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FAILURE MODE AND EFFECTS ANALYSIS IN COMBINATION WITH THE PROBLEM-SOLVING A3

Eirin Lodgaard[1,2],Øystein Pellegård[2], Geir Ringen[2] and Jon Andreas Klokkehaug[1]
(1) Norwegian University of Science and Technology, Norway
(2) SINTEF Raufoss Manufacturing, Norway

ABSTRACT
Failure Modes and Effects Analysis (FMEA) is a method that may contribute to identify and reduce risks during the product design phase. Although this is a widely used method within several fields, it has nevertheless many limitations and challenges. In this paper the traditional FMEA process is discussed and evaluated, and an evolved method to improve problem solving and root cause detection is proposed. In the study the FMEA was applied during a design phase at the company involved. The results show that the formal fulfillment of the method is not sufficient by itself to efficiently achieve quality and reliability improvement in the product design process. Consequently, to succeed with the FMEA, it is proposed to combine it with the problem-solving A3 for a deeper analysis of the root causes for the prioritized issues during the risk reduction process. A3 is named after the size of the paper where you can present the problem-solving issues in a visual and illustrative way.

Keywords: FMEA, problem-solving A3, product development

1 INTRODUCTION
One analytical method often used in the product development phase is the failure mode and effects analysis (FMEA). The main purpose is to identify and reduce the risks of failures in a system or a component in an early design phase to allow the product to have better quality and reliability before releasing it for production. Consequently, doing this will lead to solving design issues in an early phase where it incurs less cost than later on when solving changes become more complicated. Cost reduction is important in most businesses when developing the next generation of products.
The purpose of the research is to identify strengths and weaknesses of the traditional way of conducting FMEA. Additionally, use of the problem-solving A3 during the risk reduction process in the product development phase is analyzed. Research shows that formal fulfilling of the FMEA is not sufficient according to what it promises in regard to achieved improvement of efficiency and reliability [1, 2]. In many businesses, the FMEA method is a customer requirement, thus it is of great importance to make use of it for internal processes as well. How the traditional FMEA method can be improved to achieve additional value for the company by combining it with problem-solving A3 is examined. Issues which need additional action, specified from the risk analysis results in the FMEA, will be proposed for a more in-depth analysis to find the root causes.
Different types of problem-solving methods can be used to solve issues specified in the FMEA, but this paper will not include recommendations on which type to choose. This paper only outline the combination of using a problem-solving method to improve the issues detected from the ranking results in the FMEA. The results from the FMEA will be presented using an A3 report for each of the detected issues.
The first section addresses the theoretical background of the FMEA and problem-solving A3 and findings from other researchers applying those methods. Furthermore, a case study based on action research where the traditional FMEA is applied in a product development project is presented. The experiences from the action research are presented and compared with the theoretical background for both FMEA and problem-solving A3. Finally, concluding remarks are provided and proposals for further research with implementing the problem-solving A3 method in a case company is introduced.

