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APPLICATION OF THE FMEA DURING THE PRODUCT DEVELOPMENT PROCESS – DEPENDENCIES BETWEEN LEVEL OF INFORMATION AND QUALITY OF RESULT

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Keywords: FMEA, level of information, quality of information

1. Introduction

Demands on technical products increase because of changing economic conditions and growing globalization [Schwankl 2001]. This development forces companies to design innovative products in order to succeed in the market [Seghezzi et al. 2007]. The parameters time, costs and quality of products need to be combined in a sensible way to deal with this challenge [Schwankl 2001]. The quality of a product, which is a customer requirement or expectation [Seghezzi et al. 2007], is one of the most important features distinguishes a company from its competitors [Pahl and Beitz 2005].
Within the quality management framework, there is significant economic potential in avoiding failures [Göbbert 2003]. To illustrate that potential it is useful to compare the costs of a failure with the point of detection (Figure 1). Failures are understood as deviations between the actual and the desired status of a product property, the costs of a failure resulting from non-compliance of quality requirements. It is obvious that the point of detection of a failure is important because the costs of a failure grow with the the factor ten as the product development process progresses. The earlier a failure is identified during the product development process, the lower the resulting recitification costs.
However, in practice, failures are often detected too late in the product development process (Figure 2).
Therefore, the aim should be to detect a failure as early as possible in order to minimize resulting rectification costs so that detection changes from avoiding failures to discovering them.
There is a need for preventative identification of failures within the quality management framework in order to utilise economic potential.
One way to preventatively identification failures is to use the Failure Mode and Effect Analysis (FMEA). In it, failures and their risks to the customer are analysed and valuated in order to define mitigation strategies for minimization or avoidance [Schäppi et al. 2005].
If the FMEA is used as early as possible during the product development process, the usable level of information is very low. The level of information grows during the product development process and is understood as all available information, with different degrees of concretisations, according to an instant in time.
It can be assumed that the quality of information changes during the product development process as well. The quality of information shows how information satisfies the specified requirements [Mielke et al. 2011]. Requirements of the FMEA are determined by the following questions [Schäppi et al. 2005]:

- Which failure modes occur?
- What is their reason for occurance?
- How serious are the resulting damages?

- What is the level of risk?
- What has to be done in order to avoid risk?

The more comprehensive, specific and detailed the answers to these questions, the better the quality of information. The question arises whether early application of the FMEA is useful. Because of the existing influence between level of information, quality of information and the FMEA, it could be more sensible to perform it at a later time.

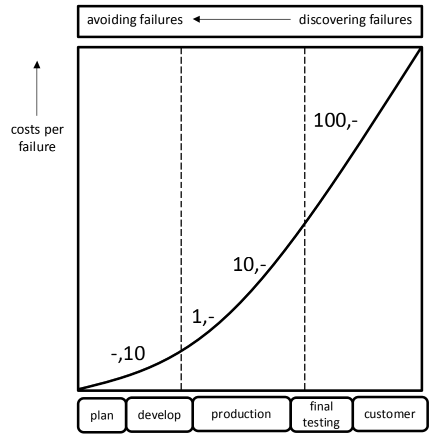

Figure 1. Costs per failure [Pfeifer 2001]

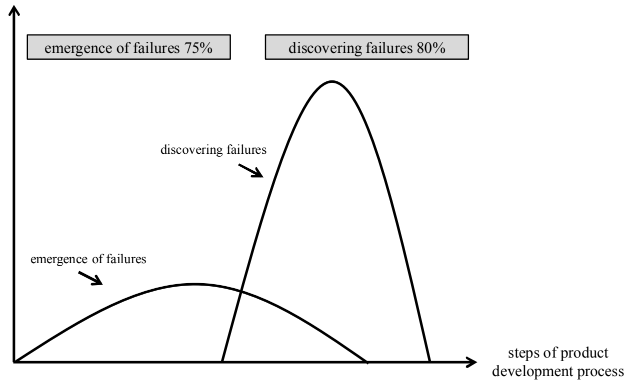

Figure 2. Emergancee and discovery of failures [Pfeifer 2001]

2. Using the FMEA during the product development process

The FMEA is a systematic procedure used to analyze a system to identify failure modes and their effect on the rest of the system [DIN EN 60812 2006]. It can be applied at any time during the entire product development process. In addition to supporting the development of new products, the FMEA can also be used for production and process changes [Schäppi et al. 2005].

