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Using TRIZ to invent failures – concept and application to go beyond traditional FMEA

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Abstract

The Failure Mode and Effects Analysis (FMEA) is a very highly established methodology for preventing failures in technical systems [1] that developed over the last five decades. It became a standard tool, especially since the introduction to the automotive industry via the QS-9000.
Despite of numerous successful applications the FMEA is limited to normal expectations of occurring failures (like the non-fulfilment of a function or small deviation from an expected value) [2]. The FMEA utilizes the breakdown structure for products or processes to identify single failure causes and effects.
Usually the FMEA provides no consideration of interconnected failures and failure scenarios.
There are a lot of good reasons for the usage of the FMEA: it is wide spread because of being a part of international standards and engineering education for a long time. To cover these drawbacks described above, additional tools for risk analysis and risk management can be used.
The Anticipatory Failure Prediction as preventive component of the Anticipatory Failure Determination (AFD) is such a method that leads to a comprehensive set of failures and failure scenarios [3], [4].
Additionally it provides procedures to "invent" possible failures in a structured but creative way [5]. Based on the analysis of both methods, ways to hybridize the methods are developed. This hybridization leads to the combination of the advantages of both methods (similar to the parallel execution of both methods), offers synergies, and expands the potential for industrial adoption by providing one elaborated tool. By using an application example the potential of the hybridized AFD-FMEA or so called Failure Mode and Effects Anticipation and Analysis (FMEAA) is pointed out.

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Keywords: Failure Mode and Effects Analysis (FMEA), Anticipatory Failure Prediction, AFD, AFP, FMEAA;

This paper is about the hybridization of the well-known preventive quality method Failure Mode and Effects Analysis (FMEA) and the TRIZ-based methodology Anticipatory Failure Determination (AFD). First an

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introduction to both methods will be given and the underlying standards will be described. Than a closer look at each method will explain how the methods work. In chapter five an approach of hybridization of the two methods is given and an example provided. The structure of the paper is shown in Fig. 1.

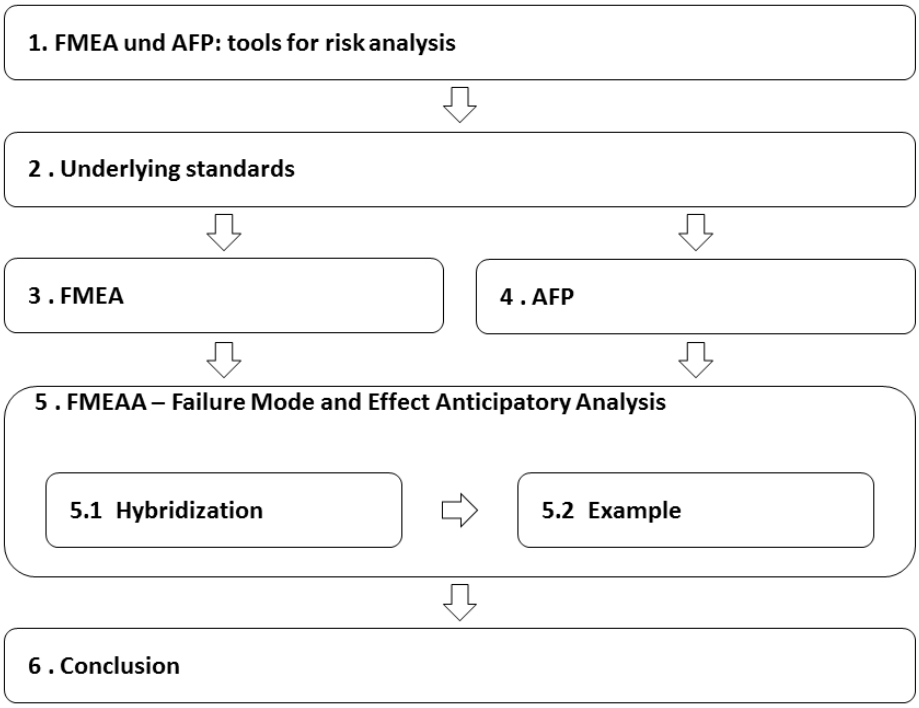

Fig. 1. Paper structure

1. FMEA and AFP: valuable tools for risk analysis

The Failure Mode and Effects Analysis (FMEA) is the most established tool for risk analysis and failure prevention in engineering. The fact, that FMEA emerged as a standard in this area, is particular the result of the implementation by QS- 9000 within the automotive industry [1]. FMEA is hugely useful to identify possible, but in some degree expected, failures, e.g. the nonperformance of a function or the minor deviation from an expected data [2].

Sooner or later every company has to experience that the number of occurred defects is still too high. The impacts can either be quite innocent or of particular importance for companies, employees, regions or the whole mankind. Failures, not expected in the slightest, are particularly fatal. They happen, when the cause of trouble cannot be derived directly from the product- or process structure. Moreover, the combination of several errors can cause more serious impacts, than each error itself.

Anyway, locating possible and future failures is by no means automatism, but rather a procedure, that requires, besides a systematic approach, lots of creativity and inventive talent. According to Frenklach it requires not only asking the characteristically FMEA- questions “why” and “what”, but furthermore asking the question “how” several times [6].

Anticipatory Failure Determination (AFD) encourages these questions. To invent failures, by inverting the problem, enables us to use other TRIZ tools for revealing hidden failures mechanisms and for predicting unexpected future failures. Using TRIZ tools allows us to achieve innovative preventive measures respectively preventive system designs. Examples from different fields of application prove the success of this procedure (e. g. [6],[7],[8],[9],[10]). Hereafter this preventive aspect will be defined as AFD Failure Prediction (AFP).

Based on Altshullers insight that TRIZ offers powerful approaches for different scopes including research and development [11], the evolution of AFD is affected by the work of other well known names e.g. Zlotin and Zusman creating AFD method in the early eighties introducing the inversion and operators as key elements [3] or V. Mitrofanov who worked on problems regarding waste elimination in manufacturing using the principle of intensification. The evolution of the AFD is shown in detail in the book "How to deal with failures (The smart way)" [5].

The implementation of the main AFP idea can be done by using different TRIZ tools and different levels of standardization. Promising lines of action and potential software support exist and are published (e.g. [3], [4], [5]). But as a matter of fact, Anticipatory Failure Determination in general is still one of the TRIZ tools that is not used very frequently [12].

Both FMEA and AFP are valuable tools for risk analysis and failure prevention even if they have different scopes. So it may make sense to use both methods complementary – e.g. Ungvari gives some suggestions, which steps of an AFP may be performed accompanying specific steps of the FMEA [4].

This work is based on such thoughts and shows the development of a hybridized method. So the aim is to not just combine the advantages of both methods – continuing the synthesis of FMEA and AFP ONE method – respectively ONE tool – shall be developed. And to increase the chance of its adoption, usability (as well as "look & feel") shall be very similar to specific, actual and common standards.

2. Underlying standards

The whole automotive supply chain pushes the standardization of method usage within the German and European engineering and quality management. The allotted standards are adopted rapidly outside of these supply chains as well, because they are very detailed, elaborated and usable. Furthermore for most companies the impact of fulfilling the automotive industries needs is vitally important to acquire new customers.

Therefore we apply the most important actual description of standards in this context– the VDA Handbook on Quality Management (Part 4: Quality assurance, especially risk analysis, methods, and procedures) [13]. In this book the FMEA is illustrated on 126 pages with very detailed descriptions of the history, different approaches and steps and examples. This demonstrates the high level of sophistication. This will be used as the specific base of this work regarding the FMEA.

In the same book there is a chapter called "TRIZ". This so far does not reflect any actual practice – it's a first introduction to the topic and shows a lot of insights and tools in a very superficial manner. So in contrast to the FMEA the sub-section on the AFP there takes just about three-fourths of one page. This illustrates that TRIZ and especially AFG are still very exclusive approaches (e.g. in Germany [ ]. The use of AFP is still a tool of experts.

In conclusion: in the observed field there is a well elaborated standard regarding the FMEA that will be used for the hybridization. And there is no existing standard regarding the AFP –in the targeted field AFP is just known by some experts and is executed using different procedures.

