Integration of Smart Data Analytics in the Product Development Process of Small and Medium-sized Enterprises (SMEs)

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Abstract

This paper identifies the particular difficulties faced by small and medium-sized enterprises (SMEs) in the product development process (PDP) and proposes concrete smart data solutions to address them. The results show a thorough evaluation of general smart data approaches as well as a particular mapping to the problems of PDP. With the help of a decision tree, SMEs in the PDP can use smart data technologies in a targeted and appropriate manner. SMEs must constantly reposition themselves in light of the current challenges posed by megatrends and Industry 4.0 in order to remain competitive. In the future, SMEs will have to innovate faster, adapt more quickly to changes and respond better to customer needs. In particular, Smart Data as a current research topic in the context of Industry 4.0 raises new problems for the design of PDP in the manufacturing industry.

Keywords
Smart Data Analytics, Product Development Process, Industry 4.0, SME, decision tree

1. Introduction
Companies around the globe must increasingly face the challenges arising from the digital transformation and the globalization of markets to ensure competitiveness. Especially for the manufacturing industry, this implies a continuous optimization of the entire product life cycle from product design to production and use to recycling (Holler et al., 2018). Therefore, the product development process (PDP) including the development, procurement, and production of products for series production is of particular importance. Industry 4.0 offers new possibilities and concepts for optimizing the PDP. These include Big Data concepts, which make it possible to collect large amounts of data, as well as Smart Data methods, which enable the evaluation and use of data (Ludwig et al., 2016). Smart Data methods in particular have the potential to increase the effectiveness and efficiency of the PDP, which in turn benefits the competitiveness of companies (Fend and Hofmann, 2020). Nevertheless, only 14% of German small and medium-sized enterprises (SMEs) use Big Data (Schröder, 2018). The low prevalence of Smart Data in SMEs can be attributed to hurdles such as the commitment of available time, financial and human resources. Furthermore, SMEs often find it difficult to assess the profitability of using Smart Data methods. In addition, SMEs often specialize in niche expertise and therefore have fewer reference projects or case studies in the PDP to guide them than, for example, car manufacturers. (Lindner and Leyh, 2019). Consequently, it is necessary to identify Smart Data methods that are suitable to address specific challenges of SMEs in PDP and to prepare them in a way that they become applicable for SMEs. The research project “SAPEQ” addresses this research gap intending to develop an IT-supported assistance

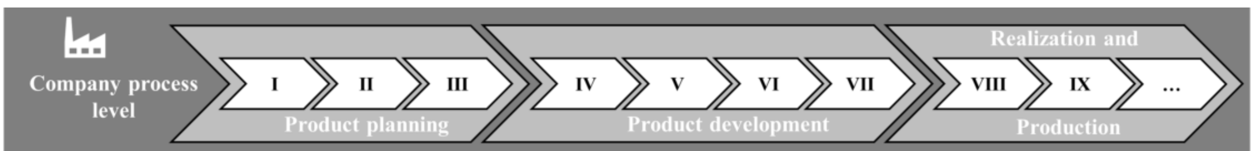
system that supports employees in the PDP of SMEs in the situational application of Smart Data methods and provides assistance in their implementation and interpretation.

2. Theoretical Foundation

To ensure a uniform understanding of the contents of this publication, the essential basic terms PDP, Big Data, and Smart Data are explained below. They form the framework for the understanding of the results obtained.

2.1 Reference Model of the Product Development Process

The PDP is a sequence of events that companies use to manufacture a product - from the initial idea or the receipt of an order to the delivery of the new product to the customer. There are certain similarities between different PDP models used in companies. Differences exist only in the design of the respective models and depend on their integration into the corporate context (Lindemann, 2009). The guideline of the Association of German Engineers (VDI) 2221 represents a general process model that serves as the basis for further consideration of the PDP. According to this model, the PDP is subdivided into the phases product planning, product development, and realization and production. The assignment contains separate sub-stages with their own activities in individual sections (Verein Deutscher Ingenieure, 2019). Based on the procedure of VDI 2221, the reference model of product development shown in Figure 1 was developed as a basis within the SAPEQ research project.