The FMEA contains 5 steps that have to be executed. First, every potential failure of a product is identified with the help of a failure mode analysis. After that, the cause and effect of each failure on the planned usage process are assigned. Every combination of failure, cause and effect is evaluated with the help of a Risk Priority Number (RPN). The RPN can be calculated using the probability, severity and detection of a failure. Finally, mitigation strategies are identified to avoid or lower severity and detection of a failure [DIN EN 60812 2006].

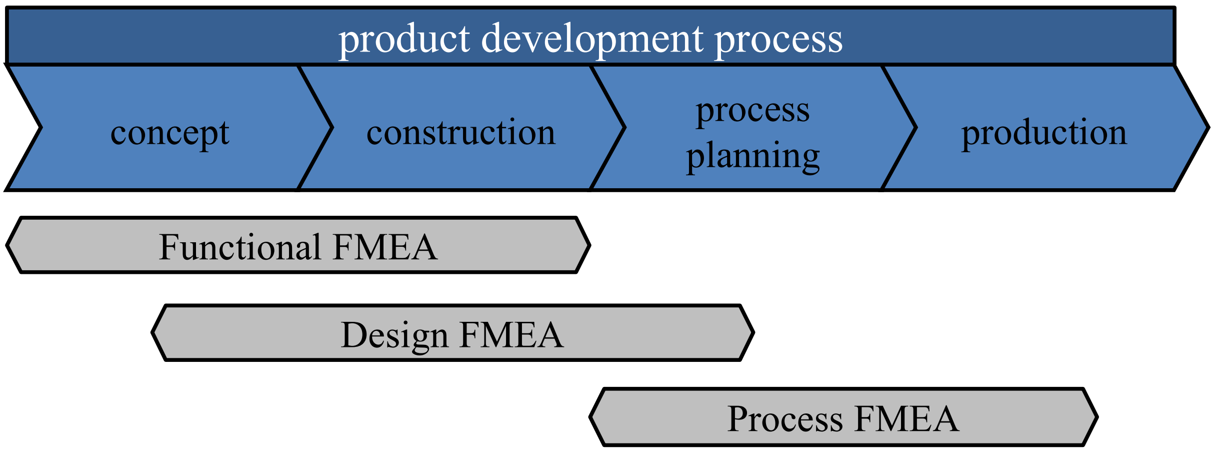

Figure 3. Division into Functional, Design and Process FMEA [Göbbert and Zürl 2006]

A few different types of FMEA exist in literature, especially in the case of division into Functional, Design and Process FMEA. Thus, the FMEA can be applied in every design phase of the product development process (Figure 3).
A Functional FMEA identifies functional faults in early design phases. Where there is a reduced number of variants a Design FMEA should be applied because a Functional FMEA cannot be used effectively [Saatweber 2011]. In it, structural faults are identified for every product component [Göbbert and Zürl 2006].
A Process FMEA analyses production and assembly processes of components to detect faults caused by process. Therefore, a comprehensive level of product properties is necessary [Hering et al. 2003]. According to Figure 3, in practice the division in Functional, Design and Process FMEA is applied partly in parallel [Göbbert and Zürl 2006].
In addition to the division shown further types of FMEA exist in literature. They deal with individual problems, for example, in the automotive or aviation industries. There are extensions of the FMEA, for example, inclusion of a criticality analysis (FMECA) or a diagnostic analysis (FMEDA).

3. Development of a strategy to analyse the influence between information and FMEA

The FMEA considers the variable level of information in an implicit way. This can be demonstrated by the division shown in Functional, Design and Process FMEAs. Each of them should be applied at different stages of the product development process with a given level of information.
To analyse the dependencies between level of information, quality of information and the FMEA, a systematisation of information along the product development process is necessary. Criteria to measure the quality of information are needed. Thus, it is possible to estimate an ideal point to perform a FMEA.