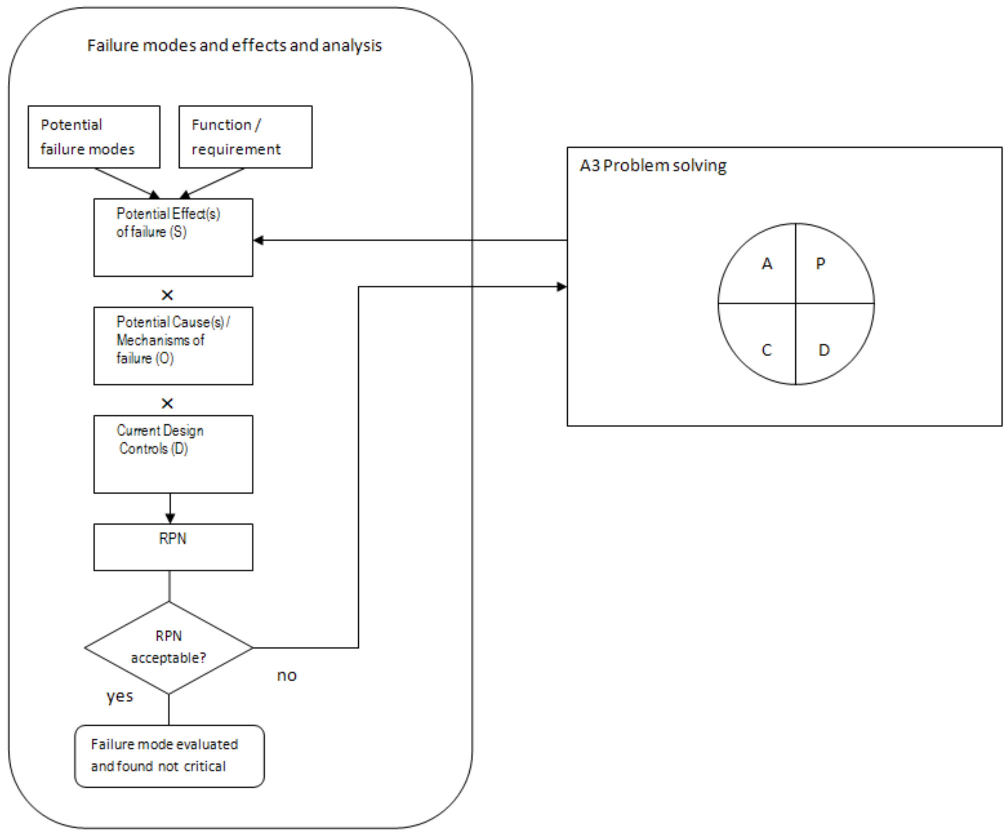

Figure 1. Workflow when combining FMEA with problem-solving A3

2 THEORETICAL BACKGOUND

This section will give an overview of the theoretical background of FMEA and problem-solving A3 method. Further, it will outline findings and experiences from other research work within the two areas.

2.1 Failure Mode and Effects Analysis

FMEA is a widely used approach to find weaknesses in the product in an early design phase before the product is released for production. The purpose of the FMEA is to ensure that the product design can meet the desired requirements for both external and internal customers. It provides a systematic way of identifying, prioritizing and acting on known and potential failure modes before the failure occurs. It is utilized to identify and reduce risks of known or potential failures in the product design to avoid unnecessary costly and difficult design changes in later stages of the design process. It is known that changes in an early phase of the product development will incur less cost than in a later phase, where the changes are more complex and where they may result in considerable work updating technical documentation and changing manufacturing processes. All changes made and actions taken to reduce the risk will be documented, helping the FMEA team to prioritize and keep focus on eliminating or reducing design concerns. This will lead to external and internal customer satisfaction by achieving the expected requirements for the desired product.

An FMEA is carried out by a cross-functional team consisting of members from areas such as product design, process, project management, and quality assurance, whose experience includes all the topics to be considered in the analysis. Normally, the same team is involved during the entire work, in addition to resources from other areas when necessary. This can typically be from manufacturing, marketing, purchasing or logistic. They are invited when issues from their area of expertise are a specific issue in the FMEA.

In the following, the traditional way of conducting FMEA, which is the most common used method, is presented. FMEA is a customer requirement in business areas such as automotive, aerospace and military. A template in a tabular form, normally a standard spreadsheet, with predefined columns is used to define risk areas. The first column defines all the functional requirements of the design for