Legend					
I	Initial project phase	IV	Product conception	VII	Testing
II	Requirements determination	V	Product definition	VIII	Pre-series phase
III	Project finalization	VI	Process definition	IX	Series phase

Figure 1. Reference model of the PDP based on VDI 2221

In this reference model, the three phases of VDI 2221 (product planning, product development, realization and production) are further elaborated on a project-specific basis. Within the phase of product planning, the strategic and operational planning of the project takes place. The strategic product planning is also known as business planning and serves to derive product structures and future markets from the company's goals. In operational product planning, the previously defined strategic goals are taken up and converted into product ideas. These product ideas are selected during product determination. This results in requirement specifications as well as product definitions, which are concretized during the development phase (Westkämper, 2006). Based on the product definition, the product goals and the requirements for the product, a marketable product is developed in the next step of product development. For this purpose, the requirements for implementation are developed in the conception phase in the form of structures as well as solution principles. The created design is worked out in detail and result in complete production documents (including drawings and parts lists) of the developed product. Finally, both physical and digital prototypes are created (Westkämper, 2006; Eigner and Stelzer, 2009). As soon as the product characteristics and production technologies have been verified, product development ends and the realization and production phase begins with the pre-series phase. At the end of this phase, the release for series production, the so-called Start of Production (SOP), follows. This presents the end of the PDP and the transition to the series and after-sales phase within the product life cycle.

2.2 From Big Data to Smart Data

To describe the term "Big Data", the central characteristics Volume, Velocity, Variety, Veracity, and Value are used in literature. The term "Big Data" refers to a large amount of data (Wierse and Riedel, 2017). Variety relates to a wide range of data that does not derive from a single source and may have different structures (Vossen et al., 2015; Wierse and Riedel, 2017). Veracity refers to the quality of the available data and is critical to the success of Big Data (Pendyala, 2018). Value describes the worth and benefit that can be derived from the available data (Cheng et al., 2018). The authors of the study "BIG DATA Future" provide a more extensive definition of "Big Data". The authors use the term "Big Data" to refer to a set of methods, tools, and technologies for collecting and analyzing these complex, fast-moving, and large data sets (Trost, 2015). This aspect is taken up by the topic "Smart Data". Literature and research understand this term to mean the intelligent, goal-oriented use and processing of all available data using expert knowledge (Trunzer et al., 2019). Jähnichen (2015) supplements this with aspects of data security and quality and defines "Smart Data" as "useful, high-quality and secure information derived from heterogeneous and very complex data sets", the processing of which is only possible through the use of semantic technologies. Jähnichen (2015) understands "Big Data" as "huge amounts of data that cannot be analyzed or processed with previous methods" and thus as a kind of raw material whose full economic potential can only be exploited when processed as "Smart Data".

2.3 Smart Data Analytics

Smart Data Analytics describes the selection and application of data-based methods for the intelligent use and decision-making. Consequently, in the context of this publication, Smart Data is understood as an extension of "Big Data" focusing on the intelligent use of data. Numerous process models exist for the concrete description of the process steps and activities associated with Smart Data. To facilitate the simplest possible presentation, this publication uses a process model consisting of the three main phases for the systematic analysis of data (Bigus, 1996; Tan et al., 2014; Küstner, 2020). Figure 2 provides an overview of the three main phases of Data Analytics including the specific activities of each phase. The first phase "Pre-Processing" is responsible for the aggregation of the individual data sets, data preparation, and the initial simplification of the data set. This is usually the most labor-intensive and time-consuming phase, as it must be performed manually. As a result, structured data that meets the specific quality requirements of the following analysis phase is produced. The structured data is analyzed in the second phase, "Processing". The Smart Data techniques used depend on the type of data as well as the analysis goal or the specific problem. In the context of this publication, classification problems, cluster analyses, regression problems, anomaly detection as well as associated problems are distinguished. Finally, the third phase "Post-Processing" deals with the confirmation of the gained knowledge as well as with the communication of the results. This requires the use of additional interpretation and evaluation tools.

