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Utility Potentials of Cyber-Physical Systems´ Field Data

Günther Schuh[1], Ramon Kreutzer[2], Marius Sodermanns[2]
[1]*Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Aachen, Germany*
[2]*Fraunhofer Institute for Production Technology IPT, Aachen, Germany*
Corresponding Author: Günther Schuh

Abstract: *Digitization, Industry 4.0 and digital business models are changing the global competition. In future, the digital connectivity of almost all industrial products will be enabled due to increasingly inexpensive and more powerful sensors. The field data generated in this way offers potential for manufacturing companies to differentiate themselves from competitors as well as to counteract the increasing commoditization of physical products. With the help of cyber-physical systems (CPS), a wide variety of utility potentials can be tapped for various players in the environment of manufacturing companies. However, these utility potentials have not yet been described in a differentiated and structured way. Consequently, the systematic implementation is only partly carried out in practice. The aim of this paper is therefore to elaborate stakeholders in the environment of manufacturing companies, which can benefit from field data of CPS. Furthermore, it is also intended to explain which concrete utility potentials can be realized.*

Keywords: *Utility potentials, cyber-physical systems, field data, smart services, digitization.*

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I. INTRODUCTION

Manufacturing companies in Germany have for years been at the forefront of international competition with their products. In order to maintain the leading positions in the future, these companies face a number of challenges. Increasing global competition and the onward commoditization of physical products lead to high price pressure as well as decreasing margins. At the same time, a trend towards buyer markets can be identified, in which increasing and more individual customer and market requirements are observed. [1–3] In order to meet these challenges, the application of information and communication technology (ICT) has a high success potential for manufacturing companies [4]. In the context of an ever growing importance of knowledge-intensive value creation, it will be crucial in the future to consider data, information and knowledge as strategic resources [5]. In addition to the classical production factors of land, labor and capital, knowledge has thus to be regarded as the fourth decisive factor [6]. Increasingly cost-effective and powerful hardware components will enable a connection of almost all industrial products in the future [7]. As a result, these products will generate field data during their application, which can be used by companies to realize various differentiation potentials [8]. In this context, the term cyber-physical systems (CPS) can be introduced as a kind of further development of mechatronic systems through the fusion of mechanical, electronic and computer science elements that are also able to network with other objects [9,10]. In Germany alone, the value-added potential of digitization and industry 4.0 is estimated to be worth up to 150 billion $ in the next five years. A central obstacle to this is cited as being insufficiently aware of the concrete utility potentials of industry 4.0 and digitization. Thus, there is a lack of transparency that can be opened up by CPS and especially by its field data generated. [11]

In addition, the environment of manufacturing companies is changing from traditional value added structures to digital ecosystems. In particular, the networking components and the field data generated by sensors lead to collaborative value added structures as shown in Fig. 1. New data ecosystems emerge in the surroundings of CPS. Subsequently, most of these further developments are based on an enormous amount of field data. Hence, with the extended features and collected data of CPS begins a new era of competition [12].

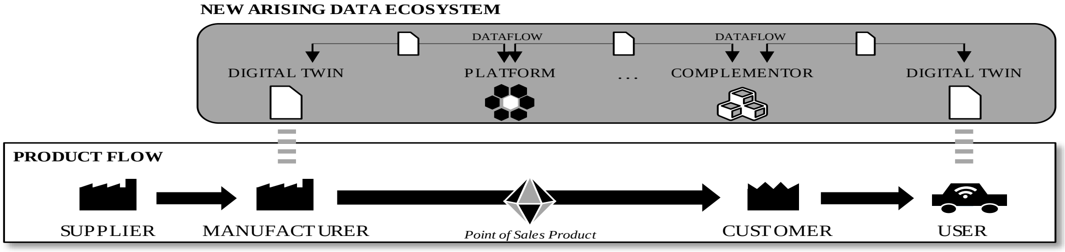


Fig. 1: Ecosystem of digitally enhanced products

Motivation/aim of the paper:
It can be stated that actors in the environment of manufacturing companies have only limited know-how about which utility potentials can be realized by the field data CPS. This results in two overarching aims which are to be answered in this paper:

1. Which actors in the environment of manufacturing companies can benefit from the field data CPS?
2. What concrete utility potentials of field data CPS can be realized for the identified actors?

The first research question is answered by a descriptive model (cf. Fig. 3, model 1 and Chapter V.A); the second by various explanatory models (cf. Fig. 3, model 3 and Chapter V.B).

II. METHODOLOGY

As this paper focusses on a problem with practical relevance the research process of applied science by ULRICH, shown in Fig. 2, will be adopted. The structured approach targets the development of models, which shape the future by describing, explaining and configuring parts of the reality [13].