3. Failure Mode and Effects Analysis (FMEA)

According to VDA [13] the Failure Mode and Effects Analysis (FMEA) is conducted in five steps.
These steps are:

- Structure Analysis (Step 1)
- Function Analysis (Step 2)
- Failure Analysis (Step 3)
- Action Analysis (Step 4)
- Optimization (Step 5)

Step 1 and Step 2 can be executed in parallel, steps 3-5 should be done sequentially. An overview of the structure analysis to the failure analysis can be seen in Fig. 2. More detailed information on how to conduct a FMEA are available from McDermott et al [1], Däuble et al. [17], and VDA [13].

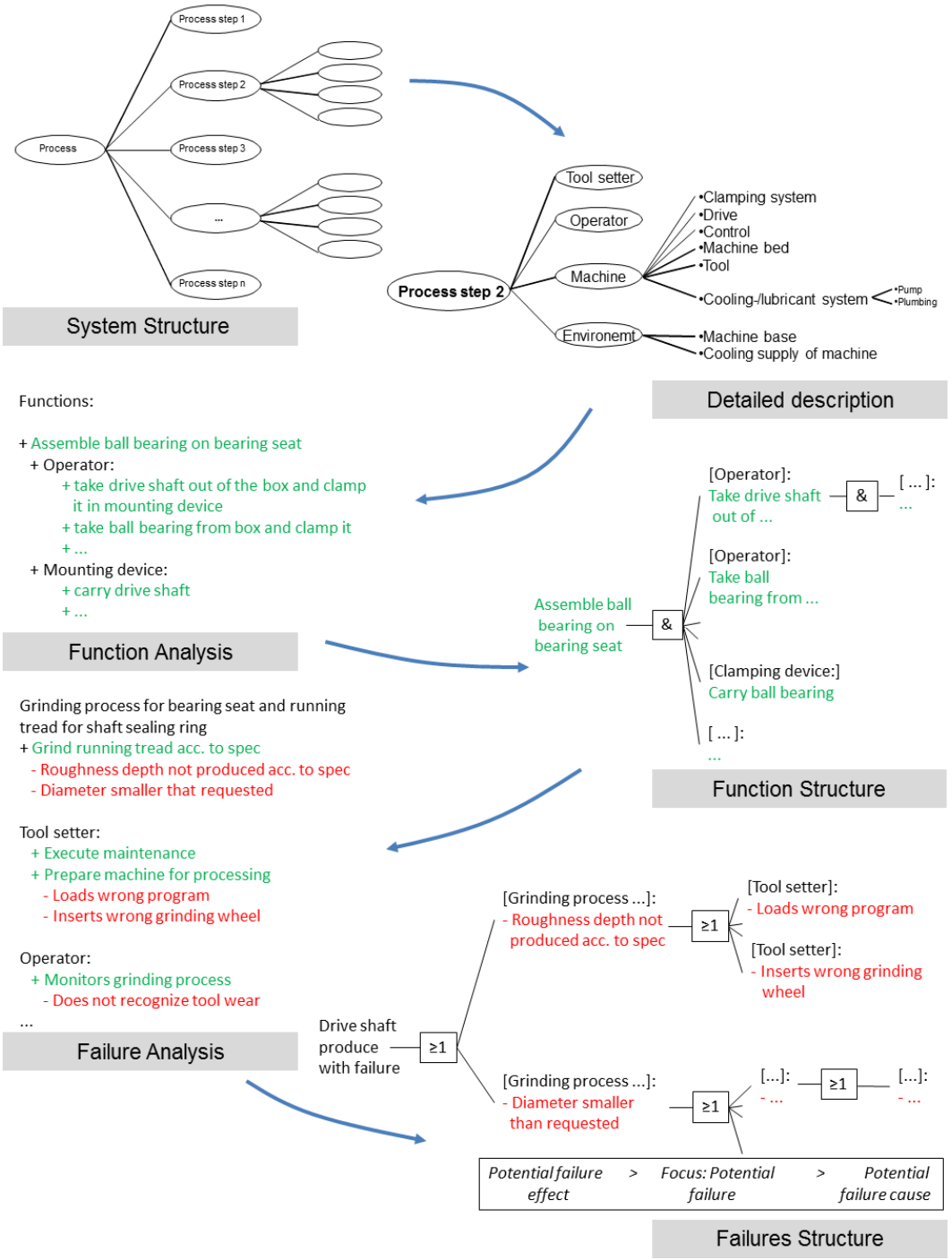

Fig. 2. FMEA overview according to [17]

3.1. Action Analysis

Goals of the action analysis are:

- Allocate existing or already taken actions to failure functions
- Rank the risk of the single failure

The actions are separated into two groups: actions for prevention of failures and actions for failure detection. **Preventive actions** during the development phase are used for process planning to reduce the probability of the failure occurrence. Preventive actions must be written clearly and comprehensibly, if necessary referred to a further document. **Detection actions** are used to find possible failures and to confirm the effectiveness of the taken actions. Similar, the detection actions must be written clearly and comprehensibly and may refer to a separate document, too.

Attached to the actions are a person responsible and an appointed date to secure the settlement of the action before serial production starts.

The state of settlement is set to:

- Untreated: collection of ideas, work on the action has not started yet.
- Decision: the action is defined, decision was not made.
- Implementation: decision about the action was made, but the action was not implemented yet.
- Closed: closed actions are settled, the effectiveness was proven and documented, and a final evaluation was made.
- Refused: refused actions are documented and need commonly an optimization.

3.2. Evaluation of the risk

The risk correlated to each failure is rated regarding the taken actions for prevention and detection.
The rating is entered in the FMEA sheet. There is:

S	Severity of the failure effect
O	Probability of the failure occurrence
D	Probability of failure detection

For ranking S, O, and D the numbers 1-10 are used, where 10 marks the highest contribution to the risk. The **severity rating** is an estimation of how serious an effect would be if a given failure did occur. In some cases it is clear how serious the problem would be, because of past experience. In other cases it is necessary to estimate the severity based on the knowledge and expertise of the team members. The best method for determining the **occurrence rating** is to use the actual data from the process. This may be in the form of failure logs or even process capability data. When actual failure data are not available, the team must estimate how often a failure mode may occur. The detection rating describes how likely it is to detect a failure or the effect of a failure. This is done by identifying the current controls that may detect a failure or failure effect. If there are no current controls the likelihood of detection will be low and the item will receive a high ranking of 9 or 10.

The risk priority number (RPN) is calculated from severity, occurrence, and detection by multiplying the single numbers:

$$RPN = S \times O \times D \tag{1}$$

The risk priority number gives a first idea at which failures one has to look first (for example all RPN>125 or the upper 40 or 50%). Beside this the single entries of the numbers have to be regarded as well. If the detection is 10, it does mean that the failure will not be detected at all. Something has to be defined to detect the failure. Same with occurrence: if the occurrence is 10 (even if severity is a middle five, the detection is high with one and the resulting RPN of 50 would not indicate that an action is necessary) some actions must be defined to reduce the likelihood of failure occurrence.

3.3. Optimization

Goals of the optimization are:

- Definition of necessary actions for improving the system.
- Estimation of the risk.
- Prove the effectiveness of the taken actions.
- Documentation of the settled actions.

If the initial state of the risk evaluation of a failure mode is not sufficient, new actions are proposed. These actions are treated according to step 4. A new state for risk evaluation is created. The actions are ranked in advance, responsible persons and due dates are defined. After execution of these actions the effectiveness is evaluated, too. Does an action not provide the targeted result the process is repeated until a sufficient result is reached. The optimization should track the following order:

- Change the process to exclude the failure cause or to gain a failure effect with little severity.
- Improve the stability of the process to minimize the likelihood of occurrence of the failure cause.
- Improve the detection of the failure.

Changes in the process lead to a new FMEA going through all five steps again for the changed area of the process. The following table shows the look of a risk evaluation of a failure (Fig. 3).

