Development and Validation of a Failure-Cause-Searching and Solution-Finding Algorithm Based on Complaint Information from the Use Phase

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Abstract - **The increasing complexity of customer requirements, production systems, and new products influences the processes of complaint management in terms of decision-making time and resource expenditure. In literature, there are various approaches to support complaint management. An analysis of these approaches shows that the state of the art reaches its limits regarding complexity. To master this problem, the department "Product Safety and Quality Engineering" has developed an algorithm for failure cause searching and solution finding. This algorithm is based on a conceptual model and a prototype was programmed in Visual Basic for Applications (VBA). The algorithm is validated using cases from stamping and forming process. The algorithm itself, the results of the validation, the critical observations, and the lessons learned are reported in this paper.**

Keywords – **Systems, Failure, Algorithm, Complaint Management, Failure-Cause, Solution-Finding**

I. INTRODUCTION

Today, the industry faces various challenges such as the complexity of products and processes [1], [2]. Customer requirements are becoming more demanding as well. To secure their market position, companies must respect customer requirements and therefore develop products with new components, functions, and design [3], [4]. However, the increasing complexity of products leads to an increased failure rate and thus to an increased number of complaints. Thus, it is mandatory to use a fast and more efficient complaint management approach to not only process and react to customer complaints promptly, but also to find the cause of the failure and eliminate it [5]. The research group of Product Safety and Quality Engineering is currently developing a targeted failure-cause-searching and solution-finding algorithm for production based on the pioneer research project "FusLa" (failure-cause-searching and solution-finding algorithm - Funding Indicator: SCHL 2225 / 1-1). The algorithm uses information that can be found in complaint texts in natural language to identify the cause of failures in production. After processing the collected information, the FusLa proposes useful actions to eliminate the detected failure. The following contribution describes an excerpt from the state of the art in science and technology about the approaches that deal with the handling of complaint information in Section II. Section III explains the development of the FusLa approach and the validation results in cooperation with two companies from the German industry are discussed in Section IV. Finally, Section V gives an overview of the research priorities to be pursued.

II. STATE OF THE ART

In this section, the current approaches related to information probing, prioritization, localization of the cause of failure, and solution-finding are analyzed according to their potentials and weaknesses. Scientific approaches and approaches from industry were examined separately.

A. Science

Beginning with the analysis of the current situation regarding scientific literature, it was found that there are already several approaches that deal with identifying the causes of failures and finding solutions. However, these approaches either do not cover the area of complaint management, or do not work algorithmically and automatically, or have only a subjective evaluation of the complaint information. In order not to exceed the scope of this paper, only the most important approaches that are relevant to this research are listed here and some of them are briefly explained as examples. A detailed analysis of all of these approaches can be found in other publications, such as [1], [6], [7], and [8].

Starting with the IGF project [9], this approach considers the information of a complaint text and divides the information into five categories to create the first failure image. However, this approach is done manually. The next important approach, carried out in [10], evaluates the failure pattern over various dimensions and generates a multidimensional priority value. Since this approach is also to be carried out manually, it does not offer any added value in terms of minimizing the resource expenditure. In addition to this approach, some interdisciplinary approaches have also been developed, such as Eisenhower principle, ABC analysis, and Pareto principle [11]. Although these approaches can be automated, they are still very subjective, qualitative, or only consider a small percentage of the complaints [7]. In the project "DSy" [12], the associated cause of failure is determined semi-automatically based on the properties of a modeled subsystem. This approach considers only embedded systems. Finally, [13] analyzes complaints using data mining techniques in combination with Six Sigma methodology in the framework of DMAIC in order to propose appropriate approaches and tools in the respective phases. This approach has been used successfully in the gastronomy industry, but an adaptation to other industries is uncertain. Table 1 illustrates the distribution of the important approaches examined in terms of their focus.

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Similar to scientific approaches, there are also practice-oriented approaches or software systems that deal with the handling of complaints. These approaches are analyzed in the following.