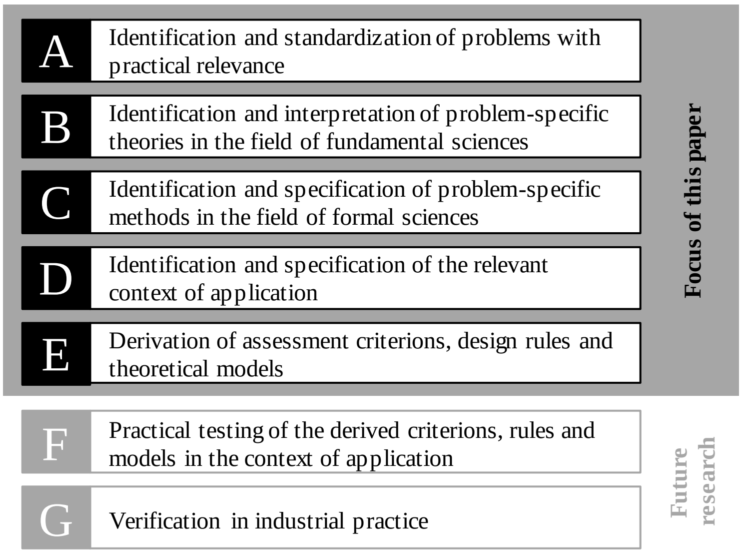


Fig. 2: Research process of applied sciences

ULRICH's research method can be divided into seven sequential process steps [13]. This paper covers steps A to E. The practical testing (step F) as well as the verification in industrial practice (step G) are not in the scope of this paper. First, problems with practical relevance need to be identified and standardized. Therefore, the first chapter focuses on the underlying practical problem, which has been derived based on past and ongoing industry projects as well as discussions with other researchers in this field. The chapters 0 and IV cover the methodological process steps B and C, in which problem-specific theories and methods from existing research are being identified, interpreted and specified. The Results chapter V of this paper addresses steps D and E of the process, in which model requirements are derived and component models are developed based on the chapters 0 and IV. The final chapter VI summarizes this paper and gives an overview of the future research in detailing the derived component models.

The method that is presented here will help manufacturing companies as a guide to systematically identify, prioritize and realize the utility potentials from field data of CPS. The methodod is similar to the system technique approach. The problem is split up into sub problems and solutions will be developed from rough to detail.

The classification can be defined as the systematic order of objects to classes [14,15]. Thereby, utility potentials are considered as objects. Based on this definition of the classification, the rough concept of the model subdivided into 3 sections can be derived.

1. First of all, a classification framework is required, which consists of a defined number of classes that define the content structure. This framework spans the possible solution and search space for the utility potentials of field data CPS.
2. Once the classification framework has been developed, the utility potentials of field data CPS are derived within classes using class specific explanation models. In the first step, a class-specific, but field data-independent solution area is worked out. This solution area consists of generic, class-specific targets that have been identified by analysing scientific literature. In the next step, the dependencies between the

capabilities of CPS and field data-independent targets are explained. If reliances are recognized, concrete utility potentials of field data CPS have been identified. If no dependencies can be found, the observed target is excluded. Thus a filtering process takes place, which is shown in Fig. 3 schematically.

3. Finally, the classification framework and the class-specific explanation models are combined to form the general model. The procedure is also shown in Fig. 3.

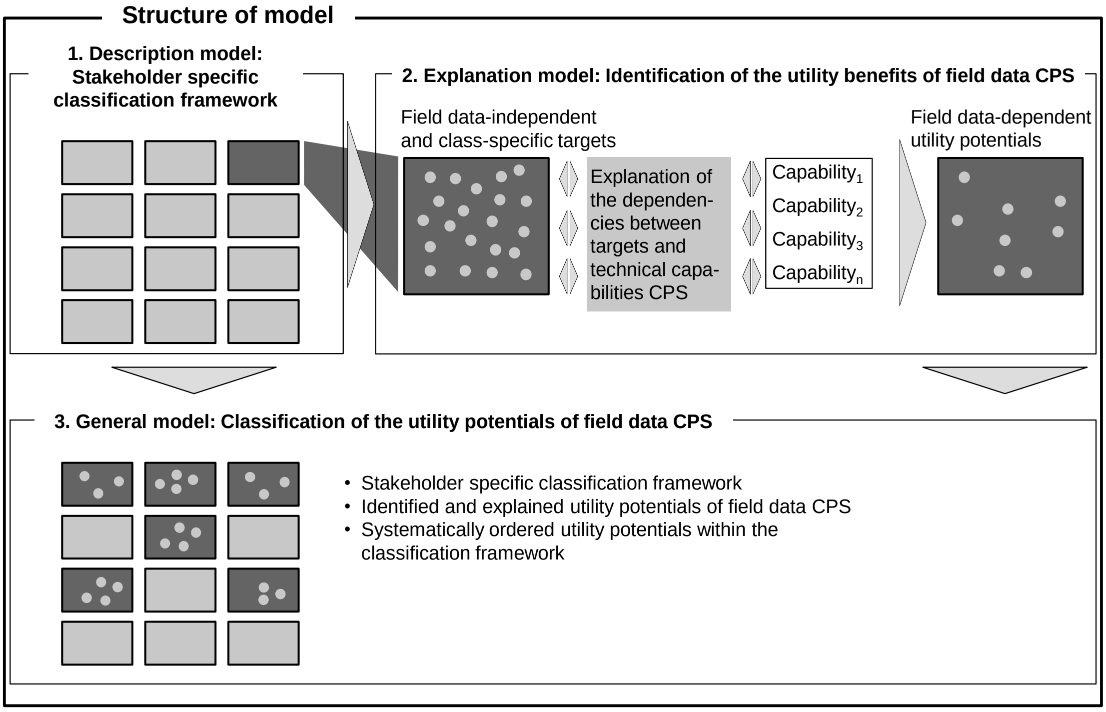


Fig. 3: Structure of model and work specification

The description model for the systematic derivation of the classification framework and the class specific explanation models are presented in Chapter V.

