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ORIGINAL PAPER

DIGITALIZATION OF INDUSTRIAL VALUE CHAINS – A REVIEW AND EVALUATION OF EXISTING USE CASES OF INDUSTRY 4.0 IN GERMANY

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ABSTRACT. **Background:** The paper presents recent results of the ongoing collaborative research project "MyCPS" (Human-centered development and application of Cyber-Physical Systems).
Methods: Within the scope of the project, 14 partners, amongst seven industrial partners, develop methods and tools to set-up applications of intelligent digitalization and automation of industrial processes.
Results: Within the paper they are over 385 use cases evaluated according to comparative criteria. Furthermore, use cases were classified due to their development stage of industry 4.0 goals and promises. The three levels 'information', 'interaction' and 'intelligence' are used to differentiate applications according to their degree of maturity in industry 4.0 terms.
Conclusion: In MyCPS, special emphasis is the role of the workforce and the interactions of the technology-led use cases with employees. Thereby, the analysis helps enterprises and researchers to self-assess key-aspects of the development of industry 4.0 use cases.

Key words: Industry 4.0, Use Cases, Technology Management, Smart Factory.

A part of this study was presented as oral presentation at the "24th International Conference on Production Research (ICPR 2017)" in Poznan, Poland from July 30 to August 3, 20017.

INTRODUCTION

"Industry 4.0" can be understood as an expected fourth industrial revolution due to intelligent digitalization and automation of products and value chain processes. It includes the integration of the real and virtual production worlds, in which products, production facilities, humans and objects merge with embedded software into intelligent and distributed systems [Ittermann and Niehaus and Hirsch-Kreinsen 2015]. For the first time, the term "Industry 4.0" was presented at the Hanover Fair in 2011 [Institut für Arbeitswissenschaft 2016]. Nevertheless there is no general definition so far [Ruiner and Wilkesmann 2016, Hofmann, Rüsch, 2017]. Following definition is often to find in current work- and industry-related literature:

"The term Industry 4.0 stands for the fourth industrial revolution, a new stage in the organization and management of the entire value chain over the life cycle of products." [Plattform Industrie 4.0 2015]

This development is based on increasingly individualized customer requirements. The idea is an integrated digital support of the complete product life cycle from development stage to the manufacturing and recycling

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processes and at least costumer related services. The availability is fundamental: all relevant information in real time through the networking of all entities involved in value creation as well as the ability to optimize the value creation at any time. Humans, objects and systems are linked together by different criteria: costs, availability and resource consignment. [Plattform Industrie 4.0 2015]

Prior to Industry 4.0, three other industrial revolutions have been already taken place. With mechanization in the middle of the 18th century the first revolution was initiated by the development of mechanical working and power machines by using water and steam power. At the beginning of the 20th century the second industrial revolution took place. Electrification, Taylorism and “Fords” assembly line lead to the mass production without any handmade or customer specific products. In the 1960’s the third industrial revolution finally evoke. Computerization has enabled automation-driven rationalization as well as variant-rich serial production [Roth 2016, Hänninen, Smedlund, Lasse, 2018].

INDUSTRY 4.0 USE CASES

Today there are a large number of application examples on the subject of "Industry 4.0". The sources for published data on applications and use cases are print-media like VDI news and public information platforms that are filled with useful knowledge about this topic [Institut für angewandte Arbeitswissenschaft 2016, Bundesministerium für Wirtschaft und Energie 2016, Landesverband Baden-Württemberg and Verband Deutscher Maschinen- und Anlagenbau 2016]. These platforms pursue the goal of securing and expanding Germany's position in the international competition through integrated industry. They help to expand the basic understanding of the topic "Industry 4.0" and to be a guide for Industry 4.0. Furthermore, an ongoing exchange is to be established between companies, politics, science, trade unions and society. [Landesverband Baden-Württemberg and Verband Deutscher Maschinen- und Anlagenbau 2016, Bundesministerium für Wirtschaft und Energie 2016]

