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Methodology to Assess the Utility Potentials of Cyber-Physical Systems´ Field Data - A Literature Review and Rough Solution Concept

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ABSTRACT

A great share of new and data driven new business models are enabled by cyber-physical systems (CPS) and – more specifically – by their field data, being generated during the CPS´ use phase. Companies within the manufacturing industry as manufacturer and provider of CPS need to position themselves strategically against new competitors, e.g. from the IT sector, by utilizing "digital utility potentials" of CPS. Yet most of those companies still lack a basic understanding, which field data can generate added value and enable certain utility potentials. Due to a lack of knowledge, of which field data is usable application, there can be no systematic prioritization ("Which data is relevant?") and no target-oriented provision for potential customers. Hence, this paper develops a model, which supports manufacturing companies in assessing, if a generic set of field data generated by CPS is able to provide value added for the user.

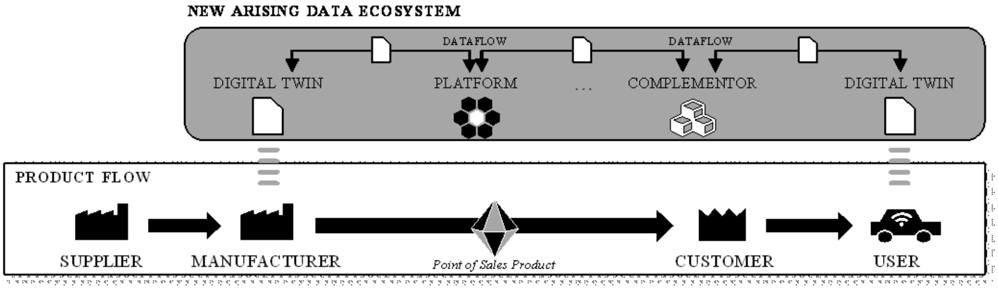
Keywords: *Cyber - physical Systems, field data, platform ecosystems, technology management*

INTRODUCTION

'Data is the new oil for the digital age' announced the vice president of the European Commission and introduced the digital agenda for the declaration of the new plan of action covering the digital transformation in Europe. This data is said to have the potential to stimulate a market over 70 billion Euro without the need of big investments [1]. This enormous potential of data- and customer-orientated business models makes the digitalization a key element for the social, economic and technological development of the knowledge society [2–4]. In addition, the importance of intangible resources (e.g. knowledge, technologies, …) for companies has heavily increased in the past few decades due to the transition from the industrial capitalism to a knowledge society [5]. Furthermore, the increasing competition is characterized by deregulation, globalization and the convergence of industries. International mobility, the availability of high-speed networks, global supply chains and outsourcing are important aspects for the possibilities of progress regarding information and communication technologies [6].

Features and services of products are highly improved by connecting integrated sensors, processors, software and network technologies with cloud systems. As Figure 1 shows, this leads to a new data ecosystem in the surrounding of CPS.

Subsequently, most of these further developments are based on an enormous amount of digital product data. Hence, with the extended features and collected data of CPS begins a new era of competition [7].



METHODOLOGY

As this paper focusses on a problem with practical relevance, it adopts the research process of applied science by ULRICH, shown in Figure 2. The structured approach targets the development of models, which shape the future by describing, explaining and configuring parts of the reality [8].