3.1 Systematisation of level of information

To systematise the level of information along the product development process, it makes sense to use product and process models. With the help of these models it is possible to illustrate the development process where they are able to represent an early stage of the planned product [Birkhofer and Kloberdanz 2007]. This paper adapts the process model of Heidemann to focus on the FMEA [Heidemann 2001]. It gives information about the use process, and the product itself, such as disturbances of product and process (Figure 4). A fundamental aspect of this model is the differentiation between the use process of the customer and the product manufactured by the company [Kloberdanz 2009] so the product itself interacts with the usage process to perform it. Known product information can be illustrated using the pyramid of product models [Sauer 2006]. It consists of four levels: function, effect, active principle and part model. Each model can be allocated to the VDI 2221 guideline, so the pyramid can be used at any time during the product development process. The pyramid's shape indicates the possible range of variants and the increasing number of defined product properties [Engelhardt 2011].
The function model divides the task into sub-functions to describe them objectively. After this, each sub-function is concretised using physical, chemical or biological effects [Birkhofer and Kloberdanz 2007]. The active principle model combines these effects with material and geometrical parameters, so a general solution to the task is given [Birkhofer and Kloberdanz 2007].
At the least, all information of the active principle model is specified until the final design of the product is done.
The pyramid of product models can also be displayed in parallel; it is then possible to illustrate information with different levels of concretisation using the Heidemann process model, for example, a sub-function and a physical effect.
With the help of the Heidemann process model the level of information can be systematised.

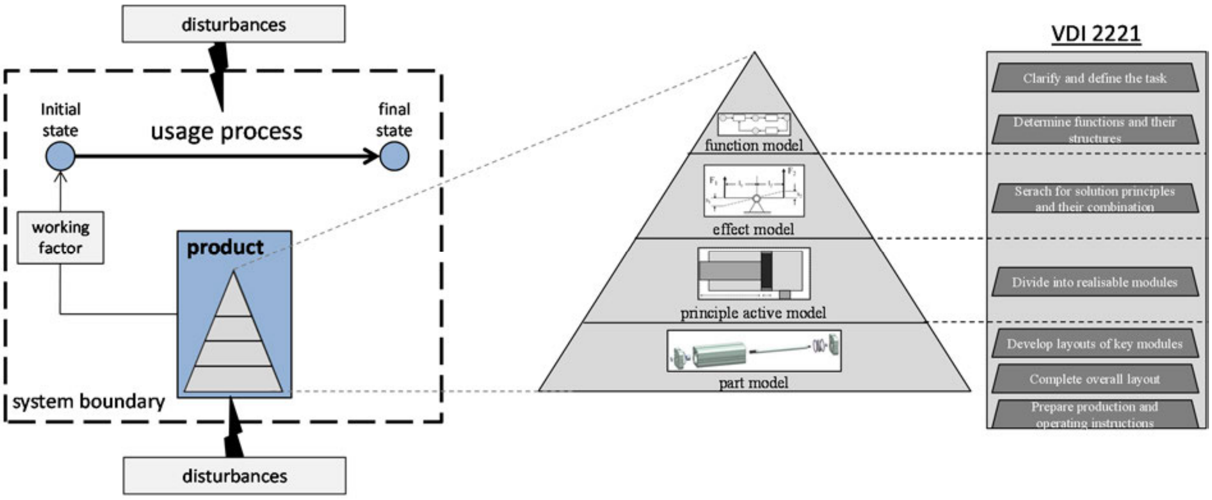

Figure 4. Systematization of level of information [Heidemann 2001], [VDI 2221]

3.2 Criteria to measure the quality of information

After systematizing the level of information, criteria are necessary to measure the quality of information.

Mielke et al. develop a hierarchical framework to understand what the quality of information means to the customer [Mielke et al. 2011]. This framework contains four target categories with 15 dimensions, based on a survey of Wang and Strong (Figure 5). Each of the target categories has a specific context.

