

Data Framework for Retrieving Failure Information From Earlier Plant Engineering Projects

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Abstract: Failures in context of industrial production are not only a burden and a main reason for committee and rework but can also be a chance. When failures occur within organizations, several authors and publications have pointed out the opportunities that come with them. Through failures, an organization gets the possibility to improve corresponding processes and avoid future mistakes preventively. This is especially true for manufacturing companies. Their customers trust that products are of a continuously high quality. In addition, these companies are facing enormous challenges, for example a higher product variety or an increasing product and production plant complexity. In times of limited human and financial resources, these challenges have a huge influence on the transfer of failure information. Often, companies (are forced to) have a structured process for how to handle failures within the organization, but fail to transfer the important information gained from them to a parallel plant or to a future project. Therefore, the aim of this paper is to present a framework, which allows retrieving earlier failures at the early stage of the plant engineering phase. This serves as a basis for the further development of a supporting system in the FertiRob project. To ensure transferability in industrial practice, the framework is explained using a real-life application demonstrator. In addition, an adjusted Why-Not-Analysis with (industry) project partners is conducted. This analysis shows that there are points that need to be considered in further development while the basic implementation is possible.

Keywords: Failure management, Information management, PPR model, Plant engineering, Production, Failure retrieval

1. Introduction

The extent of the occurrence of failures in companies can be illustrated by the example of the automotive industry. Only in 2020, 30.3 million passenger cars were recalled because of safety defects in the reference market of USA. This corresponds to an average recall rate of 208 %. (Center for Automotive Management 2021) Moreover, failures can cause major damages to companies. These become particularly unpleasant when they reach the customer, and a complaint arises. For example, it can become expensive and the reputation with the customer suffers (Sitko-Lutek et al 2010). This may be one reason why a lot of research has been done on customer complaints. However, internal failures can also lead to problems, such as rising costs e.g. due to the additional effort to eliminate the problem.

Nevertheless, *"In the simplest terms, failure is the ultimate teacher."* (Maidique & Zirger 1985, p. 309). This sentence is still valid today. Therefore, it is very important that companies learn from failures and use the information generated in the production process to avoid repeating them. In addition, the later a failure is discovered, the more expensive it becomes. The so-called Rule-of-Ten describes this vividly (see Figure 1). It is therefore important to identify and eliminate (potential) failures as early as possible, ideally already in the planning phase.

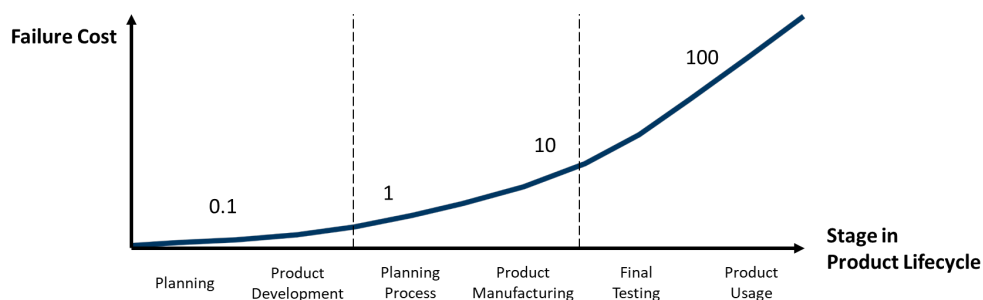


Figure 1: Rule of Ten (Schmitt & Pfeifer 2015, p. 3)

Nowadays, that is not easy. The customers' demands for product and process quality are getting higher (Günther et al 2022). On the other hand, some trends mean that companies are facing ever greater challenges with regard to failure management. For example, a high degree of product individualisation increases data complexity (Tuertmann et al 2016). Increasing complexity of products and processes also leads to more (potential) failures (Ansari et al 2020). New technologies, e.g. Digital Twins or vision-based quality assurance, can support failure management, but wherever people work or plan something, failures can and will occur.

From a quality point of view, this paper deals with the research question, how a data framework for failure information may look, so that this information can be transferred to the right person and thus be eliminated already in the planning phase. For this purpose, chapter 2 first gives an overview of failure management, information management and important basic terms. Based on this, the problem description of the paper is concretized. Chapter 3 explains the proposal of the paper with the help of an example. On the one hand, to ensure that the methodology is fundamentally practical and, on the other hand, to find out how this methodology can be improved for a real implementation, an adapted Why-Not-Analysis with industry and research experts is presented in chapter 4. In chapter 5, a summary is given, and the next planned steps are indicated.

