Triz tools to enhance risk management

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Abstract

This paper discloses an innovative step by step method based on TRIZ tools used according to the general approach suggested by FMEA. The aim of the proposed method consists in building an improved risk management model for design and to enhance the capability of anticipating problems and technical solutions to reduce failure occurrence. The method adopts tools used to model the system, such as functionality, Su-Fields models, resource evaluation and tools dedicated to problem solving such as standard solutions. The resulting method allows a better definition of the system decomposition and functioning and provides a sharp definition of the events and failures potentially occurring into the system, which is not provided by standard FMEA. Moreover, the high importance given to resources since the beginning of the method is extremely effective for understanding system evolution and to generate resource-based solution to problems dealing with product risk. The overall method has been developed so that technicians are not supposed to have a high level expertise in TRIZ tools. In order to evaluate the method it was tested with students with basic level TRIZ education and some application with industrial case studies were performed.

Keywords

Risk Management, FMEA, TRIZ, ENV model, Su-Field.

1 INTRODUCTION

As product development cycles shrink and as products themselves grow more and more complex, managing risk in the product development process becomes increasingly critical. Preventing product failures in the early stage of product design, by adopting a proactive approach, is much more effective rather than reacting to a non-conformance. Actually, once reached the end of pipe most of technical solutions are already taken and any change highly affects costs. Some tools have been developed to foresee, assess and prevent product failure or malfunctioning mainly concerning design phase and production process. By the way companies are still quite reluctant to adopt risk management tools, especially for the design process whether it is not imposed by standards or customers' requirements. Moreover it is a wrong common understanding that reliability is only based on mathematics and statistics and it should be relegated to logistics or maintenance departments [1]. The main reason for companies to avoid risk management activities relies on the high time needed and uncertainty of the quality of results achieved with traditional tools. Actually, since products requirements constantly increase and acceptable failures rate drops dramatically, available tools to face risk management are not getting better quickly enough. The paper shows some results achieved within a research activity on this topic. In particular the goal is to make risk management tools more appealing for companies by trying to provide better results involving fewer resources.

The paper in §2 shows a short state of the art concerning reliability engineering and risk management focusing on Failure Mode and Effect Analysis (FMEA) and TRIZ. The third paragraph describes the new method proposed to prevent design-caused failures. In §4 a case study shows a practical application of the method performed by students at the end of a TRIZ course at University of Bergamoo. Finally, some conclusions about this work and future activities on this topic are drawn.

2 BACKGROUND

2.1 Reliability Engineering

A deterministic reliability analysis process is built on the prevention of failures and the understanding of how and why failures occur. To effectively minimize the occurrence of failures, designers should have an excellent knowledge of the failure mechanisms which can be caused by incorrect design, manufacturing, or can be introduced by outside of the system (i.e. by users or environment). In any case dealing properly with failures involves a clear understanding of the physics of failures. When failure mechanisms are know and appropriately considered in each step of product lifecycle they can be minimized (preventive approach) or the system can be protected against them (compensative approach) through careful engineering measures [2].

Risk Management is a crucial part of reliability design and an effective application to every day company life bring several benefits [3]:

- Formal Methodology: Risk Management is a structured tool for day-to- day decision-making.
- Formal Procedures: When unanticipated problems occur (such as external events that were not foreseeable), Risk Management can help keeping on top of problem issues and efficiently contribute to their solution.
- Added Value: A single averted risk on a product or operation can pay for many, if not all, Risk Management activities. Recent examples exist where customers have used the contractor's proposed Risk Management process and evaluation of candidate risks as a key evaluation parameter in competitive procurements. Thus, if performed effectively, Risk Management may not only help a project avert potential performance,

cost, and schedule impacts, but it may also help win a contract.

- Forward-Looking: Risk Management provides leverage on the front-end of a project and helps to avoid costly performance, cost, and schedule problems downstream.