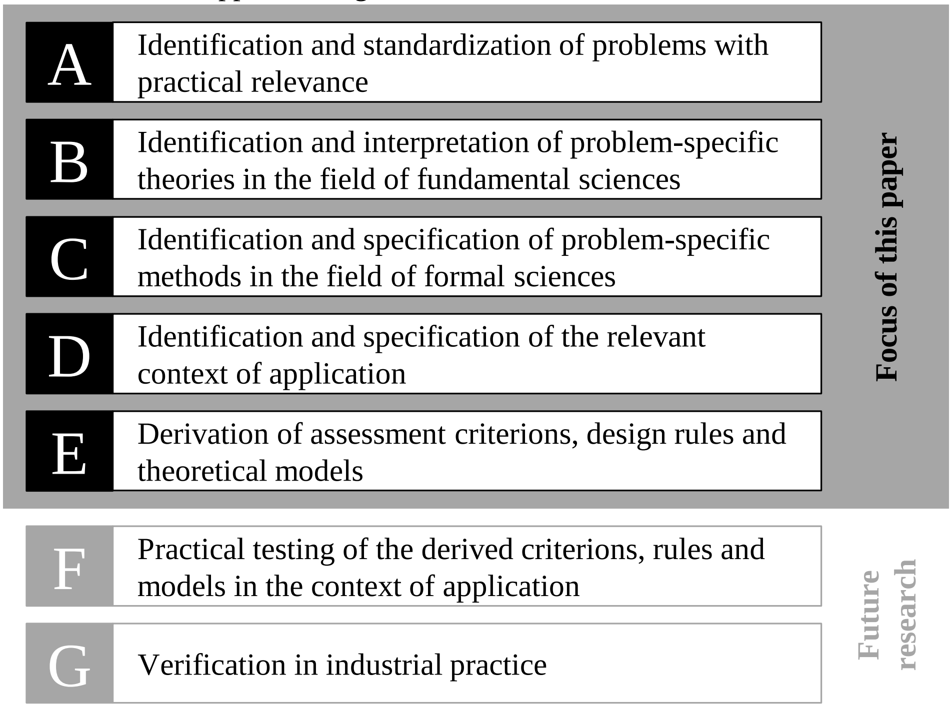


Figure2. *Research process of applied sciences*

ULRICH's methodology consists of seven sequential process steps [8]. This paper covers steps A to E. The practical testing (step F) as well as the industrial verification (step G) are not in the scope of this paper. First, problems with practical relevance need to be identified and summarized. Therefore, the first section 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 following sections cover the methodological process steps B and C, in which theories, hypotheses and methods from existing research are being identified, analysed and interpreted. The results of this paper address steps D and E of the methodology, in which model requirements were derived and component models were developed. Conclusively, a final section summarizes this paper and gives an overview of the future research in detailing the derived component models.

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.

Utility

The etymological origin of "utility" is the Latin word, utilitas"(lat. usefulness). Thus, utility is something that is advantageous or useful. As follows, first, the concept of utility will be detailed and second, utility potentials and categories will be explained.

Concept

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. Most of these subjects focus on the study of customer or consumption utility. The interdisciplinary consideration of utility led to numerous definitions. [9–11] 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 [12]. The authors NIESCHLAG ET AL. suggest a similar definition and consider utility as a measure of need satisfaction that can only be assessed by subjective criteria. As a result, this measure is difficult to be verified inter subjectively [11]. SCHRADER outlines the fact. that the satisfaction of an individual’s needs is always the basic prerequisite for any kind of utility [13]. Two different utility theories have become established in economics: The cardinal utility theory and the ordinal utility theory. The former traces back to the economist GOSSEN (1854), in which the benefit is described as an absolute and measurable unit. Motivated by the criticism to this theory, that the absolute quantification of a utility is difficult or even impossible due to its subjectivity, HICKS (1939) developed the ordinal utility theory or rather the indifference curve analysis. By this, the utility of different consumer decisions and bundles of goods is ordered and prioritized by means of a so-called desirability, without performing a quantification [14]. Both utility theories enable to justify the prioritization and decisions of individuals for certain beneficial actions. 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.

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Utility Potentials and Utility Categories

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, two types of potential benefits are highlighted which are defined as follows:

- Utility potential of CPS: 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.
- Utility potential of a concrete data set: If a concrete field data set is examined with regard to its potential utility, the extent to which the data set is able to satisfy the knowledge or information needs of utility categories is adressed.