both external and internal customer. The next step is to analyze how each function can fail according to type of failure mode. Further, it will be considered which effect these failure modes will have on the product if they occur during use of the product. After the effect is considered, all causes of each failure mode are to be investigated. The result will normally include more than one cause for each of the failure modes because each failure mode typically has several different kinds of causes to arise. To assure the occurrence not to take place, preventive and/or detection control is the next step to consider. Typical preventive measures are design test, simulation and calculation. The design control include all tests and other tasks which are already done and also those which are planned to complete during design phase. Further, the FMEA team assesses the severity of the effects, the likelihood of occurrence of the cause and the probability of detection of the failure mode. Some appreciate to do the risk ranking as they place effect of failure, causes and control. Others prefer to do this afterwards. It is not decisive for the end results of the FMEA. The FMEA method is constructed to end up with a risk priority number (RPN): the product of multiplying the three risk elements severity, occurrences and detection for each failure mode. Severity is defined as the result of a failure effect on the function of a system perceived by the user; occurrence defines the cause of a failure and its frequency probability; detection defines control measures and their efficiency. The score for severity, occurrence and detection is normally set from 1-10 and then the maximum RPN will be 1000 and the lowest will be 1.
The output from an FMEA is an action plan where corrective actions must be defined, based on the results of severity, occurrences and detection of each potential failure mode. Which one to prioritize for further action will be different based on evaluation criteria. The most common criteria for implementing actions to reduce the risks of failure is the use of the RPN score[3]. If the RPN is higher than a predefined value, or the individual values exceed a set limit, actions have to be taken. Others use the severity score multiplied with occurrence score or a combination of severity score and the RPN score. Cassanelli highlights that the RPN number is undertaken on expense of the substantial occurrence factors [2]. Occurrence of the failure is important to consider for assuring criteria for when action is necessary. The companies where the customers require that a FMEA are performed normally have guidelines for how they shall evaluate risks, and when to put on additional actions to reduce risks.
Although many companies use the FMEA method, it still has limitations and challenges related to efficiently achieving sufficient results. Several researchers have discussed the value of FMEA, whether the method itself is sufficient for the value added purpose of improvement on the product design [1],[2], [4]. Other researchers' highlight its strengths as the results help the organizations to identify the potential failure modes, their causes and take action during product development [5], [6], [7]. A lot of research claims that the formal fulfilling of the FMEA method is not sufficient to achieve the promised results. Consequently, their research combines the FMEA method with other methods to add value, as for instance:

- Fault insertion testing [1]
- Cost-based FMEA [4]
- Quality function deployment [8], [9]
- Knowledge-based approach to FMEA [10, 11]
- Reliability modeling [12]

The FMEA method's most evident strengths are that it is a simple system and if used systematically secures a chain of evidence and a strong link between theory and empirical knowledge. It encourages reuse of knowledge if the solutions to the problems identified are documented and used as input for new projects. It leads to a sharing of knowledge through joint reviews and it provides a visual, easy-to-read overview of the areas that need to be addressed. Only those failure modes that the FMEA team has considered will be covered in the analysis. Here the knowledge and experience of the participants influence on the result and it is possible that they omit important failure modes [12].
A common failure for organizations is to be satisfied by completion of the FMEA, hence believe that the product will be designed according to plan without a living FMEA [1]. The FMEA is a living document that needs to be updated through the whole design phase to achieve the desired improvement.

2.2 Problem-solving A3 method

Results from learning cycles can be documented as explicit knowledge, by text and visualization, on a single sheet of paper. In the literature this is called A3 [13]. This documenting process forces engineers to collaborate and reflect upon actions, increasing the likelihood of making a robust and reliable design. Another feature associated with this problem-solving approach is its effective and streamlined way to communicate problems through visualization, help point out clear objectives prior to a meeting, gather the right people, prepare participants, and separate information sharing from problem solving, which eases understanding and leads to faster and better decisions. The A3 method is one of several methods developed by Toyota to strengthen their ability to relentlessly improve operational performance in a structured way. Although A3 reports primarily was made to be a problem-solving tool in conjunction with a PDCA based management, they can also be used for keeping track of changes and project status [14]. Done properly, A3 as a problem-solving method helps problem solvers to address the root causes of problems which surface in everyday work. The structured approach is often depicted on the problem-solving A3 as a LAMDA (Look, Ask, Model, Discuss, and Act) process or the similar PDCA (Plan, Do, Check, Act) process. However, filtering and compressing thoughts into one sheet of paper in such a way that others have all their questions answered by reading it is not necessarily straightforward. As noted by Kennedy [15], the process of making an A3 calls for reflection and deeper understanding of the problem at hand, or as stated by Liker [16], "*It's much more about disciplined thinking than about any particular A3 writing technique.*" It is also emphasized that the A3 method only works if it is the engineers themselves who contain and maintain the information; only then is it credible so that others may use the knowledge. The power of the A3 method derives not from the report itself, but rater from the company culture and mindset required for the implementation of an A3 method [13].

