Validation of a Failure Cause Searching and Solution Finding Algorithm for Failures in Production

Based on Complaints of a Company in the Field of Stamping and Metal Forming

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***Abstract*—The increasing complexity of new products, production systems as well as customer requirements, bring out huge challenges for companies. Especially regarding the complaint management process, it is necessary to ask how these challenges can still be managed and controlled by individual employees. Current approaches and software systems help to minimize the effect of these challenges but they also reach their limits because of the complexity. For this reason, the research group "Product Safety and Quality" has developed an algorithm to search failure cause and to find a solution to support the complaint management process in identifying failures in the production system and eliminating them. This algorithm was initially based on a conceptual model and was subsequently implemented based on VBA in Excel. The result was the first prototype of this algorithm. To evaluate the algorithm in terms of possible weak points and potentials for improvement, the prototype was validated in the industry in the field of stamping and metal forming. The results of this evaluation are reported in this paper and lessons learned are summarized in the conclusion.**

Keywords-Complexity; Systems; Failure; Algorithm; Complaint; Solution.

I. INTRODUCTION

Due to the Industry 4.0 changes, companies in Germany face ongoing and new challenges: The increasing complexity of products and processes, huge investments, and the lack of skilled workers are just a few that can be listed here [1], [2]. Companies are also confronted with a variety of new but also very individual requirements, which have to be fulfilled in order to maintain competitiveness in the market [2]. In addition, there is the trend that customers want more and more individual, newer and also fascinating products.

However, this trend is critical for companies when customers face failures and complain about the product [3], [4]. In this case, it is important to react very quickly, to recognize the cause of the unfulfilled requirement, eliminate it and thus to satisfy the customer again. But do companies even have the opportunity or the skill to react that quickly?

With the focus on an increasing flow of information in recent years, it becomes apparent that companies are usually unable to handle this amount of information with conventional approaches. This can also be observed in complaint management, where the use of methods such as the 8D-Report and also a catalog of software systems such as RM Babtec, CWA Smart-Process or CASQ-it RUF help to reduce the processing effort and the use of important resources (e.g. time, personnel and costs). The increasing complexity and the increasing relationships between the system elements, on the other hand, are not taken into account [5]. Moreover, many companies have no suitable complaint management process, so that the valuable potential of complaints, e.g., the improvement of production or product system and thus the increase of quality, remains completely unused. Due to this restriction, the worst-case scenario is that the complaint management process is increasingly seen as a burden and not as an opportunity [6], [7]. As a result, further potentials of complaints, including a customer-oriented product development or increased customer satisfaction, will be missed.

To counteract this problem, the research group Product Safety and Quality Engineering is currently developing a targeted failure cause searching and solution finding algorithm for production, based on the fundamental research project "FusLa" (Failure cause searching and solution finding algorithm – Funding indicator: SCHL 2225 / 1-1). With this algorithm, it will be possible to make the potential of available complaint information more useful. The FusLa also has to deal with the complexity of production systems, by choosing a suitable model approach for socio-technical systems. This should not only promote the effectiveness of the complaint processing but also increase the attractiveness for the employees. This is necessary to quickly identify and eliminate failure causes in production in order to reduce or even prevent defective products or wastage. Currently, only the prototype of the FusLa has been programmed within the project. Nevertheless, the validation is absolutely necessary in order to examine the conceptual model with regard to its applicability.

For this reason, a company, which has its expertise in the field of stamping and metal forming, was engaged for the validation. To protect the company's anonymity and internal know-how, all company-related information has been anonymized. Furthermore, only the results of the validation (running through all four phases) and the question of whether FusLa can currently be used in industry are presented in this paper. [1], [8], [9] prove a scientific gap regarding FusLa after analyzing state of the art and research projects in the field of complaint information probing, prioritization of complaints, failure cause localization in the production or solution finding for failure causes. In order to ensure the transparency of the validation results, Section II gives an overview of current approaches in science and industry. Section III introduces the conceptual model that led to the development of the FusLa prototype. After that, Section IV presents the validation in the stamping and metal forming company and the collected results. Finally, Section V presents conclusions based on the results and an outlook on future research projects.

II. State of the Art

Some approaches have already prevailed in science and industry. The following Section presents approaches, which are associated with information probing, prioritization, localization of failure cause or solution finding. These are briefly discussed below with regard to their applicability in relation to the present problem:

A. Science

The presented approaches primarily consider the information probing:

The IGF project [10] initially classifies information in a complaint into five categories. Subsequently, the information is analyzed and a first failure image is generated. However, this approach relies on the manual exploration of complaint information. The approach presented in [11] uses text mining algorithms to automatically assess the quality of 8D reports using some metrics such as readability. Although the information in the complaint is probed for text analysis, the focus is on the assessment of the quality and not on the search for a root cause or finding a solution.

The DFG project in [12] initially collects the complaint information uniformly before analyzing and using it. Although the information is eventually used for product development, it does not focus on returning the information to the production.

In the project in [13], a sensor was developed to probe complaint information from online forums. The basis for this was formed by various products and services, but use for the purpose of failure cause localization and solution finding in production was not considered.

The last project associated with information probing, which should be also mentioned, is the project „Learning Failure Management (LeaF)“ [14]. In this project, failure data is to be recorded and structured uniformly in order to improve failure management by means of data mining. However, this project is still in its initial phase and therefore cannot be evaluated.

The first of the two publications presented below considers the prioritization of complaints and the second one, the failure cause localization.

In [15] a company-specific approach is described, which prioritizes the complaint in a multi-dimensional way. In the evaluation of failure image, different evaluation dimensions are compared with different failure images and a priority value is determined. However, this approach must be done manually.

The project „DSy“ [16] semi-automatically determines the associated failure cause based on the characteristics of a modeled subsystem. However, it only considers embedded systems.

Finally, those approaches have presented that deal with the solution finding. The last contribution of this Section includes all of the presented topics.

The MTQM method proposed in [17] aims to optimize assembly processes based on the previous failure, reliability and cost impact analyzes. However, only assembly processes and prospective actions are considered and no optimization potentials due to actual causes of failure.