According to Oxford Dictionaries, a category is “a class or division of people or things regarded as having particular shared characteristics”. If in the further course of the paper a utility category in mentioned, it describes a concrete, empirical way in which CPS generate a benefit for stakeholders through the satisfaction of needs.

CPS

The term smart product or cyber-physical product (CPP) is seen by BECHTHOLD ET AL. as a physical object with an embedded system, which disposes of computing power, data storage and some kind of network connectivity. [15]

Within its proposal for the implementation strategy of Industry 4.0 the joint project PLATTFORM INDUSTRIE 4.0 of the German associations BITKOM and VDMA defines the term CPS as “[…] embedded systems, production-, logistic-, engineering, coordination - and management processes as well as internet services, which collect physical data via sensors and react physically via actuators, interconnected via digital networks, using globally available data and services and having multimodal human-machine-interfaces.” Furthermore, CPS provide open socio-technical systems, which facilitate a set of novel functions, services and properties. [16] Similar to this is the definition by SPATH ET AL., following which CPS are intelligent, via decentral control self-operating objects, that are connected within an internet of data and services among each other [17].

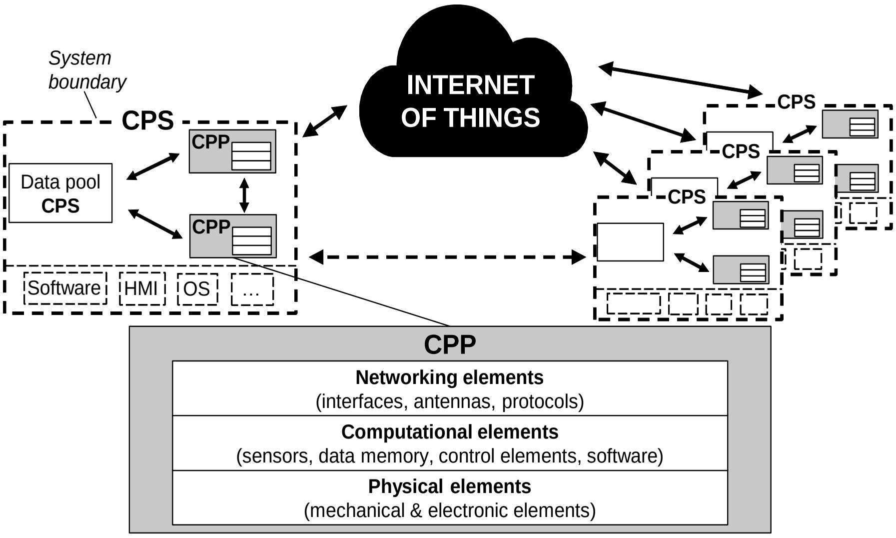

Figure3. *Connection of CPP and CPS*

Based on these thoughts, the differentiation of CPP and CPS as shown in Figure 3 is described as follows: Due to the characteristics of a CPP, a "self-organized embedding in environments of other products" allows the integration by itself into already existing environments of CPP. In this way, several CPPs form a CPS. They share common interfaces as well as protocols and feed their data generated by sensors and actuators into a common data pool. The CPS is enclosed by a physical system boundary, however, in contrast to the CPP (closed networked), it communicates cross-system with other CPS (open networked). Another difference between CPS and CPP is the interaction with (end-) users: These always interact with a CPS directly, but with a CPP often via the Human-Machine-Interface (HMI) of the CPS. Overall, CPS are more complex in this way.

The six technological properties of CPS, which are outlined in Figure 4, are the consolidated result of a literature analysis of a total of twelve relevant paper, each dealing with the properties of CPS. The properties described in Figure 4 build on one another. The technological basic skill of CPS is always the connectivity. This enables an interactivity of the CPS with the environment, the CPS with other systems as well as within the CPS.