On the other hand several issues are still wide open to further innovation and solutions to critical points are requested. Lack of knowledge to understand all potential failure modes can be somehow compensated by experience for existing products but it is crucial each time a new technical solution is adopted. This may slow down the innovation process and contribute in failing to attend the rapid changes requested by competition. Once drawn the way failures may happen, next critical point concerns how to find the way to assess risks features. For instance, it's generally recognized that using past performance or historical data to identify probability of occurrence of risks is not really working all that well. Moreover, existing state of the art tools do not yet overcome the need for a number of skilled people thinking about risks for a considerable and, sometimes unpredictable, amount of time.

2.2 Risk management tools for product design

Reliability engineering first appeared for aerospace applications and models to understand and handle risk and prevent failures were developed. Several improvements have been carried out so far and tools are still refining. By the way the underlying logic is so brilliant that it still is appreciated after almost half a century from the first application. The complimentary top-down Fault Tree Analysis (FTA) approach and bottom-up Failure Mode and Effect Analysis (FMEA) are still used nowadays, as well as Hazard and Operability analysis (HAZOP) and What-if checklist.

FTA [4] is the most commonly used technique for causal analysis in risk and reliability studies. It is a top-down approach to failure analysis, starting with a potential undesirable event (accident) called a top event, and then determining all the ways it can happen. The analysis proceeds by determining how the top event can be caused by individual or combined lower level failures or events and the causes of the top event are connected through Boolean gates. FTA leads to improved understanding of system characteristics. Design flaws but also insufficient operational and maintenance procedures may be revealed and corrected during the fault tree construction. FTA model is frequently built together with a FMEA model because they give different perspective on the same system.

Failure Modes and Effects Analysis [5,6], is an organized approach to identify failure modes that could either directly result in, or contribute significantly to, the identified accident scenario by a multi-discipline team familiar with the product or process. The failure modes and failure causes are identified initially and are used as the starting point for the FMEA. A design FMEA is an analytical technique utilized primarily by a Design Responsible Engineer and his / her team as a means to assure that, to the extent possible, potential failure modes and their associated causes/mechanisms have been considered and addressed.

An FMEA can be described as a systemized group of activities intended to:

- Recognize and evaluate the potential failure of a product or a process and its effects,
- Identify actions which could eliminate or reduce the chance of the potential failure occurring, and
- Document the process. It is complementary to the design process of defining positively what a design must do to satisfy the customer.

FMEA outcome is a spreadsheet listing all potentially failing elements, failure modes, effects and severity of failure modes, their causes and occurrence. Together with failures detection information these data are used to calculate a risk index called Risk Priority Number (RPN) which can be used to rank failures and adopt preventive actions. After design improvements the failure analysis should be performed again to ensure RPN values are below the chosen threshold.

HAZard and OPerability analysis (HAZOP) [7], is a structured technique whose goal is to determine and evaluate failures from the point of view of safety of men and machine in contact with the system. It requires a multi-discipline team performing a systematic study of a process using guide words to discover how deviations from the design intent can occur in equipment, actions, or materials, and whether the consequences of these deviations can result in a hazard.

The results of the HAZOP analysis are the team's recommendations, which include identification of hazards and the recommendations for changes in design, procedures, etc. to improve the safety of the system. Deviations during normal, startup, shutdown, and maintenance operations are discussed by the team and are included in the HAZOP.

2.3 FMEA integrations

Along five decades of applications and refinements a number of synergies, more or less effective, have been proposed to integrate FMEA technique with other methodologies used in product development, production, and maintenance. Integration has the goal to create a synergy between two ways of performing product/process design to gather:

- A more robust and quicker approach.
- A better flow of product/process knowledge.
- An easier introduction of new method and tools within the company.

FMEA most frequent and effective contamination has been with Quality engineering because of the strict interaction with reliability issues of product and production processes.

In [8] the relationship between major quality tools such as quality function development (QFD), FMEA, design of experiments (DOE) and statistical process control (SPC) is analyzed through an extensive review of the literature and the concurrent quality engineering philosophy, and a basic structure for the integration of quality tools is presented.