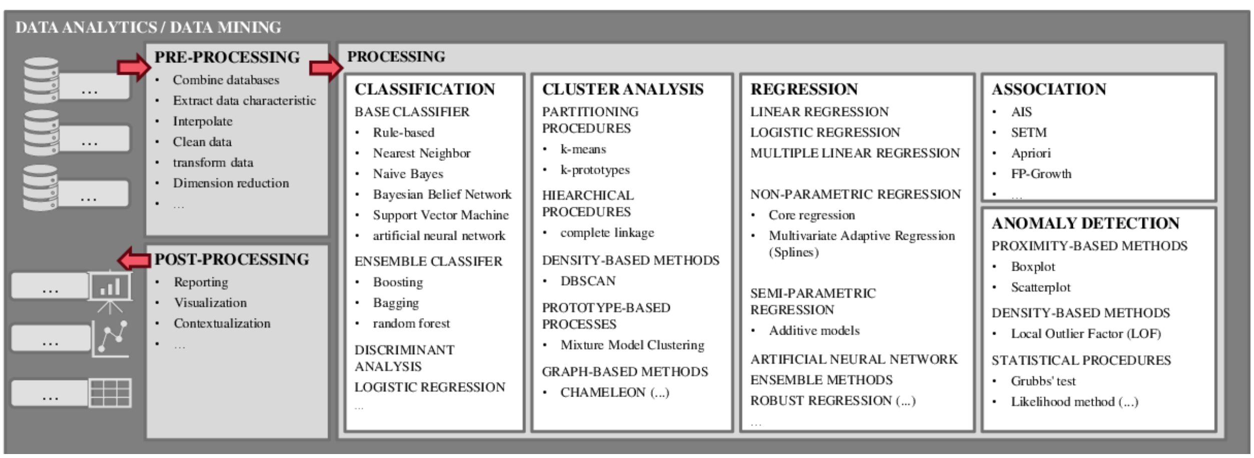


Figure 2. Overview of Smart Data Methods

3. Research Methodology

A two-stage approach was used to identify SME-specific challenges in the PDP in a decision tree and associated Smart Data methods to master these challenges. In the first step (top-down approach), challenges in the PDP were identified based on an international literature analysis and examined for their practical relevance with qualitative expert interviews. Expert interviews are considered a widely used method in empirical social research (Meuser and Nagel, 2009; Kaiser, 2014). They represent a systematic and theory-based method of data collection whereby exclusive knowledge about processes, strategies, and instruments is obtained through oral interviews (Gläser, 2010). For the execution of expert interviews, a purposeful selection of persons is made in advance (Helfferich, 2014). Experts are defined as persons who have extensive knowledge of subject-specific topics (Pfadenhauer, 2009). Expert interviews are often conducted in a semi-structured form. With this approach, the interviewer is flexible in the order of the questions and can thus ensure a natural course of the interview (Misoch, 2015). A guideline is prepared for the interview, which determines the course of the conservation. The questions contained in the guideline are designed in an open form (Helfferich, 2014). This means that the topics are predetermined by the guideline, but due to the flexibility of the interview, the complexity of the answers varies (Misoch, 2015).

In this research, the interview procedure developed by Kaiser (2014) is used. According to this, the execution of an expert interview can be divided into the phases "planning", "execution" and "analysis". In the planning phase, the experts for the interviews are identified and the guideline for the interviews is prepared. A group of people with at least three years of professional experience in the PDP is identified as experts. The qualitative content analysis according to Mayring (2016) is used for the analysis of the expert interviews` results. The evaluation is based on the interview protocols and a developed category system for the evaluation (Mayring, 2016)(Mayring, 2016)[26](Mayring, 2016)(Mayring, 2016)[26](Mayring, 2016)(2016). (Mayring, 2016). In the second step (bottom-up approach), the challenges and their causes are identified from the company's perspective with the help of expert workshops. Within these workshops, concrete challenges at the working level in the PDP are analyzed through structured brainstorming for the problem areas identified in the first step. Based on these challenges, issues of the SMEs in the PDP are derived and brought into dependency relationships. A question is understood as the comprehensible formulation of the challenges from the company's perspective. The dependency relationships between the questions are documented as a design structure matrix, which enables a transfer into a decision tree. Furthermore, Smart Data methods are assigned to the individual challenges with the help of expert workshops. The assignment is done using a dependency matrix. Afterwards, the decision tree is implemented as a Chat-bot. Users can find their specific path through the decision tree structure using the dialog form and reach their situational challenge.

4 Results and Discussion

In the following, the results are determined, evaluated, and explained. This is based on the findings within the research project “SAPEQ”.

4.1 Literature-based identification of PDP-specific challenges

First, the challenges in the PDP were examined with the help of a systematic, international literature research. For this purpose, specialized conferences, dissertations, and journal articles were analyzed. The focus is on conferences with a design methodology orientation to justice the predominantly physical product developments of manufacturing SMEs. An overview of the analyzed conferences can be found in Table 1.