III. THEORETICAL BACKGROUND

The following section describes the most important theoretical concepts, which the paper is based on. Apart from the term "utility", this will be CPS and field data.

A. Utility potentials

The etymological origin of "utility" is the Latin word „utilitas" (lat. usefulness). Thus, utility is something that is advantageous or useful. The concept of utility as well as utility-based considerations have existed since the eighteenth century, when they were first introduced into microeconomics by ADAM SMITH. In the further course, until today the concept of utility is used in various scientific disciplines, such as sociology or quality management. According to HOHL, the concept of utility is considered as a subjective measure of satisfaction of a need. Thus, a utility directly depends on the needs of an individual and is therefore always subjective [16]. The present research project regards the subjectivity of a utility. For this reason, the paper does not aim to quantify the utility of the field data of CPS.

It can be summarized that utility is a measure of satisfaction of needs which is highly subjective (this can be attributed to the individual needs or aims which are pursued from the perspective of the different subjects) and can therefore only be quantified with very high effort.

The term potential is derived etymologically from the Latin term "potentia" (lat. strength, power). It is used in many subjects and describes, according to Oxford Dictionaries, "latent qualities or abilities that may be developed and may lead to future success and usefulness". In the present research project, potential benefits are highlighted which are defined as follows: The paper uses the term utility potential to address a theoretical utility CPS, that can be realized for a stakeholder based on the technological properties of CPS. This utility potential may already been successfully implemented in an application, but this is not a necessary criterion.

B. CPS

Physical Structure of CPS

For a better understanding of CPS, their physical structure and components are to be worked out. GEISBERGER ET AL. describe CPS as embedded systems, which can detect physical processes by means of sensors and act on them by means of actuators. CPS are also able to network with other systems and to interact with humans via a multi-modal human-machine interface. [1] Thus, CPS have different components. These include sonsors, actuators, mechanical and electronic hardware, a networking module as well as a microcontroller and, if necessary, a human-machine interface. [17,18] A schematic and very simplified structure is shown in Fig. 4. For a better understanding, vehicle-specific examples are also presented.

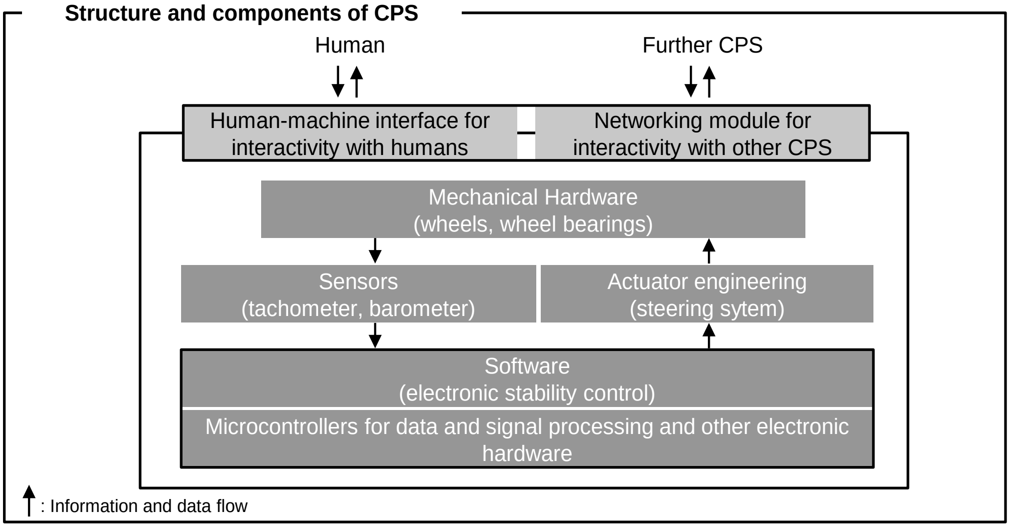


Fig. 4: Simplified structure of cyber-physical systems based on [17,18]

Technological capabilities of CPS

Next, the technical capabilities of CPS are to be described. This insight helps to understand how CPS can be used by manufacturing companies to realize various utility potentials. The technical capabilities of CPS developed here therefore serve to elucidate certain utility potentials within class specific explanatory models (cf. chapter V.B). [19]

Capabilities	Abstract	Manifestations
Connectivity	Possibility of networking with other CPS.	• 1-to-1 • 1-to-n • n-to-n
Interactivity	CPS interchange via data communication. Interactions with the user via HMI.	• 1-to-1 • 1-to-n • n-to-n
Context sensitivity	CPS know their context (application and environmental situation), their state as well as the user and other connected CPS. This context can be monitored by their connectivity.	• System limited • Cross-system
Context adaptivity	CPS adapt themselves to the respective application and environment. Through interaction and coordination with other CPS, an optimal system behavior can be justified.	• System limited • Cross-system
Multifunctionality/ Digital realization of functions	Through programmable hardware, actuators and a high software share, the possibility of a digital realization of functions for increasing system functionality with the same physical hardware is obtained.	/
Digital subsequent integration of functions	The ability of the digital realization of functions in conjunction with the connectivity allows a subsequent (after point-of-sales) digital integration of functions.	/