3 RESEARCH METHOD

The following section outlines the company involved in the research and the research method used. The company chosen is a leading developer and manufacturer of ammunition systems and missile and space propulsion products, with about 1900 employees worldwide. Additionally, the company is involved in demilitarization of ammunition. Their main strategy is to develop and produce high-tech defense and aerospace niche products. They have a leading market position in several of their targeted product segments and want to maintain and develop this position by spending above 12% of annual turnover on R&D activities. To secure their position as a leader in the provision of defense equipment also in the future, they have to be able to provide high-tech niche products. Consequently, this requires an efficient and optimized product development process throughout the whole organization. To achieve this one of their aims is to incorporate a unified way of thinking, based on principles for first-class development. To develop their working approach the company is engaged in a research program that focuses on lean product development, with NTNU and SINTEF Raufoss Manufacturing as research partners. This enabled an opportunity to analyze the usefulness of the FMEA method to achieve efficiently product development process in a company which is in a world leading market regard to product development. The existing processes for product design control were based mainly on design review. The FMEA method was initiated into two product designs in a defined timeline. The highly skilled professionals from the company involved in this research had experience in the fields of project management, marketing, product design, simulation, calculation, product testing, manufacturing process and quality assurance.

The aim of this paper is to evaluate the approach to the implementation of the FMEA into a new product in the product development phase. The scope of interest is to identify which strengths and weaknesses the FMEA method has as it is used today. Another issue is whether the A3 approach, as a problem solving method, is an appropriate method used for solving actual problems identified in the FMEA. Action-based research was chosen since the involved participants from the company were inexperienced users of the FMEA method and the researchers had long experience within the field.

Action research is a valuable method where both researchers and professionals at a company collaborate to develop theory in the field. The action research cycle – diagnosing, planning, action, reflection, and evaluation of the results – was followed during the research [17]. Field notes with observations and experiences from the research project were written throughout the whole FMEA process. The next section will present the data gathered through the action-research-based project and discuss them relative to the existing literature.

4 RESULTS AND DISCUSSION

4.1 Challenges and strengths regarding FMEA

A specific product development project was chosen to initiate the FMEA. The project had two related products, which they needed to examine using FMEA due to customer requirements.

The systematic FMEA method was applied to the design phase, particularly to identify risk of potential failures. The project members were mainly the same when examining the two different products. The team members must be clear on the purpose of the FMEA before starting on the analysis. The first step was training the project team in the FMEA method before starting the real process on the defined project. Templates for FMEA were prepared by the researchers and applied by the project team. Which opportunities such a method could give was explained and some examples of function requirements, failure causes, effects, detection and severity classification were presented.

With the aim to fulfill the templates, the meetings were started with defining the function requirements for the assembled product. Next, were to define the potential failure modes and the effect of each failure mode for each of the defined functional requirement and to define the failure causes of the failure mode and which controls were done or planned to do. The last step was the rating of severity, occurrence and detection. After each meeting with the project team, the researchers recorded how the processes moved on with emphasis on how the team members experienced the process. Figure 2 shows a graphical presentation of the meetings needed to complete the FMEA for the two products called C1 and C2. A total of 9 meetings were held during a time period of 4 weeks.