A particularly important tool for the analysis of failure-stopping processes is developed in [18]. The quality-related key figures which are developed, among other things, are used for targeting and together with further information to derive recommendations for action.

For complaint analysis, the approach in [19] uses a decision tree, data mining, and the Six Sigma methodology in the framework of DMAIC to propose an approach and tools at each stage. The approach was tested in the gastronomy sector with a positive result. However, it is uncertain how the approach could be customized to complaints or other industries.

B. Industry

Next to the scientific approaches listed under Section II.A, there are also practice-oriented approaches that deal with complaint management. One of these is the 8D report, which is well known but has already been discussed extensively in [1]. The considered software systems usually require manual operation and are based on the knowledge of individuals. For example, it has been shown, because of the extensivity of the information that can be probed by software systems, most of the information must be manually entered into the software.

Even accessing existing databases does not completely solve this problem because the systems are too complex. Similarly, the quantitative, multi-dimensional prioritization of complaints by a software system is not possible. Also, the localization of the failure cause must be done manually as well as the elimination of these.

The approach in [20] uses a smartphone app to allow customers to submit complaints, display failure location, ID, date, time and the complaint reason via a Google Maps interface. Nevertheless, the information collected is too superficial to determine the cause of the failure and furthermore the focus is not on products.

The method presented in [21] is intended to detect quality problems by means of machine learning at an early stage and thus to prevent complaints. Although the approach has great potential, it requires a large number of complaints and focuses on early detection while not describing the solution finding process.

For readout, structuring, and evaluating of complaint documents, [22] uses text and data mining. Accordingly, the documents are examined for similar content to derive patterns of customer complaints. Nevertheless, the approach does not consider the determination of critical organizational areas, failure causes, and solutions.

Finally, the approach according to [23] should be mentioned, in which text mining is also used to analyze customer complaints. However, the focus here is on identifying customer requirements in order to use them for product development. The Outcome-Driven Innovation (ODI) method is used to collect this data and then forward it to the appropriate experts. As before, the large amount of complaints needed is an obstacle and also the focus is not on the localization of failure cause and solution finding.

It has been shown that despite many approaches, which are dealing with complaints and preparation of information through different methods such as Text Mining, there is so far no approach that considers failure cause localization and solution finding. Furthermore, there are no interfaces between text mining and company-specific information systems in order to make the existing knowledge available for the system.

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

The prototype of the failure cause searching and solution finding algorithm was programmed based on a conceptual model. The conceptual model, which is summarized in Figure 1, is based on extensive analysis of literature, the evaluation of 13 different software systems that are currently on the market, and the adaptation of available approaches of artificial intelligence to deal with large amounts of data. In order to develop the model, requirements based on the advantages and disadvantages of the respective research projects and software systems were derived. The baseline is a conceptual model, which considers the phases of production as well as usage. It divides the algorithm into a total of four main phases [1]. The production phase includes all processes that are needed to produce the corresponding product. The usage phase, on the other hand, focuses on the application of the product direct by the customer. The four main phases are "information probing", "prioritization", "failure cause localization", and "solution finding". In the first phase (information probing), relevant complaint information is probed from the arising complaint text during the usage phase. Based on that, quantitative values are calculated in the second phase (prioritization) to define a mostly objectively priority of the complaint. The priority is calculated using both the complaint information probed from the first phase and information from the information systems of the organization. With the knowledge of the most relevant complaint, the third phase (failure cause localization) is initiated. It serves to localize the existing failure cause within a production system during the production phase. In the final phase (solution finding), the localized failure cause is finally eliminated [1]. In order to make the individual phases and their processes more transparent, these are explained in more detail in the following Sections. This paper deliberately talks about information and not data. Unlike many research projects, the present paper defines information (e.g., a specific temperature specification) as linked data (e.g., numerous measured values of temperature). So it is talked about complaint information and not complaint data.

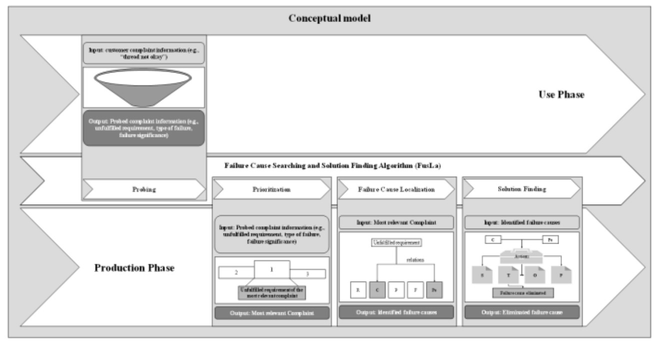

Figure 1. Conceptual model of the Failure Cause Searching and Solution Finding Algorithm

A. *Information Probing*

Information probing is the starting point for effective and goal-oriented failure cause searching and solution finding. In this phase, the complaint text will be analyzed for relevant complaint information. Current approaches, as shown in [1], using manual evaluation of complaint texts, which increases the need for resources in comparison with an automated evaluation. However, the conceptual model of FusLa provides a different approach for the information probing. Automated processes pursue the goal of collecting relevant complaint information more effectively. But how can such an automated procedure be realized? The answer is hidden in the connection between existing information systems of the company and the analysis of the complaint text. Unlike the fact that an employee, who is responsible for the handling of complaints, is not able to permanently monitor all information systems of the company, the FusLa has exactly such an interface. This means that the FusLa decomposes the complaint text into individual text modules, compares those with the existing information systems in the company (e.g., customer or order system) and collects all necessary information (e.g., customer or order numbers) for further processing. In order to achieve this comparison, however, a structure was developed according to differentiate relevant and less relevant complaint information. In addition, rules to specify the procedure for the FusLa have been defined. The structure includes a total of six different types of information, including, information about the complaining organization or information about the order of the complained product. These types are further divided into individual information modules, such as the name or the identification number of the complaining organization.