Failure effect	S	Failure mode	Failure Cause	Prevention action	O	Detection action	D	RPN	Resp./ Date
Drive shaft produced with failures [Main process drive shaft]	8	Roughness depth not produced according to spec [Grinding process for bearing seat and running tread for shaft sealing ring]	Peripheral surface speed too low [Grinding machine]	Use well tested drive for the grinding machine	2	Online control of peripheral surface speed	2	32	

Fig. 3. Risk evaluation of a failure mode [17]

4. Anticipatory Failure Prediction – AFP

Since there is no AFP-standard this work will refer to the detailed process description of S. Visnepolschi (one of the authors of this work). This process includes the following eight steps [5]:

Step 1: Obtaining information

In this first step the expectations for the AFP project have to be defined. Usually there is the need for a “practically safe” system – a system that will not collapse, injure anyone or cause some trouble for the responsible persons or institutions [14]. After this definition a set of well-proven questions supports the gathering and/or

creation of necessary information. These questions help to explore the system of interest, its structure, its functioning, undesired effects, its environment and the history of the system.

Step 2: Developing a System Diagram

The System Diagram visualizes cause-and-effect connections in the functioning of the system. The favoured notation is based on the problem formulation notation [15] [16]. So the system diagram for the AFP should include the useful and harmful functions (or operations). In this case an important event or a meaningful state of the system may also be considered as a "function". The functions are the knots of the diagram that are connected by cause-effect links. The diagram also indicates the primary useful function of the system. An example is given in Fig. 4.

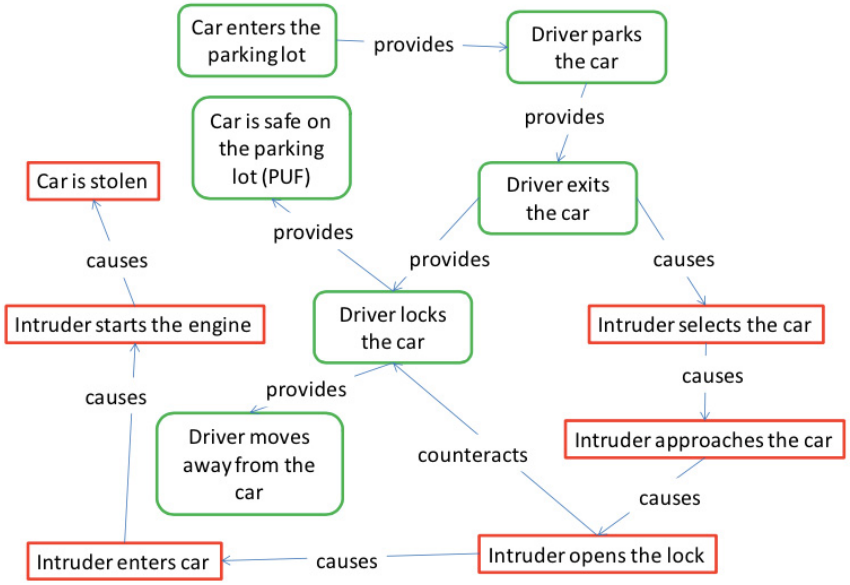

Fig. 4. Example System Diagram [5]

Step 3: Identifying Focal Points

Focal Points are the zones or weak points of the system that may cause the biggest weakness of the system or the greatest danger. So using the system diagram the focal points are represented by useful functions that lead to big weakness and harmful functions that cause great danger. Typically focal points in the system diagram have a high number of incoming and outgoing links and are strongly connected with the systems functioning. The approach to concentrate on Focal Points emphasizes the intention to identify the unexpected and especial critical failures.

Step 4: Generating Failure Hypotheses

The generation of failure hypotheses is divided in two stages: the development of "AFP Directions" and the application of Checklists and Operators.

A systematic way to develop the AFP Directions is given by the consequent utilisation of the SEOR- model regarding the Focal Points. SEOR stands for: **S**ource **E**ffect **O**bject **R**esult. An example for the SEOR-Model can be described as follows: to destroy (melt) an Object (a plastic pad) the harmful Source (a heating device) should be placed close the Object. Conversely: to protect the plastic pad (opposite effect), it should be moved

away from the harmful Source (the heating device). The AFP Directions are abstract commands that are challenging readers to develop failure hypothesis (e.g.: Find ways to strengthen harmful impact on the Focal Point!). Fig. 5 shows the SEOR-configurations to formulate the AFP Directions.

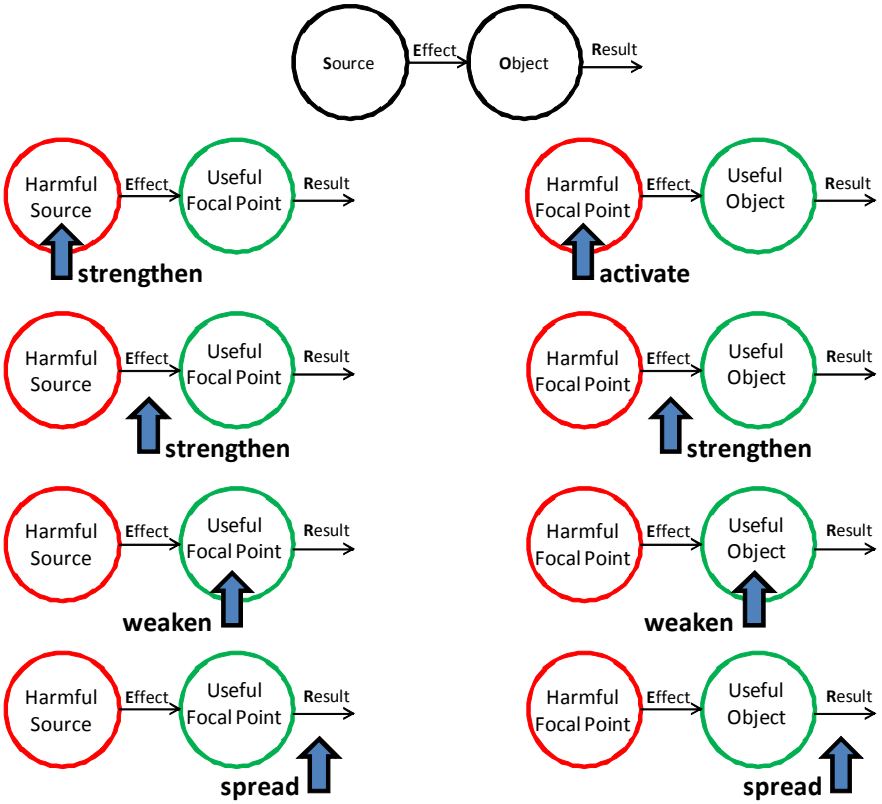

Fig. 5. SEOR configuration [5]

Answering the commands of the AFP Directions leads to a first list of failure hypotheses. With this systematic approach even more failure hypotheses can be found as just with intuition.

The Checklists and Operators can now be used to enforce this effect dramatically. This well structured lists (e. g. typically hazardous materials, typically hazardous processes, typically hazardous individuals ...) and Operators (concrete but not specific thought-provoking impulses, derived from different TRIZ- tools and experience in AFD) let the list of failure hypotheses expand even more.

Step 5: Generating Failure Scenarios

This step continues the search for failures in two ways: Inventing most dangerous failures and combining resources of multiple failures.

Inventing the most dangerous failures is a procedure supported through particular checklists. Checklists can be found at [5]. It encompasses the attempts to intensify already found possible failures and to explore possibilities to hide the failures. The combination of multiple failures helps creating failure scenarios with intensified impact on the system.

Step 6: Assessing Risks

The process of evaluating the risks in AFP is based on the definition of hazard and likelihood. But these two factors may be used in a different way [5]:

Regarding the hazard failure hypotheses and scenarios have just to be judged whether they are causing injury to human beings, danger to the systems functioning or pollution or not.

Regarding the likelihood estimation is very hard for potential critical errors that are invented by thinking about the most dangerous failures and the combination of different errors. Instead of guessing the likelihood of failure exposure the likelihood can be evaluated by the evaluation of the availability of the existing resources that are necessary to provide the failure.

As a result of this consideration failure scenarios and hypotheses can be defined as very important, if they are very hazardous and the resources to provide the failure are available (at the moment or under specific but possible conditions). Failures not very hazardous but likely to occur or failures very hazardous less likely to occur are designated as "second priority". The lowest priority group includes the failure scenarios and hypotheses that are not very hazardous less likely to occur.