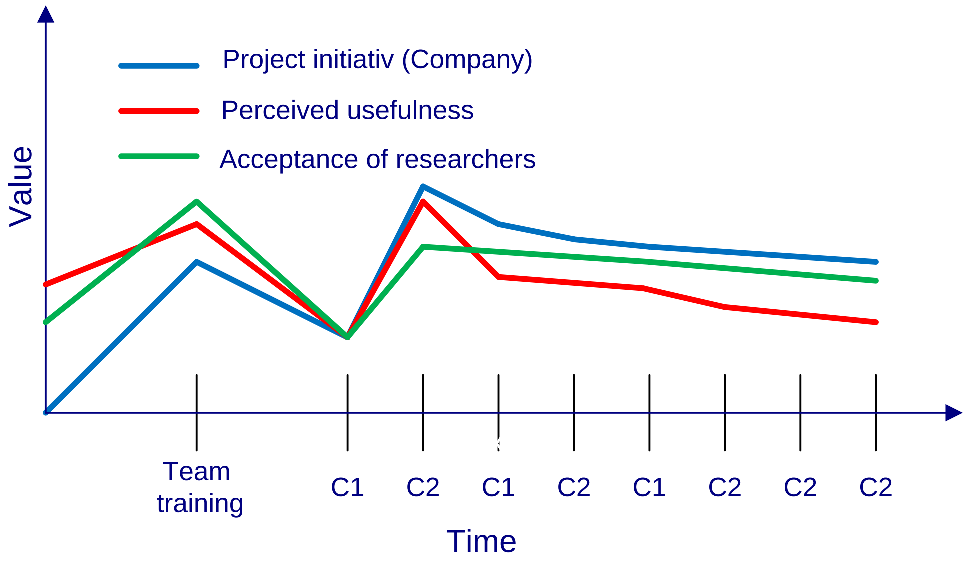

Figure 2. Graphical time presentation of perceived FMEA value

The figure shows that the initiative and enthusiasm was high after the team training, before the start of the actual work. For the first meeting, C1, when the actual FMEA started for product 1, all of the curves have a dip. During this stage the participants were not sure the content in the FMEA was correct and would add value to the overall product. For the initiative and the perceived usefulness, the dip is also due to the definitions in the FMEA still being new and the method unfamiliar for the project team. The project team also had difficulties deciding on which level of detail they should have on the failure causes. This led to discussions between the team members. The rating of severity, occurrence and detection was also criticized by the team because it was not easy to precisely determine. Some assumption was necessary in order to deal with the assessments of the ratings, and achieving a unified rating among the team members was difficult. The dip in the acceptance-of-researcher curve is due to the team expecting more help and guidance than they got from the researchers.

For the second meeting, C2, which was the first meeting where FMEA was used on the other product, all the measured values increased again. The reason is probably a combination of factors. Depending on learning style, it is common to experience a period of frustration before mastering a task [18]. The project manager was better prepared and was seen as more credible by the team members, who also had become more unified in their view on which level of detail they should have on the failure causes and on the ratings. The project team had also begun to feel more ownership to the process and took more initiative in the meeting. The third meeting shows a decrease again as the breakthrough effect from the last meeting had started to wear off. The last meetings for both products show a small decrease in the measured values. These decreases are most likely due to the project teams not finding any design issues that they were not already aware of and they felt the FMEA used to much time on obvious issues.

After completing the first issue of the FMEA, one of the things the participants highlighted was that a challenge regarding this method was the relation between time consumption and output value. But it was also emphasized that one of the strengths of the FMEA was the total structured overview of the product regarding the requirements, all potential risk you may have and all issues which are under control. It gives a quick and easy overview of where to take further necessary actions to achieve a product with the desired quality, and may help reduce the amount of design changes in later phases where it is more expensive. This overview can also be used to document the project status for the customer. Table 1shows a summary of experienced strengths and weaknesses of the FMEA method in view of what the project team expected to achieve of this work.

Strengths of the FMEA	Weaknesses of the FMEA
Structured way to illustrate and satisfy customer requirements	Time consumed in proportion to the value of the output
Project team collaborates about design issues	Difficult to decide level of analysis
Structured product overview with regard to requirements and their severity	Difficult to achieve a unified rating among the team
Overview of all known and potential risks and actions to prevent failure	Spend too much time on obvious issues
Overview of where to put further necessary actions to fulfill customer requirements	FMEA is used because it is a customer requirement
Reduce amount of design changes in later phases where they are more costly	Not sufficient in-depth studies for root cause analysis – independent of level
Reuse of information from existing FMEAs	Subjective method
Extensive knowledge about the product	Difficult to achieve FMEA as a living document
	Failure modes can be overlooked.
	Contains failure modes that the team already has considered.
	Reuse of knowledge between teams is hard to achieve