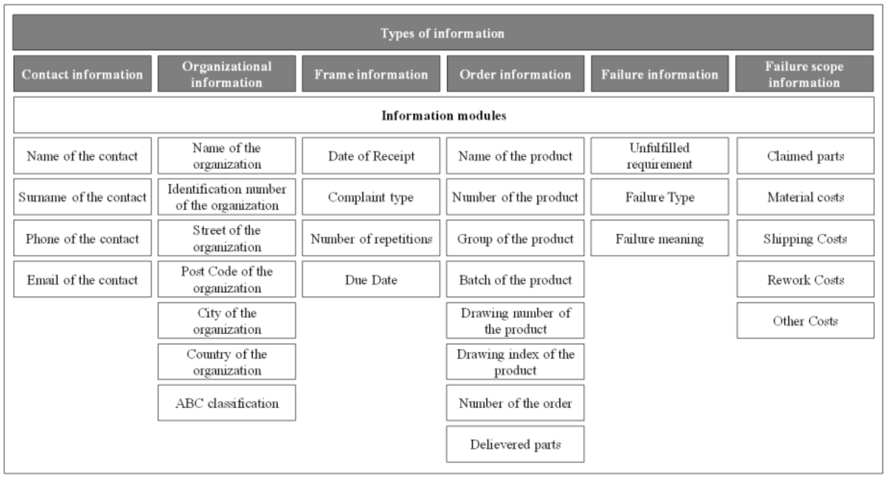

Figure 2. Structure of the Information Probing, including all types of information as well as the information modules

This means that information types, such as "contact information", act as a group and the information modules only reflect the respectively relevant information, for example, the "name of the contact person". The corresponding information types and information modules were derived on the basis of the results of the literature analysis and software evaluation [1].

In addition to the structure, some rules were assigned to the algorithm. These rules are defined as for/if loops and determine the decisions and boundaries of the algorithm. A total of six different loops were defined, which are used, for example, to recognize the unfulfilled requirement or to recognize customer information. Each of these loops makes it possible to filter different information modules from the complaint text or the existing information systems, in order to finally establish a solid basis for the further evaluation of the complaint.

To increase the comprehensibility of the loops, the first loop for "identifying the order number" is explained as an example. The presentation of other loops is discussed in detail in [24] and is therefore not part of this paper. As already mentioned, the algorithm can probe the relevant complaint information by comparing the information contained in the complaint text with the information saved in the information systems of the company. In the first loop, a technique of Natural Language Processing (NLP), the so-called Tokenization, is used initially. Above all, a distinction between Values and Strings is made here possible. These tokens are then compared with the order numbers in the organization's order system. If the algorithm identifies a match, it extracts the corresponding order number and identifies related information, including the customer or the delivered product and automatically filters it. If the probing is unsuccessful, the algorithm will start the next loop.

For reference, the defined information types and information modules are summarized in Figure 2.

B. Prioritization

The prioritization presents the second phase of the FusLa. This phase is absolutely necessary in order to recognize the complaints, which are most critical for a company, at an early stage.

Current approaches from both science and industry make use of subjective prioritization methods or categorizations/rank orders [1]. Since one-dimensional prioritization, which is based on subjective impressions may lead to an incorrect complaint priority, it is inappropriate to use such methods. To avoid that, the conceptual model of the FusLa provides a multi-dimensional prioritization, which is mostly objective and thus less prone to misjudgment.

In order to be able to realize this form of prioritization, a total of nine different dimensions is derived, including "Classification of the Customer (D1)" or the "Failure History (D8)". All of these dimensions include a dimension value and a weighting value. Since a detailed explanation of the dimensions exceeds the scope of this paper, these dimensions are briefly summarized in Table I. However, in order not to reduce the transparency by the short presentation of the individual dimensions, a detailed presentation of the dimensions is set out in [25], including the individual values and weightings which are ultimately required for the calculation of the priority.

TABLE I. DIMENSIONS OF PRIORITIZATION

No.	Dimension	Description
1	Customer Classification	Customers are ranked for their relevance to the organization. Based on this ABC classification, a quantitative classification is derived.
2	Date information	The due date and the date of submission of the complaint are essential for the calculation of the remaining work required to deal with the complaint. In addition, the urgency also influences the priority.

No.	Dimension	Description
3	Amount of complaint products	The extent of an unfulfilled requirement, which is calculated by the proportion of products complaint in total, is recorded in the 3rd dimension.
4	Repetitions	If the unfulfilled requirement occurs in several batches of one product, it can be count as a repetition. This parameter shows how often the unfulfilled requirement has been recorded and increases the priority on repeated occurrence.
5	Failure Type	It can be distinguished between very different failures, for example, dimensional failure or document failure. Depending on the severity of the failure for the customer, measured by the type of failure, the priority will be influenced.
6	Failure Meaning	Similar to the failure type, a distinction is also made between the meaning of an unfulfilled requirement. Based on the impact, for example, on the customer or merely the product itself, it decides the importance of failure and thus the priority of a complaint.
7	Product Sales	The product sales divided by the total sales of an organization show the importance of a product for an organization. Accordingly, this ratio is also included in the priority.
8	Failure History	The number of single failures of a product in terms of the total number of failures for all products over the entire production period shows the proportion of failures compared to all other product failures. The larger the share the more critical the complaint.
9	Amount of Costs	Similar to the failure history, the proportion of the individual costs by complaints of a product in terms of the total costs of all products over the entire production period can be evaluated. This shows, which resources are spent on handling the complaint.