TABLE I
THE IMPORTANT APPROACHES WITH THEIR DISADVANTAGES

Focus	Approaches	
	Ref.	Disadvantage
Information probing	[9]	Not automated
	[14]	Focuses only on quality of information in 8D reports
	[15]	Focuses on product development
	[16]	Focuses on online forums
	[17]	The project is still in its initial steps.
Information prioritization	[10]	Not automated
Localization of the cause of failure	[12]	Focuses on embedded systems
Solution finding	[13]	Branch-specific, hard to tailor to other industries
	[18]	Focuses on assembly processes and prospective measures

B. *Industry*

The well-known method of the 8D-report, which could also be implemented with software, reaches its limits. Reference [1] has shown that a lot of collected information still has to be entered into the software and the whole process is dependent on the know-how of the employee. Therefore, there is no great saving in time and personnel. The 8D-Report offers no multidimensional prioritization of complaints and information probing. Additionally, the localization of failure causes and appropriate actions must still be done manually. A technical study was conducted in [19] on collecting complaint information. Within this study, a smartphone app was developed, by which customers can submit their complaints via an interface to Google Maps. However, the information collected is not specifically intended to localize the failure causes. The methodology developed in [20] uses Artificial Intelligence (AI) as a support to identify quality problems at an early stage to avoid complaints. Despite the great potential of this research, one disadvantage is that using AI requires a lot of initial work. Furthermore, this study does not deal with finding a solution. Reference [21] continuously analyzes failure documentation using text mining techniques and looks for similar cases to create a customer complaint pattern. However, this approach does not consider the identification of critical organizational areas, causes of the failure, or appropriate solutions. Text mining was also used in [22] to analyze the complaints and collect information. The goal was to derive customer requirements from this information to develop the product via the Outcome-Driven Innovation (ODI) methodology. This methodology does not analyze the failure cause and solution-finding either.

In summary, based on the analysis of scientific as well as practice-oriented literature, it was found that no approach deals with failure-cause-localization and solution-finding. Furthermore, AI-based approaches cannot be easily implemented and communication with existing software systems is difficult. Therefore, it makes sense to develop a new approach to speed up the processing of customer complaints, localize the failure cause, and propose appropriate measures.

III. FAILURE-CAUSE-SEARCHING AND SOLUTION-FINDING ALGORITHM (FUSLA)

In order to develop the FusLa algorithm, requirements for the algorithm were derived based on the state of the art, which were explained in detail in [5]. Following the requirements, the basis of the algorithm was developed in the form of a conceptual model. This model considers the production (manufacturing processes) and usage phase (customer application) in parallel and is divided into four main phases [1]. These main phases are further explained below.

A. *Information Probing:*

To achieve the goal of FusLa, the relevant information must be extracted from a complaint text. In contrast to most of the other approaches, FusLa has an automatic information probing [1]. The algorithm is supported by the Tokenization technique from the field of Natural Language Processing (NLP). Within the tokenization technique, the text is subdivided into smaller individual text modules of high and low relevance. The text modules are then compared with the company's information systems (e.g. customer or order system) so that only relevant information is probed and prepared for further processing. An information structure was initially developed as the basis for this comparison. The structure comprises a total of six different types of information, which are subdivided into individual modules of information. For example, contact information is a type of information that is subdivided into four modules: first name, last name, phone number, and Email of the contact. All of the six types of information and their modules can be found in [23] in detail.

Parallel to this information structure, some rules were applied to the algorithm to specify the procedure of FusLa. These rules consist of six for-loops and conditional statements that allow the algorithm to probe information gathered from the complaint texts and the company's information systems accurately and reliably. These loops were examined in detail in [6].

B. *Prioritization:*

It is necessary to be able to differentiate the complaints in terms of their importance and criticality. In contrast to the current approaches of prioritization, the second phase of FusLa allows an objective prioritization of complaints based on a multi-dimensional calculation [1]. In order not to exceed the scope of this contribution, the 9 dimensions of prioritization will not be discussed in detail but instead are to be found in [7]. All 9 dimensions of prioritization are calculated quantitatively with their specific formula, extracted from the literature. The result is called the dimension value ($DW_j = 1 - 9$). Subsequently, all 9 dimension values are normalized between 1 and 10 to allow the weighting of them ($G_j = 1 - 9$) [24]. This provides the importance of all dimensions.