QFD and FMEA are both effective tools utilized in the course of product development, however there are potential limitations if they are used separately. As they possess the characteristic of sharing the bottom database in an integrated quality management system, their integration may solve this issue. Based on an elaborate analysis of advantages and disadvantages of QFD and FMEA, [9] proposes an integration model which four kinds of FMEA are incorporated into the four phase model of QFD.

There exist also several cross fertilization examples of FMEA and others technique outside reliability and quality context.

In [10] a new approach is proposed to enhance FMEA capabilities through its integration with Kano model. In almost all of the existing resources of failure mode and effect analysis (FMEA), "severity" is being determined from the designers' point of view, not from the customers' side. This evolves the current approaches for determination of severity and "risk priority number" (RPN) through classifying severities according to customers' perceptions.

Some efforts have been done also to merge more than two methods as shown in [11] where FMEA, QFD and TRIZ are the ingredients of a product development process.

2.4 TRIZ and FMEA

TRIZ is the most comprehensive systematic innovation and creativity methodology ever developed. Its main goal is to solve unconventional problems and to forecast technologies and future products, but it also provides a method to face reliability issues. By means of the Subversion Analysis concept TRIZ can help in those situations where an unexpected problem has occurred, and where we don't know the source or cause of the problem.

Subversion Analysis [12] also implemented as Anticipatory Failure Determination AFD [13] has several parallels with established methods like FMEA, HAZOP, or fault-tree analysis. The main difference is that it forces users to take a much more proactive approach to finding causes of problems. As a consequence, systems designed with this approach are less vulnerable to unpredicted failures. The logic of Subversion Analysis relies on finding all the ways to destroy the system we are designing. After this task we can much more easily design the system so that those modes of failure are eliminated or, at least, taken into account when implementing corrective actions.

Subversion Analysis is about inventing failures. In this sense it has simply capsized the inventive problem solving: if we can invent a failure then we can use other TRIZ tools to eliminate it. Subversion Analysis is typically carried out as a systematic process.

The key steps in the process involve the two inversions of the problem; firstly to allow us to 'invent the failure' (how would I design a system that failed in the way my system actually has), and then to re-transform the invented failure into a means of preventing the failure in the future.

Main steps of a generic Subversion Analysis process are:

1) Problem definition;

2) Formulation of inverted problem;

3) Define function;

4) Identify failure modes;

5) Describe effect;

6) Determine cause;

7) Identify failure hypothesis;

8) Search for solution.

In the followings Subversion analysis basic logic will be used and inversion of the problem will be performed, by the way the paradigm will not follow classical TRIZ way of performing failure determination.

3 NEW PARADIGM FOR RISK MANAGEMENT

This paragraph shows the new paradigm developed to manage the risk of product failure or malfunctioning. The underlying philosophy corresponds to the Design FMEA logic of defining failure modes evaluating criticalities and risks. By the way some new steps are introduced to bring benefits to the whole process. The procedure starts with a general understanding of system functionality. This is not trivial and avoids bad understanding and misleading formulation of the real design intent. The procedure maintains the bottom up logic of FMEA and system is analysed starting from its components and their negative effects. Basic modelling tools are introduced to improve system understanding and to gather a better list of potential malfunctioning without involving several experts. The evaluation is performed in order to ease as much as possible the following step of problem solving with the goal of reduce or eliminate product weakness.

In the followings each step is shortly described and then the whole procedure will be applied to a case study to show a real application.

3.1 Step 1: Identify Primary Function

The use of Energy Material Signal (EMS) [14] and Element Name Value (ENV) [15] models to the whole technical system helps defining its overall primary function that otherwise could be misunderstood. EMS model suggest assessing the variation in the flux of energy, material and signal/information in order to determine what the system really stands for. EMS provides a clear description of any kind of technical system without the need of going into details. ENV model describes the system by means of its capability to change the Value of one or more Features of the Element, turning it from Object to the desired Product (Figure 1).

Figure 1: ENV model to define Primary Function.