Table 1. Summary of strengths and weaknesses of the FMEA

4.2 Can A3 thinking help to improve the FMEA?

Due to reported FMEA weaknesses and pitfalls together with demand for improved project reporting systems in the case company, problem-solving A3 was proposed as an appropriate tool. The project manager claimed that existing documenting systems were too bureaucratic and inappropriate for long-term projects. As a result people tend to ignore or delay documentation, increasing the risk of missing important information, loosing track of changes, reinventing and eventually failing on reviews and decision gates. In combination with the mandatory risk assessment methodology, FMEA, problem-solving A3 was seen as convenient to overcome the traditional partial learning cycles. However, the project team had to be convinced that A3 thinking is useful in order to succeed. Therefore, the first step to anchor the improvement idea, and integrate and educate external researchers and the case company project team, was to participate on an A3 seminar. This event was important to secure a common language and to pinpoint improvements. The next step was to outline a few problem-solving A3 examples to demonstrate practical usefulness of the tool for the project team. When presented for the team, arguments like "*too time consuming*", "*we are lean*", and "*rapid changes easily devaluate written documentation*" were voiced, thus focusing on the cons rather than the pros. This was a predictable behavior, in line with change theory that claims that individuals will mobilize resistance to every change that occurs as a threat to conventional ways of doing things. With this theory in mind, an action research approach, with close collaboration between the project team and external researchers over time, was undertaken to secure continuous focus on A3 thinking. Included in this approach is implementation of problem-solving A3 as a tool, experiencing the tool in real work life situations, combining problem-solving A3 and FMEA, reflection and documentation. By linking the use of problem-solving A3 to the most critical issues detected in the FMEA it was assumed that more formal and complete learning cycles could be undertaken. The project group headed out by outlining a template problem-solving A3, suitable for solving highlighted issues in the FMEA. Problem-solving A3's were conducted for several actual problems, and followed up as living documents in project meetings. After calculating the RPN whit that determine the areas with highest priority for corrective action, problem-solving A3 is used to solve the problem (see figure 1). The solotion found using the problem-solving A3 are then used as feedback to the FMEA. Figure 3 shows an example from the project where the problem-solving A3 was used to find the root cause of a problem identified in the FMEA.

