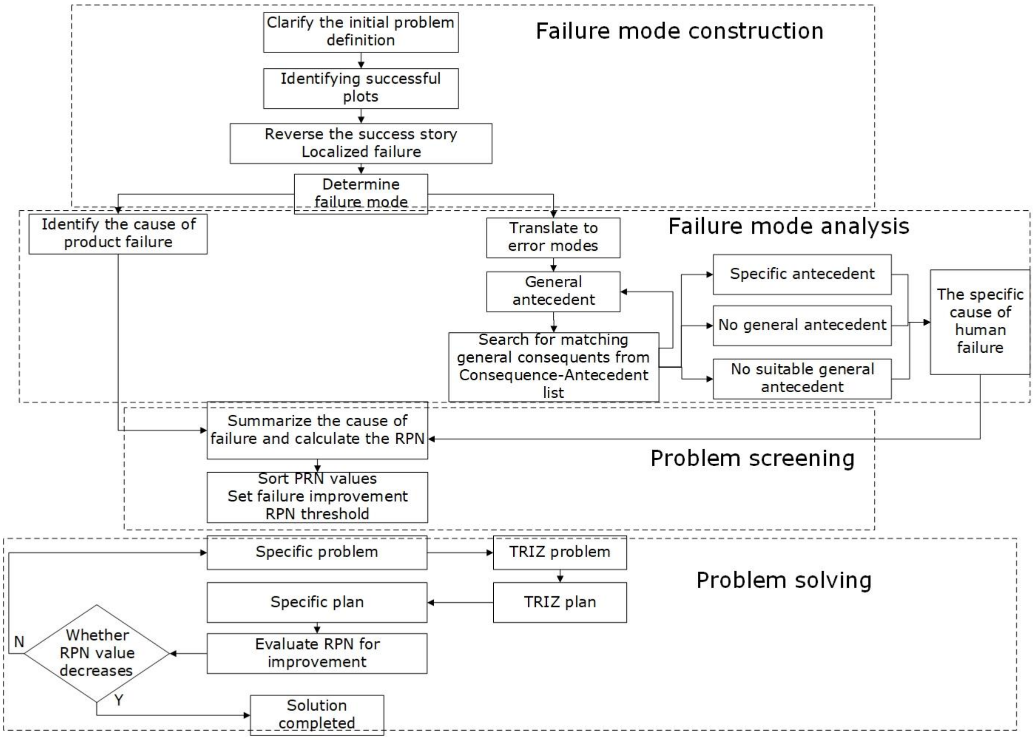

Fig. 1: Flow chart of the proposed iACTC.

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 causes for the product improvement.

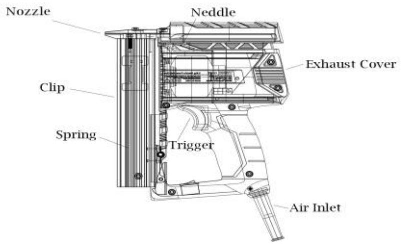

Fig. 2: DC FF-F30B nail gun.

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. A nail is pushed to the gun nozzle for the next use.

Tab. 1: Working process of the pneumatic nail gun.

(1) Failure mode construction: Based on the working process of the pneumatic nail gun listed in Table 1, Failures of the product were analyzed through inverting the successful working stage to determine failure modes and locate 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 so that the nail hits the cavity to extend operations for several times.

(2) Failure mode analysis: Causes of product failures were searched based on failure modes identified in Table 2. The CREAM analysis was performed to considering 8 types of error modes for failure causes of different classification groups to find corresponding failure causes.

(3) Problem screening: The failure causes were summarized. RPN values were calculated by Eqn. (1) and ranked for all failure causes. Threshold values were decided according to the 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) The nail and inner wall of the cavity multiple collisions result in a large gap of the cavity, and more than one nail ejected. 4) Multiple strikes of the firing pin result in the head of the firing pin being abraded and deformed, and the nail groove not coming out properly. 5) Not adding lubricating oil before using each time results in that the gun components cannot be maintained in good conditions.

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 cannot nail 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.

Tab. 2: Failure modes of the nail gun.

(4) Problem solving: Conflicts were first identified to solve causes of failures using the TRIZ tool. 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". Through the contradiction analysis of failure causes, the spatial 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.

Aiming at the problem that the user did not add the lubricant before using, the nail gun air inlet was improved. The air inlet is changed into a hollow, and the internal oil is stored. An oil injection hole is designed at the bottom, and an oil switch is added to the side, as shown in the nail gun air inlet in Figure 3. 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 closes to the pipe wall can block the oil outlet hole and ensure that the oil will not leak. When the air pipe is removed at the end of the work, the oil outlet switch is reset under the action of the spring to ensure the normal sealing of the internal lubricating oil. The process of automatically adding lubricant is shown in Figure 4. RPN values of the solutions are significantly reduced compared to the original RPN as shown in Table 3, which proves that the proposed method is feasible and effective.

Conclusions:

This paper integrated the AFD and CREAM methods to search for causes of failure modes. The TRIZ tool was used to find solutions to avoid or reduce the failure causes. The proposed iACTC failure analysis model improved the failure analysis effectively. The feasibility of the proposed method was verified in the case study of the failure analysis of a pneumatic nail gun. Further work will test the solution in actual applications of the product.

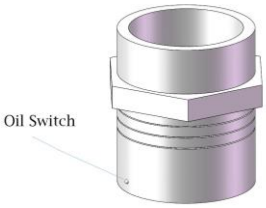

Fig. 3: Nail gun air inlet.

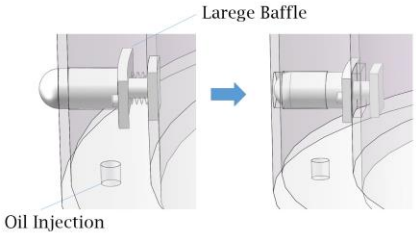

Fig. 4: Process of the automatic lubrication.

Product problem	*Improved Severity*	*Improved Occurrence*	*Improved Detection*	*Improved RPN*	*Original RPN*
1. Dust and outside matter entered in the nail groove results in the nail groove not coming out properly.	5	4	3	60	280
2. The spring in the nail groove for a long-time results in that the elastic potential energy is low, and the elastic force is reduced for the nail not being properly ejected.	6	5	4	120	252
3. The nail and inner wall of the cavity multiple collisions results in a large gap of the cavity, and more than one nail ejected.	5	3	4	60	336
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.	7	6	5	210	252
5. Not adding lubricating oil before using each time results in that components cannot be maintained in good conditions.	3	1	4	12	270

Tab. 3: RPN values of solutions.

References:

[1] Chybowski, L.; Gawdzińska, K.; Souchkov, V.: Applying the Anticipatory Failure Determination at a VeryEarly Stage of a System'S Development: Overview and Case Study, Multidisciplinary Aspects of Production Engineering, 2018, 1(1), 205-215. https://doi.org/10.2478/mape-2018-0027

[2] Sunday, E.: Extension and modification of anticipatory failure determination approach based on I-TRIZ, University of Stavanger, Norway, 2014.

[3] Da Silva, R-F.; De Carvalho, M-A.: Anticipatory Failure Determination (AFD) for Product Reliability Analysis: A Comparison Between AFD and Failure Mode and Effects Analysis (FMEA) for Identifying Potential Failure Modes, Advances in Systematic Creativity, Palgrave Macmillan, Cham, 2019:181-200. https://doi.org/10.1007/978-3-319-78075-7_12

[4] The Innovation Tools Handbook, Volume 3: Creative Tools, Methods, and Techniques that Every Innovator Must Know. CRC Press, 2016.