Table 1. List of analyzed conferences

Conferences	Vintage	Papers
Joint colloquium on construction technology	2017, 2019	56
Stuttgart Symposium for Product Development	2017, 2019	67
DfX Symposium	2016	28

A total of 151 publications were analysed, and filtered for their relevance regarding the presentation of challenges and their causal drivers within the PDP. Only publications with a corresponding relevance were considered further. As such, 22 publications were identified. The identified challenges were then subjected to categorization. In total, six superordinate categories of the identified challenges could be formed: (1) Requirements are not properly identified or incorporated within the PDP, (2) Requirements within the PDP are not fulfilled, (3) Schedule is not met, (4) Financial goals are not met, (5) Insufficient knowledge management, (6) Insufficient process structuring and formalization. These challenges are shaped by the megatrends of globalization, increasing customer demands, and digitalization.

Requirements are not correctly identified or incorporated within the PDP

The rapid changes in markets and technologies lead to uncertainty regarding the determination of customer requirements int the early phases of the PDP. Customer-centric product development thus results in frequent changes in product requirements and demands increased flexibility from the company to meet these fluctuating and uncertain requirements. The definition of the desired product requirements is becoming increasingly difficult for customers and leads to a reduction in available development times. Customers are less and less able to express their requirements explicitly, as the range of functions and the dependencies between functions has increased. Another factor is disruptive technologies, which are seen as drivers of rapidly changing customer requirements, as customer appreciation of outdated technologies is increasingly declining (Krause et al., 2016) Additionally, there is insufficient or imprecise information about the requirements in product development, so that decisions are based on incomplete information (Wang and Kjellberg, 2016; Corves et al., 2019)(Wang and Kjellberg, 2016)(Wang and Kjellberg, 2016)(Wang and Kjellberg, 2016).[29](Wang and Kjellberg, 2016).(Wang and Kjellberg, 2016).[28](Wang and Kjellberg, 2016). Accordingly, the customer requirements only become concrete during the project. This challenge can be overcome by an agile approach of the PDP (Corves et al., 2019).

Requirements within the PDP are not fulfilled
The changes in customer demands have an impact on the complexity of product requirements, respectively their fulfilment within the PDP. Furthermore, a study by Wang and Kjellberg (2016) shows (Wang and Kjellberg, 2016) that communication barriers related to product requirements, tasks, and project progress in a PDP are increasing. Growing organizational structures mean that products in the PDP are not only designed by the development team but that upstream and downstream process steps have a considerable influence on product and process design. The PDP is thus subject to interdisciplinary collaboration (Voegele and Brehm, 2013) Furthermore, the dynamic business environment increasingly demands individualized products (Wickel, 2017). By producing customized variants, companies create a unique selling proposition that helps them gain a competitive advantage. Nevertheless, it must be taken into account that an increased number of variants increases the requirements to be fulfilled and consequently the costs in the PDP (Schulz, 2014; Krause et al., 2016). Increasing quality requirements are another factor that makes it more difficult to fulfil the growing demands. These quality requirements derive from customer requirements as well as from regulatory requirements, such as standards (Wickel, 2017). The complexity of the products to be developed is also increasing due to a higher proportion of necessary software developments (Binz et al., 2019) Due to continuously changing customer requirements, software development is associated with a high degree of uncertainty. As a result, due to numerous existing dependencies, minimal changes in the software requirements have a significant impact on the overall design (Wickel, 2017).

The Schedule is not met and Financial goals are not met
Increasing customer demands combined with highly competitive markets lead to shorter market and innovation cycles, which in turn demand shorter development cycles (Wang and Kjellberg, 2016; Wickel, 2017). This results in increased cost pressure within the PDP. At the same time, the increasing complexity of product development leads to higher development costs (Wickel, 2017). A conflict of objectives for companies emerges between cost-driving product individualization and efforts to reduce costs in the PDP through efficient and lean process design (Binz et al., 2019).

Insufficient Knowledge Management
From the previous paragraphs, it can be stated that there is a great need within the PDP to reduce costs and shorten development times. Among other things, this requires effective knowledge management to increase the efficiency of the PDP. This can be justified by the fact that process-critical action knowledge can reduce wrong decisions and extra work. Nevertheless, industrial practice shows that knowledge management is usually not implemented successfully, mainly due to the lack of a company-specific awareness of knowledge management and a process-oriented view. In this context, the PDP is regarded as a knowledge-intensive process (Binz et al., 2019).