Fig. 5: Consolidated technological capabilities of CPS

C. Field data

The literature analysis revealed three characteristics, which can be used to differentiate between field data [18,20–22]:

- Several definitions of field data have a temporal character. This describes when the data is collected and is hereinafter referred to as the survey date. Another criterion is the survey source, which specifies from whom or what the data and information originate. Further, a distinction is made between different survey types. Data and information can be collected, for example, by means of written maintenance and service reports, decentralised customer surveys for market research or digitally by means of corresponding automatic recording devices.
- On the basis of the present explanations, field data from CPS can be defined as data which is collected during the use phase of the CPS. This survey is performed by automatic data entry systems of the CPS. Hence, the data source is the CPS itself.

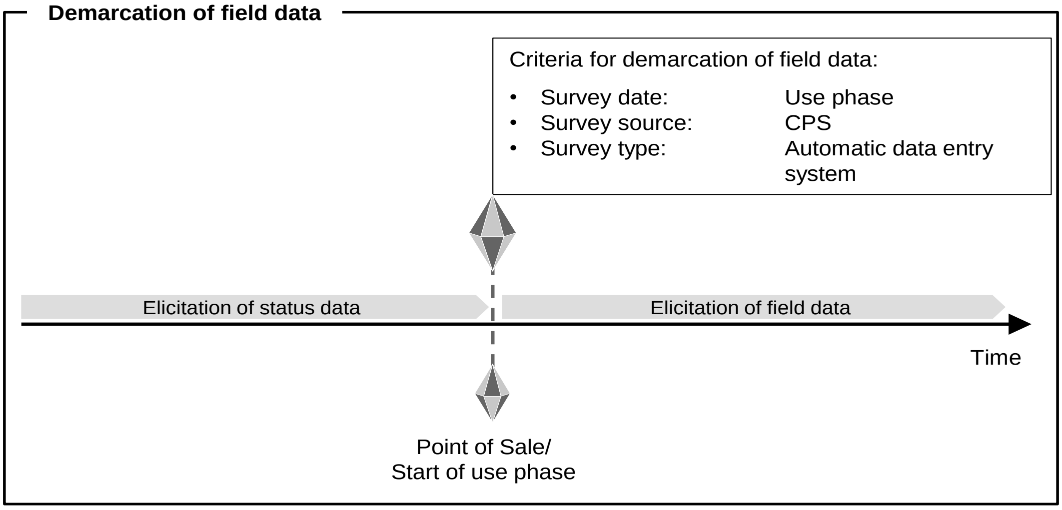


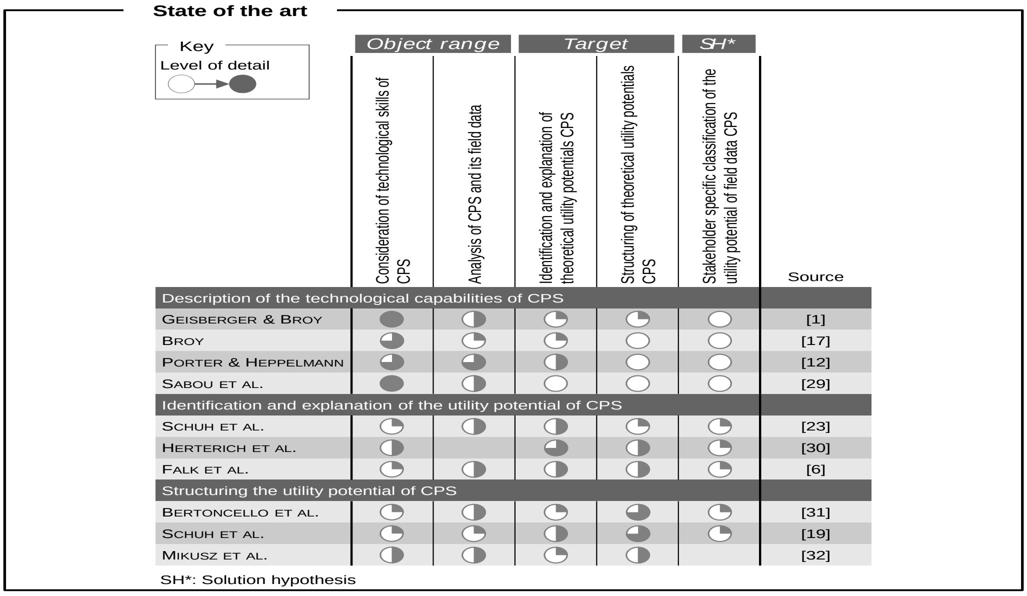
Fig. 6: Restriction of field data of cyber-physical systems based on [22]

IV. STATE OF RESEARCH

In the following chapter, the current state of the art will be presented. For this purpose, selected works which are assigned to different thematic priorities were briefly described and critically assessed. Research has been carried out on works which

- describe the technical capabilities of CPS,
- identify and explain the utility potentials of field data CPS,
- as well as structure or classify these utility potentials.

The following figure shows the result of the literature research.