Step 7: Preventing Probable Failures

The prevention of the failures should be started by developing a system diagram (see step 2) for each failure hypothesis or scenario that is to consider. These diagrams are the starting point to find the solutions to prevent the failures. The diagrams show failure mechanism chains and contradictions. Just analyzing these diagrams can produce reliable solutions. With the help of checklists, operators or some other TRIZ-tools more effective solutions can be developed.

Operators and checklists for preventing or eliminating the failure are [5]:

- Removing the source of harm or changing its properties
- Modifying the harmful effect
- Counteract the harmful effect
- …

Step 8: Evaluating Results

The evaluation of the results shows if the solution really can be implemented preventing the failure completely. To prove that the solutions should be examined in detail – like in the procedure described so far, now the solutions have also to be checked with a simplified Express-AFP procedure.

5. Hybridization of FMEA and AFP: The Failure Mode and Effects Anticipation and Analysis – FMEAA

Both, the FMEA and the AFP bring advantages for their use. On one hand the FMEA for example the linear process for completion that is well accepted and standardized, on the other hand AFP here for example the invention of failures that are "out of the box". Differences and advantages can be seen in comparison at [4], especially the synthesis of FMEA and AFD is given as possibilities (see Table 1).

Table 1 Potential synthesis of FMEA and AFD [4]

FMEA Step	AFD Integral
Potential Failure Mode	Failure Prediction Mode of AFD
	Cause – effect diagrams for the system (sub-system, component)
	Automatic Inverted Problem formulation
	Automatic access to AFD knowledge base (Checklists and Operators)
Potential Effects of Failure	Access to AFD knowledge base, in particular the checklists:
	Destroying the system's resistance to a specific effect
	Making the system vulnerable
	Intensifying the failure
	Masking the failure
Potential Causes/Mechanisms of Failure	Application of Failure Analysis mode of AFD™, in particular:
	Cause – effect diagrams for the system (sub-system, component)
	Localizing the failure
	Automatic Inverted Problem formulation
	Identifying general methods of providing the
	failure
	Identifying components necessary for
	providing the failure
	Revealing components of the failure among the system resources
	Automatic access to AFD knowledge base
Recommended Actions	Application of Prevention and/or Elimination of the Failure mode of the AFD, in particular:
	Automatic Problem formulation
	Automatic access to AFD knowledge base, in particular the Operators:
	Eliminating the causes of the failure
	Removing the source of harm or change its properties
	Modifying the harmful effect
	Counteracting the harmful effect
	Isolating the system from the harmful effect
	Increasing the system's resistance to the harmful effect
	Modifying or substituting the object effected by harm
	Localizing the harmful effect
	Reducing the harmful effect
	'Blending in' defects
	Transient using of a harmful effect

Unfortunately no really hybridization of the tools is given. Regarding literature it is only pointed out that the Anticipatory Failure Determination can improve the FMEA, but no way of make “one” method was presented.

Now we present a way of hybridizing FMEA and AFP where FMEA still takes the stronger part, because:

- FMEA is a received standard,

- people are used to the FMEA,
- it is quick to learn,
- we start from a known way of thinking and integrate AFP easily into it,
- there is no jumping between the single methods.

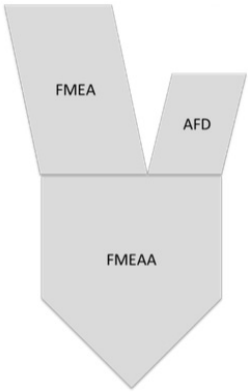

Fig. 6. Hybridization of FMEA and AFP: FMEA will be the stronger part in hybridizing the tools to the Failure Mode and Effects Anticipatory Analysis (FMEAA)

Drawbacks that might occur from hybridizing in this way instead of using both methods as separate tools next to one another may lie on AFP side:

- not all unexpected failures may be invented (however, outside the AFP such failures are most likely to
- not being predicted at all)
- not that detailed checklists and tools may be received (non the less, much more instructive and illustrative than any other)

Therefore we kept the same structure as in the description of the FMEA (see Table 2).

Table 2 Structure of the hybridization of FMEA and AFP

	Objective	**Tools**	**Result**
5.1 FMEAA Structure	Modeling the system structure	FMEA structure and function tree AFP checklist	Basic structure of the system Basic information about the system
5.2 Function Analysis	Modeling the functions of the system	FMEA Function Analysis AFP cause and effect model with functions	Model of functions and their cause and effect relationship
5.3 FMEAA Failure Analysis	Building the failure structure of the system	FMEA Failure Analysis AFP cause and effect model FMEA Form sheet AFP Focal Points SEOR model	Failures, invented failures and their cause- and-effect-relationship Failure scenarios
5.4 Action Analysis and risk assessment	Assessing potential risk in the system	FMEA form sheet FMEAA risk assessment based on AFP risk assessment FMEAA form sheet	FMEAA form sheet with failures that need action
5.5 Optimization	Set measurements for potential failures with high risk assessment	Creativity techniques TRIZ tools	Measurement list to be executed

5.1. FMEAA-System Structure

For this step the system structuring approach of the FMEA is used. Doing so, we already answer the questions of the AFP-Questions for obtaining the necessary information "what is the name of the system?" and "what is the system structure?"- In addition to the FMEA procedure, we ask the following questions of the AFP questionnaire:

- Are there any drawbacks or side effects?
- What is around?
- What is the super system?
- What is the system history?
- Asking these additional questions gives us the possibilities to identify more failures and do it quite easily.

5.2. FMEAA-Function Analysis

In first step the function analysis is performed like in the FMEA. For each system element functions are written down and the function structure is created as well. All these collected functions are considered to be "useful" functions (UF) in the meaning of AFP's system diagram as they are intended to be part of the system for a good reason. The Primary Useful Function (PUF) is taken from the UF's of the first level as in our example like "Assembly of the complete product" (see Fig. 7).

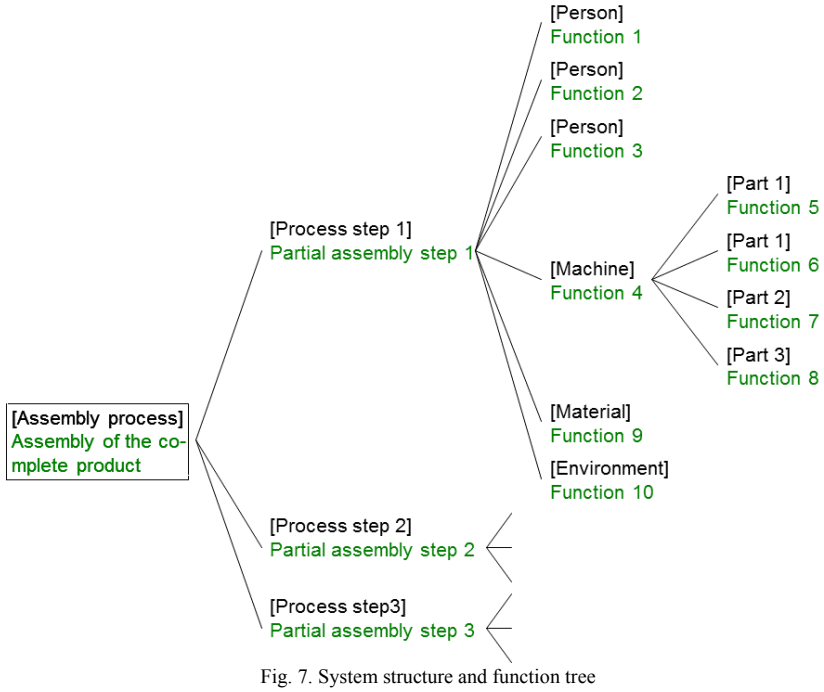

Fig. 7. System structure and function tree

Now, the elements of the system structure and the combination of the function tree are transferred to the AFP system diagram functions (as knots) and cause-and-effect relationships expressed by links – i.e. arrows (see Fig. 8).