Due to sensors and actuators, CPS have a context sensitivity, which indicates the knowledge of the relevant application and environment condition. Based on this, CPS have a context additivity, so they adjust themselves to the respective application and environment. Thus, they can aim for an optimal system behaviour. Multi functionality describes the possibility to replace certain system functionalities to date using individual hardware by software. Digital subsequent functional integration describes the skill to activate or improve functionalities even after the point-of-sale of the CPS (i.e. using an over-the-air update).

Tech. skills	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.	/

Figure4. *Consolidated technological skills of CPS based on [7, 16–27]*

Hence, a CPS is an object, which has physical and digital attributes. These digital attributes are context-specific data sets, which are generated about the product and its surroundings using sensors and actors, afterwards being transmitted and stored in a decentralized way via information and communication technology.

Field Data

WOHLTMANN distinguishes four basic types of data: Input, output, core, numeric and alphanumeric data [18]. This very basic classification is too generous for this research project and should therefore be described in more detail. VERTESI ET AL. consider data as embedded in a data economy in which they must first be produced before they are used, filed, obtained or shared [19].

In the context of CPS, which are developed and produced by manufacturing companies, this means that data can be distinguished by those generated during the product engineering process (PEP) about the product (e.g. exact and component-specific deviation from the actual to a predefined target geometry) [20] and such data, which is collected via sensors and actuators during the use phase of the product or system. The latter contain, for example, information about the condition of the system, its components, the user behaviour or the respective context. The described distinction of condition data and field data is visualized in Figure 5.

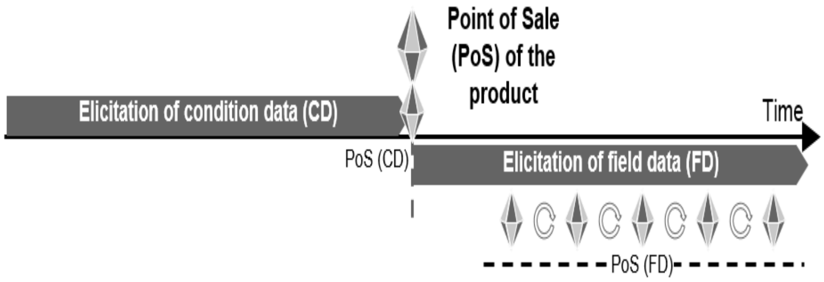

Figure5. *Distinction of field data and condition data*

State of Research

Although there are existing approaches in the scientific literature that examine the benefits and utility potentials of CPS, these have several deficits. For example, only specific sectors or CPS (e.g. "Connected Car"), applications or stakeholders are considered (e.g. the return of field data to optimize the product development). Furthermore, the identified potentials of investigated CPS are not related to the information needs and the respective field data sets used for the implementation. Above all, the CPS-independent, comprehensive potential benefits as well as the field data required for an implementation have not been systematically analysed yet.

In principle, the scientific work within this topic can be assigned to the following streams:

- Approaches that describe the technological properties and potential benefits of CPS
- Approaches for determining the benefits of sensor-based field and usage data
- Approaches for the investigation of prerequisites and enablers for the implementation of potential benefits of CPS

Approaches that Describe the Technological Properties and Potential Benefits of CPS

Within this stream, authors explain in different specificity how a CPS is built up and which of the components interact with one another. In this way, they characterize the technological skills of CPS. Based on these skills, potential benefits of the CPS are deduced and often illustrated with empirical application examples

Approaches to Determine the Benefits of Sensor-Based Field and Usage Data

The scientific work within this stream places field and usage data at the centre of their considerations. At that, it can be differentiated between system-specific (cf. [21] considering only the "connected car") and cross-system approaches (cf. [22] and [23]).

Approaches for the Investigation of Prerequisites and Enablers for the Implementation of Potential Benefits of CPS

The aim of this stream is to examine certain benefits of CPS concerning relevant prerequisites and enablers that required for a successful implementation. The prerequisites being examined in the scientific literature vary at different degrees of abstraction. For instance the circumstances, which must be created by economics or legislation are investigated at a very generic level. Due to the complexity of such questions, this is usually done in common with representatives from industry, politics and research (cf. [24] or [3]).