	Object range		Target		SH*	
	Consideration of technological skills of CPS	Analysis of CPS and its field data	Identification and explanation of theoretical utility potentials CPS	Structuring of theoretical utility potentials CPS	Stakeholder specific classification of the utility potential of field data CPS	Source
Description of the technological capabilities of CPS						
Geisberger & Broy	●	◑	◔	◔	○	[1]
Broy	◕	◔	◔	○	○	[17]
Porter & Heppelmann	◕	◕	◑	○	○	[12]
Sabou et al.	●	◑	○	○	○	[29]
Identification and explanation of the utility potential of CPS						
Schuh et al.	◔	◑	◑	◔	◔	[23]
Herterich et al.	◑		◕	◑	◔	[30]
Falk et al.	◔	◑	◑	◑	◔	[6]
Structuring the utility potential of CPS						
Bertoncello et al.	◔	◑	◔	◕	◔	[31]
Schuh et al.	◔	◔	◑	◕	◔	[19]
Mikusz et al.	◑	◑	◔	◑		[32]

SH*: Solution hypothesis

Fig. 7: State of the art

From the above-mentioned observations within the state of the art, the following research deficits can be pointed out:

- Based on the literature research, it can be stated as an first deficit that so far there has not been a sufficient scientific explanation, identification and naming of the utility potentials of field data CPS. Certainly, isolated utility potentials of field data CPS are mentioned in corresponding studies, but these are often not scientifically explained or refer to a specific practical application case, such as the automotive industry.
- As a further deficit, it can be stated that there is also no research work that systematically organizes and structures the utility potentials within a stakeholder-specific classification framework.

V. RESULTS

A. Description model for the derivation of a stakeholder-specific classification framework

After the superordinate model structure has been worked out beforehand (cf. Fig. 73), the derivation of a proper classification framework is to be carried out. In order to take the high subjectivity of the concept into account, a stakeholder-specific classification framework is to be developed. Accordingly, it is necessary to first select stakeholders for whom utility potentials of field data CPS can be realized.

Selection of stakeholders

For this purpose the “Ecosystem of digitally enhanced products” (cf. Fig. 1) is used. The supplier, the manufacturer as well as the customer of the CPS can be named as classic stakeholders. Others in the context of CPS are the platform operator and the complementer. A total of five stakeholders can thus be identified. The order and identification of the utility potentials within these five classes would take place at a too high level of abstraction. For this reason, additional classes are to be added to increase the level of granularity.

Enhancement of additional classes

The enhancement of additional classes will continue to be based on the CPS-Lifecycle. The five stakeholders mentioned above and the CPS-Lifecycle (Development, Manufacturing, Use and End-of-Life) span the outer scope of the classification framework. Classes are to be supplemented, which are oriented on the stakeholders and the CPS-Lifecycle.

For suppliers and manufacturers, these are the classes of development, manufacturing and service. The complementer develops complementary services and subsequently performs them. The customer goes through the decision phase before the CPS is purchased and used. The platform operator develops platform standards and manages the platform ecosystem. The classification framework is shown in Fig. 8.

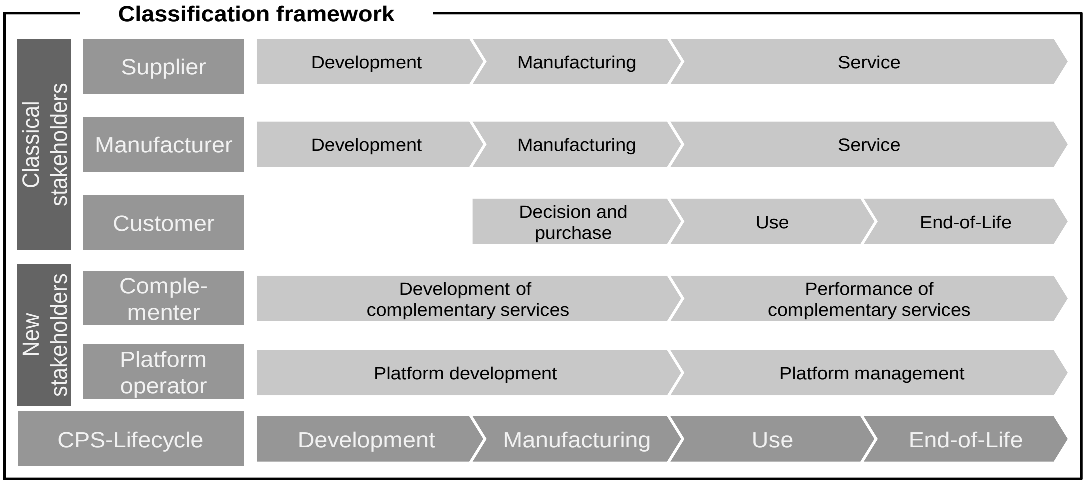


Fig. 8: Classification framework for classifying the utility potentials of field data CPS

Selection and segmentation of classes:

In order to derive utility potentials in these classes, they need to be detailed even more. For this purpose, the service phase is divided into three further subclasses. These are based on the customer's phases of the purchase, use and end-of-life. This enables a more precise order and identification of utility potentials within the classes. Furthermore, the class of manufacturing is not to be examined in detail. The area of observation work is on the field data of CPS, i. e. data generated during the use of CPS after it has left the production facilities. A term in which data plays a central role is that of ‘Industry 4.0’. One of the aims of Industrie 4.0 is to tap new rationalization potentials during manufacturing by using data. [6]. Priority is given to production data, which is generated during the manufacturing of CPS and not during its use. [23]. However, this does not mean that CPSs used in manufacturing are excluded from the scope of this work. For example, machine tools used in manufacturing represent CPS, which generate field data during their use phase. In this case, the owner of these machine tools would be considered as a customer or user, whereas the machine tool supplier would represent the manufacturer. In addition, the classes Development and Service of the stakeholders Supplier, Manufacturer and Complementor are grouped together as one class type. The reasons and assumptions for this summary are explained below.