Analyzing different publications and databases, a total number of 385 application examples was identified. The main sources were the application maps of the German platform Industry 4.0 (“Plattform Industrie 4.0”) [Bundesministerium für Wirtschaft und Energie 2016] and the ongoing competition “100 Orte für Industrie 4.0 in Baden-Württemberg” [Landesverband Baden-Württemberg and Verband Deutscher Maschinen- und Anlagenbau 2016, Eling, Lehmann, 2017]. Whereas all examples are considered to be applications of Industry 4.0, the scope of the examples spreads over a wide range of topics and ideas. In order to analyze and classify the use cases a review and evaluation considering different criteria was carried out. The data set is subdivided into specific criteria to quickly classify new examples, to compare the examples and to provide an overview of the applications. After gathering data and some discussion we have come to conclusion to cluster the given information in some categories. This classification allows various information to be retrieved. Information about the manufacturer, such as the name of the company, the industry, the company size, the contact person and the location is listed. The application description, the technologies, the relevant areas of activity and the development stages are also presented for the application itself. In addition, the motivation is added as well as implementation problems and success factors, benefits and the industry 4.0 aspects of the applications. Secondary, interaction forms in the human technology interaction (HTI), affected stakeholders as well as the opportunities and challenges in relation to humans are also taken into account and reproduced. To illustrate the structure of the table, an example is presented in the following section.

The application example is "iBin", an intelligent container from Würth Industrieservice GmbH & Co. KG. The container is depicted in Figure 1.

- Company: Würth Industrieservice GmbH & Co. KG
- Industrial sector: Logistics

- Company size: large enterprise (>5000)
- Location: Baden-Württemberg, Germany (zip code: 97980)
- Implementation reasons: Delays due to missing C-parts
- Application description:
  - Container is equipped with cameras monitoring the C-parts (e. g. screws)
  - Time and accurate determination of the stock by regular optical level measurement
  - Transmission of the filling level via radio channel at communication station (time slot communication method)
  - Automatic ordering
- Implementation problems / success factors: None
- Development state: market-ready, operational operation
- Industry 4.0 aspects:
  - Direct horizontal integration between manufacturer and supplier
  - Decentralized collection of information
  - Real-time control
  - Flexible positioning of the containers by radio transmission
  - Transparency of stocks

Source: Landesverband Baden-Württemberg and Verband Deutscher Maschinen- und Anlagenbau 2016

Fig. 1. iBin

- Benefits:
  - Security of supply
  - Optimal storage utilization by precise delivery
  - Elimination of the scheduling processes
  - Consumption-controlled delivery, no manually order required
  - Retrofitting without changing existing processes
  - Optimization of material flow
- Areas of activity: Logistics
- Stakeholder: Logistics operator
- Development stage: Information
- Interaction forms in HRI: Substitution
- Opportunities in relation to humans: None
- Challenges in relations to humans: fewer employees are required [IFF 2015]

The applications are diverse, ranging from support to the relocation of activity to the replacement of assembly operators by machines. There are workplaces, which are adapted to employee's needs. Intelligent products are brought to the respective workplace by driverless transport systems and enroll themselves in the system. The operator receives all relevant information and a step-by-step instruction as well as a "Pick by Light" instruction. In other applications, sensors are integrated into the tools and give feedback on the quality of the work. In addition, there are many applications in which the operator works hand in hand with a robot on a product or receives additional information or support from an expert through augmented reality systems, such as smartwatches or data glasses. Currently, most of the applications are still in the prototype phase and will be launched in the next future.

EVALUATION RESULTS OF INDUSTRY 4.0 APPLICATIONS

One of the central questions of this paper deals with the question, which conclusions can be drawn from previously implemented Industry 4.0 application examples in Germany. For this purpose, data set is evaluated according to specific criteria, which were mentioned above.

Activity and stakeholders

First, it is discussed in which area of a company the application cases are placed. Figure 2 shows which areas of activity, which are affected. Five activity areas can be defined.

In addition to production, which accounts for approximately 69% of applications, examples for industry 4.0 are found in service, design & engineering and logistics areas. These numbers are characteristic due to the development of industry 4.0 activities in production as a main field. There are some applications that cannot be allocated to one area, because they take effect the whole enterprise. However, the probability is relatively low with approx. 10%.

A second criterion is the analysis of the stakeholder.