2. Literature Overview

2.1 Failure and Failure Management

Haghi et al (2018) mentioned that there have been several attempts to define *failure* precisely. In practice, the ISO 9000 definition is mostly used. It describes a failure as a not fulfilled requirement. A requirement is a *"need or expectation that is stated, generally implied or obligatory"*. (ISO 9000 2015, p. 46) Therefore, a failure exists when a need or expectation has not been met.

With regard to failure management (specifically complaint management), a great deal of research has been carried out in the marketing field (Schmitt & Linder 2013). From a quality management perspective, failure management is the control of interdepartmental measures for the elimination of occurring failures and for failure prevention (Linß 2018). Several methods and processes for dealing with failures preventively have been established. One, which is widely used in practice, is the Failure Mode and Effects Analysis (FMEA). The aim of this method is to determine how units and processes could fail in order to find appropriate actions that can prevent potential failures. It is important to identify possible failure modes, which are related to their causes and effects on hardware, software, human actions and the influence on each other. (DIN EN 60812 2015) The FMEA can be done on product (Design-FMEA) or process (Process-FMEA) basis. In principle, the FMEA is a preventive method, but can also be used reactively when failures have occurred (Schmitt & Pfeifer 2015). It is a *"living"* document, which is why the current planning status must always be taken into account (Brückner 2019). Therefore, it is also possible, for example, to update new emerging failures. The final status of an FMEA can then be used for future similar products. Although this is a good way to learn from occurred failures in advance, it involves the risk that the file becomes very long and failures are *"dragged along"* which may no longer occur in practice.

For the description of process steps in the handling of failures, several reference models exist. One is the reference process developed in the SAFE project (Crostack & Klute 2008). Further examples are Goldszmidt et al (2011) or Kristes (2012). In practice, the 8D-Report is widely used. It has its roots in the automotive industry and consists of eight steps - Building a Team, Problem Description, Definition of Immediate Measures, Root Cause Analysis, Definition of Corrective Measures, Implementation of Corrective Measures, Avoidance of Failure Repetition and Appreciate Team Performance. (Jacoby 2022) The 8D-Report provides a systematic approach but is on the other hand very time-consuming to process (Brückner 2019). Additionally, in context of failure information storage, the 8D report does not specify a standard for how failure information must be described (Heinrichsmeyer, Schluter & Ansari 2019).

In research, several concepts on how to use failure information have been developed. Schröder (2016) developed a system that supports the troubleshooting process by using information from the current failure to find similar ones from the past. For this, he defined a fixed classification structure and then used similarity algorithms on it. In the project Leaf, a great deal of focus was placed on failure center detection based on clustering algorithms (Schmitt 2021). Heinrichsmeyer (2020) developed a system for supporting failure management, into which a failure database was also integrated. A suggestion, as to which failure can help with the current case, is not given proactively, but must be found with the help of the complaint ID. Schmitt & Linder (2013) integrated the concept of long-term knowledge transfer into the Aachener Quality Management

Model. It connects the Quality Forward- and Quality Backward Chain by flowing the information into the Quality Forward Chain after failure correction.

It can be generally stated that although the topic of utilizing information on failures that have occurred is considered important in research, there is no well-known methodology for retrieving information in the early phase of plant engineering.

2.2 Information Management and Waste

More than ever, all disciplines are facing the challenge of finding the right information in the information overload of digital age. Organizing the supply and flow of information is the responsibility of information management (Krcmar 2015).

Particularly in the case of failures, the root cause and the recognition of failures often does not belong to one person or process step, so that the challenge is to handle failure information in its life cycle. Thereby, the data and information life cycle includes all steps of data and information processing, planning, sourcing, structuring and storing, administration, use and refinement, distribution, actualization and disposal (Bodendorf 2006) (Hildebrand, Gebauer & Mielke 2021).