Inadequate process structuring and formalisation
To meet the challenge of fluctuating customer needs, agilization of the PDP is required. Uncertain and incomplete information on product requirements make an agile approach in the PDP necessary. This enables iterative coordination with customers to reconcile the previous project status and to determine the current customer requirements. Agility means the ability of a company to react quickly to dynamic changes in requirements (Corves et al., 2019). Implementing agility in the PDP is achieved by introduction and integration of an agile team. In this regard, team composition is especially fraught with challenges when dealing with a company with a rigid, hierarchical organizational structure (Schmidt et al., 2018). This means that agilization of the PDP alone is not sufficient, but also requires the establishment of an agile culture (Bertelsmann Stiftung, 2017).

4.2 Validation of literature-based challenges in the PDP
To validate the six previously identified categories of challenges and to generate further insights into the PDP, 20 interviews were conducted with a total of 23 experts. Three of the expert interviews were conducted with two experts from the same company. Furthermore, the expert interviews were conducted both in-person and by telephone. The development of the interview guideline is based on the systematic literature review on challenges in the PDP. As a

result, the interview guideline is divided into five overarching categories: (1) Status Quo of Smart Data in the PDP, (2) Drivers of Change, (3) Agile Methods, (4) Challenges in the PDP, (5) Future Perspectives. According to the reference model of the PDP (Chapter 2.1), ten experts assigned themselves to the phase of product development, followed by nine experts who assigned themselves to the product planning phase. Six experts assign themselves to the phase of realization and production. Nine experts were not assignment within the reference model because their activities relate to PDP-related activities. In addition, 16 experts stated professional experience of more than 16 years, three experts stated professional experience of between one and five years, and four experts made no statement in this regard. A summary of the core statements of the experts can be found in Table 2. The challenges identified by the literature review were confirmed and supplemented by the statements of the experts.

Table 2. Results of the expert interviews

Category	Summary
(1) Status Quo of Smart Data in the PDP	The experts almost unanimously report that the PDP has developed from an informal, dynamic process to a very structured and formalized process. According to the experts, only a limited set of known methods is applied within the PDP. Smart Data methods are only applied sporadically.
(2) Drivers of change	According to the experts, megatrends such as the increasing digitalization of products and processes have a major influence on the PDP. According to the statements of the experts, the acceleration of product development and the increase in specific framework conditions (e.g. regulatory requirements) of individual industries represent further drivers.
(3) Agile methods	The experts see a high potential in the use of agile methods, especially in the early phases in the PDP. According to the experts, an agile design requires a transformation of the corporate culture and an expansion of the competencies of the employees.
(4) Challenges in the PDP	An assessment of the relevance of the identified challenge categories shows a comparable response pattern among the experts. The greatest challenges are seen as the failure to meet requirements within the PDP and inadequate knowledge management. Furthermore, the experts emphasize the difficulty of achieving financial goals.
(5) Future perspectives	According to the experts, the PDP will evolve iteratively in the future and adapt to current circumstances. The product lifecycle will increasingly shorten and make the PDP more agile.

After the literature-based identification of the challenges in the PDP as well as their verification through the qualitative expert interviews, the causes of these challenges from a company perspective were identified with the help of expert workshops.

4.3 Identification of the root causes of the validated challenges in the PDP

The concrete challenges at the working level in the PDP, including their causes, were identified and compared with the previously identified challenge categories. This bottom-up approach serves both as concretization and verification of the challenge categories. A total of five expert workshops were conducted with nine experts. Within the workshops, the experts brainstormed freely to identify all possible challenges. Subsequently, the identified challenges were prioritized with the help of cause-effect diagrams (Ishikawa – diagrams). Figure 3 shows an example of the cause-effect diagram for the challenge "Miscalculation concerning resources".

After identifying the causes of each challenge, the experts were asked to assign the challenges to the literature-based challenge categories. If an assignment to the existing challenge categories does not make sense, the experts had the opportunity to form new categories. During the expert workshops, the six existing challenge categories proved to be sufficient, and are considered to be verified in the following.

4.4 Derivation of the structure of the decision tree

For the situational recording of challenges within the PDP of SMEs, questions in the PDP derive from the previously identified challenges and causes. The derivation of the questions is carried out using the 5-Why method. This is done by asking for the cause until no other subdivision related to the PDP is found.