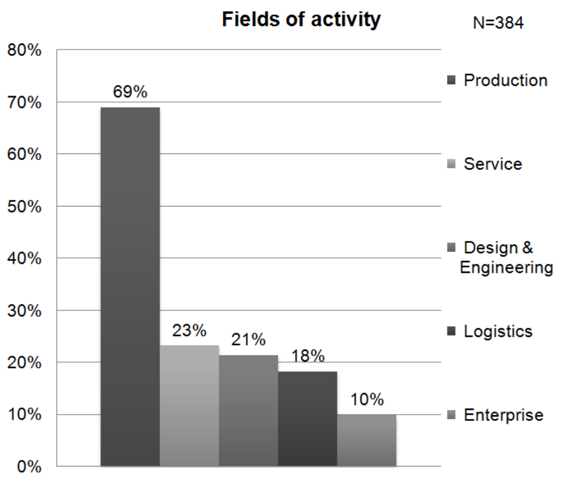


Fig. 2. Fields of activity

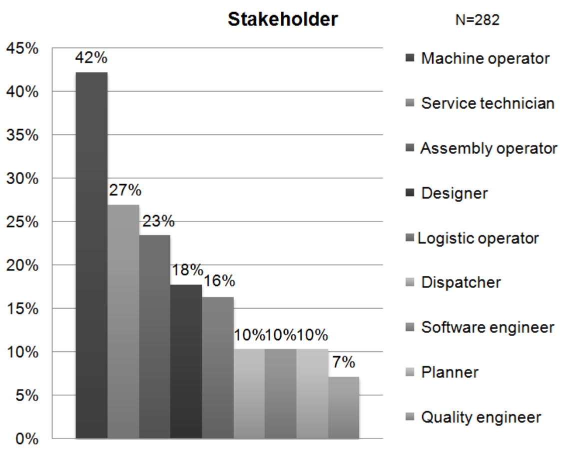


Fig. 3. Stakeholder

In Figure 3, the involved stakeholders are listed. Quality engineers, planners, software engineers and designers are stakeholders of design & engineering unit. With approximately 42%, machine operators are primarily involved in the examples in this area, because most applications took place in the production area. Service technicians (about 27%) in the service sector are the second most frequent stakeholder. Assembly operators are with about 23% the third-most frequently actor, who are affected by industry 4.0 applications. Designers take a small role with 18%, similar to the logistics operator 16%. Dispatcher, software engineers and planner are the stable part of the stakeholders with 10% respectively. The smallest group consists of quality engineers with only 7% of stakeholders.

Reasons for implementation and the resulting benefits

In addition to activity areas and stakeholders, who are affected, reasons for industry 4.0 use-case implementation as well as resulting benefits are discussed. Two different reasons for implementation are identified. On the one hand companies perceive a problem and wish to use the application to solve this problem. On the other hand, companies want to take part in global market competition in the future and develop new applications for their own production. Figure 4 shows existing problems and Figure 5 visualize optimization reasons of existing applications.

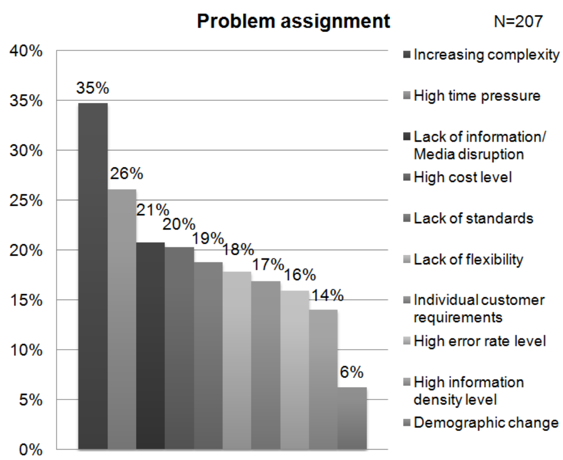


Fig. 4. Problem assignment

Nowadays the main problems is increasing complexity of products and processes according to batch size one and variety of versions in manufacturing. Other problems are hidden information, missing standardization and lack of flexibility in the company. Moreover, growing customer specific products, high level of information density and demographic change have been causing problems. Some companies do not use industry 4.0 applications to solve existing problems. They use them as an opportunity to advance their enterprise by networking, elimination of media disruption, or flexibility improvement. They try to find their company in a strong market position in the future.

Figure 5 shows the optimization reasons. Networking, flexibility and increasing efficiency variate about 20 % and other categories have similar pattern to understand these variation better further studies are necessary.