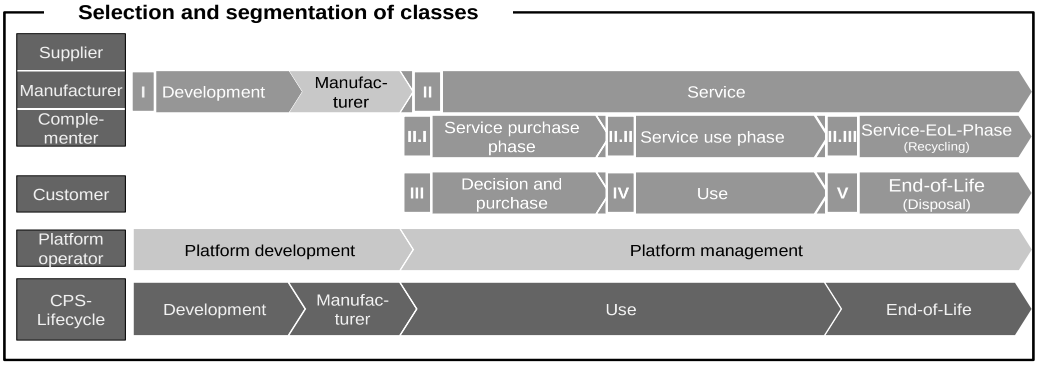


Fig. 9: Selection and segmentation of classes

B. Class-specific explanation models

Following, the utility potentials that can be realized for the supplier and manufacturer during the service phase will be investigated. Thus, only a section of the general model is considered by presenting a single, class-specific explanation model. As in Fig. 3 shown, generic and field-data-independent targets which companies, suppliers and manufacturers pursue during their service phase are initially worked out. These targets are then examined for their interdependencies with the technological capabilities of CPS, whereby utility potentials are identified and explained.

To elaborate the field data-independent targets and influencing factors for the quality of service, appropriate scientific studies and technical literature are consulted. While the scientific literature agrees that service quality can be divided into several quality dimensions, there is no agreement regarding the content of these dimensions [24]. Due to the heterogeneity of services and differences in the concept of quality, there are a large number of approaches in which generic quality characteristics for services are described [25]. As a result of the multitude of these approaches, service quality is one of the most widely discussed topics in the service literature [26]. Approaches according to Parasuraman et al, Grönroos or Donabedian can be named as known attempts to decompose the service quality. [25,27]

A further approach, which divides the quality of service into quality dimensions and then presents the influencing factors on the service quality, has been developed by BRUHN. Therefore BRUHN carries out a hierarchical dimensioning of the service quality based on three service dimensions, which results in a multifactorial construct. [3] Fig. 10 shows this decomposition.

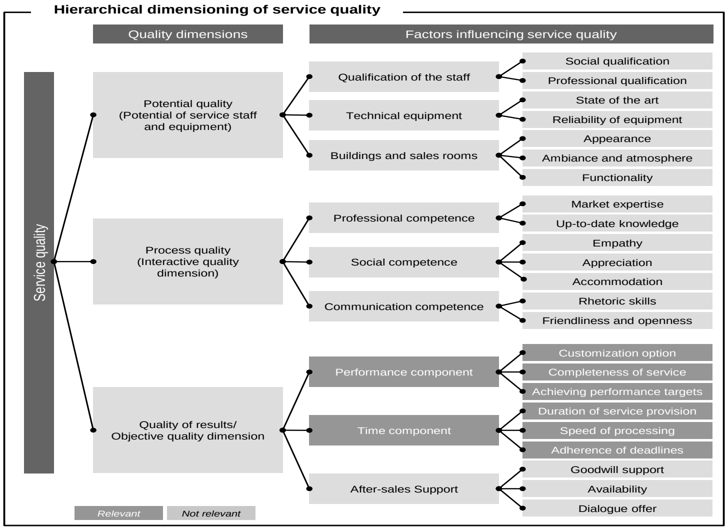


Fig. 10: Hierarchical dimensioning of service quality based on [3,26]

The first quality dimension, the potential quality, describes the potential of the service provider regarding the qualification and equipment of its staff. The second dimension refers to the interactive process of service provision, e.g. the communication competence of service personnel. The third dimension quality of results is related to the actual temporal and technical result of the service. The individual dimensions are broken down to the lowest abstraction level of the influencing factors. [3]

Restriction of the inspection area:

First of all, the field of view is limited by excluding different quality dimensions and influencing factors. The potential quality includes the technical equipment of the company as well as the qualification of the employees. These are factors that depend on personnel policy or investments in service technologies. The influencing factors of process quality relate primarily to the interactive and interpersonal way in which the service has been provided. This depends primarily on how well the service personnel are trained. For these quality dimensions, concrete utility potentials of field data CPS can be excluded. Within the quality of results, the influencing factors of the performance and temporal components are to be examined for their utility potentials.