Based on the presented dimensions, quantitative values are calculated and included in a final priority for a complaint. In order to be able to guarantee the comparability and compatibility of the individual dimension values, these are additionally normalized to a range of 1-10. A slightly wider, but also narrower interval can be selected. For this purpose, only the formula needs to be adjusted. It should be considered, however, that the distinction between values decreases at closer intervals. In this case, a range of 1-10 is sufficient. The formula (1) derived from [26] is used for this purpose:

$$NDW_{ij} = 9 \cdot \left(\frac{DW_{ij} - DW_{min,\, ij}}{DW_{max,\, ij} - DW_{min,\, ij}} \right) + 1 \qquad (1)$$

DW_{ij} = Dimension value of the dimension j of the complaint i
$DW_{min,\, ij}$ = Minimum of the dimension values of the dimension j of the complaint i
$DW_{max,\, ij}$ = Maximum of the dimension values of the dimension j of the complaint i
NDW_{ij} = Normalized dimension value of the dimension j of the complaint i

The normalized dimension values are used in a further step to derive a weighting of the respective dimension. This step is necessary to mostly objectively assess the importance of the dimension to the organization itself. In order to do this, all dimension values of all the so far completed complaints are summed up to form an average value. This ensures that, on the one hand, all complaints that have been processed are included in the weighting, and on the other hand, the weighting automatically adapts with new complaints. Once the weighting of the respective dimensions has been determined, the priority of the actual complaint is calculated in the last step. Furthermore, the following formula is used.

$$P_i = \sum_{j=1,\ i=1}^{n} NDW_{ij} \times G_{ij} \qquad (2)$$

G_{ij} = Weighting value of the dimension j of the complaint i
NDW_{ij} = Normalized dimension value of the dimension j of the complaint i

After prioritization, the third phase of the failure cause searching and solution finding algorithm can be initiated with the most relevant complaint. What this phase looks like is explained in the following Section.

C. Failure Cause Localization

During the failure cause localization phase, the FusLa should identify all possible causes of failures within the production system. An evaluation of current approaches with regard to their ability to localize the cause of failures, it turns out that they rely on a subjective assessment by a single employee or team [1]. Despite the experience or expertise, the employee responsible for handling the complaint is not able to observe the enormous complexity of a production system, e.g. with all its components, processes or persons. This is not necessarily due to the employee, but simply to the variety of system elements and their interaction. Particularly in the case of changing production systems or newly hired employees, a subjective search for failure causes is nearly impossible.

To counteract this problem, the FusLa was developed based on the so-called Enhanced Demand Compliant Design (eDeCoDe) approach by Winzer [27] and Nicklas [28], to the modeling socio-technical systems. It uses five standardized views (requirements, components, functions, processes, and person) to classify system elements. Using different matrices, including Design Structure or Domain Mapping Matrices, the interrelations between the individual system elements are recorded and displayed transparently with a notation of 1 (relation) and 0 (no relation). This principle is shown in Figure 3 as an example.

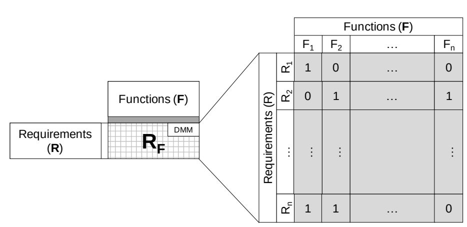

Figure 3. Example of a Domain Mapping Matrix

The merging of all matrices, in the form of a multi-domain matrix, results in a model of the production system, which can be mapped in the form of a multi-domain graph as shown in Figure 4 as an example.

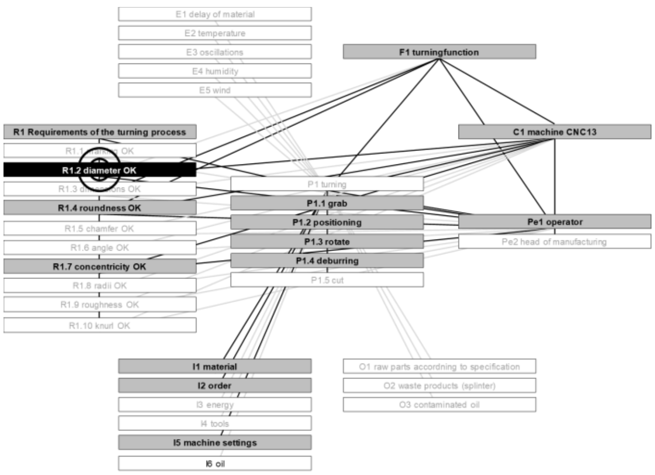

Figure 4. Localization example based on [1]

Based on this model, it is now possible to evaluate the interrelations between the individual system elements. The FusLa examines which notation, whether 0 or 1, exists between a system element (e.g. the positioning process) and the unfulfilled requirement (in this case the diameter). If this notation is present, the algorithm identifies the corresponding system elements as a possible cause of the failure. This is extremely helpful, especially with regard to the available complaints. In this way, the traceability can be ensured comprehensibly and transparently.

This means that it is possible to retrace the unfulfilled requirement from the complaint to the interrelated system elements, e.g., components (machines) or processes (turning process). Without this possibility, the failure cause localization is also very random and less goal-oriented.

D. Solution Finding

With the last phase of the FusLa, failure causes which are highly probable can be eliminated by appropriate measures. This is essential to avoid the repetition of complaints regarding the same requirement. In order to define effective actions, it makes sense to identify the most likely failure causes. In order to estimate the probability of failure causes, different categories of failure cause information were formed. These categories, as summarized in Table II, are intended to provide a semi-quantitative estimate of probability.

TABLE II. FAILURE CAUSE INFORMATION CATEGORIES

Failure Cause (System Element)	Failure Cause Information
Requirement	Definition date of the requirement
	Release date of the requirement
	Drawing index for the requirement (Adjustment delivery and drawing)
Component	The failure rate of the component
	Availability of the component
	Maintenance date of the component
Process	Standardization status of the process
	Release date of the process
	Environmental conditions of the process
	The correctness of the input of the process
	The capability of the process
Person	Technical competence (process-dependent) of the person
	Methodical competence (process-dependent) of the person
	Personal competence (process-dependent) of the person

It can be seen that different information on failure causes is analyzed depending on the system element. Among other things, for a component-related failure cause (e.g., a machine), quantitative values such as failure rate or availability may be used for the probability estimation. Thus, for example, in the case of a high failure rate, a high probability of causing the unfulfilled requirement can be assumed. However, in the case of personal failure causes (e.g., operators), process-dependent competencies are identified and compared with the person's competences to determine whether the person was fit to perform the process. If deviations are detected with regard to their competences, the person seems to be a very probable failure cause. With this approach, it is possible to identify the most likely failure causes.