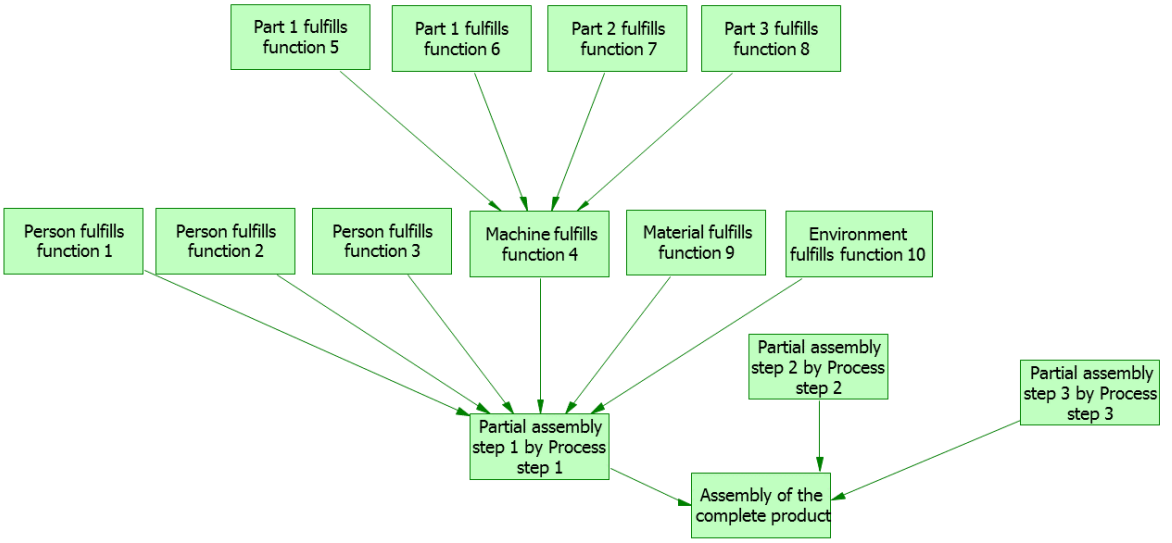

Fig. 8. Function tree in FMEAA notation (according to AFP notation)

5.3. FMEAA-Failure Analysis

Now potential failures of the functions are collected, as we usually do in the FMEA. The failures are attached to the functions they belong to (Fig. 9). The structure of the failures is created according to the function diagram. As one can see parts of the failure structure repeat for failures that might cause other failures (e.g. Failure 8 in Fig. 10).

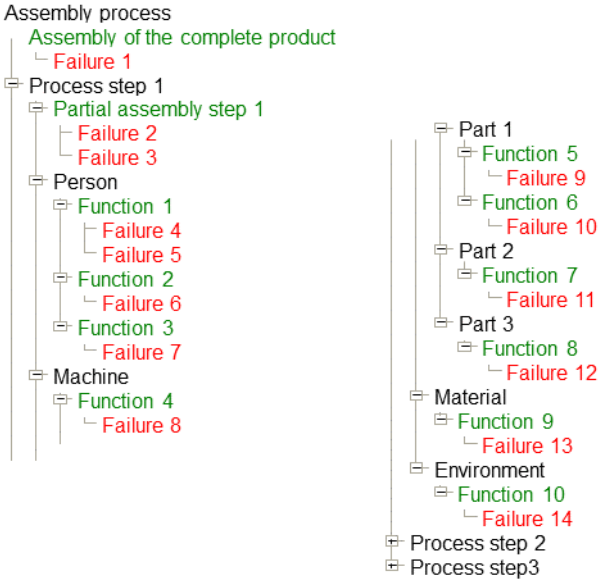

Fig. 9. Functions and attached failures

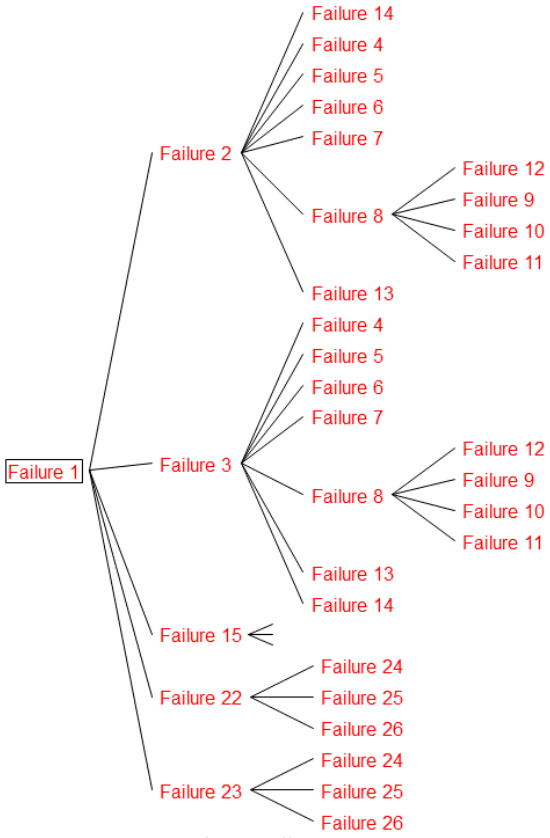

Fig. 10. Failure structure

Next, to transmit the failures to the system diagram, three steps must be accomplished:

Step 1: Insert failures and failure modes as harmful functions related to the useful functions in the AFP diagram (Fig. 11).

Step 2: Ask the questions “does a failure cause another failure?” and “is a failure caused by another failure?” for each failure in the diagram. If you can answer the question with ‘yes’, draw the cause-effect link between the failures (Fig. 12).

Step 3: Fill in the FMEA form sheet.

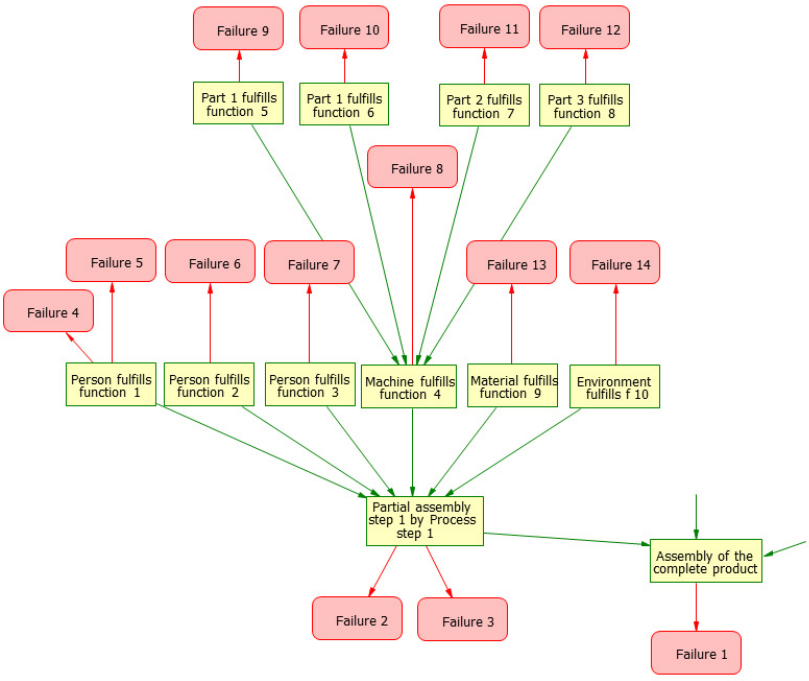

Fig. 11. Step 1: Failures (harmful functions) attached to useful functions (partial view)

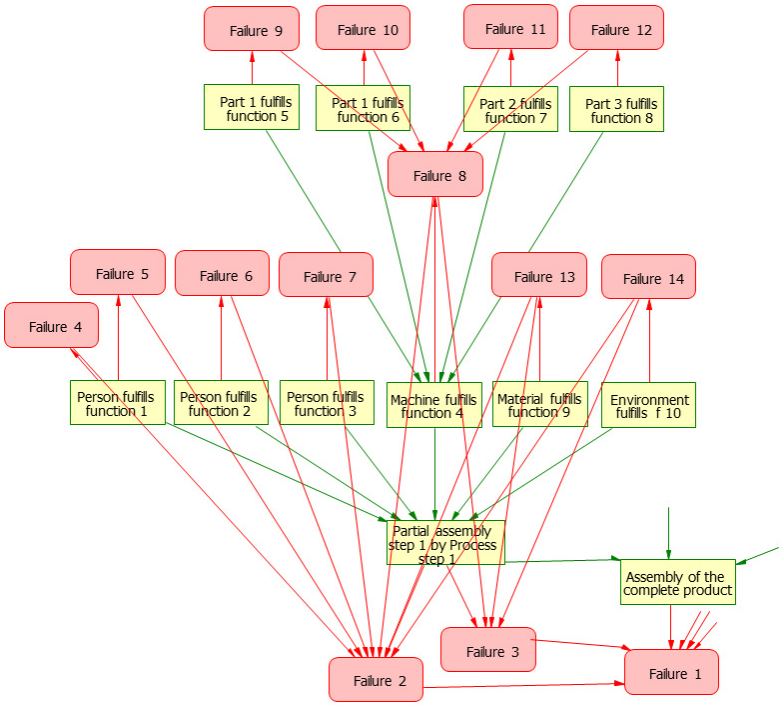

Fig. 12. FMEAA system diagram including all cause and effect connections

Filling the form sheet can be divided into several sub procedures:

Step 3.a:

Search for failure chains containing three parts and insert them to the form sheet (see Fig. 13).