On the other hand, there are scientific papers which either intensively investigate individual potential benefits or individual enablers thoroughly. The first category includes, for example, the work of MAMROT [25] or SCHMITT ET AL. [26] which examine, how the product development can be improved by field data. The last-mentioned category includes, for example, the work of SCHUMM ET AL. [27], the present research project as well as the preparatory work of the author, which examines the potential benefits of CPS regarding just one enabler – the field data which is required for the implementation.

Summary of the Assessment of Existing Approaches and Positioning of the Paper

An assessment of the existing approaches is based on various criteria, which may be divided into two groups. The first group of criteria refers to the object area of this paper:

Consideration of technological skills of CPS

Description of applications and potential benefits of CPS

Consideration of field data of CPS

Consideration of usage data of CPS

The second group of criteria is dedicated to the target area: The extent to which the paper treats the sub-objectives of this research project:

- Structuring (theoretically derived) potential benefits of CPS
- Technological characterization of field and usage data of CPS
- Identification of empirical benefit categories of CPS
- Determination of the information need regarding field data of specific benefit categories and utility potentials

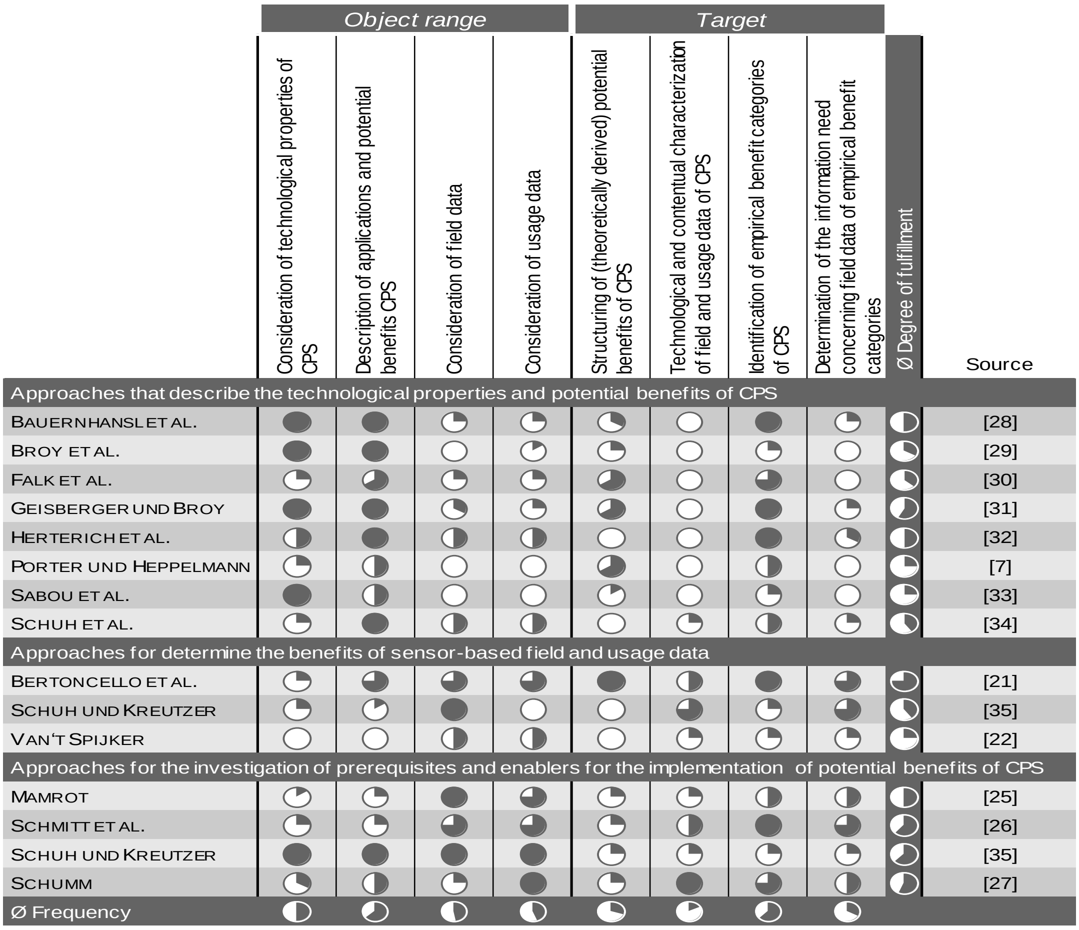

Figure6. *Comparison of the state of research [7,21,25–35]*

As shown in Figure 6, partial aspects of the research project are already addressed in varying degrees of intensity in existing scientific literature. However, the "Ø degree of fulfilment" calculated in the last column of Error! Reference source not found. shows, that none of the approaches presented satisfies the selected criteria in its entirety. Further conclusions on the literature analysis can be obtained by examining the last line "Ø frequency". It shows, that the average frequency with which the criteria of the object area "Consideration of field data of CPS" and "Consideration of usage data of CPS" as well as the criterion from the target area "Technological characterization of field and usage data of CPS" are the subject of the considerations, is rather small. All three of these criteria are a core component of the present research project.

Furthermore, the approaches which address the technological skills and potential benefits of CPS structure these to a certain extent - and therefore address the object area at least in parts - but rarely consider field and usage data which is needed in order to implement such potential benefits. For this reason, existing approaches are insufficient to fulfil the target area of the present paper.