3.2 Step 2: Define Elements and Effects

After defining the Primary Function the technical system is divided into elements being either components of the technical system, elements of the super system or fields, according to a standard multiscreen resource analysis. Initially, the element list is built taking into account every single element not to miss the chance of finding all failure modes. In the following steps some elements will not be considered any more in order to speed up the analysis. Once elements are defined for each of them a list of effect is created by experts of the product development process. Since our final goal is building a set of failure modes, negative effects must be considered as well (Figure 2).

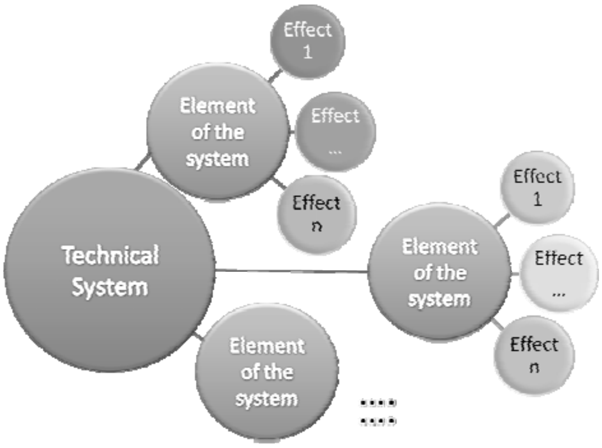

Figure 2: Elements an negative effects tree.

3.3 Step 3: Model Effects with ENV model

Once elements (including fields) and related effects are completely defined it is required to assess product risk according to FMEA criteria. This means that all potential failure modes must be identified. ENV model is used again but now focusing on each single element describing the effects in terms of features and values of each feature. At first, to describe the design intent, nominal (design) values are considered, afterwards values are decrease and increased to extreme values and emerging conditions are analysed as potential failure modes (Table 1).

Element	Name (feature)	Value DESIGN	Value REDUCED	Value INCREASED
Wire	Section	10 mm^2	0,1 mm^2	1 m^2
	Elasticity	Flexible	Perfectly rigid	Flabby

Table 1: ENV model used to find failure modes, example of an electrical wire.

3.4 Step 4: Assess risk via RPN

In this step, according to FMEA tables [16] the severity of damage produced by each failure mode, the probability of its occurrence and the ease of detection must be considered and assessed on a 0-10 scale. Starting from the most critical elements (i.e. those associated with the most critical effects) the failure modes are evaluated and Risk Priority Number (RPN) is calculated.

3.5 Step 5: Su-Field modelling

In this step the substance-field model of each critical situation is built, according to subversion analysis logic, in order to create the 'machine' to make the product fail. Standard solutions, mostly of class 1, must be used to complete the harmful machine and resource analysis play a key role to bring an abstract solution back to reality level.

3.6 Step 6: Application of Standard Solutions

Finally, when all critical situations have been drawn and boosted up by means of subversion analysis, the functions created to destroy the technical system are considered as negative (see Figure 3). Thus a reliability issue has been switched into a problem solving task that can be run by means of classical TRIZ problem solving tools, e.g. standard solutions.

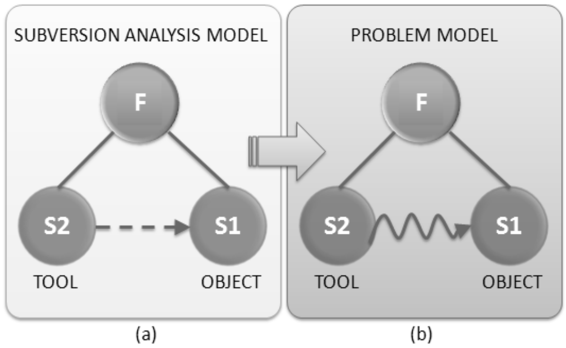

Figure 3: Su-Fields models showing (a) insufficient interaction according to subversion logic (b) same interaction considered negative to solve the problem .

4 CASE STUDY

The procedure described so far has been tested on several case studies on household appliances. Students of the last year of course of both mechanical and managerial engineering with basic knowledge on TRIZ fundamentals were asked to perform a risk management analysis task using the new procedure. The results obtained were examined to fix some problems in the procedure and refine it.