The following principle for flow of data and information is based on the approach of Jünemann (1989) and is described as follows: the right information at the right time in the right quantity at the right place in the right quality (Augustin 1990). Therefore, the information need can be seen as a key lever as well as a standardized management and flow of data and information (Karch, Schleipen & Lüder 2023). In detail, it is necessary to identify and eliminate inefficiencies in data and information flow, starting with misinformation, which affects the quantity and quality of data and information for a specific purpose as well as the process of data collection. Once the right information has been selected, the task is to provide it efficiently to the user in a standardized workflow. (Karch et al 2023)

2.3 Concretization of the Problem Description

After clarifying the terminology and environment, this chapter details the problem addressed in this paper (see Figure 2). This paper focuses on production, which is why only the Plant Engineering, Production and Customer Usage phases are integrated demonstratively in Figure 2. Within these Product Life Cycle phases, different failures can occur. When this happens at the customer side, it is particularly significant for a company (see chapter 1). During product manufacturing, costs are also incurred, e.g. for lost materials or reworking. However, it is not as serious as a failure occurrence at the customer. A failure during planning has the lowest criticality because there is, normally, still a lot of time to prevent and avoid it. Also, because failures that have already occurred once, have the possibility of reappearing in a new project. The plant engineering phase is therefore a good time to look at these failures and define ways of eliminating them. To do this, a data framework must be defined which supports the plant engineer by transferring the correct information to this phase. This paper describes the model that can be used to isolate potentially important failure information at an early stage of the Product Life Cycle, especially at the plant engineering phase.

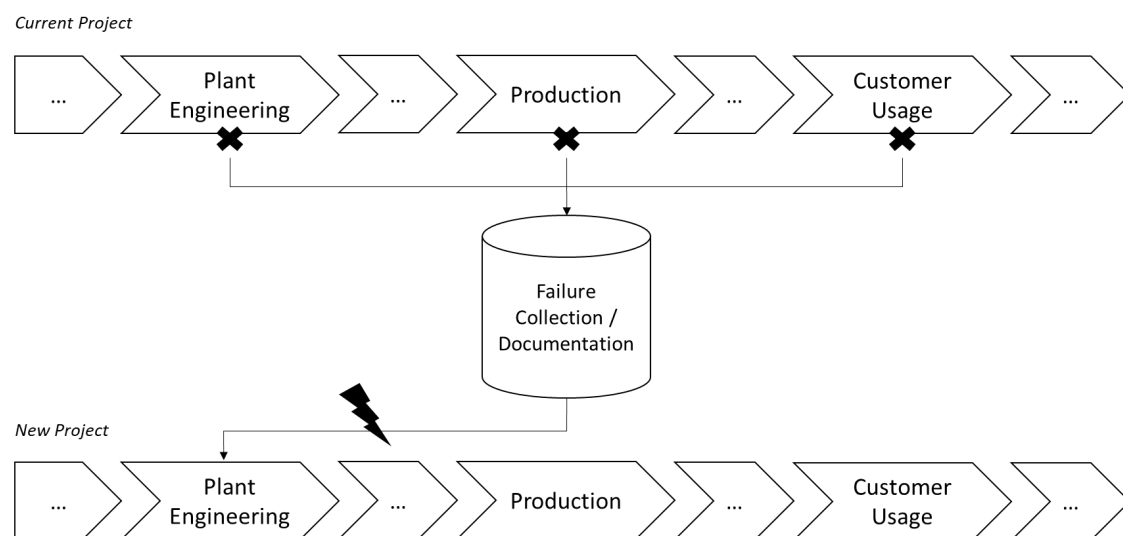


Figure 2: Illustration of the Problem Description of this Paper

3. Conceptual Implementation

3.1 Selection of Base Model

A major challenge in failure management is the fact that people from different departments in the company are involved, all of whom have different functions with different resources and skills (Wu et al 2019). Referring to Figure 2, people from the Manufacturing Engineering department are responsible for plant engineering, while Quality employees are mainly involved in failure handling. In order to develop a system that provides the right information, a model must be taken as a basis that acts as an interface between these departments and makes the needed knowledge explicit. The PPR-Model (Product – Process – Resource) with its focus on the essential aspects of a production plant appears to be suitable for this purpose.

Figure 3 describes the basic functionality of this model. A product, which can also be a single component within the assembly, a process that handles the product and a resource that implements the respective process are connected to each other by so-called PPR-Connectors (Schleipen & Drath 2009). It has been shown that the PPR-Model is very well suited for complex planning structures (Drath 2021). Several researchers in the context of production and plant engineering apply this model to structure and store complex plants and facilities (e.g. Lämmle, Seeber & Kogan 2020, Schäffer 2021). In the context of Industry 4.0, this model serves as the basis for initial considerations on how automatic resource selection can be implemented for plant engineering (Plattform Industrie 4.0 2022). This model is also supported by AutomationML, an XML-based data exchange format for the engineering context. Through the *PPRConnector* interface class, the different objects can be linked semantically with each other. (AutomationML – Whitepaper 1, IEC 62714-1 2018)