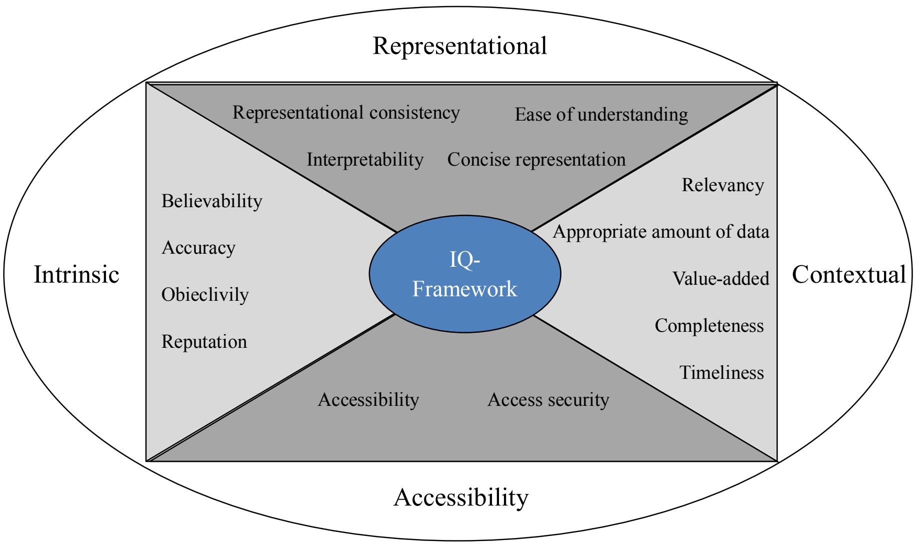

Figure 5. IQ-Framework [Mielke et al. 2011]

The target category *Accessibility* analyses how the system deals with information. In this case it refers to the working steps of the FMEA. The working steps are specified in a norm, so their influence on the quality of information doesn't change during the product development process. This is the reason why the category *Accessibility* will not be investigated here. The target category *Representational* is also not relevant to this paper as it analyses the way information is presented, which is already defined in FMEA worksheets so the effect of this category does not change either.

The target categories *Intrinsic* and *Contextual* deal with the content and benefit of information, which are used as a baseline in this paper. To ensure reliable results on the quality of information, the dimensions have to be measured during the product development process.

3.3 Dependencies between level of information, quality of information and the FMEA

This section connects the level and quality of information with the FMEA. It makes sense to consider the FMEA as a system that works with information, so the level of information is used as the input to generate FMEA results (Figure 6). In the following sections, input and output of the FMEA will be analysed.