In order to be able to eliminate those, it is necessary to derive appropriate actions. This is achieved through the application of the "STOP principle", a classification, which was able to establish itself in the field of safety engineering [29]. The STOP principle provides four different forms of actions, including substitutive (S), technical (T), organizational (O) and personal (P) actions. It is intended to start with personal actions because these are usually quick to implement and do not require a huge amount of resources. If these actions are not sufficient, organizational, then technical and ultimately substitutive actions have to be derived.

To illustrate what such actions may look like, Table III shows an excerpt of actions for person-related failure causes.

TABLE III. ACTIONS FOR PERSON RELATED FAILURE CAUSE

Failure Cause: Person	
Substitutional Actions (S)	
Action 1	Job Rotation of the Person
Technical Actions (T)	
Action 1	Implement an IT system for knowledge transfer and training
Action 2	Provide knowledge base or wikis for best practice solutions
Organizational Actions (O)	

Failure Cause: Person	
Action 1	Improve education and training opportunities
Action 2	Prepare standardized process instructions for processes
Action 3	Training for newly recruited persons, who act as a substitute or for persons with part-time employment
Action 4	Integrate competencies into the quality management system
Action 5	Plan and conduct conversations and coaching sessions
Action 6	Promote a working atmosphere for employees through additional offers
Action 7	Incorporate personnel support more strongly in the corporate philosophy
Action 8	Selection of suitable persons for the execution of the process
Personal Actions (P)	
Action 1	Regular sensitization of persons
Action 2	Instruction and advice to the persons
Action 3	Supervision of persons by supervisors

Table III illustrates that very different measures are proposed by the algorithm depending on the type of action, i.e., S, T, O or P. However, the user of the algorithm is still left to decide, which action he wants to select and implement. The decision provided by the user is then documented for subsequent complaints and taken into account for similar complaints.

In order to investigate the applicability of the presented algorithm, it was validated in a company in the field of stamping and metal forming. The results are shown in the next section.

IV. Validation of the Failure Cause Searching and Solution Finding Algorithm

The validation of the prototype of FusLa is a very important step to highlight the improvement potentials as well as weaknesses to initiate the continuous improvement process. For the validation, a company in the field of stamping and metal forming was engaged. This company provided insights into complaint management and application of the algorithm through several complaint examples. Again, it is pointed out that in order to preserve the anonymity of the company and to protect its internal know-how, all company-related information has been anonymized, so that the following chapter only shows the validation results.

It should also be noted that the implementation in Visual Basic for Applications (VBA) does not serve to create a software system based on the conceptual model. Otherwise, it serves only to prove the applicability of the conceptual model of the algorithm by its specific application. Due to the fact that MS Office is used as a documentation basis in many companies, it makes sense to simplify the interface through the deliberate use of VBA and not, for example, Python or C++.

In order to be able to present the validation results in a transparent manner, both the company and the application example are presented briefly.

A. Presentation of the company for stamping and forming technology

The company, which agreed to validate the FusLa, has its expertise in the field of stamping and metal forming. Among other things, this field includes the production of a wide variety of stamped, bent and deep-drawn parts. Due to the broad product portfolio, different industries are covered. As a basis for the validation, the company provided us with complaints about various available products. Due to the extent of all validation results, this paper deals only with the complaint of the KSGD product. Nevertheless, it can be summarized that the results of further validations correspond to those of the KSGD product, but in particular, the massive influence of the quality of the complaints on the assessment by FusLa can be emphasized.

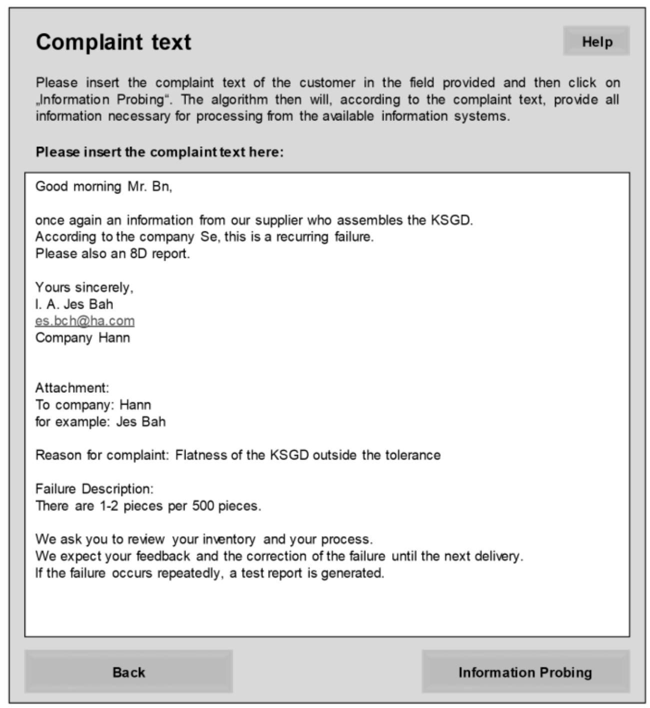

Figure 5. Complaint text of the product KSGD

Another complaint was validated analogously for comparison possibilities. It can be seen that only the abbreviations of the selected product are mentioned. This serves to protect the internal know-how and possible anonymity reduction by tracing the products back to the company.

B. Preparation of company-related information

In order to be validated, it is necessary to collect all useful company-related information. These are saved in very different information systems. In order not to have to establish every interface to each information system, the information systems were modeled in the form of an excel sheet. However, the principle of access to information systems is not affected. In total, three different information systems are replicated.

These include the customer system, the order system, and the product system. Based on the replication of the information systems, a model of the production system was created using the eDeCoDe approach. Altogether 74 requirements, 8 functions, 29 processes with 22 inputs and 11 outputs, 9 components, and 10 involved persons are elicited. Furthermore, inspections of documents (e.g., technical drawings, inspection plans) are analyzed and some discussions are held with process owners.