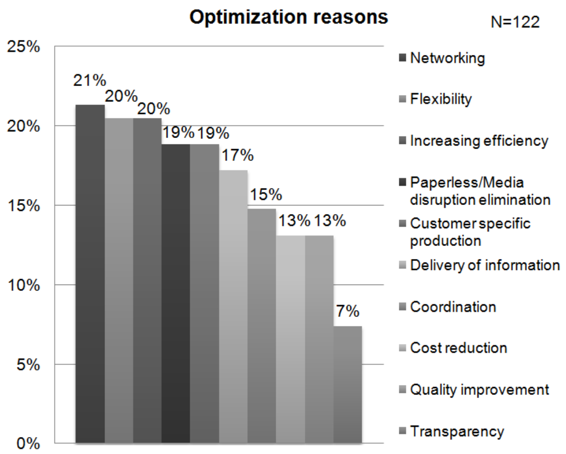


Fig. 5. Optimization reasons

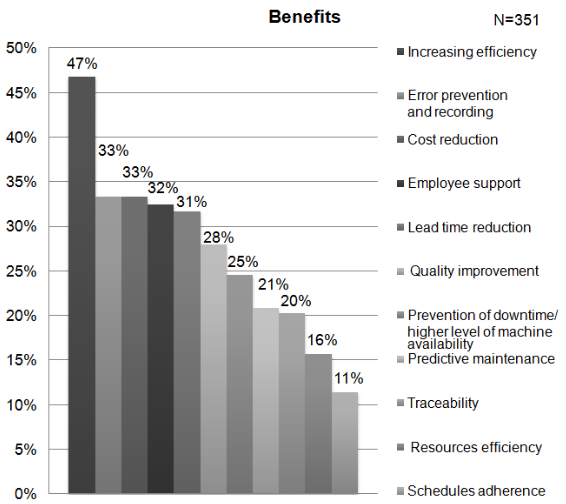


Fig. 6. Benefits

As Figure 6 shows increasing efficiency is the most common benefit of industry 4.0 so far. Relatively comparable scores can be defined as cost reduction, employee support, errors prevention and recording and minimization of lead time. The other important benefits are demonstrated. The distribution presents a typical example of optimization projects in production area. First and the main purpose to increase efficiency is to observe.

Industry 4.0 aspects and technologies

The industry 4.0 applications meet expectations as listed in Figure 7. In addition, technologies used as well as their development stage are presented below. Figure 7 points 11 criteria that have been derived of industry 4.0 applications.

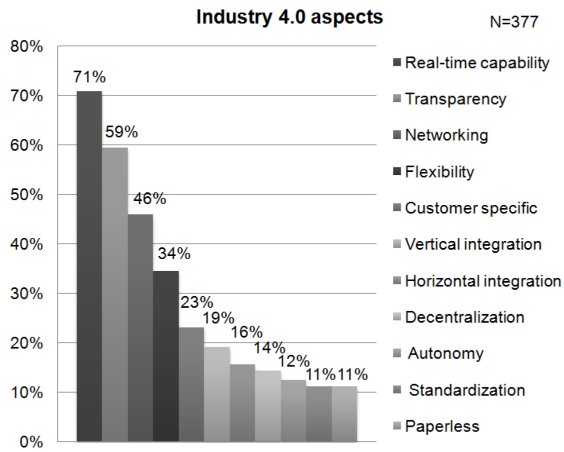


Fig. 7. Industry 4.0 aspects

Real-time capability, networking, customer specific products and integration are often apart of Industry 4.0 definitions. These aspects are reflected in evaluated applications. Transparency and flexibility enable companies to adapt quickly and easily to new situations. There are a small number of applications which include terms like decentralization, autonomy or standardization. The explanation is that the development of digital transformation is relative new. As a result, the applications and the technologies, which are contained in them, are still in their early stages and have to be developed.

Applications can be defined into three levels: information, interaction and intelligence. This differentiation represents a taxonomy of industrial digital transformation development stages. Information level means that data is gathered and transparent for their further use. Many of the applications are in the information development stage. This is reflected in Figure 8 with approximately 65%.

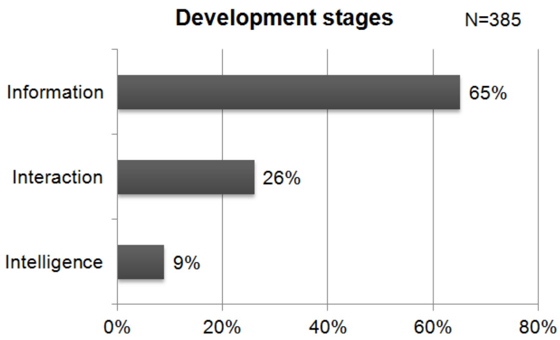


Fig. 8. Development stages

The data from information level is used for network communication or interaction between humans, machines and products in manufacturing. This level is called interaction and subsumes 26% of the given use-cases.

