

Using Fuzzy Process Models to Improve Technical Customer Services: A Case Study for Heating Facilities

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Abstract: In this article, a mobile, internet-based service tool for the support of technical customer service processes is described. The tool uses a fuzzy component structuring repair information formatted for multimedia use and makes this information available to customer service technicians through the process-oriented use of mobile end devices. Through the use of mobile technologies in connection with the knowledge of experienced customer service technicians with respect to inspection, maintenance and servicing work and through the processing of this knowledge in accordance with fuzzy rules, the efficiency of the service process can be increased. The potential use of this system is exemplified by means of a real-life application from the heating, air conditioning and sanitary engineering (HAS) branch.

1 Introduction

1.1 Objective and Approach

Under the heading of business process management, the planning, controlling and monitoring of the processes carried out when rendering services within the structure of a company are acknowledged as being significant instruments for corporate management both in theory and in practice. Through the use of standardized procedures and integrated software tools in the IT-oriented structuring, implementation and monitoring of business processes, the knowledge contained within an organization can, in many cases, be made available successfully.

One major factor that causes an increase in the complexity of processes within companies is the integrated examination of an rising number of process steps, available customer data and wide-ranging product variants, all of which need to be taken into consideration. This calls for appropriate management methods and supportive software tools. The rising proportion of intangible resources also causes changes in the quality of business processes. The role played by knowledge-related work and services in the process of value creation is constantly increasing. For over 30 years now, the process of

value creation in “industrialized nations” has been attributable more to the supply of services, than to the production of material goods and the percentage is currently around 70% [WR07].

The machinery and plant construction sector is Germany’s largest industrial sector [VDMA08]. In response to an increase in competition, manufacturers of machinery and plants are expanding and improving the services they provide, particularly in the field of technical customer services (TCS), the interface between the manufacturing of products and their actual use [LaLo76; Czep80; Peel87; StLa89; BoKL06; Harr07].

In order to adequately perform the tasks associated with these services, a technical customer services unit must be provided with the correct “information mix”. In this respect, a central problem is determining the scope and point in time of the information relevant to the decision-making process, together with the degree to which it has been compressed [SaBo03; Timm05]. Current approaches to providing support for TCS frequently fail because of the increased complexity of the machinery and the associated increase in the requirement for representation of the service supply processes. The consequences are defective start-up, maintenance and repair work, which results in prolonged down times for machinery leading to higher prices for customers and a loss of market shares for the manufacturer.

The circumstance described above is, initially, counteracted by integrating the manner in which physical products and service-related modules of information are taken into consideration and by bringing together these two production factors to create efficient and mobile service processes that are made available to the TCS. Thanks to the creation of a new bundle as a result of this integrated study, consisting of one material product plus services, it is possible to provide the TCS unit with all that is necessary to ensure that the start-up, servicing, maintenance and repair of machinery and plant are carried out in a customer-friendly manner.

1.2 Our Contribution

The contrast between the construction of models for human behavior and the mechanical processing of information clashes with requirements for the continuous support of planning functions, from managerial planning to the implementation on an information technology level of business processes. The depiction of the resources available during both thinking and acting and the provision of IT-support for decision-making processes and interaction, call for an extension of the range of instruments available for the modeling process, which incorporates the specific characteristics of human thought. In this article, the Event-driven Process Chain (EPC) [KeNS92] is used as a representative of the many available specialist conceptual modeling methods.

One strategy for resolving the issue of reducing the complexity occasioned by the characteristics of human ways of thinking and for increasing the extent to which computer-assisted systems can be controlled, albeit one that has to date been used only to a limited extent, is provided by technologies from the field of Artificial Intelligence (AI). One sub-category of AI research that has been highly successful in providing explanations of human ways of thinking for use in computer systems can be found in the

methods from the fuzzy set theory, artificial neural networks and evolutionary algorithms, all of which come under the general heading of soft computing [Zade94; Zade97; Boni97]. The central finding of soft computing technologies is the transfer of the human capacity for processing statements that are imprecise, uncertain and endowed with truth values on a sliding scale. Here, the explication of this vagueness takes place on the basis of precise mathematical models, which makes it possible for this to be reproduced within information systems. Using the fuzzy set theory, conclusions can be reached on the basis of unclear or incomplete data. Decision-making patterns can, with the assistance of artificial neural networks, be learned from data and emulated by means of applying them to fresh data. New and partly creative problem-solving techniques can be found by evolutionary algorithms.