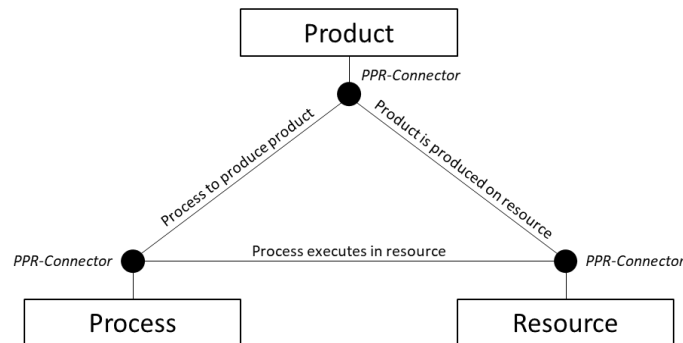


Figure 3: Elements of the PPR Model (Schleipen & Drath 2009)

3.2 Extension to Include Failure Management

The idea of this paper is based on the PPR-Model extended by the component *Failure*. To be compliant with the definitions from chapter 2, requirements describe a product. Together, this results in a uniform structure that can be saved digitally. Figure 4 illustrates the basic idea.

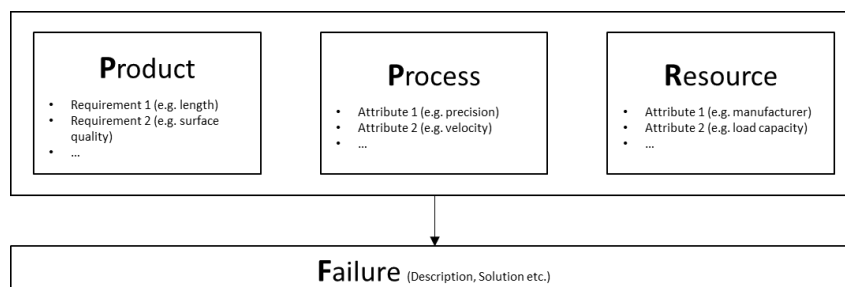


Figure 4: Connection PPR - Failure

The clear separation of the various units of information enables them to be entered in a way that is both timely and accountable separated. During the plant engineering itself, information on how (process) and with what (resources) products are handled can be saved by the production planning employee. If a failure occurs, the corresponding information is added by a quality engineer. In this way, the model combines both points of view. This addresses the problem described in chapter 3.1.

This concept will be explained exemplary through the first station of a research demonstrator, the so-called *COssembly*, which is located in the Learning and Research Factory of the Ruhr-University Bochum (Kulesa, Boshoff & Kuhlenkötter 2022). A detailed process of the joining sequence would exceed the scope of this paper, but the layout of the station and the corresponding product of the final assembly are shown in Figure 5.