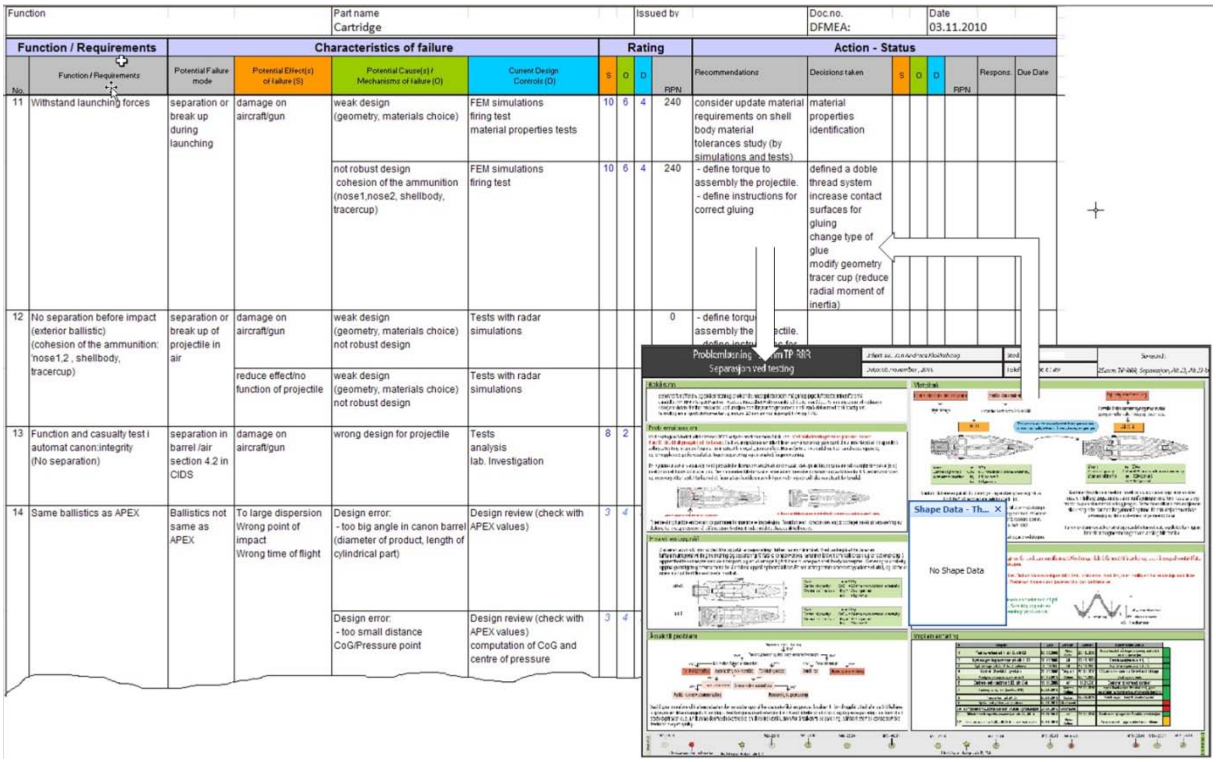

Figure 3. Root cause solving using problem-solving A3

Implementation of A3 as a problem-solving and documentation method in a product development department has not been an easy ride. However, valuable experiences can be drawn from this try-out. First of all: change needs a reason, it requires time, and a continuous stream of reminders. Emphasized reasons in this project were the need to improve the product development process and to improve compliancy to required customer documentation. Time, in terms of this action research project, was limited to 4 weeks – this should of course have been for a more extended period. Still, the intensity of the collaboration may compensate for the limited time slot, something which also can be accounted for in number of reminders. Nevertheless, the following aspects are important to note when implementing A3 thinking:

- The illustrative nature of a problem-solving A3 report was reported by many users as valuable – particularly in team discussions, a correct, updated and informative A3 report could act as a catalyst for agreement upon definitions, history and facts. Hence, an A3 report helps the team getting to the point.
- Problem-solving A3's help to elabore and gett a deeper understanding of complex problems. But,

linking it to FMEA needs a more refined selection method than just looking for “red spots”. The users report that in order to spend time constructing an A3 reports, it should be related to cases providing the largest learning potential – consequently, highlighted issues in the FMEA should also be evaluated against learning potential, not only product risk.

- Problem-solving A3, done properly, serves as a living document which provides both the customer and the organization with rich information about how the product development team solves upcoming problems. This benefit is especially important for the case company which performs long term projects – often 8–10 year programs with several design reviews and gates along the way.
- Problem-solving A3 as a required method for documenting ideas, solutions and performance was reported beneficiary in keeping project and FMEA progress. By appointing a responsible person and a time schedule for solving a specific problem, a problem-solving A3 helps documenting progress, what is learned, what has to be done etc in a way that keep people prepared for a multitude of meetings.

Although, initially, there was a perceived resistance from the project team regarding problem-solving A3 as a new tool, after several weeks the motivation to use it seems improved. The above aspects witness that the users, under certain conditions, see some degree of usefulness in A3 thinking in combination with FMEA.

5 CONCLUDING REMARKS

FMEA was carried out to provide valuable findings to enhance the traditional FMEA method. A lot of recent research shows that experience in performing FMEA is poor and many companies struggle to use the method sufficiently as it remains a document without life. The scope of interest was to identify strengths and weaknesses of the traditional way of performing FMEA. The next step was to implement the problem-solving A3 method in the FMEA to improve the method, getting in-depth analysis of critical issues outlined in the FMEA.

This paper demonstrated that the project team was not satisfied with the traditional FMEA method. The participants highlighted that this method gives a structured overview of requirements and their potential risks, but it was a time consuming method regarding the output of the method. They expected more added value for the project and too many obvious issues were addressed.

The process of introducing problem-solving A3 shows that they were in the beginning sceptical to implement a new tool, but after several weeks the motivation seemed to improve. It is not easy to implement changes in companies. To really make a change in way of working with using problem-solving A3 method in combination with the mandatory FMEA interest must be truly advocated by the management and be supported within the management of each project team.

To secure validity of the proposed method, further work needs to be done. Further research should be done where the project team, on their own, without the assistance of researchers, employs the problem-solving A3 method systematically in combination with the FMEA during the whole lifetime of the development project. Combining these two approaches should yield better results than applying the conventional approach of the FMEA alone.

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Contact: Eirin Lodgaard
Norwegian University of Science and Technology
Department of Engineering Design and Materials
7491Trondheim
Norway
Tel: +47 995 443 58
Email: eirin.lodgaard@sintef.no

Eirin Lodgaard is a PhD candidate in the Department of Engineering Design and Materials at the Norwegian University of Science and Technology. The PhD project has the main focus about continuous improvement processes in the product design process.