In this article, we introduce the idea of a process-oriented service tool for the support of technical customer service processes in the machinery and plant construction sector. This tool makes use of a fuzzy component for structuring repair information formatted for multimedia use and makes this information available to customer service technicians through the use of mobile end devices. Through the use of mobile technologies in connection with the explication of knowledge from experienced customer service technicians with respect to inspection, maintenance and servicing work and through the processing of this knowledge in accordance with fuzzy rules, the efficiency of the service process can be increased. The potential use of this system is exemplified on a use case from the heating, air conditioning and sanitary engineering (HAS) branch.

2 Technical Service Processes in Technical Customer Services

2.1 The Information Basis for Service Processes

The core idea for the service process modeling that forms the basis of the approach pursued here is the differentiation between the function, structure and service processes in technical facilities [TWLN07]. Both the functions of a technical facility and its service processes are directly connected with its structure. Figure 1 shows how this interrelationship is reproduced and used with the function structure being used as the basis for defining the fault, identifying the groups of components relevant for the performance of that function and suggesting appropriate service processes.

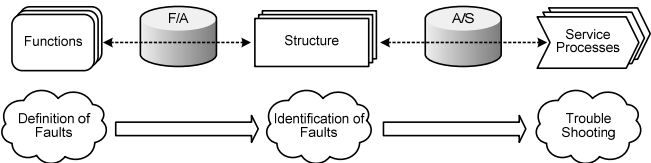


Figure 1: Functions, structure and service processes of technical facilities [TWLN07]

Functions The modeling of the functions in a technical facility forms the basis for the definition of a problem, which can be seen as the “breakdown of a function”. As opposed to definitions of potential problems, the functions of a technical facility can be

listed and classified into technical groups of components, which will eventually serve as points of reference for the work of the TCS unit.

Groups of components The technical classification of the facility into various groups of components stands in contrast to the functional classification process. This technical classification arises out of technical product development. The interlinking of groups of components with functions takes place on the basis of the technical sharing of tasks on a technical level – a group of components is assigned to the functions for which it is needed. The objective here is to identify groups of components that may potentially be the cause of any given problem.

Service processes The objective of the diagnosis of a problem is the rectification of that problem, which in turn is achieved by means of carrying out service processes on the groups of components of the technical facility. This is made possible by interlinking service processes with groups of components on a range of different levels of detail. Through the composition of multiple groups of components, functions that go beyond the sum of the individual functions of these groups of components emerge. A heater, for example, can heat water, which is something none of its groups of components can accomplish on their own.

Once particular groups of components have been identified as the possible sources of the problem using the functional classification described above, measures for the rectification of this problem can then be selected and implemented via the link with the service processes.

2.2 An Example of a Service Process Model

A realistic application scenario follows as an illustration of the approach described above. This scenario describes a fault in an appliance for heating water. This appliance is found to be defective by the customer service technician at the customer's premises. The starting point for the scenario is the fault "Hot water is not hot" – in other words, a problem has occurred within the appliance that interferes with its function and as a result the water inside the appliance is no longer being heated as intended. The handling of this repair process places great demands upon the TCS unit, because almost every component of this heating installation can be a potential cause for this fault. This real-life scenario is based upon a heating high efficiency system boiler, ecoTec plus 196/3-5 type, from Vaillant Deutschland GmbH & Co.KG.

In preparation for repairing the defect, the manufacturer must start by making the necessary service process information available for the product that has become defective. This service information includes the functional, product and service process structure, together with the service process models, which should be accompanied by the relevant technical documentation. Within the framework of this scenario, a service process emerges that is portrayed in part in Figure 2. The links between the models are realized partly by means of "process signposts" that are contained within the expanded scope of the language of the EPC. For the sake of simplicity, we have decided not to separate all the various functional refinements into their component parts. They are indicated alongside the corresponding EPC functions by the symbol "▣".