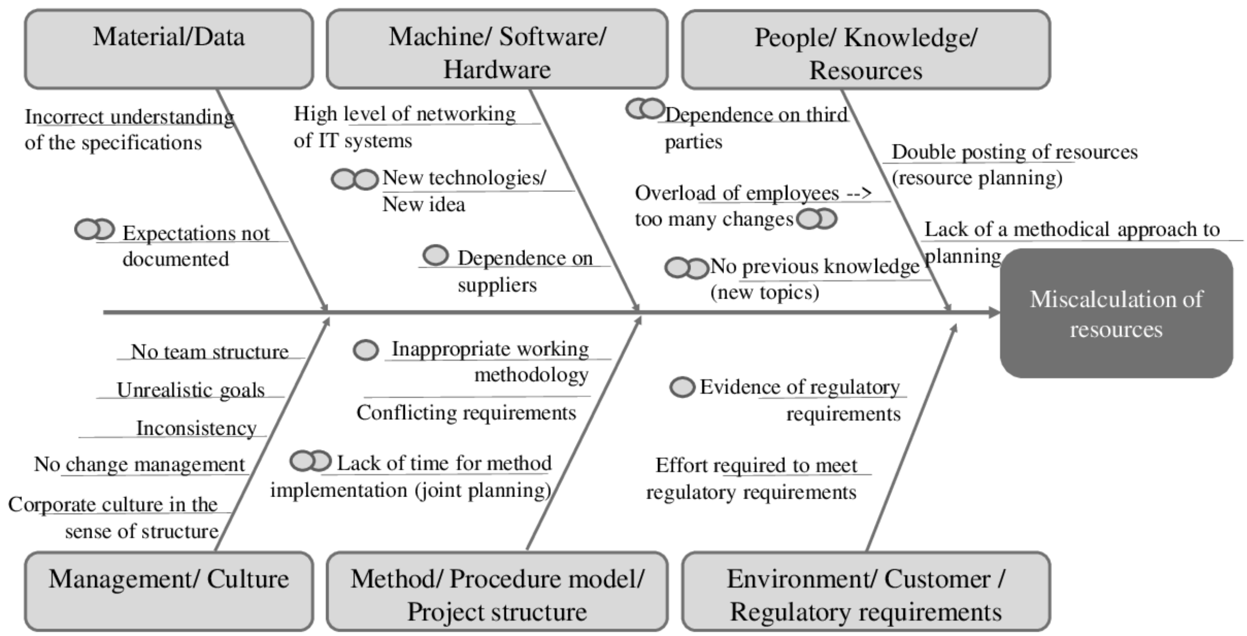


Figure 3. Example of an elaborated Ishikawa diagram

Afterwards, these questions are placed in dependency relationships within a Design Structure Matrix. A separate Design Structure Matrix is created for each challenge category. A decision tree is built based on the structure of the individual matrices. This way of structuring the questions supports SMEs in terms of a situation-specific approach. The structure ensures that employees are guided to the relevant challenges in the PDP. The decision tree created in this way is divided into the six challenge categories.