Derivation of concrete utility potentials:

Therefore, the influencing factors of the

- Customization option,
- Completeness of service,
- Achievement of performance targets,
- Duration of service provision,
- Speed of processing
- and adherence of deadlines

are examined with regard to potential benefits. The dependencies between these influencing factors and the technical capabilities of CPS are worked out to identify and explain the utility potentials. The context sensitivity and the digital function integration can be emphasized with regard to the technological capabilities used for the explanation.

Customization option:

This influencing factor implies that the customer appreciates a multi-faceted support offer, as an individual and customized service package can be put together. If, on the other hand, the company's service offering is low, the possibilities for individualization for the customer are also severely limited. Based on the influencing factor of the customization option, a total of two company utility potentials can be derived.

First it can be deduced that an increase in the scope of services represents a utility potential for the company. The context sensitivity as well as the capability of digital function integration can be used to explain this utility potential. The context sensitivity of CPS enables companies to offer new services that could not have been offered before without field data and context knowledge. This aspect is also transferable to the capability of digital functional integration, which means that service can be provided by the company regardless of location and time. For a better understanding, the following is a short example. A company that sells machine tools can provide the customer with suitable CNC technology data for its own machine tool inventory. If the company has contextual knowledge about which specific materials the customer is working on, customized CNC programs can be offered in a context-dependent manner and, if necessary, can be provided independent of time and location. [6]

Another utility potential of field data CPS is the increase in service flexibility. RÖSNER defines service flexibility as a company's proactive and reactive ability to change the services it offers. [28]. On the basis of this definition, the correlation between the influencing factor of the customisation option and the utility potential of increased service flexibility can be demonstrated. With an enhanced ability of the company to change its support, the service flexibility of the company increases at the same time. The context sensitivity allows the proactive provision of services. The digital function integration enables these services to be provided independent of time and place. Context sensitivity and field data enable the context and service requirements of the customer to be monitored. In addition, the service can be provided anywhere and at any time with the help of digital function integration.

Completeness of service and Achievement of performance targets:

A further service-specific utility potential can be derived from the two influencing factors of completeness of service and achievement of performance targets. Contextual knowledge about the service recipient and the relevant consumable object provides information that enables the company to plan the services to be performed more precisely in advance. This results in an increased achievement of targets and a complete service. As an example, the maintenance of a machine can be cited, which is carried out by a service employee at a customer's site. The exact condition of the machine is known through contextual knowledge. This means that all the necessary spare parts can be procured in advance and thus complete maintenance of the machine can be carried out. This improves the service accuracy of the company that provides the support.

Duration of service provision und Speed of processing:

Other influencing factors are the duration of service provision and speed of processing. Context sensitivity and contextual knowledge enable a service creation process, which can be planned in advance more precisely and thus be performed faster and without complications. In addition, the digital function integration makes it possible to provide purely digital services faster and independent of time and location. This can lead to a shortening of the service execution time.

Adherence of deadlines:

A final factor influencing service quality is adherence of deadlines. If service can be better planned and more precisely provided through contextual knowledge, this increases adherence of deadlines for individual service activities.

The service-specific utility potentials derived from the individual influencing factors are shown in Fig. 11. Furthermore, the reference to the technological capabilities of CPS is presented.

Influencing factors on service quality as well as resulting utility potentials

Influencing factors by [BRUH16]	Explanation	Reference to new service options	Derived utility potentials
Customization options	Possibility to extend the scope of service by new ways of providing services.	• Contextual performance • Time-independent performance • Local-independent performance	Increase the scope of services
	Possibility to quickly, proactively or proactively adjust the service performance.	• Contextual performance • Time-independent performance • Local-independent performance	Increase service flexibility
Achieving targets and completeness of service	As precise as possible knowledge of how the service target can be achieved ensures that the target is reached.	• Contextual performance	Increase service accuracy
Duration of service provision and speed of processing	Knowledge of the service to be provided and the new service possibilities shortens the time needed to produce the service and the entire service process.	• Contextual performance • Time-independent performance • Local-independent performance	Reduce service execution time
Adherence or deadlines	Forward-looking planning of all company service activities is made more precise and improved.	• Contextual performance	Increase adherence to service deadlines

Fig. 11: Utility potentials in the service phase based on [BRUH16, S.43]

C. Overall model for classifying the utility potential of field data CPS

The approach of creating class specific explanatory models for other classes of the classification framework is repeated. As a result, this leads to an overall model which classifies the utility potentials of field data CPS. A comprehensive explanation of all utility potential would exceed range this paper. Therefore, only the results of this investigation are shown in Fig. 12. By means of an extensive literature analysis and synthesis with the properties CPS (cf. Fig. 5), it was possible to derive and explain a total of 24 utility potentials (cf. Fig. 12.) The utility potentials which were derived above (in the Service Use Phase class) can be found in Fig. 12 in the number UP11 - UP15.