It is possible to raise specific criticisms of this service process model of the rectification of the fault, “Hot water does not heat up”, thus calling into question whether it should be adopted without due reflection for the purposes being pursued in this sample application. These points of criticism are analyzed in detail below and combined in the form of a statement of the objectives of any further action.

2.3 A Discussion of the Service Process Model

Figure 2 initially makes the high level of complexity in representing service processes through modeling clear. Using systems theory, it is possible to state that in relation to service process models, this is a consequence of the large number of speech artifacts required to described the process, as well as a result of their variability, which is in turn geared towards the wide variety of machinery and plants available from different manufacturers. For instance, in the present case study a wide variety of activities and decision-making nodes have to be modeled, although only a few components can be identified as the original cause of the fault, “Hot water is not hot”.

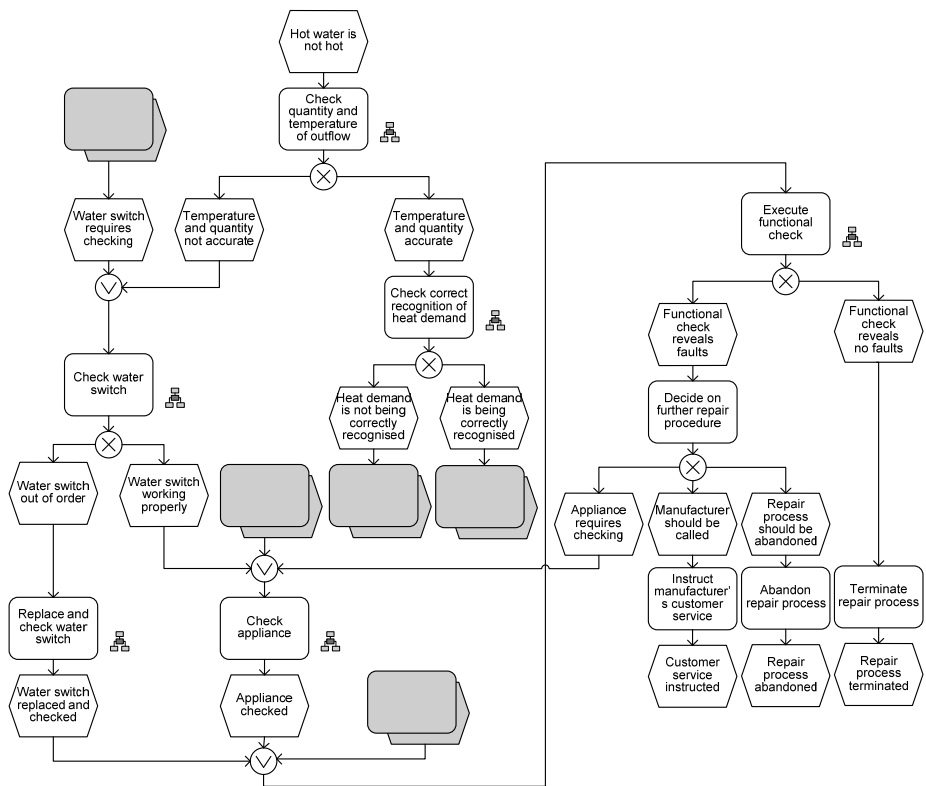


Figure 2: EPC model “Hot water is not hot” (in part)

As is customary in process modeling, the designators for model elements used in the service process model “Hot water is not hot” closely follow technical terminology, in

order to ensure that the model can be used as a starting point for the implementation of the application systems. It is true that this close imitation of existing technical terminology is supposed to reduce the risk of any misinterpretation – however, misunderstandings and false conclusions arising out of the ambiguity inherent in natural speech cannot be wholly excluded. In the present model (c.f. Figure 2), it is part of the run-time that the quantity and temperature of the outflow should be checked at the beginning of the service process. Then further activities on the part of the TCS unit are envisaged in order to rectify this fault depending on the two mutually exclusive possible outcomes of this test. Admittedly, the actual meaning of the word “correct” in relation to quantities of water discharged or temperature value is not directly apparent from the context here. If the model is being consulted solely as a means of recommending a course of action for the provision of services by the customer service department, then this does not present a problem. A customer services technician will, by virtue of his knowledge and experience, generally be in a position to interpret the measured or estimated values as correct or incorrect.