C. *Application of the Failure Cause Searching and Solution Finding Algorithm*

With the help of this information basis, the actual application of the FusLa could be carried out.

1) *Information Probing*

The application of the FusLa is initiated by the first phase, the information probing. The provided complaint text is transferred to the FusLa and the information probing is started as shown in Figure 6.

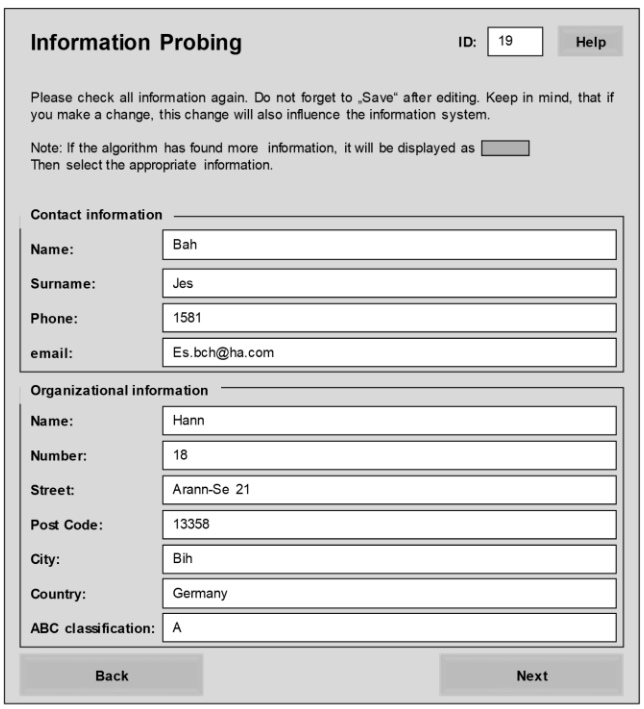

Figure 6. Information Probing_1 for the complaints of the product KSGD

From Figure 6, it can be seen that the algorithm declared different information as relevant and translated them into the appropriate fields of the information probing surface. By accessing the customer system of the company, the algorithm also succeeded in capturing all other information, for example, with regard to the customer's address or its classification. It also turns out that the algorithm is able to probe the correct information for the further handling of the complaint. This is a mandatory requirement for goal-oriented and precise failure cause searching and solution finding.

In the next step, the algorithm should probe all relevant order and frame information regarding the claimed product. Among other things, the product name, product number or the order number itself are listed here. The first weaknesses of the prototype of the algorithm were revealed during this step. Due to the fact that the complaint text contained no product number, order number or even batch, the algorithm did not recognize, which product-specific delivery is concerned. The weaknesses are presented in Figure 7. This shows that it makes sense to establish the possibility of recognizing the product name. In this case, the algorithm would have recognized the name KSGD and probs all relevant product information. For this reason, the information probing is extended by another loop, which also checks the product name in complaint text.

Figure 7. Information Probing_2 for the complaints of the product KSGD

Another weakness was shown regarding the due date of the complaint. There was no deadline in the complaint text, so the algorithm could not track how many days the organization would have left for handling the complaint. For this reason, another loop has been added to the algorithm. This allows the algorithm to access the contractual provisions between the customer and the organization with regard to the processing time interval of complaints. This information is used by the algorithm to calculate a determination of the due date. If this process is unsuccessful, precisely defined strings are also implemented, which allow the algorithm to probe out time limits from the complaint text.

In the final step of information probing, the algorithm should probe all failure and failure scope information. That means it should recognize the unfulfilled requirement and assign a failure type as well as meaning to it. The result of the validation shows that the algorithm recognizes that there is a failure (e.g., flatness out of tolerance), but it does not select this failure correctly. Within the complaint text, an exact indication of the unfulfilled requirement was missing. So the user had to choose between the different requirements of flatness and thus received a direct estimate of the type and meaning of the failure. This process is presented in Figure 8.

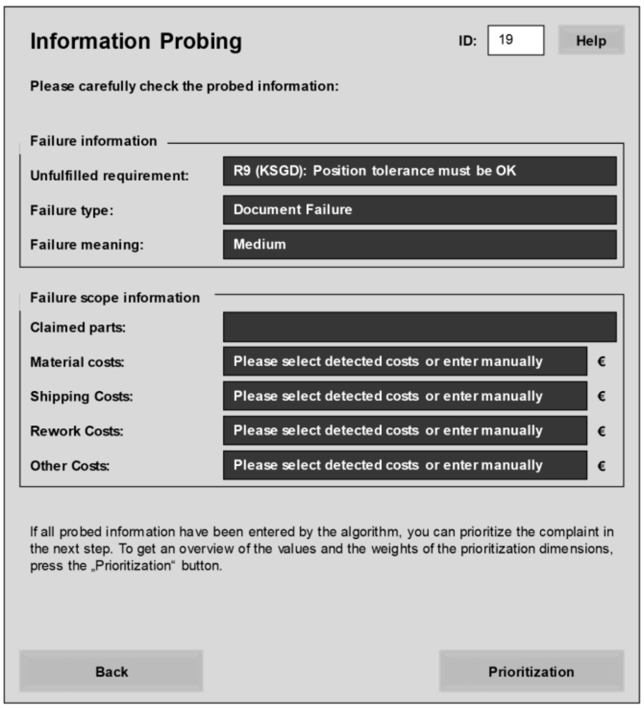

Figure 8. Information Probing_3 for the complaints of the product KSGD

How this problem can be solved is not yet defined. In the further phases of the project, however, the aim is to probe out the unfulfilled requirement via the customer's failure description in the complaint text.

Another problem was the exploration of the costs. In discussion with the company, it was found that the customer usually makes no statement about the costs and mostly only assigns an estimate of the affected products. In this case, no costs and only an estimation of 1-2 affected products were included in the complaint text. This is not enough for automated evaluation. However, since, according to the company, this information only occurs in a few complaints, it should be questioned whether it is actually relevant to the handling of the complaint or whether it should only be collected at the end of the handling process. Currently, an optional exploration of the costs is considered, in which the user decides whether and which costs should be extracted. However, this is not sufficient if automation of the process is the goal.