Finally, when the weight of the respective dimensions has been determined, the priority of the complaint i (Pi) will be calculated by (1):

$$P_i = \sum_{j=1,i=1}^{n} NDW_{ij} \times G_{ij} \qquad (1)$$

$P_i = Priority\ of\ the\ complaint\ i$
$n = Number\ of\ complaints$
$NDW = normalized\ dimensions\ value$
$G_{ij} = Weight\ of\ complaint\ i\ in\ dimension\ j$

C. *Failure-Cause-Localization:*

The main disadvantage of current approaches for failure-cause-localization is that the evaluation of causes depends on the employees [1]. This counts as a disadvantage because the consideration of all elements of a production system is impossible or too time-consuming for employees due to the complexity of the system. This becomes even more difficult if the production system is dynamic. FusLa counteracts this problem by using a generic modeling approach called "Enhanced Demand Compliant Design" (eDeCoDe). The eDeCoDe was developed by Winzer [25] and Nicklas [26] to model socio-technical systems [5]. This approach categorizes the system elements into five standard views (Requirements, Components, Functions, Processes, and People) and considers interactions of these views using matrices, such as the Design Structure Matrix (DSM) or the Domain Mapping Matrix (DMM). The combination of all standard views results in a multidimensional system model of the production system, which can be visualized as a multi-domain graph as shown in Fig. 1 [5].

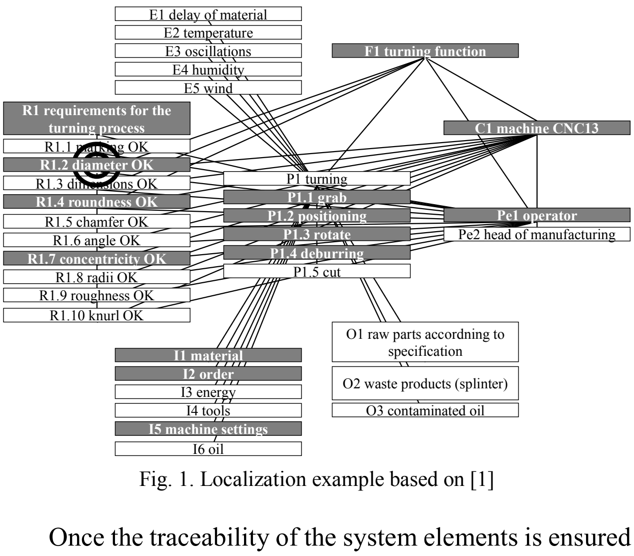

Fig. 1. Localization example based on [1]

Once the traceability of the system elements is ensured by the multidimensional graph, FusLa analyzes the system model and detects all system elements that correlate with the unfulfilled requirement (failure). Thereby the algorithm can identify possible causes of the failure [8]. This means that the FusLa can trace the specified failure in the complaint text back to the individual system elements in the production system.

In this stage, the possible failure causes have been localized and the FusLa can process the information and suggest suitable measures to eliminate the failure cause in the next phase.

D. *Solution-Finding:*

To define sensible measures and solutions to eliminate failure, it is useful to identify the most probable causes of failure. The FusLa can quantify the probability of a failure cause by categorizing relevant information about the failure cause. The relevant information is mapped to 4 categories based on the location of the failure cause (the system elements of eDeCoDe). A further explanation of these categories are omitted from this paper but can be found in [23].

To find and define the appropriate corrective action for each defined category, the STOP-principle is recommended here. STOP is a classification of measures that have become established in the field of safety engineering [27]. This principle defines four different types of measures, including substitutive (S), technical (T), organizational (O), and personal (P) measures [25]. Although the FusLa can propose various failure type-related measures based on the STOP-principle, it cannot yet select the most suitable measure. Therefore, in this phase, the decision about the measure to be used depends on the employee. However, the decision made by employees is documented to be used again in similar cases.

The FusLa concept still had to be examined for its applicability in industry. Therefore, it was tested in two companies of the German industry and the results of the validation are discussed in the following.

IV. VALIDATION OF THE FUSLA IN INDUSTRY

A. *Preparation*

It was mentioned that the FusLa communicates with the company's existing information systems to interpret the information in the complaint text. This means that for the implementation of the algorithm in a company different Application Programming Interfaces (APIs) must be available for communication between the FusLa and other existing information systems of the company. As the programming of such interfaces is outside the scope of this research project, the necessary information was compiled in different Excel worksheets, mapped among each other, and provided for evaluation by the FusLa. Herewith, a sociotechnical production system model based on the eDeCoDe logic was developed. For this purpose, not only various documentation such as technical drawings and test plans were analyzed, but also the direct cooperation with the production manager paved the way to understand the whole interactions within the production processes and to create a better and more accurate system model. The validation was based on a meticulous customer complaint in both companies regarding an unfulfilled requirement for the product SGW (Company A) and the product KSGD (Company B).

The product SGW is usually installed in private cars as a safety component and the product KSGD is a cover part of a type of housing.