If, however, the representation of the process is intended to serve as the basis for the implementation of a mobile application system then the statements present in the model must be formalized, in order to allow them to be processed automatically.

To ensure the success of a mechanical processing of this kind it is, for example, possible for appliance-specific quantitative threshold values or ranges to be defined for the values to be measured. The decisions to be made during the service, maintenance or repair procedure are then made with reference to these specifications, depending on whether the given threshold values are exceeded or fallen short of, or on whether or not the values measured fall within a prescribed range. For example, in the case of the combination water heater with flue attachment for heat and hot water on which this application is based, the rate of flow is 5.5 liters per minute at an outflow temperature of 60°C (corresponds to 140°F). If the ranges for the determination of a correct combination of outflow quantity and temperature were to be set at 4–5 liters per minute and 55–65°C, then the measurement of 54.9°C would be deemed incorrect, regardless of the outflow quantity measured. This contradicts actual customer service practice where such exclusion criteria are seldom adhered to. In fact, the customer service technician applies implicit compensation mechanisms that balance out any exceedance of the threshold values with better values in other areas. The rules for these interdependent cause-effect relationships are, in general, not documented and are based upon the knowledge and experience of customer service technicians.

Setting aside the problems posed by sharply-defined threshold values, in the EPC model “Hot water is not hot” the sequence of checking functions and replace-and-check functions was determined at the time of the appliance’s construction. However, during the actual run-time of the application system intended to provide support for the provision of these services, this static perspective on the activities required from the TCS unit during a service process is not desirable. Thus, during the process of service, maintenance and repair it is entirely normal to find situations in which the rectification of a defect may become directly apparent to the experienced customer service operative by means of measured or estimated values. If the TCS unit were to orient itself

exclusively on the inflexible specifications provided by the process model this would, on occasion, lead to the implementation of work processes not necessarily conducive to the identification or rectification of the defect in question. To date, the service process model has not included any representation of the dynamic needed in the sequence of checking functions if superfluous activities are to be avoided.

3 Support for the Provision of Services through Fuzzy Process Modeling and Controlling

3.1 Expansion of the Service Process Model through the Inclusion of Fuzzy Data

Figure 3 shows the fuzzy expansion of the service process model “Hot water is not hot”. The process is depicted in the form of a fuzzy event-driven process chain [TALL06; ThDL07]. The fuzzy constructs of the EPC are identified using grey shading. Initially, the designators for model elements used in the fuzzy EPC model “Hot water is not hot” are abstracted from the concrete functions of specific technical installations, their construction and the customer service activities necessary for their servicing and maintenance. To this extent, the fuzzy process model displays a higher level of abstraction than the “sharp” EPC models shown previously. The interdependencies between functions, components and the activities required on these components, as derived in Section 2.1 as the basis of information for service processes, need not be taken into consideration for the purpose of reaching a decision until the actual run-time of the process.

Depending upon the respective function tests, specific tasks must be carried out on the component parts by the customer service operatives – that is to say, the component parts must be maintained, repaired or replaced or the appliance must be set up. The decision with respect to the type of task to be carried out is taken during the actual run-time with the help of the function test in question. In addition, the “termination criteria” set out in the sharp service process model, which relates to the general termination of the repair process or the establishment of contact with the manufacturer’s customer service team are also taken into consideration. If it is not possible to use the inputted data and/or the measured values automatically read in as a basis for the decision-making process, the operator for the decision within the process model plans a return to the function tests, in order to give the customer service technician the opportunity to input further information. In this manner, the sequence of checking functions and replace-and-check functions previously, in the sharp case study, determined while the process of the provision of services was first set up, is broken up and is not defined until the actual run-time of the process represented.