2) Prioritization

After all steps of the information probing have been carried out, the second phase of the FusLa, the so-called prioritization, is to be examined. The basis for the prioritization is the complaint information generated in the information probing phase. In order to check whether the algorithm can make a reasonable prioritization for the corresponding complaints, the complaint of the KSGD was compared to a second complaint about a product called SHD. Similar to KSGD, product SHD is also from the automotive sector. Since the comparison limited to two complaints, the dimension values are in the range of 1, 5 or 10 and the weighting values in the range of 5 and 5.5. Nevertheless, this is sufficient to investigate how meaningful the results are. The evaluation of the prioritization is illustrated in Figure 9.

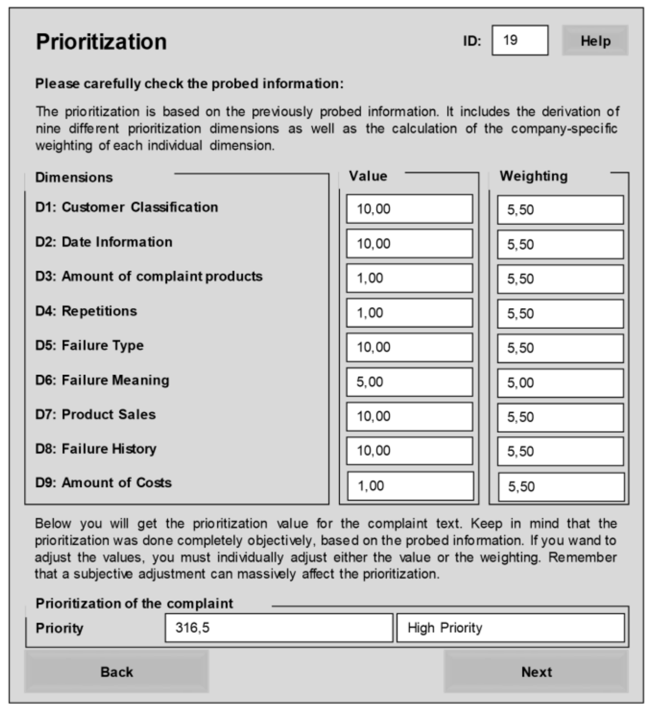

Figure 9. Prioritization for the complaints of the product KSGD

From Figure 9, it can be seen that the algorithm classifies the complaint with a high priority of 316.5. The evaluation of prioritization initially shows that normalization is successful for a range of 1-10 for each dimension. It also turns out that each of the dimension values and weighting values is plausible on the basis of the previously probed information. Also, the priority value for this complaint is comprehensible and correct. Thus it could be shown that the prioritization was successful from a mathematical point of view.

Nevertheless, it must be questioned whether the priority value also reflects the reality of the company. Through a discussion with the employees of the complaints management department, it could be confirmed that this complaint was very relevant and furthermore, properly prioritized. The result is an effective prioritization of the complaint. In order to work out whether the localization of failure causes is also meaningful, this phase is examined in the next step.

3) Failure Cause Localization

The failure cause localization is determined both on the complaint information recorded in the information probing and also on the production system model developed in the preparation of the information basis. In order to be able to record the actual cause of the unfulfilled requirement, the relations of the requirement to the other system elements were examined. The result was a selection of possible failure causes, which is illustrated in Figure 10 based on the eDeCoDe views. It should be noted that the functional view of the realization is represented by the component view and is furthermore, not listed again.

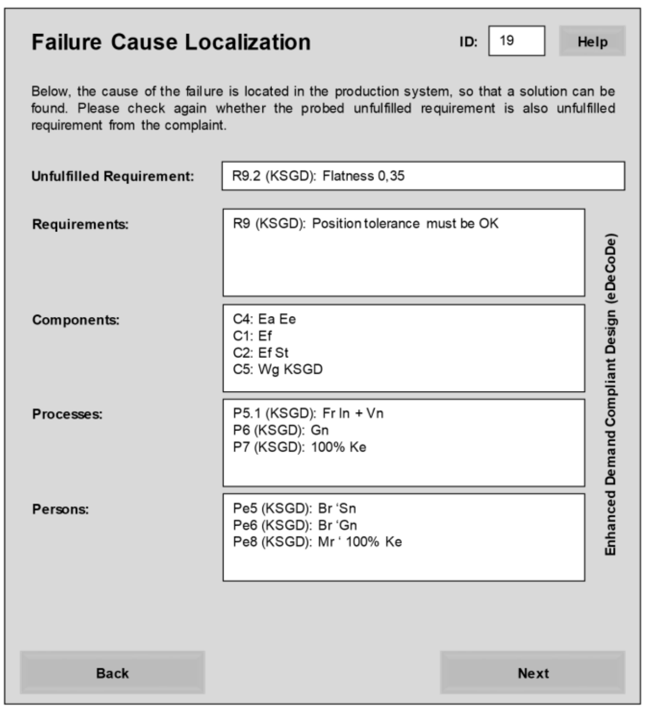

Figure 10. Failure Cause Localization for the complaints of the product KSGD

It can be seen that the algorithm could assign different failure causes. Among other things, four different components (machines/tools) and three processes were identified. Nevertheless, a variety of improvement potentials emerged when locating the cause of the failure. On the one hand, it became clear through a discussion with the complaint manager that the failure causes are indeed plausible, but that they do not cover all possible causes. The company also wanted to display the system elements, which are not only used to realize the requirement but are also expected to influence the requirement within the previous or following process, such as processes of hardening or surface treatment. This would be recommended especially for very case-specific complaints. This was realized by the eDeCoDe model of the production system, which now also considers indirect relations between the system elements.

A key weakness of the algorithm was illustrated by the estimation of the semi-quantitative probability over the defined failure cause information of Table II. It turned out that much of the information, as shown in Figure 11, was not collected at all and furthermore, cannot be used as a basis for valuation.