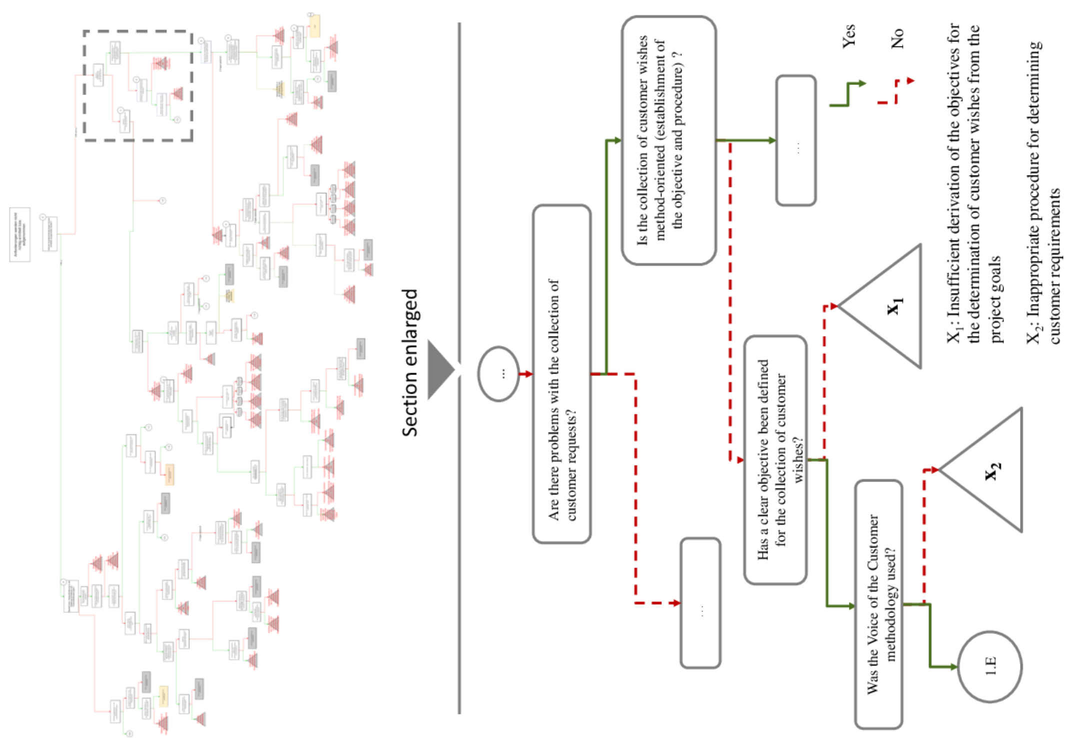


Figure 4. Excerpt from the decision tree

Figure 4 shows an excerpt of the decision tree. To reduce complexity, the paths of the decision tree are marked by coloured arrows. Thus, a green dotted arrow indicates approval and the red arrow indicates disapproval. Furthermore, triangles represent the challenges within the decision tree. It should be noted that the options of approval or rejection must also have an exit option from the decision tree. This option occurs when the path leads to a challenge that is not in the context of the PDP. The successful creation of the decision tree is followed by the selection of appropriate Smart Data methods to address these challenges.

4.5 Selection of suitable Smart Data Methods

The Smart Data methods mentioned in Chapter 2.3 were compared to the challenges identified using an evaluation matrix. For this purpose, an expert workshop was conducted with five experts. Within the expert workshop, the individual challenges were presented and possible Smart Data methods for overcoming them were discussed. By building consensus among the experts, the suitability of individual Smart Data methods was determined along the process model presented in Chapter 2.3. For example, hypothesis tests are suitable for evaluating whether a change in customer requirements can be statistically proven. To make a differentiated statement of suitability, five gradations were selected. For editorial reasons, Figure 5 shows an abbreviated excerpt of the assignment of the Smart Data methods to the challenges. To increase clarity, only the top level of the process model is shown. Subsequently, an IT-based implementation of the concept was carried out.