A fuzzy system is being used here to support of the decision-making process. The embedding of the fuzzy information required takes place with the assistance of units from the organization, data objects and services that display fuzzy attributes. In this spirit, these attributes should in each case be interpreted as linguistic variables. In Figure 3, this is factored in by means of the fuzzy data objects *Quantity of outflow* and *Temperature of outflow*. Further model elements such as, for example, the data object

Tool and the organizational unit *Customer service* are annotated as sharp speech constructs relating to the central checking function of the fuzzy EPC model.

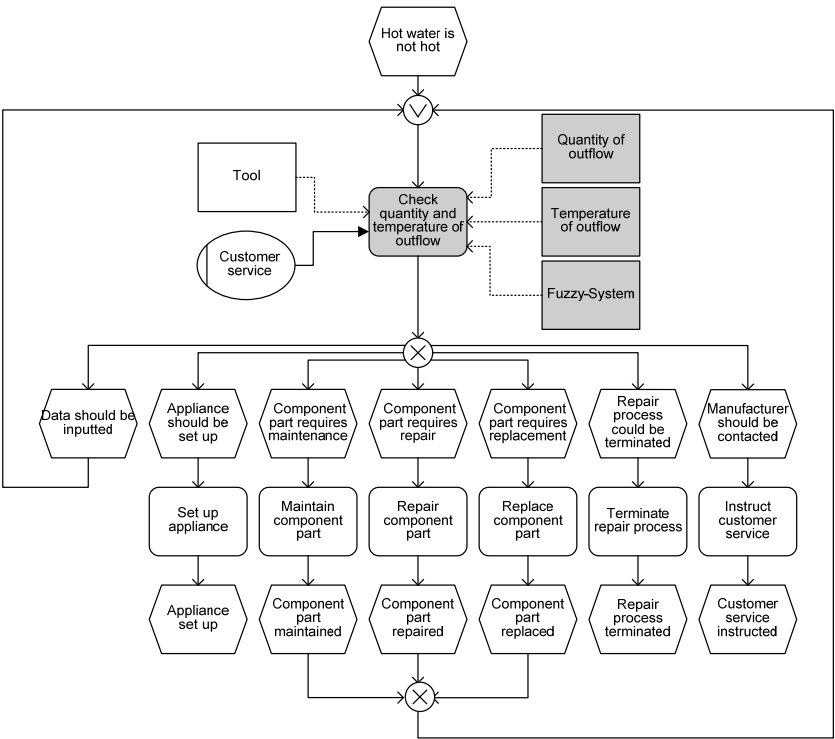


Figure 3: Fuzzy EPC model “Hot water is not hot”

3.2 How the Embedded Fuzzy System Works

The fundamental concept for using fuzzy systems support in the decision-making processes of the sample application under consideration orients itself on the measured values for the quantity and temperature of the outflow. The activities required by the customer service team in the further course of their service provision are dependent upon these values.

The incoming data values for the quantity and temperature of the outflow are implemented internally within the system according to their degree of membership. This fuzzification of the measured values is accompanied by the fuzzy inference process, which involves the use of language to describe, on the basis of the if-then rules determined in a rule basis, the value of the output quantity to be defined, which in the present instance entails giving priority to checking the water switch. Finally, this value is transformed into a sharp value through a process of defuzzification.

Initially, the constituent parts of the specification of the fuzzy system are the definition of the linguistic variables and the membership functions of the linguistic terms that describe in words the continuous input and output quantities.

In the present case for example, three terms, namely “cold”, “warm” and “hot”, are initially defined to describe the continuous quantity “Outflow temperature” by means of a linguistic variable (c.f. Figure 4, left).