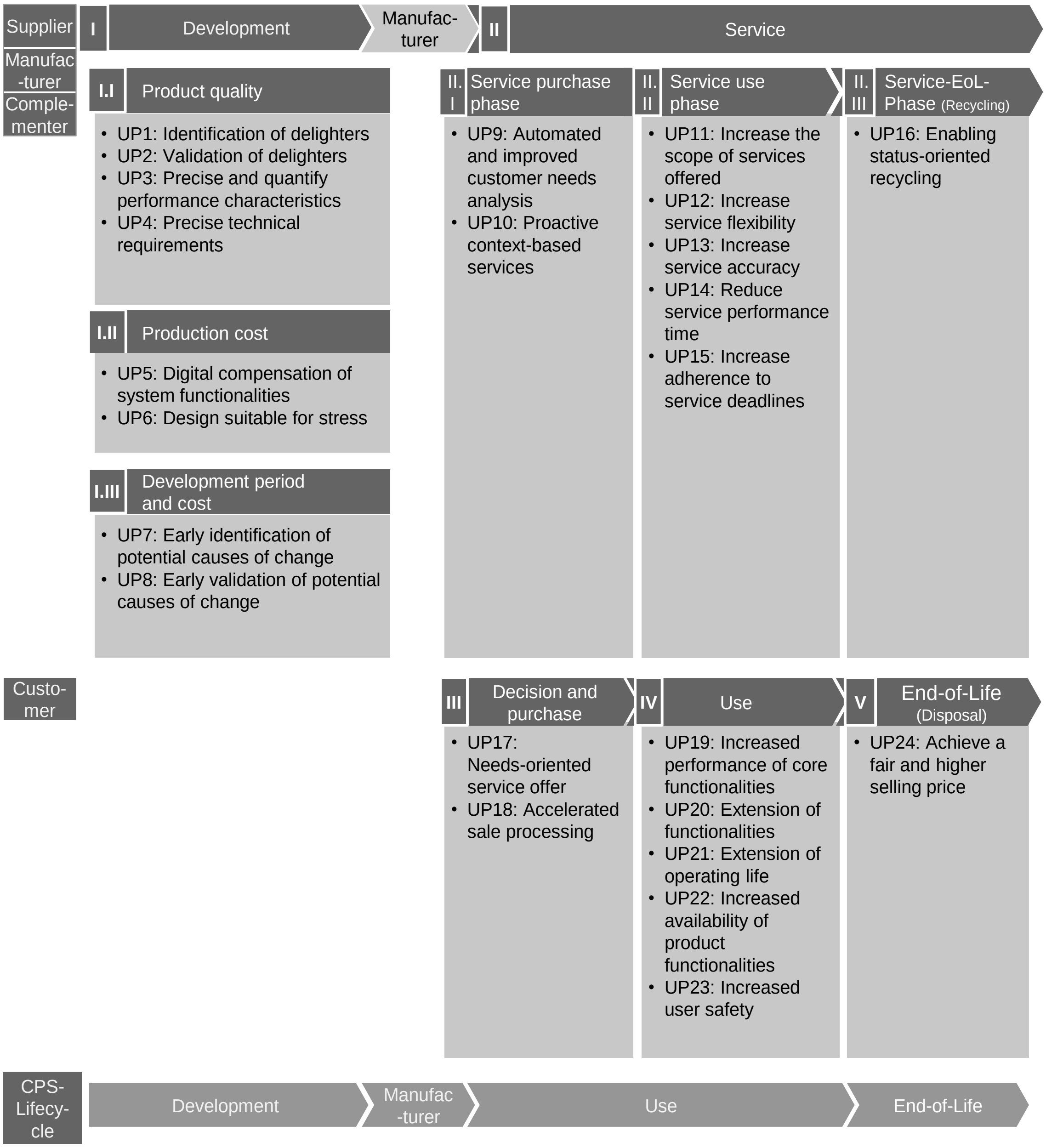


Fig. 12: Overview of the model for classifying the utility potentials (UP) of field data CPS

VI. CONCLUSION

Summary/Conclusion of the company's development phase

In the development phase of CPS, utility potentials are structured on the basis of the target dimensions product quality, manufacturing costs and development time. Field data can be used to achieve a more precise understanding of customer needs and desired product functionalities, particularly in the context of development specific product quality. By analyzing field data, companies can identify and validate delighters. Furthermore performance feature values can be specified more precisely on the basis of field data. When it comes to manufacturing costs, field data can be used to implement a stress-compliant design, which on the one hand increases technical product quality and at the same time reduces manufacturing costs. Another potential by decreasing development time is that CPSs can be employed to validate causes of change as early as possible.

Summary/Conclusion on the company's service phase and the customer's utilization phase:

The vast majority of utility potentials can be identified during the company's service phase and the customer's use phase. Thus it can be conducted, that these phases will become increasingly important for companies to differentiate themselves. In concrete terms, new types of services can be developed and the services offered can be improved overall. Innovative service offerings enable customized services and an better alignment with customer needs. Moreover, the use of field data allows the services to be planned more exactly in advance and thus provide them more precisely and faster.

Different utility potentials can also be realized for the customer during the purchase, use and end-of-life phase. Within the purchase phase, the customer can be offered demand-oriented services which are aligned to the current context of the customer. In the use phase of the CPS, customer benefits are improved by increasing the performance of the core functionalities. Additionally, the product functionalities can also be extended to include functions that generate significant added value for the customer. The operating life, product availability and user safety can also be enhanced.

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