Step 3.b:

Complete chains of two failures and single failures for failure effects and failure cause and insert the new failures into diagram and form sheet (see Fig. 13).

Step 3.c:

Search for Focal Points. This sub process realizes the AFP approach to create failure hypotheses. In contrast to the AFP we recommend to follow just two ways to identify focal points:

- Focal Points are points at the system diagram that have many arrows (incoming and outgoing) [5] and Points accumulation or concentration of substance, energy or information; crossing points; zones of conflict or just points with "bad reputation" [3]. To identify those points use the notes made at chapter 3.1 "History of the product and known drawbacks".

Step 3.d:

Now invent failures for the focal points. Use the SEOR model to create this failure hypotheses and scenarios. As a result you will receive new failures that have to be added to the system diagram.

Step 3.e:

To complete this action, you have to repeat the action described at steps 3.a and 3.b. That is: the now added failures establish new failure chains, couples or single failures. The mentioned steps are essential to complete these chains and to bring all the new information about failures hypotheses and scenarios into the FMEAA form sheet. At this point it is important to flag the entries on the form sheet that arise from this step 3.e (e. g. using another line colour in the spreadsheet or an indicating column "FP"). So an FMEAA instruction has to include the subject how to utilize the SEOR model. For this purpose the SEOR model checklists [3] can be applied. Amongst others there are checklists for:

- Typical Harmful Impacts
  - Mechanical
  - Thermical
  - Chemical
  - …
- Typical Sources of High Danger
- Typical Disturbance of Flow
- Typical Functional Failures
- Typical Resources Capable of Producing Harmful impact
- …

For detailed information about the checklists see [3] and [5].

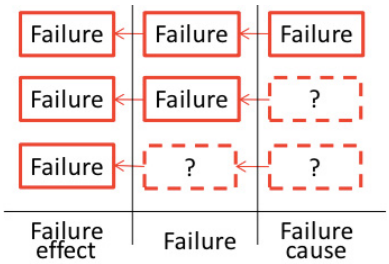

Fig. 13. Completion of failure chains

Source	Function	Failure Effect	S	Failure mode	Failure Cause
	Partial assembly step 1	Failure 1		Failure 2	Failure 5
	Partial assembly step 1	Failure 1		Failure 3	Failure 13
	Partial assembly step 1	Failure 1		Failure 3	Failure 14
	…	…		…	…
FP	Machine fulfills function 9	Material might corrode in use		cleaning chemicals remain on part and salt water from environment	washing process is insufficent

Fig. 14. Example for filling the form sheet (failures coming from inventing failures are marked by FP for Failure Prediction)

5.4. Action Analysis and risk assessment

The action analysis for the ‘normal’ failures is carried out like in the FMEA by noting down the taken actions for prevention and detection. Based on this the ratings for severity, occurrence, and detection are entered and the Risk Priority Number is calculated.

The failures marked with ‘FP’ are considered on another way of risk assessment that is more close to the AFP – but the result has to match with the standard FMEA calculations.

- The detection probability ‘D’ by definition is rated as a ‘ten’, because the ‘FP’-failures we look at are the unexpected ones and naturally no detection action was taken for that.
- For the occurrence ‘O’ we have to assume the likelihood whether the necessary resources for creating the failure are available or not. Fig. 15 shows the occurrence rating choices

Description	Occurrence rating O
More than one resource available and others can possibly appear under certain conditions: **--> likely to occur**	10
No resources available, but some can possibly appear under certain conditions: **--> less likely to occur**	5
No resources available and not likely to appear (there are no resources present in the situation and the possiblity of their appearance is zero)	0

Fig. 15. Assessing the occurrence for Failure Prediction

Same has to be fulfilled for the severity of a failure. Fig. 16 gives an overview on how to rank the severity S for failures of the failure prediction.

Description	Severity S
Very hazardous Failure is capable of - Causing injury to human - Polluting the environment - Jeopardizing the systems function - Making any other serious impact (defined particular in the indivdual case)	10
Not very hazardous All other failures	0

Fig. 16. Assessment of the severity S

The form sheet with the action analysis and the risk assessment is shown below.

Source	Function	Failure Effect	S	Failure mode	Failure Cause	Preventive action	O	Detection action	D	RPN	Resp./Date
	Partial assembly step 1	Failure 1	8	Failure 2	Failure 5	Taken action #1	4	Measuring prodedure D-24231	3	96	
	Partial assembly step 1	Failure 1	8	Failure 3	Failure 13		9	Part can not be used in next step	2	144	
	Partial assembly step 1	Failure 1	8	Failure 3	Failure 14	Taken action #2	3	Part can not be used in next step	2	48	
	...	...		...	...					0	
FP	Machine fulfills function 9	Material might corrode in use	10	cleaning chemicals remain on part and salt water from environment	washing process is insufficent		5		10	500	

Fig. 17. FMEAA form sheet

5.5. Optimization

Optimization takes place as in usual FMEA. Looking at Risk Priority Number (RPN), Detection rating, and Occurrence rating those failures are picked up, that need improvement.

The unexpected 'FP'-failures resulting from the failure prediction regarding the Focal Points may be rated with the numbers 1000, 500 or 0. That is: this kind of failures for sure is not considered if the necessary resources are not available or the impact of the failure is not very severe.

At this point anyone may use its own collection of methods to do the optimization. Doubtless TRIZ- methods are a good choice at this point and naturally we recommend their application. However, to border the FMEAA clearly, we don't include TRIZ-tools for optimization.

6. Example

The example will be presented using a lock that is intended to lock doors for privacy reasons like bathroom doors or similar. The main structure can be seen in Fig. 18.

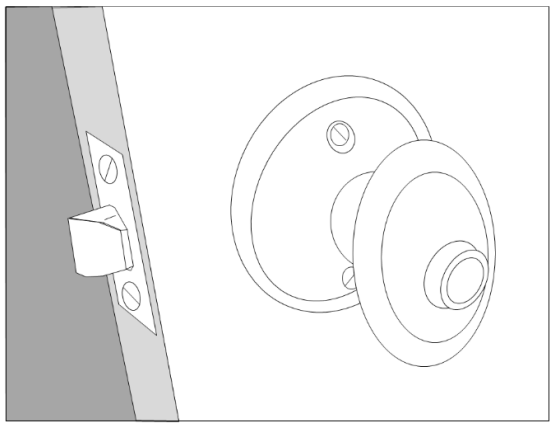

Fig. 18. Example product: door lock

The FMEAA system structure can be defined as following:

- What is around?: There is the door in that the lock is assembled.
- What is the super system?: The super system is the room that is used for privacy (e.g. bath room).
- What is the system's history?: Design is pretty well know. Some details have been changed due to design reasons.

The functions for the system are analyzed and the function structure is created.