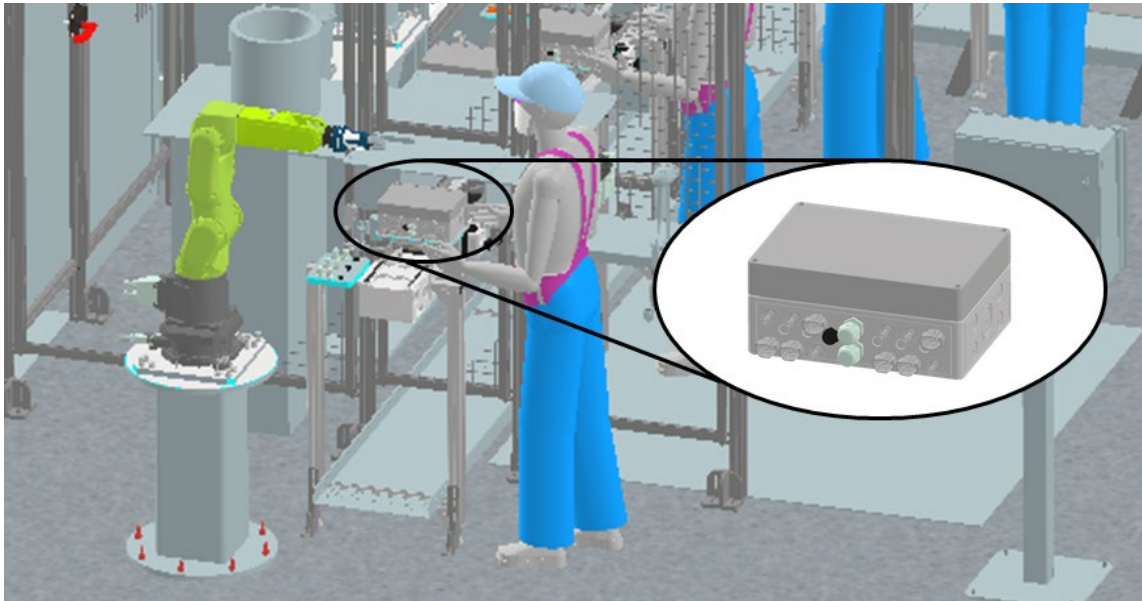


Figure 5: Layout of COssembly station 010 and assembled part

The product used as a demonstrative example is the nut with which the worker fastens a screw (black in the smaller picture) from the inside. In order for the screw to fit well through the nut without being loose, the inner diameter must be 12 (max. + 0.01) Millimeters. This represents the requirement of the product *nut*. The *worker* is the active part, therefore he or she is the resource and *fastening* is the process. If the hole diameter of the nut is too small (e.g. 11.9 Millimeters), this represents the *failure*. If the planner now searches for “nut”, “fastening” and “worker” (e.g. with the help of a ready-made tool that can access the plant’s data), he or she will find the indication that there has been a problem before and that he or she must pay attention to it when planning. For example, the internal dimension of the nut can be measured more frequently at the supplier’s side, so that the probability of getting bad components on the system is minimized. This approach supports internal quality management because failures can now be observed preventively.

4. Evaluation Based on Expert Feedback

4.1 Evaluation Procedure

To ensure the basic practicability of the model, feedback was obtained from experts. The aim of this evaluation was on the one hand to work out possible points of criticism, but also to get suggestions for improvements from the (industry) partners. This was achieved through an adjusted *Why-Not-Analysis*. Figure 6 shows the overall procedure of this evaluation.

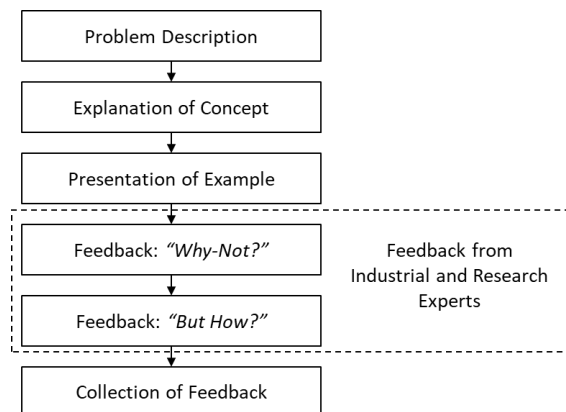


Figure 6: Evaluation Procedure

First, the problem was explained to the partners. In total, 29 people from 14 different organizations were present. Eleven of the organizations are industrial companies, three are research institutions. The experts come from the field of plant engineering, quality management, robotics and information technology. This ensured that a holistic view of the problem would be taken. Afterwards, the basic solution concept was explained and illustrated with an industry-related example. Then, a piece of paper was first distributed, which contained the following sentence: “This concept can never work because ...” (*Why-Not?*) Below this, there was blank space so that the experts could give their feedback on why, in their opinion, this data framework is not suitable for practice. Then a second card was distributed, which looked exactly like the first one. Instead of the previous sentence, it now said: “But if the following is adapted, then it will be really good.” (*But How?*). Now, the participants could share which aspects need to be considered for further processing. Finally, both cards were collected, and the results evaluated.

4.2 Evaluation Results

The most important challenges, which were mentioned individually by the participants, are summarized below. Immediately after that, in order to establish a direct connection between challenge and improvement, the proposed solutions are shown which were pointed out by the participants.

One of the most frequently mentioned challenges was the high amount of time probably needed. Because of the stressful daily business, entering the information seemed bureaucratic for the participants. Even if the information is important for later tasks, only what is needed for the direct fulfilment of the current task is done (“*People won’t do it!*”). Feedback was also given that the information input itself can take a long time. To address these challenges, a simplification of the input, both for the PPR and the failure part, has been proposed. This can be achieved by having a predefined input mask and a standardized workflow in the later software (demonstrator). Best practice would be to get the possibility to use the information entry process within the tools that are used for the tasks anyway, e.g. CAD-Programs for Layout Planning. For the failure part, a suggestion was made that an interface for automatic failure recording in production would be useful so that information is available digitally in advance. If failure classes are defined beforehand, a lot of manual effort could also be reduced here. In the context of knowledge sharing, facilitating data entry plays a particularly important role in the method described in this paper. Only if all participants in the process provide information of a good quality, a retrieval of the right information can take place.