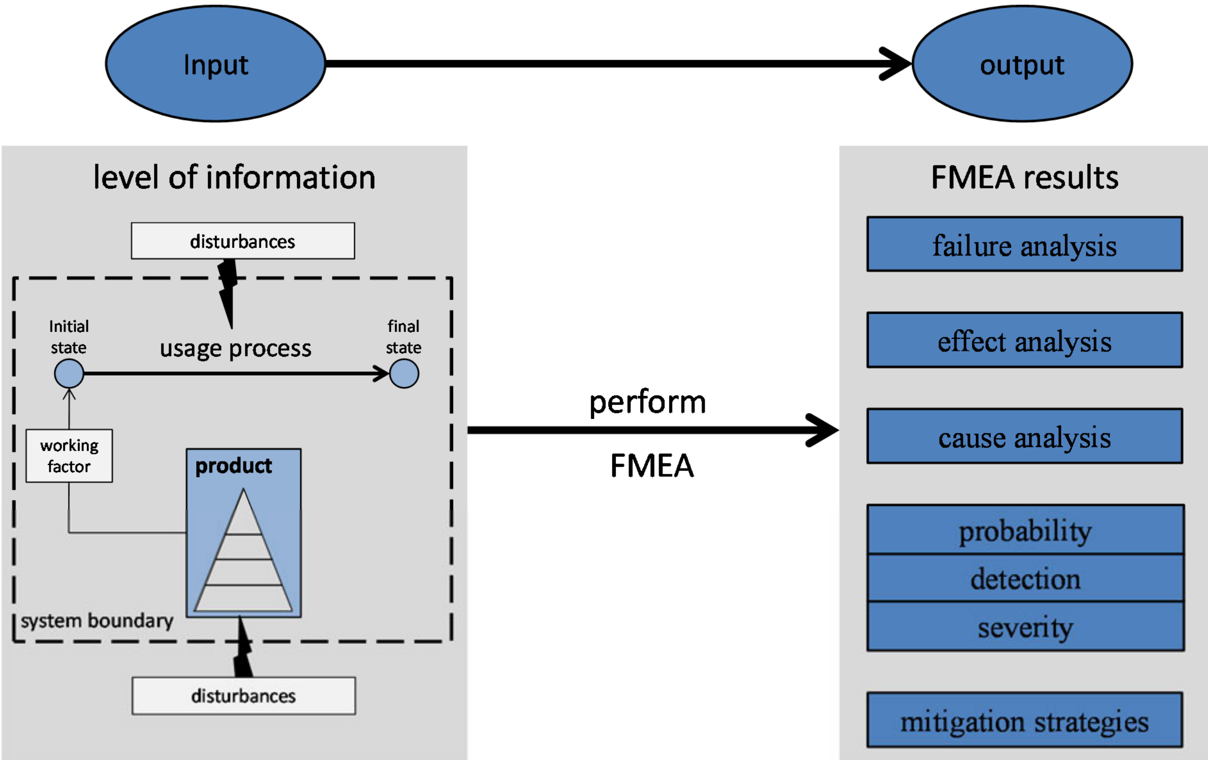

Figure 6. Input and output of an FMEA

3.3.1 Measuring the quality of information of the FMEA input

Before the quality of information can be measured, the quality changes with each step of product development, where the granularity of a step can be adjusted to individual needs (Figure 7).
This change can be measured by comparing the level of information before and after a step, so that the measurement is based on a relative change. Dimensions of the target categories *Intrinsic* and *Contextual* are used to describe relative changes.
According to Figure 7, dimension 1, for example, has declined during the first step of product development and then increases again. This procedure can be transferred to the remaining dimensions so that it is possible to show how each dimension changes during the product development process. With the help of this information, the quality of information can be described at any time.

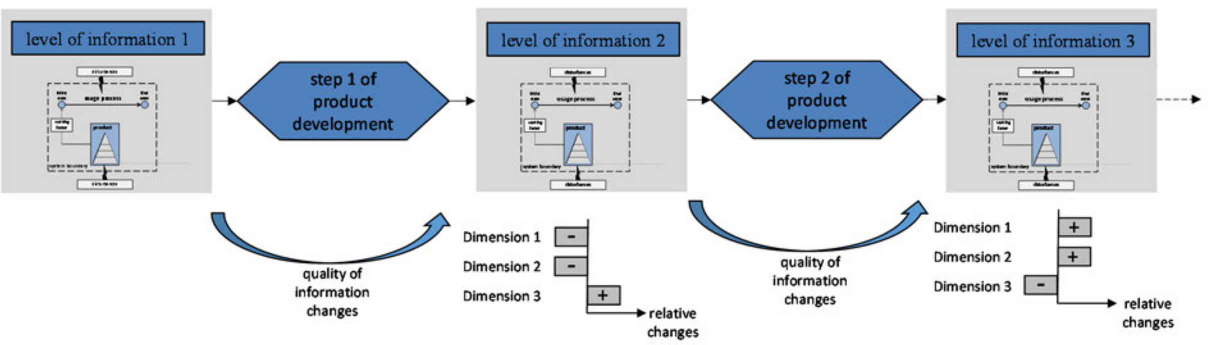

Figure 7. Quality of information of the FMEA input

3.3.2 Measuring the quality of information of the FMEA output

After analysing the input of the FMEA the output is considered. There are dependencies between input and output, such as dependencies between the FMEA results (Figure 8). The use process affects the effect analysis, such as the severity of a failure. Contrary to this, information of the product models pyramid has an influence on the remaining FMEA results.