In the following the application on a domestic hairdryer (Figure 4) of the new FMEA-TRIZ procedure is described to provide an example of a real application.

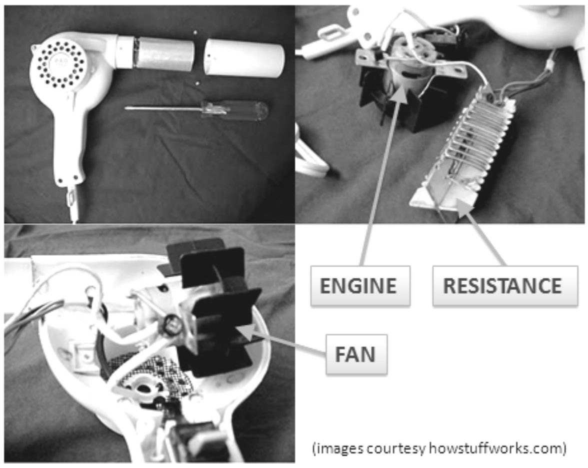

Figure 4: Hairdryer and main components.

4.1 Step 1

According to the EMS formulation (Figure 5) the hairdryer has the goal to transform still cold air into a rapid and hot air flow. According to the ENV model and with a wider perspective the tool of the system is the hot air flow, the Element is the hair, features are humidity and shape, which can assume respectively values wet and dry, and unshaped and combed (Table 2). Thus the functions performed by the hairdryer are to dry hair and to shape it.

Figure 5: EMS model of a hairdryer.

Element	Name (feature)	Value Object	Value Product	Function
Hair	Humidity	Wet	Dry	**To dry**
	Shape	Unshaped	Combed	**To shape**

Table 2: ENV model to define function(s) of a hairdryer.

4.2 Step 2

In this step elements of the system are defined and listed. Mental inertia would bring the analyst to consider only material resources or the bill of material of the system. Resource checklist and multiscreen approach can be used to be sure not to forget elements that may play a key role in a failure mode. For instance, the design operating temperature or the average operating time are information resources; the way electrical energy enters the system and is transformed by different components into mechanical and thermal is an energy resource. Table 3 shows a partial list of elements taken into consideration for the analysis.

Element list	Resource class
Electric Energy	ENERGY
Design operating temp.	INFORMATION
Max temp. allowed	
Operating time	
Engine	MATERIAL
Fan	
El. Resistance	
Switch	
Wires	
Environment air	
...	

Table 3: Part of the Element list.

After element list is complete and validated for each element all negative effects are listed. A fragment of the result obtained is reported in Table 4.

Element list	Effects
Electric Energy	Excessive el. current
	Insufficient el. current
Max temp. allowed	Underestimated temp.
	Overestimate temp.
Engine	Produce noise
	Can't rotate
	Rotate too slowly
	Rotate too quickly
	Vibrate
	Overheat
	Burns
Fan	Produce noise
	Blade failure
	Rotate too slowly
	Vibrates
	Can't rotate
El. Resistance	Heat insufficiently
	Overheat
	Melt down
...	

Table 4: Part of Negative effect list for each element.

4.3 Step 3

In this step failure modes are determined starting from negative effects of the elements listed before. Moving values of features from an extreme value to the opposite one is quite easy to define a set of potential malfunctioning even without being product experts.

Students split into small groups were able to perform such a critical task providing almost the same results. A small part of the spreadsheet is shown in Table 5.

4.4 Step 4

According to normal FMEA procedure Severity, Occurrence and Detectability are evaluated and 0 to 10 marks are assigned to each failure mode by means of referring tables [16]. The Risk Priority Number and Criticality is then calculated, as shown in Table 5.

Element	Name	Value (vs. design)	Effect	RPN
El. energy	Current intensity	Higher	Electrocution	20
		Lower	Engine and resistance fail	12
Max temp. allowed	Temperature	Higher	Overheating of hairdryer	14
		Lower	Useless shut down of hairdryer	10
	...	...	...	
Engine	Rotation speed	Higher	Overheating	18
			Mechanical failure	24
		Lower	Poor performance	8
		Absent	Hairdryer fails	12
	Noise	Higher	Acoustic discomfort	8
	Vibration	Higher	User's perceived value	8
	...	...	...	
Fan	Rotation speed	Higher	Increased noise	8
		Absent	Air is not moved	10
	...	...	...	