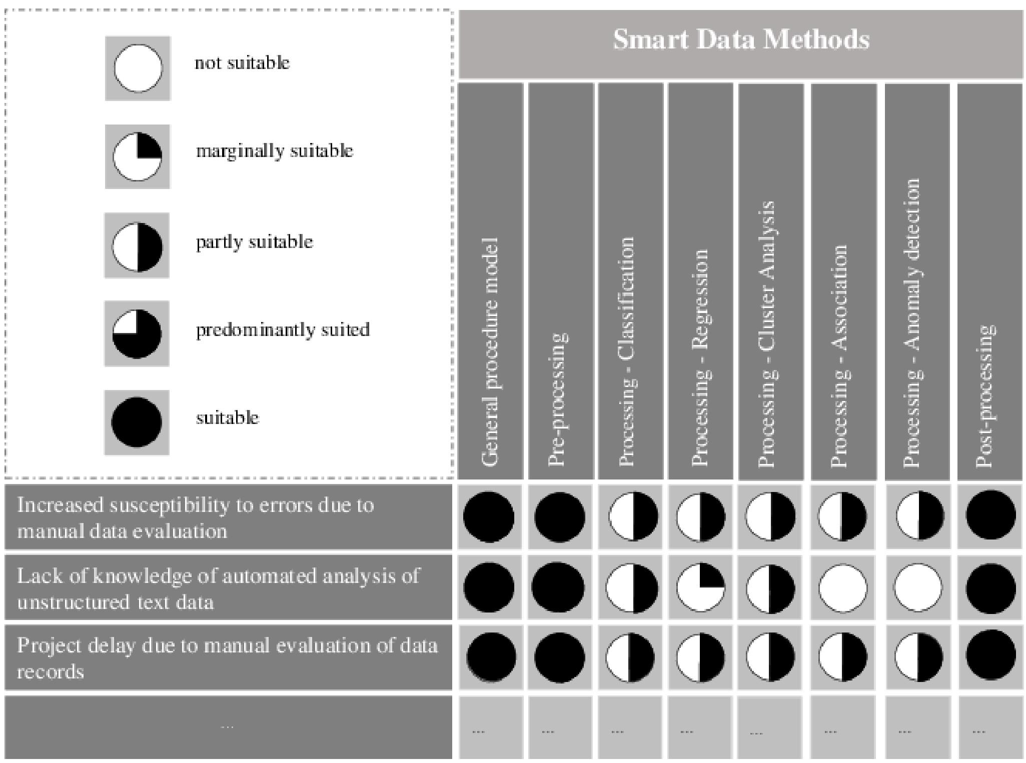


Figure 5. Excerpt from the assignment of Smart Data Methods to challenges

4.6 IT-based Implementation

To support the employees within the PDP in the best possible way to master the challenges with the help of Smart Data, the decision tree developed in chapter 4.4 is implemented as a Chat-bot. Furthermore, the Smart Data methods assigned in chapter 4.5 are stored as concrete solutions within the Chat-bot. The prototypical implementation is done within the free application ®SnatchBot, which allows creating web-based Chat-bots. Figure 6 shows the start page of the SAPEQ Chat-bot.

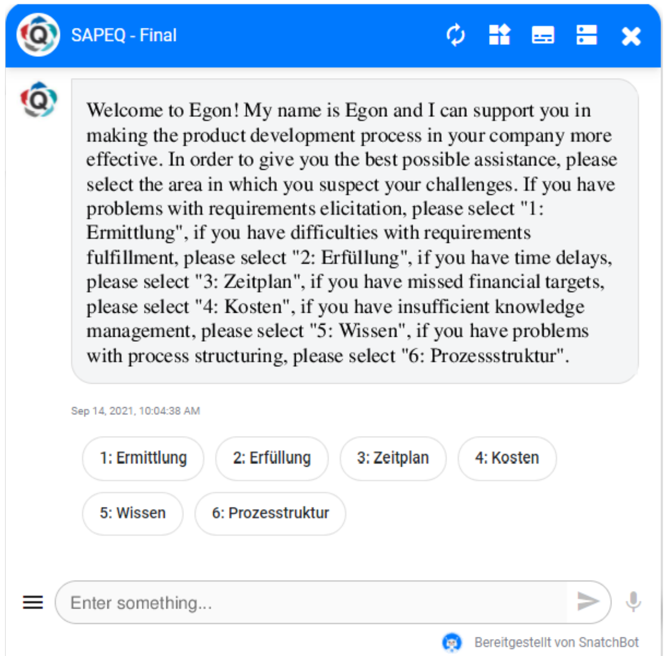


Figure 6. Graphical user interface of the Chat-bot

To avoid linguistic ambiguities, only predefined response options are integrated into the first iteration loop of the Chat-bot. In summary, a functional Chat-bot that identifies the specific challenges in the PDP and proposes appropriate Smart Data methods to solve them was successfully created.

5. Conclusion and Need for Further research

In the context of this publication, challenges in the PDP were identified through a two-step procedure and implemented within a decision tree in an IT-based manner. In the first step, six challenge categories were identified based on literature using a top-down approach. To verify the relevance and completeness of these challenge categories for the industrial practice of SMEs, 20 expert interviews were conducted. Within the expert interviews, the six categories were confirmed and refined. In the second step, the concrete challenges were identified by a bottom-up approach through five expert workshops and the causes of these challenges were determined. Finally, both procedures were combined and the identified challenges were compared with the previously identified six challenge categories. This comparison confirmed the six identified challenge categories and thus served as verification. Furthermore, this comparison enabled the challenge categories to be underpinned by concrete challenges at the working level in the PDP. Based on these challenges, questions were derived in the PDP to identify the concrete challenge within the PDP. The derived questions were brought into dependency relationships and transferred into a decision tree, which represents a systematic procedure within the PDP. Subsequently, the challenges in the PDP were compared with Smart Data methods. As a result of this matching, a method recommendation was made that represents the best possible way to address the specific challenge. Finally, this decision tree was implemented IT-based through a Chat-bot.

Further, necessary research activities include the preparation of the respective Smart Data methods so that employees in SMEs are enabled to apply them without additional training. To this end, a concept for enabling employees to carry out and interpret the respective methods is to be developed. In doing so, it should be considered that the existing Smart Data potentials of SMEs are exhausted when using the methods. With the goal to enable independent and low-resource application, the concept has to be developed as a demonstrator in the form of an easily accessible web-based assistance system, which will allow iterative validation.

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