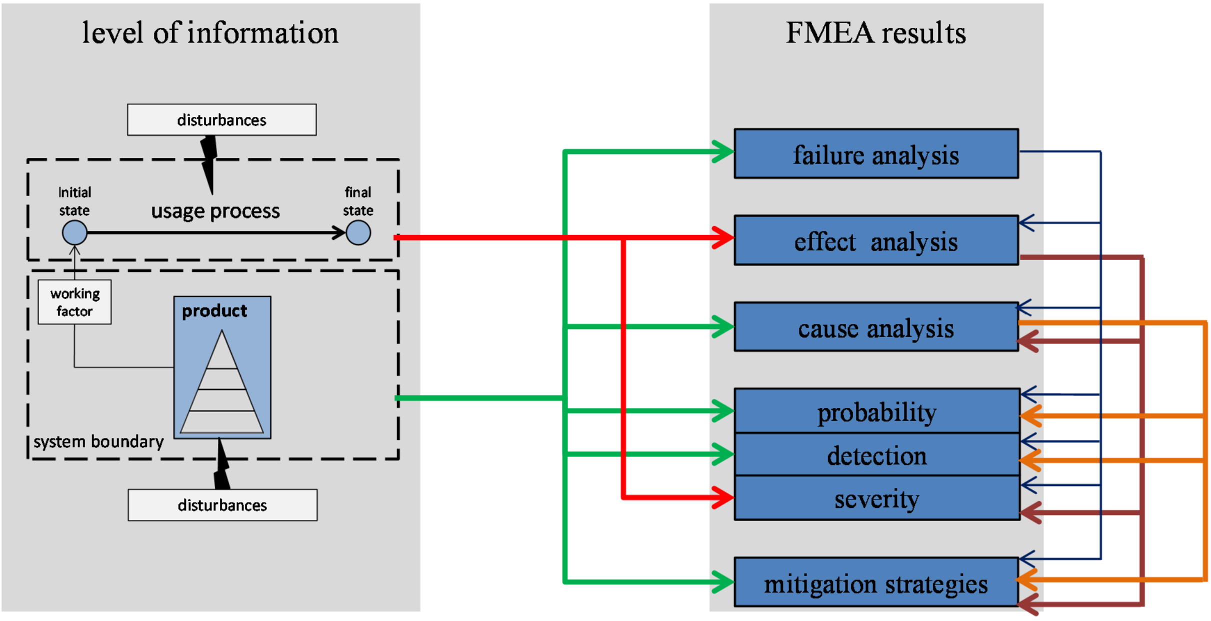

Figure 8. Dependencies between input and output

The dependencies between the FMEA outputs are also shown in Figure 8. They continue to grow along the FMEA working steps, so the sensitivity grows too. To illustrate the sensitivity, the FMEA results can be transferred into a matrix (Figure 9). With its help it is possible to measure the dependencies by using the IQ framework shown in Figure 5, where each dimension is analysed in a separate matrix. The measurement shows how the rows affect the columns. This influence has to be measured with the help of the dimensions of the IQ Framework. Figure 9 illustrates that by using the dimension *Completeness*, the failure mode analysis affect on the effect analysis can be measured. It is possible that the dimension grows, stays constant or declines. In this case, it is obvious that the *Completeness* continuously declines.

The matrix of each dimension can be used to determine the quality of information along the FMEA results.

Dimension *Completeness*

	effect analysis	cause analysis	probability	detection	severity	mitigation strategies
failure analysis	-	-	-	-	-	-
effect analysis		-			-	-
cause analysis			-	-		-

Figure 9. Quality of information of the FMEA output

4. Evaluation of the dependencies

The approach shown in Section 3 is now evaluated in extracts with the help of a pneumatic cylinder. The step of product development from a function model to an effect model is considered. First, the level of information before and after the step has to be illustrated (Figure 10).