The approaches for determining the benefits of field and usage data, in turn, focus only to a limited extent on the object area of CPS and therefore cannot contribute to the criterion "Structuring of (theoretically derived) potential benefits of CPS" in the target area. Paper from the subject field “Investigation of prerequisites for the implementation of potential benefits of CPS” again address no field and usage data in the object area - and therefore do not fulfil the criterion from the target area “Technological and contentual characterization of field and usage data of CPS".

From the above-mentioned observations within the state of research, the following research needs can be derived:

Deficit1. No Comprehensive Classification of Theoretical Potential Benefits of CPS Field Data

In the state of research, there are no works that systematically classify and structure the theoretical potential benefits of CPS. The approaches which were investigated rather focus on the technologies that are relevant to the design and use of CPS, or they are very detailed in terms of individual potential benefits that focus on certain industries or applications only. So far, there is no approach which derives the theoretical potential benefits of CPS from the relevant stakeholders of CPS and thus classifies them.

Deficit2. Lack of Synthesis from Empirical Observed Benefit Categories of CPS and Field-Data-Related Information Needs

Furthermore, there are no approaches in the relevant scientific literature which, by means of a systematic analysis of applications in practice, make a synthesis of specific benefit categories as well as field and usage data which is required for an implementation. This research deficit correlates with the fact that in scientific literature, a model which allows a generic description of field and usage data does not yet exist. However, such a description model is mandatory to accomplish such a synthesis.

Deficit3. No Practical Approach for Determining the Potential Benefits of Field Data of CPS

In the end, research has not yet developed a practical approach that allows manufacturing companies to determine potential benefits of field data of CPS. The above-mentioned lack of overview regarding to theoretically addressable potential benefits and the lack of knowledge about data needed by benefit categories leads to the issue, which field data are usable and realizable in the application. Thus, no systematic prioritization ("Which data is relevant?") and no targeted provision of data for potential customers can take place. Consequently, the potential benefits of field data CPS cannot be fully exploited.

The listed research deficits are to be addressed within the present research project.