One point that was mentioned several times in the survey was the fact that there are failures where it is difficult to trace them to exactly one process because of different influencing factors. This can also be the case if there is a problematic chain of processes that results in a failure. This fact is especially true for failures with a high level of complexity. Feedback was that in such cases it is good to focus precisely on one root cause. Information on which further factors still exist can be integrated into the failure description as an addition.

The last, more often mentioned challenge concerns the complicated transferability of the information to other circumstances (“*Product, Process and Resource are likely to vary greatly from plant to plant*”). In practice, there are (almost) no two identical PPR connections. Reinforced by the individualization trend of products mentioned in chapter 1, each final product, for example, has a very high proportion of individually developed components. To meet this challenge, the idea was mentioned to find a meaningful abstraction or classification system for all necessary individual information. Explicitly, an already existing industrial classification system can be used for this, e.g. eClass for *products* and *resources* (eClass) or DIN 8580 (2022) for *processes*. Figure 7 illustrates an example of how such a classification can look for a nut (hence for the aspect *product*). Each component that is used in a final product can now be specifically assigned to the last classification level. However, retrieval does not have to take place at this hierarchy level, but e.g. at a level above it. In this way, a more general search can be made for similar circumstances.

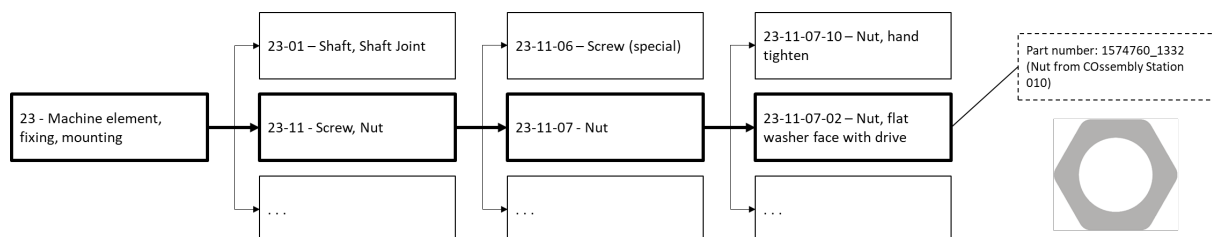


Figure 7: Exemplary Classification for the Used nut Based on eClass

One challenge was not explicitly mentioned by the experts but is very important in this context. The success of the method shown depends on the size of the database, i.e. on the number of failures that have been saved. If there are too few failures in the database, the application is not worthwhile. If there is a large number of failures, the user gets a lot of suggestions, most of which are probably irrelevant for the specific application. The challenge here is to show the user only those failures that are most likely to be relevant to his or her use case. One way of dealing with this was shown by Schröder (2016). There, a current failure was compared with failures that had already occurred using Case-Based Reasoning and similarity algorithms, and similarity measures were calculated. This logic can also be applied to products, processes and resources (at the plant engineering phase), so that in the end only those failures are displayed that have the highest correspondence with the current situation. This ensures that only relevant information is available to the user.

5. Summary and Outlook

This paper showed how a standardized data framework might look so that failures that have occurred in other projects can be accessed already in the early phase of plant engineering. For this purpose, the established PPR model is extended to include the failure component. This addressed the problem that in practice different person are responsible for plant engineering and failure management. The practicality was demonstrated on the one hand by explaining the framework on a real demonstrator. On the other hand, feedback was obtained from practitioners and research partners through an adapted Why-Not-Analysis. It was shown that, basically, the framework is suitable for describing failures in such a way that they can be found again. However, some points have to be considered for the future implementation, which would improve the whole concept and make it more practical.

This real implementation in form of a software demonstrator is the authors' next step. Care has to be taken to ensure that a holistic concept emerges that takes into account all the challenges and suggestions for improvement from chapter 4.2. Based on this demonstrator, the next step is to try out different similarity algorithms to find out which one is best suited for specific use cases. Also, one aspect which will be looked at is how the overall system can support established quality management methods (e.g. FMEA or 8D-Report from chapter 2). The goal is not to create a completely new method, but a support for the end users.

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