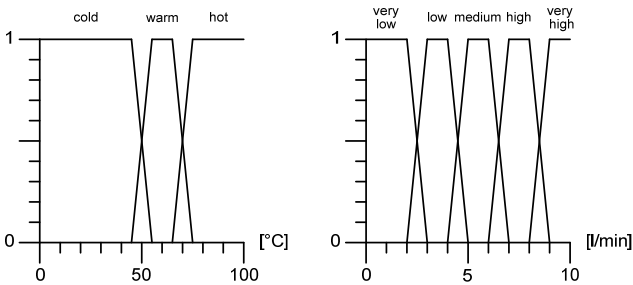


Figure 4: Membership functions of the linguistic variables “Outflow temperature” (left) and “Outflow quantity” (right) for the fuzzification of the input quantities

Depending on the current temperature value hot water appliance’s outflow, these terms describe the measured and/or imported temperature more or less correctly. In a similar fashion, the linguistic variable “Output quantity” is characterized using the terms “very low”, “low”, “medium”, “high” and “very high” and by the mapping these values on a graph (c.f. Figure 4, right). Here, the definitions of the membership functions for the input quantities are based on the combination wall-mounted water heater with flue attachment for heat and hot water on which this application is based. The ideal outflow quantity for it is 5.5 liters per minute and the ideal outflow temperature 60°C. In Figure 4, it can be recognized with respect to both of these linguistic variables that the membership functions are symmetrically constructed around these ideal values.

While the opening situation is described by means of the linguistic variables “outflow quantity” and “outflow temperature”, the level of priority to be accorded to when checking the water switch can be derived with the help of the established rules. In this respect the importance of carrying out this check is given a fuzzy evaluation with the help of a linguistic variable depending on its values. Figure 5 displays the construction of the membership functions of the linguistic variable “Priority to the water switch”. This priority should have a numerical value between 0 and 100 percent.

The behavior of the fuzzy system in the various situations entailed in the service process is determined by the rule basis. Here, each rule has an if-component (antecedent) and a then-component (consequence). In the if-component of a rule, the situation in which the rule is to be applied is described with the help of the input variables, following which the then-component is used to model the corresponding reaction. The evaluation of the rules is in turn influenced by the selection of operators. Here, the minimum operator frequently represents the word “And” and the maximum operator frequently represents the word “Or” [e.g. ZiZy80].

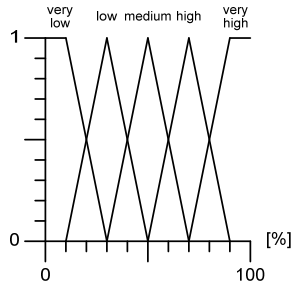


Figure 5: Membership functions of the linguistic variable “Priority accorded to the water switch” for the defuzzification of the output quantities

Table 1 displays the rule basis for determining the level of priority to be accorded to when checking the warm water switch on the basis of the input situations described by the variables “outflow quantity” and “outflow temperature”. If, for example, the available data indicates “cold” hot water and a “low” outflow quantity at the tapping point, then this should lead to a “high” level of priority for checking the water switch. On the other hand, a “warm” outflow temperature coupled with a “medium” outflow quantity should result in a “very low” evaluation of this priority. As a result of the overlapping of the membership functions, it is possible for multiple rules to come into play. The outcomes of the individual rules should, therefore, be drawn together into an overall statement at the conclusion. Then, finally, this overall statement should be used as the source for deriving the sharp values for the output quantity, which will in general be required. A range of methods exist for the defuzzification process and depending upon the circumstances of their application they will, even in the decision-making process concerning the repair procedure, represent the required behavior and the accompanying feasible outcomes.

| Priority given to checking the water switch | | Outflow quantity | | | | |
|---|------|------------------|------|----------|------|-----------|
| | | very low | low | medium | high | very high |
| Outflow temperature | cold | high | high | medium | high | high |
| | warm | medium | low | very low | low | medium |
| | hot | high | high | medium | high | high |

Table 1: Rule basis for determining the priority to be accorded to checking of the water switch

The procedure for determining the priority values can also be carried over to other groups of components and/or types of faults in this application. In order to produce a secure fault diagnosis, these values should be consulted by means of the mobile application system to be implemented. One sample calculation of the priority value of the output quantity at 0.42 (for reasons of space, the requirement for a demonstration of the calculation with the help of the fuzzy system previously specified is waived) does not constitute a definite indication that the water switch is the cause of the fault “Hot water does not heat up” and the element should therefore be replaced and checked directly following the evaluation of the measurements for the outflow quantity and temperature.