Table 5: ENV model and RPN assessment.

4.5 Step 5

Engine results to be one of the most critical components since several failures with high RPN have been identified. Thus, we started the analysis from it and in the followings the analysis for the most critical event, engine mechanical failure (RPN=24), is presented.

Next task consist in identifying the causes for the effect "mechanical failure" of the component engine and the field that enable such interaction, as shown in Table 6.

What to do next is to search for resources that can cause the effect asking simple questions according to this template:

Is there any <kind of resource> inside the system able to provide a <cause> such that the <element> will be affected by <effect>?

For the first cause in table 6, "collision", the question is:

Is there any <system resources, e.g. blade fragment or ball of dust> inside the system able to provide a <collision> such that the <engine> will be affected by <a mechanical failure>?

Element	Effect	Cause	Field
Engine	Mechanical failure prevent engine from working	Collision	Mechanical
		Friction	
		Shock	
		Deformation	
		Humidity/water	Chemical
		Chemical reactions	
		Melting	Thermal
		Freezing	
		Burning	
		Over current/tension	Electric
		Static charge/shock	
		Magnetic waves El-magn. Waves Laser Plasma	Electro magnetic
...	...	...	...

Table 6: Fields enabling mechanical failure.

Appling this template for any item of the resource list a complete set of scenarios of the mechanisms to destroy the system is provided. Once the most likely to work are selected the su-field models are easily created since object, field and tool are already defined. Figure 6(a) shows an example of su-field interaction of a machine creating a failure.

In most cases the interaction between tools and abject is not sufficient and it could be amplified by means of standard solutions for a system whose function is not performed at the desired level (i.e. standards 1-1-2 to 1-1-5 and 2-1-1 to 2-2-6).

4.6 Step 6

Last step consist in inverting the problem for the second time, which is bringing it back to the original meaning of preventing failures. Operatively this is done by turning positive interaction (either sufficient or not) of the subversion su-field model into negative interactions as shown in figure 6(b).

By doing this we have finally switched a reliability issue into a problem solving activity for which traditional TRIZ tools can be applied. In particular having a model of the problem in terms of su-field in which a harmful interaction must be eliminated, once again standard solution will help us finding a solution (i.e. standards 1-2-1 to 1-2-5) as shown in figure 6(c).

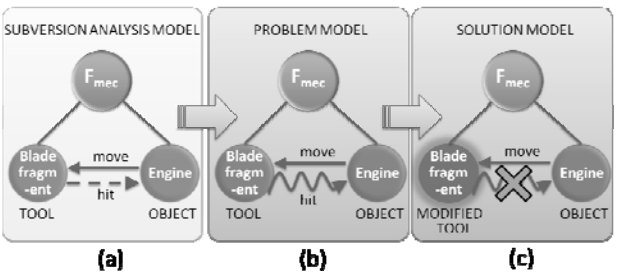

Figure 6: Example of transition from (a) failing machine model to (b) problem model to (c) solution model.

5 SUMMARY

This paper after defining the working context of reliability engineering and risk management propose a new way of facing risk in design. Starting from FMEA concept and TRIZ subversion analysis a new procedure has been built in order to enhance existing tools by introducing ENV models and using resource and standard solutions. A case study has been presented in order to clarify the logic and the application of the tools.

The presented case study refers to a product that is completely defined and available on the market. This condition is a bit easier if compared to the development of a brand new product. Traditional risk analysis is strongly based on components details and experience. The proposed way of performing risk assessment is shifted to a functional level in which some details can be neglected without the risk of missing the goal.

Future works on this topic will bring this procedure into a real industrial product development process in order to look for weak points students' testing may have neglected. Moreover the application to larger systems will probably require some more refinements to help designer dealing with a large amount of data.

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