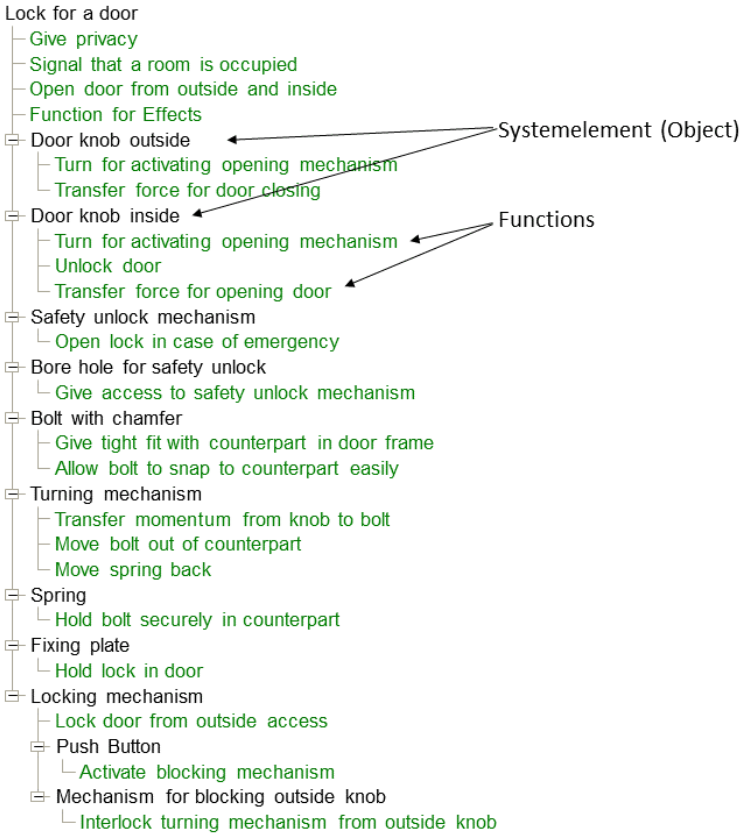

Fig. 19. Functions of the system Door lock

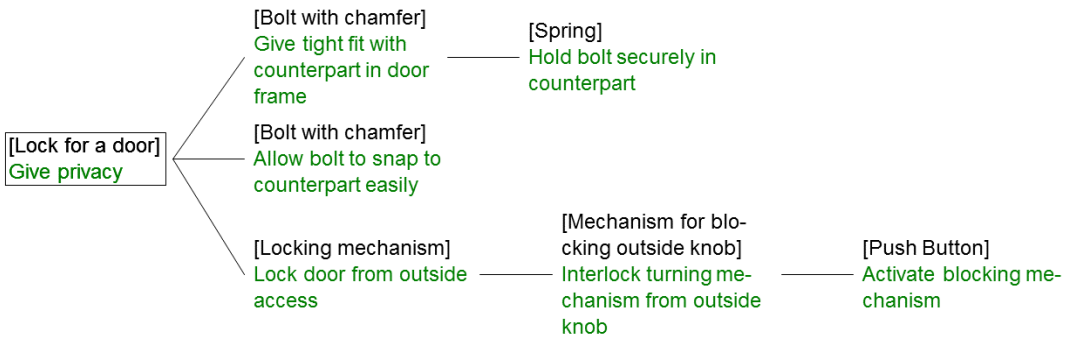

Fig. 20. Function tree for the partial function (Give privacy)

After the structure for the functions of the lock is built, the structure is transferred to the AFP notation shown in Fig. 21.

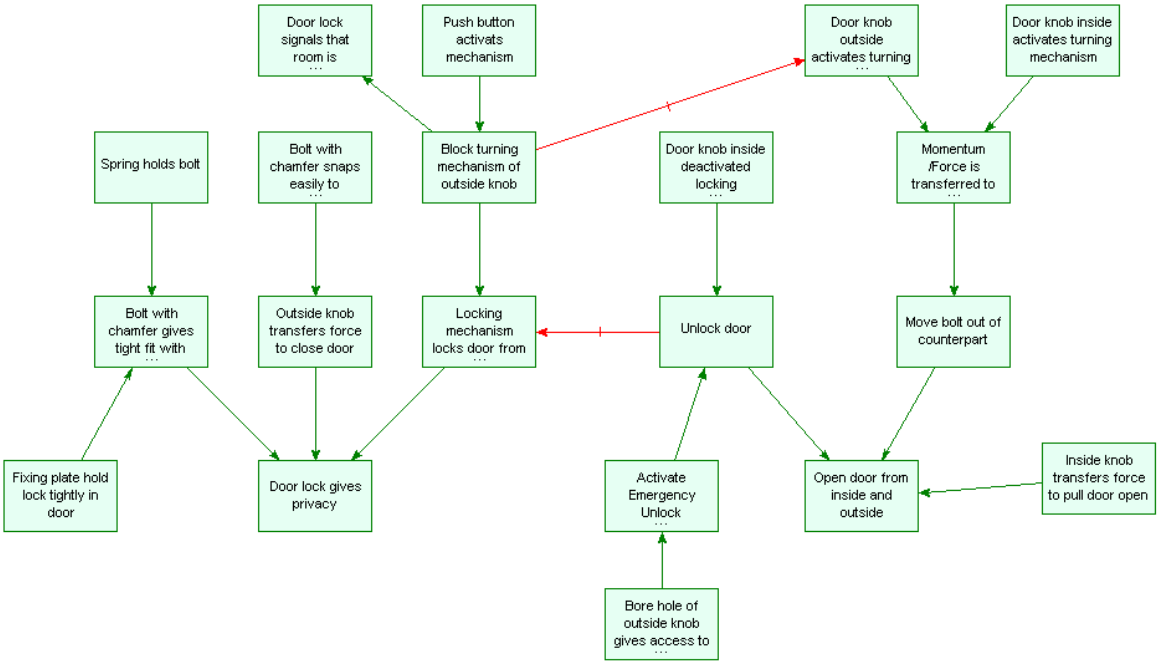

Fig. 21. Functions of the lock described in AFP notation

The typical failures (as they are provided for FMEA) are collected and the failure structure is created. The result of this activity is shown in Fig. 22. There the complete connections for the cause-and-effect- relations are represented.

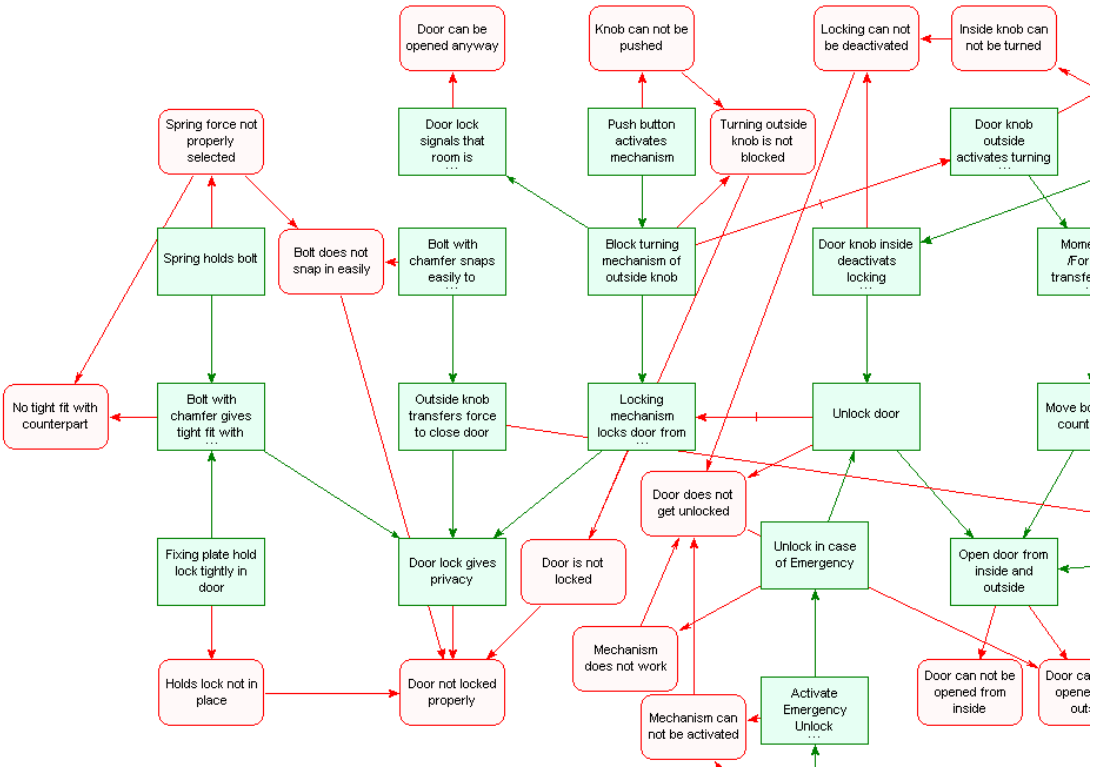

Fig. 22. FMEAA diagram with functions and failures in cause-and-effect notation (partial view)