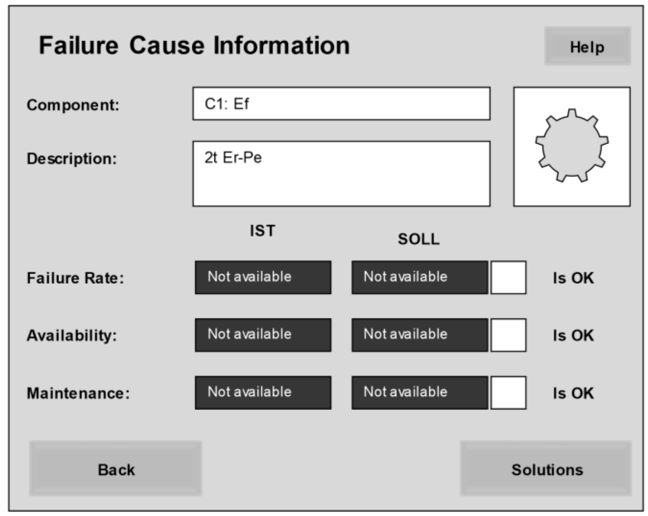

Figure 11. Failure Cause information (explicit Component C1: Ef) for the complaints of the product KSGD

In addition, it became apparent that a comparison between actual and required input is hardly possible without a specification by the customer. Competencies could be used for the persons, but these were also not complete. Furthermore, an adaptation of the probability estimation in the algorithm must be developed, in order to provide results even if there is an insufficient information basis. It would make sense to provide an interface to existing systems, for example, CAQ systems or smart machines, which allow access to real-time-based data and information. The documentation of such data/information has to be also continuous and complete.

4) Solution finding

In the last phase of the algorithm, actions to eliminate the cause of the failure should be derived. To implement this phase, actions based on the STOP principle is used. Figure 12 shows how these tools were presented by the algorithm.

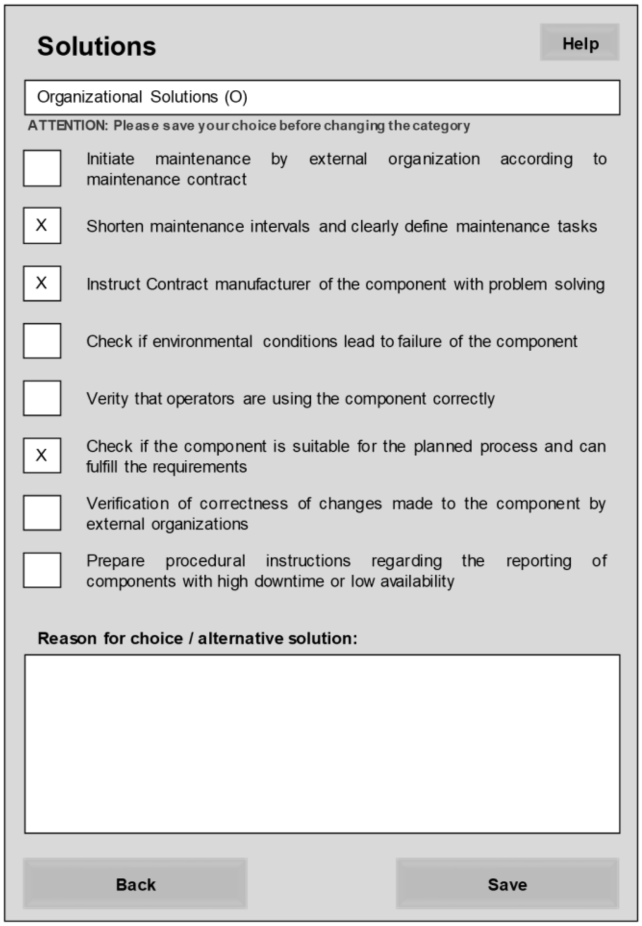

Figure 12. Actions (explicit Component C1: Ef) for the complaints of the product KSGD

It can be seen that the algorithm provides different actions to the user. These must be manually selected by the user to ensure the best possible combination of actions. The result of the validation showed that the algorithm is able to present helpful guidelines. The possibility of selecting predefined actions saves resources like time. Likewise, the user can also enter individual alternative solutions. With the help of all these possibilities, each of the recognized failure causes could be eliminated. Nevertheless, this process is currently still manual. The idea is to implement this process via an AI. It can be considered only in further research projects.

V. CONCLUSION AND FUTURE WORK

The validation of the FusLa based on complaints from the company in the field of stamping and metal forming showed both the possibilities and the weaknesses of FusLa. Beginning with information probing, it turned out that while the algorithm is able to distinguish relevant information from less relevant information, the FusLa still has problems probing it. Although the algorithm was able to record the contact person of the customer, it was not possible to probe the order information because of the insufficient validation of the complaint text. The next phase of prioritization showed that the algorithm has the ability to face and prioritize complaints. Through collaboration with the company, the meaningfulness of the prioritization value for the complaint could be confirmed. However, the third phase of the algorithm still poses major problems. On the one hand, although the algorithm recognized failure causes, these did not include the system elements, which not only realizes the requirement but also influences it. In terms of probability estimation, the algorithm reached its limits due to a lack of information. With the last phase, the solution finding, it was possible to derive suitable actions based on the STOP principle. These were quite capable of eliminating the most likely failure causes.

The quintessence shows that the algorithm has great potential, but also it is still in the stage of a prototype.

In order to improve the algorithm, the following main research areas are needed. First of all, a study should be done on how the quality of different complaint texts affects the information probing. This would highlight the need for standardization of complaint texts or more capable natural language parser. Furthermore, it is necessary to investigate how the probability of failure causes can be derived on the basis of an incomplete failure cause information. Only in this way it is possible to differentiate between more probable and less probable failure causes. Lastly, the user-friendliness of the algorithm for people in the industry should be investigated. Since the industry is the most important user of such an algorithm, it must achieve acceptance.

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