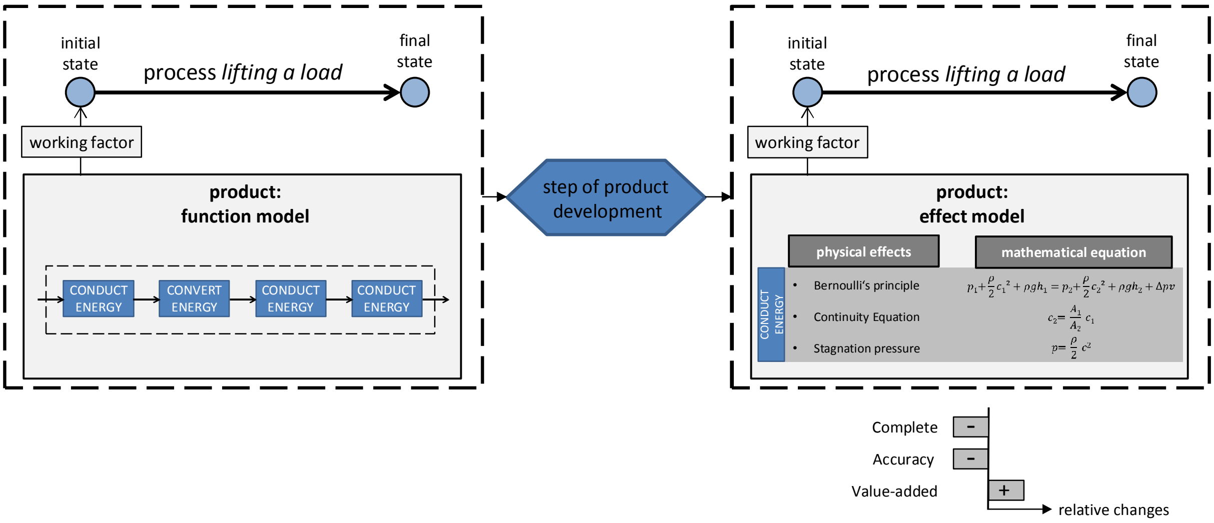

Figure 10. Measurement of quality of information using a pneumatic cylinder

The level of information before the step contains a function model that describes how the pneumatic cylinder works in principle, such as the use process *lifting a load*. Then, the information is transferred into an effect model. For example, the first sub-function *Conduct* is concretized by the physical effects *Bernoulli's principle*, *Continuity Equation* and *Stagnation pressure*, whereas the usage process does not change.

After that, the quality of information is measured with the help of the changing level of information. The dimensions *Completeness, Accuracy and Value-added* are chosen. The dimensions *Completeness* and *Accuracy* decline during the step of product development. There are many opportunities to concretise the first sub-function *Conduct*, so it is possible that the effects mentioned are not enough to describe it. Maybe the effect *Compression* is necessary for a comprehensive description, so the *Completeness* of the information declines. Some of the chosen physical effects could not be predestined to describe sub-functions, which is why the *Accuracy* of the information declines as well.

However, the dimension *Value-added* grows. The identified physical effects can be expressed by a mathematical term. With the help of variables, potential failures, effects and causes are identified more easily and specifically. For example, the variable Δp illustrates that differential pressure drops could be a cause of suboptimal piston movements.

After demonstrating how the quality of information of the FMEA is changed, the output is analysed. Therefore, the following figure shows possible failures, effects and causes, such as mitigation strategies, which are based on the effect *Bernoulli's principle* (Figure 11).

To measure the quality of information of the FMEA results, the same dimensions mentioned above are used. According to the dimension *Completeness,* the number of identified results declines, which can be justified by the increasing possibilities along the FMEA working steps, which is why the dimension also declines.

The dimension *Accuracy* declines because of growing sensitivity. For example, if a failure is defined incorrectly, the cause and the mitigation strategy may be incorrect too.

The FMEA examines problems that might arise during the product development process so that the benefit grows with every additional piece of information along the FMEA results. The benefit of the FMEA results is part of the dimension *Value-added*, so this dimension grows as well.

failure mode		effect	cause	mitigation strategy
bernoulli's principle	pressure 2 is too high/low	Usage process *lifting a load* cannot be performed or only in part	an ambient pressure that is too low	pressure control
			contaminated air	...
			...	...
	height 2 is too high/small		constructional faults	constructive adjustments
			...	...
			...	...

Figure 11. FMEA results of a pneumatic cylinder

5. Results

This paper shows a way to systematise the level of information during the product development process with the help of the process model of Heidemann. Thus, it is possible to illustrate all information at a certain instant in time and use them to perform the FMEA. After that, the dimensions *Completeness, Accuracy and Value-added* are selected to measure the quality of information of the FMEA Input. The dimensions *Completeness* and *Accuracy* decline and the dimension *Value-added* grows. If the measurement is extended to include the whole product development process, it illustrates a downwards and upwards trend (Figure 12).