For some focal points the AFP approach is conducted and new ideas for failures are invented. Some of the questions from the checklists used to invent failures are for example:

- Determine what typical harm can be provided to [the] (Push button activates mechanism).
- Try to deteriorate the useful impact of [the] (Push button activates mechanism) on [the] (Block turning mechanism of outside knob).
- Consider additional ways to deteriorate [the] (Push button activates mechanism).
- Try to increase the vulnerability of [the] (Push button activates mechanism).
- Consider utilizing the resources of surrounding systems to deteriorate [the] (Push button activates mechanism).
- …

Doing this, new failures and with that failure scenarios are invented. For the above mentioned push button for example the failure “pressed unintended” can be derived from the questions. The next questions for creating a scenario are: what resources within the system are needed to create that failure? We need something to push the button and we need some movement to do so. First let’s look for the movement. This can be provided easily by a person opening the door or pushing the door by walking through. Second we need something to push the button. This can be the wall of the super system or something hanging on the door (like clothes or a bath robe). One additional failure is needed to make this scenario happen. The door stop, that is normally there, must be broken or missing. With that scenario somebody can close and lock the door unintended from the outside with no person inside to open the door again. And now consider even more that one has not an appropriate tool to activate the emergency mechanism. The person will not be able to open the door and to access the room. The updated diagram with the invented failure can be seen in the next figure.

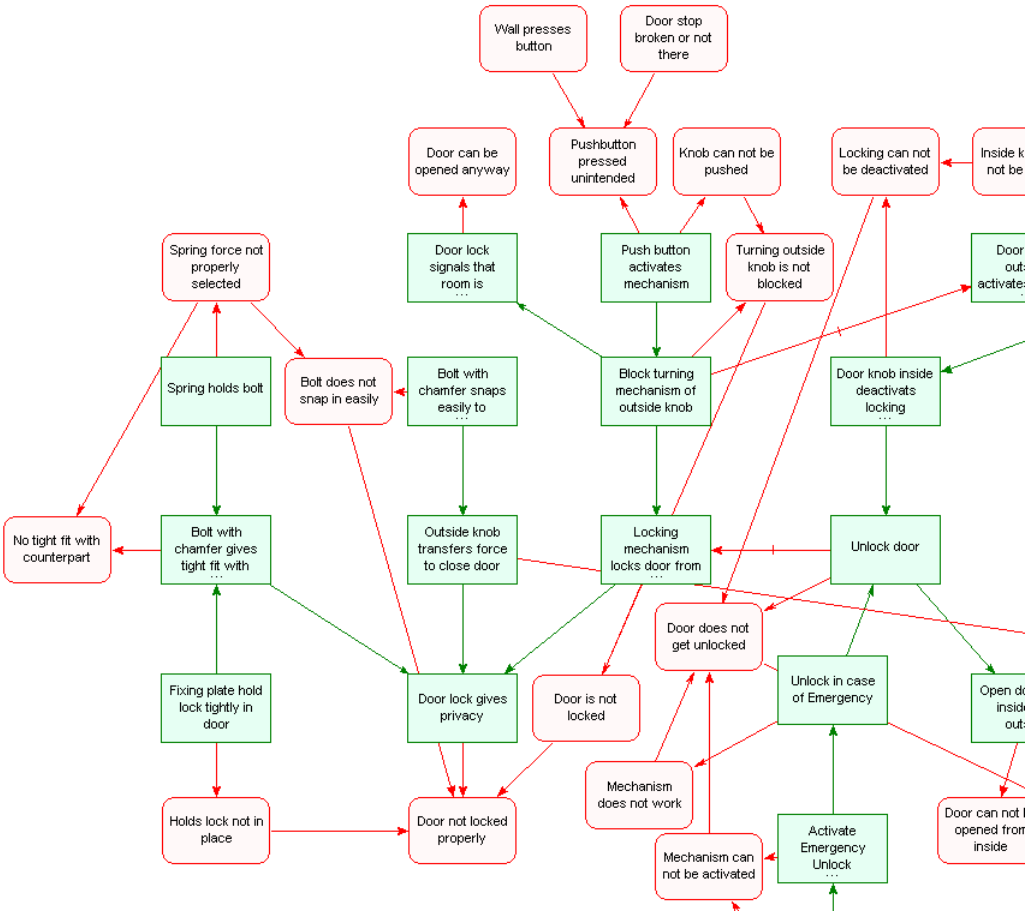

Fig. 23. FMEAA diagram updated with the invented failure (see “pushbutton pressed unintended”)

With that diagram the FMEAA sheet is derived (Fig. 24). The risk assessment for the invented failure is 10 for severity, because it is a main failure of the system’s function. The occurrence is rated with 5, because it is likely that the resources needed to produce that failure might occur under certain conditions. The detection is rated 10, because for that failure no detection has been provided, yet.

Looking at that failure scenario a counteracting measurement can be found easily: hide the push button inside the knob that way that it can be pressed only with the finger by intention and not by any other item available in the surrounding.

Source	Function	Failure Effect	S	Failure mode	Failure Cause	Preventive action	O	Detection action	D	RPN	Resp./Date
FMEA	Give privacy	Privacy is not given	8	Door not locked properly	No tight fit with counterpart	Designed according regulatory specifcations	3	Design test	3	72	
FMEA	Give privacy	Privacy is not given	8	Door not locked properly	Bolt does not snap in easily	Angle of chamfer is designed that no self-retention occures	3	Lab test for material behaviour	2	48	
FMEA	Give privacy	Privacy is not given	8	Door not locked properly	Activating knob can not be pressed	Known design is used	3	Design test	2	48	
FMEA	Give privacy	Privacy is not given	8	Door not locked properly	Mechanism does not block turning mechanism	Known design is used	3	Design test	3	72	
FMEA	Open door from outside and inside	No access to room	10	Door can not be opened from outside	Bolt does not move far back enough too open door	Designed according regulatory specifcations	3	Design test	3	90	
FMEA	Open door from outside and inside	No access to room	10	Door can not be opened from outside	Knob can not be turned	Big enough diameter for knob is used	3	Design test	3	90	
FMEA	Open door from outside and inside	Person is locked in room	10	Door can not be opended from inside	Knob can not be turned	Big enough diameter for knob is used	3	Design test	3	90	
FMEA	Open door from outside and inside	Person is locked in room	10	Door can not be opended from inside	Turning mechanism is broken	Special material for turning mechanism is used	3	Lifetime testing	3	90	
	...	...		...	...						
	...	...		...	...					0	
FP	Open door from outside and inside	Door can not be opened from outside and nobody inside room	10	Push button is pressed unintended	Door stop is missing and wall (or other part in environment) pushes button		5		10	500	

Fig. 24. FMEAA sheet developed from diagram (partial view with one invented failure scenario)

7. Conclusion

Bringing two methods together? Integrating methods? Is it possible? This can be answered clearly with ‘yes’. FMEAA combines the better of two methods for the advantage of the user. Dealing with (the common) failures as before and finding more critical failures within the same process FMEAA is presenting a solution. Paying attention to the Focal Points, inventing failures around the Focal Points using the concept of resources and the completion of failure chains to create failure hypotheses and even failure scenarios adds some essential assets of the AFP to the common FMEA standard.

These standards are almost kept by the FMEAA. For the typical FMEA user (following the standards given in [13]) the new way of identifying system structures and failures is on one hand very close to the common way but on the other hand introducing the user to a notation and thinking that is preparing also the usage of TRIZ in later stages.

We rate the FMEAA in this current version as a method in an early stage of its evolution. The work on instructions, tests, evaluations and further development of the FMEAA are in progress. Besides the

improvement of the FMEAA the adaption of TRIZ as the preferred methodology for the optimization stage is also one of the next steps to go.

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