Rather, the intention in the present case is that further data should be measured or inputted into the mobile application system by the customer service technician.

4 Discussion

Based on problems posed in service process modeling, the deployment of fuzzy systems described above is justified in three respects. *First*, because natural language is used for modeling the framework of rules and is, at the same time, linked to numerical values by means of the definition of terms. Alongside the automatic processability of this service-related knowledge, complex cause-effect relationships can be documented intuitively and comprehended by the party providing the services. To this extent, the service technician can “understand” how an application system based on fuzzy rules derives its recommendations. Therefore, a system of this type is not seen exclusively as a “black box” and its acceptance among users can be increased significantly. *Second*, one characteristic of the fuzzy system constructed in this application is that the sequence in which the rules are applied doesn’t need to be specified and the database itself does not have to be complete, in order to make a reliable decision. This proceeds in accordance with the requirement formulated in Section 3.1, that the depictions of work processes in a process model should not be provided in an inflexible form. Thus, by and by, measured and/or estimated values can flow into the result of the evaluation in accordance with the evaluation of the rules, without having to run through a rigidly prescribed decision tree in sequence. Once sufficient data is available for a secure decision-making process then, with the help of the fuzzy controller, a decision can be made with respect to subsequent procedures during the service process. *Third*, the re-use of frameworks of rules and data already collected during the run-time of the service processes is a further key benefit in using such a fuzzified procedure as described above in modeling service process models. When for example, making a minor adjustment to the service process model only, such as an adjustment based on new findings with regard to a fault in a component – then the old rules need only be modified to a minor extent or it may even be possible to use them directly, in part at least. This means that the rules constitute a key knowledge component that can be re-used by the technical customer service team within individual service models across the board with respect to different types of faults and for different groups of components and even at different locations. In addition, the measured values that have already been read in for the outflow quantity and temperature can be taken into consideration directly as input data in subsequent functions of the service process, without having to be re-collected.

It could, for example, happen that, in the course of the service process, the gate valve at the front of the heating appliance is at a position that prevents the appliance from producing hot water in the correct manner. If the position of the gate valve needs to be corrected, then the outflow quantity and the outflow temperature will already have been collected at the tapping point and can be taken into consideration further evaluating the data. Here, the “rules of thumb” for the determining the perfect position of the gate valve can be collected in a rule-based manner, thus also making an evaluation of data by means of a fuzzy system possible.

5 Conclusion

In this article, the concept of a process-oriented service tool for supporting technical customer service process tools in the machinery and plant construction sector has been presented and then expanded by taking fuzzy data into consideration. The tool provides support for customer service technicians in deciding how to proceed with the service process. This decision is reached with the help of the fuzzy system that has been put in place.

Using the fuzzy EPC, findings formulated in natural language can be reproduced within the model in mathematical terms and then be re-used automatically. In terms of the design of the model, it must be pointed out that the adaptation of a process can be confined to only adapt the technical knowledge stored in the rules governing the decision-making process. Since the rule-basis is based on if-then rules, the functional behavior of the systems is comparatively easy to comprehend, system decisions are rendered transparent and it becomes possible to integrate available knowledge relatively simply. In the event of modifications in the process being controlled, old rules can be directly carried over or require minor modifications only. The continual improvement of the process definitions is thus made easier.

The creation of service process models for providing support to technical customer service teams clearly involves an extremely high outlay, which may well exceed any potential savings later achieved as a result of repair decisions that can be executed automatically. In order to make the expansion illustrated here available to the user – that is, to the designer or user of the model – it is necessary for fuzzy aspects to be integrated into the modeling tools. At the same time, in addition to the use of the manual explication techniques presented above, the application of automatic procedures on the basis of historical process instance data also needs to be considered. To this end, in [AdTL06] a proposal based on artificial neural networks was presented that, as an approach from the context of soft computing, directly supports the technology developed here.

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