B. Validation and Results

Now that the preparation of the validation is complete, the actual validation of the algorithm can be done through performing the four phases, from information probing to solution-finding. A detailed explanation of the validation of the four phases including screenshots of the respective surfaces, which are programmed to test the functionality of the algorithm, is intentionally excluded from this paper but can be read in [28] for company A and in [23] for company B.

The key observations from implementation of FusLa are: (i) successful information Probing, (ii) Dependencies on complaint text quality, (iii) Identification of a risk during prioritization, despite the successful prioritization, (iv) Problems with mapping of unfulfilled requirement to failure, (v) Dependencies on existing system model of the company regarding accuracy. The findings of the validation as well as strengths and weaknesses of the algorithm in each phase are discussed below in detail.

During the implementation of the first phase of the FusLa (information probing), it was found that the algorithm correctly analyzed the complaint text. The FusLa compared all information in the text with the information from the information systems of the company and filtered the relevant information and entered it in the designated field. Due to this successful analysis, the algorithm was also able to filter and contribute additional information about the customer or product, which was not contained in the complaint text. At the end of this phase, it was found that despite the detailed explanation of the failure in the complaint text, the algorithm was not able to map the actual unfulfilled requirement to the failure. Although it has listed all requirements relevant to the product, the employee still has to be relied upon to select the unfulfilled requirement from the list. The cause of this problem is the non-standardized format of the complaint texts. In the second phase (prioritization), the algorithm could easily calculate the dimensional value of all 9 dimensions including their weightings according to the probed information from the first phase. The results are accurate from a purely mathematical point of view. After an interview with the experts in the company, it was found that the mathematically calculated values also have a veritable meaning, i.e. the calculated priority value of this complaint corresponds to the real priority of the complaint. During the implementation of this phase, it was clarified that a correct prioritization of the complaint depends very much on the quality of the information given in the text. In the worst case, the lack of information can lead to an incorrect prioritization value and consequently to a wrong decision regarding the appropriate measures or resources for troubleshooting. This problem can be solved by standardizing complaint texts. In the third phase (failure-cause-localization) the algorithm has been able to identify the possible cause of the failure. Subsequently, it was discussed by the company experts whether the results are credible. All identified failure causes correspond to the actual cause of the failure but in contrast to the company (A), not all possible causes have been found in the company (B). At this stage, it was affirmed that the accuracy of the results does not only depend on the quality of the text, but also the quality of the model of the production system. The more accurate and complete the system model is, the more plausible are the results of the FusLa. To counteract this problem, an interface to the company's CAQ systems or smart systems for real-time information exchange would be helpful. Within the last phase (solution-finding), the FusLa should be able to suggest reasonable measures to the employee for the elimination of the cause of the failure, i.e. the phase of solution-finding. This phase was carried out without encountering any problems and the FusLa has successfully proposed different measures according to the failure category while being completely independent of the quality of the text or the system model. At this point, it should be mentioned again that the best corrective action should be chosen by the employee from the list and also the employee should decide whether this action should be implemented or not. If none of the suggested measures would be suitable, the employee can document his suggested measures in the field provided, and these will be considered in later analyses. This phase can be automated by using AI, but this kind of solution was not analyzed in this research project.

V. CONCLUSION

Starting with the analysis of the scientific and technical literature, it was found that the state of the art methods, such as 8D-Report, reach their limits in terms of automating the handling of complaints and consequently in saving resources. This means, developing a generic approach makes sense in this regard. The FusLa strives to achieve this goal by matching the information contained in a complaint text with the company's existing information systems in the first phase. Thus, the contained useful information can be filtered out of the text and then be used to prioritize the complaints. Subsequently, using the company's production system model, the possible causes of failure are identified and can be eliminated by proposing appropriate actions according to the category of the failure and based on the STOP-principle. During the validation of the FusLa in the German industry, it has been shown that the functionality of the algorithm depends on the quality of the complaint text and the system model of the production. This means that a lack of information within the system model or even the complaint text impairs the results of the FusLa. This problem can be eliminated by preparing a complaint input mask for the customers and by improving the company’s system model itself. To summarize the findings, it can be said that even though the algorithm is a prototype, it shows great potential. To improve the algorithm and to be able to use its potential optimally, further research projects are necessary. How does the quality of the different complaint texts influence the functionality of the algorithm? Does it make more sense to provide an input mask for the customers or is an extensive application of NLP techniques better? How can the identified possible failure causes be prioritized to detect the most probable failure cause? These research questions can provide a basis for further researches and the answer to these questions can optimize the application and implementation of the FusLa algorithm.

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