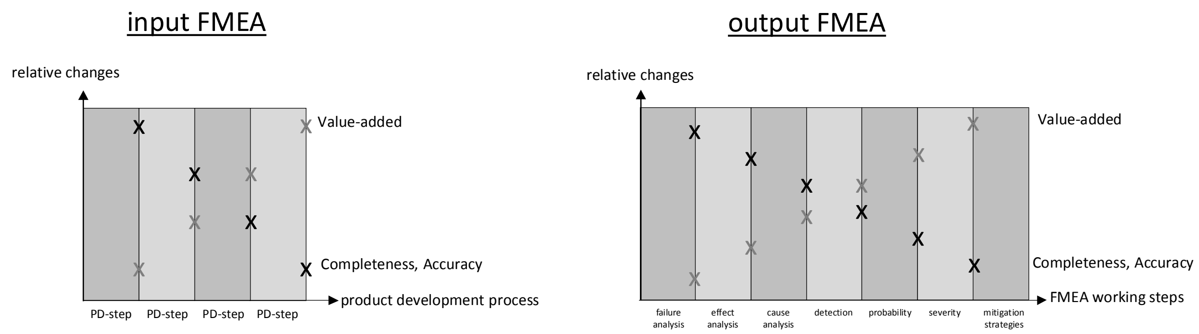

Figure 12. Upwards and downwards trends of different dimensions

After this, the FMEA output is then analysed. It was determined that dependencies between input and output exist, such as between the outputs themselves so that sensitivity grows along the FMEA working steps. With the help of these results, the quality of information was measured using the same dimensions used to measure input. Here, the dimensions *Completeness* and *Accuracy* also decline and the dimension *Value-added* grows (Figure 12).

6. Conclusions

The results of this paper highlight dependencies between the level of information, the quality of information and the FMEA, with the help of the IQ Framework. The upwards and downwards trends of the dimensions *Completeness, Accuracy and Value-added* can be used to estimate the ideal time to perform an FMEA (Figure 13). Therefore, every dimension needs a minimum level so that the FMEA can focus on problems that might arise during the product development process. According to the dimensions *Value-added* and *Completeness*, an FMEA should not be performed too early or too late.
To specify the point in time to perform an FMEA in more detail, the remaining dimensions can be involved in further investigations.

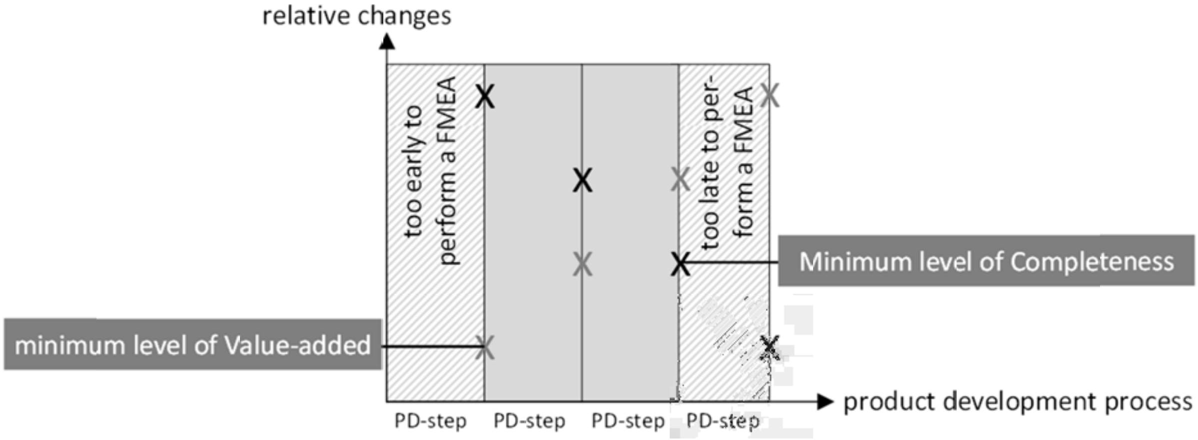

Figure 13. Determination of the ideal time to perform an FMEA

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