RESULTS

The following methodology presented will help manufacturing companies as a guide to systematically identify, prioritize and realize the benefit potential from field data of CPS. The generic approach that is used to build this model is similar to the system technique approach. The problem is split up into sub problems and solutions will be developed from rough to detail. In the following, the five steps of the methodology (shown in Figure 7) are described.

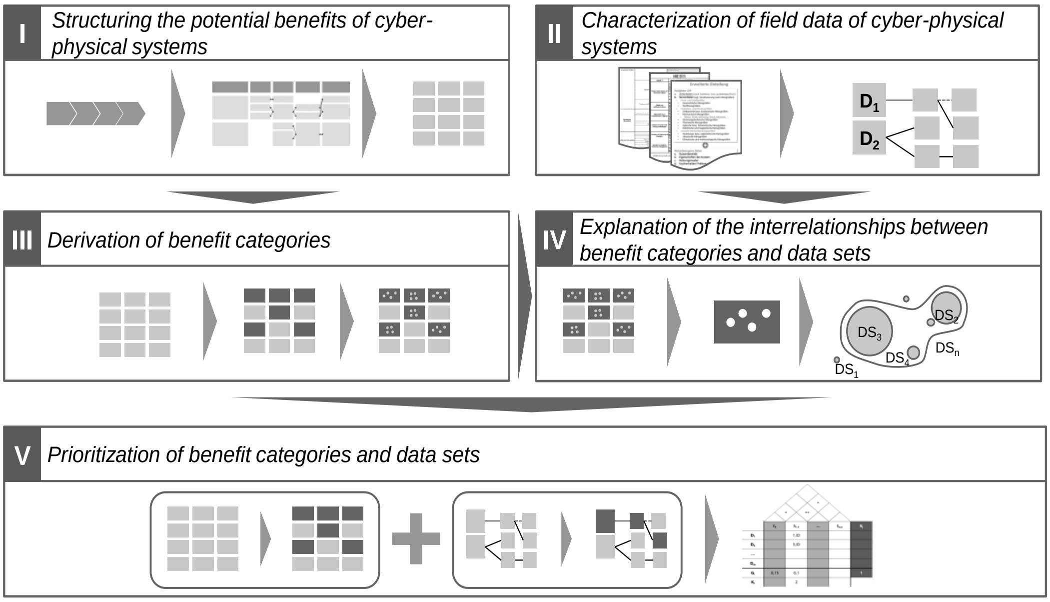

Figure7. *Structure of model and work specification*

To structure the benefit potential of CPS, a classification is needed. This classification must take relevant stakeholders of CPS into account (in order to address the subjectivity of “utility”). Based on appropriate criteria, generic classes are derived. In a second step, the classes are examined concerning the stakeholder´s need (e.g. needs of product development department). By comparing the needs with the technological properties of CPS, potential benefits of CPS are derived (Step I).

To examine field data regarding its suitability to fulfil benefit potentials, a model needs to be worked out with witch field data can be described generically. Therefore a data model is developed, which is characterizing field data technically and by its content (Step II). Step III will use an empirical-inductive approach to examine existing use case to show, how exactly a benefit is generated by CPS and show, which type of field data is used for which type of use category in the existing use cases. To do so, the interaction between field data and benefit categories is examined and described (Step IV). To simplify the usage of the model there will be a method to prioritize benefit categories as well as relevant field data (Step V).

Conclusion

It was shown, that manufacturing companies can use utility potentials of CPS to create unique selling points. A thorough literature analysis has shown, that there is a need for methodology to assess the utility potentials of CPS´ field data. Hence, a rough concept for such a methodology was derived. As a result, the user of the methodology gains knowledge about the theoretical usage potentials of CPS as well as empirical use categories, which have been used successfully within a prioritized class of utility potentials (e.g. “Development”). Furthermore, the user gains knowledge about the information demand, which must be met to convert the benefit potential. Ultimately, he gets to know which field data was used in the existing use cases in order to fulfil the information demand.

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