The third level is called intelligence. In this stage production facilities control themselves and make decisions independently by so called artificial intelligence without any influence [2, 37]. Only 9% of the use cases of the database have reached this level.

The given use-cases enable to evaluate technologies in the analyzed data. Technologies are grouped in technology fields. Thus, a total of seven technology fields can be discussed in relation to Industry 4.0. They are shown in Figure 9.

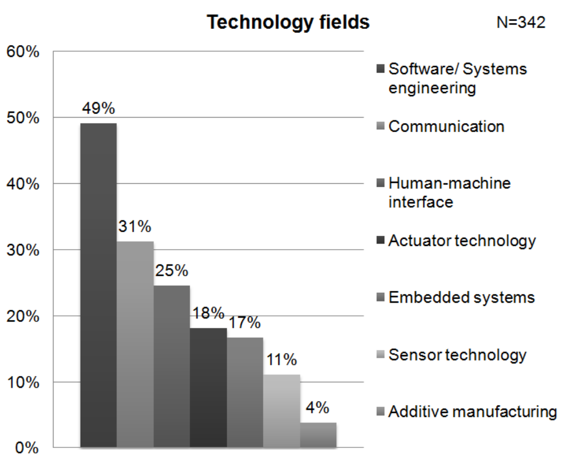


Fig. 9. Technology fields

49% of the given use-cases can be classified in the field of software and systems engineering. On the one hand this technology is used for decentralized control of the components, on the other hand to process large amounts of data. Software technology is fundamental for industry 4.0 and is getting inevitable in future use-cases for example for networking or intelligent components.

Furthermore, communication plays an important role. All involved shareholders can use wireless as well as wire-bound communication technologies for instance WLAN, NFC, platforms and cloud-computing. These technologies are a common basis for networking and sharing of data and services.

Human-Machine-Interfaces are to be found in 25% of the evaluated use-cases. Technologies like Virtual Reality or Augmented Reality support humans work in industry 4.0 framework.

Sensor technology aims to collect, record and process gathered information and data. This technology field represents 11% of use-cases.

The embedded systems are similar to the sensors. Components of the sensor system are integrated with intelligent microcontrollers, memory modules and processors in order to be able to interpret and process information independently. The technology field actuator is used to implement the processed information in the physical environment. This transforms electronic signals into mechanical work or other physical quantities.

The last used technology field is additive production. With this technology, highly complex components can be produced by layered material application. However, this technology field has only been used in 4% of the applications.

Humans in integrated industry

The last section examines effects of the application examples on relations between humans and industry 4.0 framework. It estimates to which extent technologies influence individuals and what kind of opportunities or challenges can be derived from them. Classification of potential short-term and long-term aspects of Industry 4.0 applications is observed. As a first step, direct interaction between humans and technology in terms of Human-Technology-Interaction at workplace level is estimated. The level of cooperative work between humans and technology differs in between industry 4.0 applications. Four interaction types can be distinguished. They are described using concepts of collaboration, cooperation, coexistence and substitution in Figure 10.

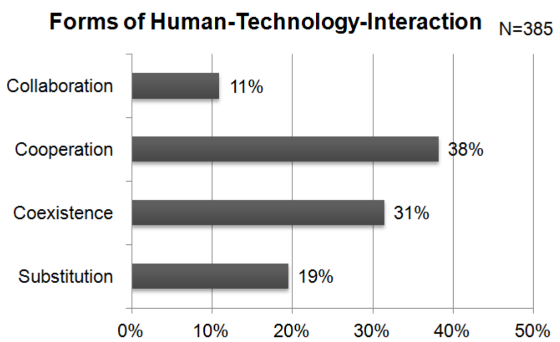
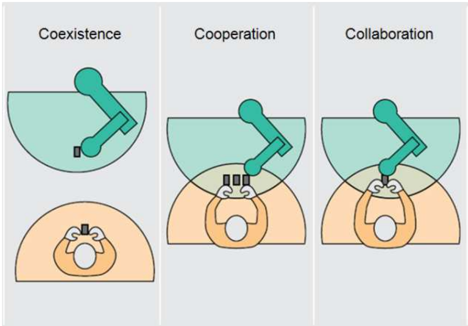


Fig. 10. Technology fields

In case of coexistence, worker and a machine have no common working space at all time. Moreover, they do not pursue a common goal while working. This issue is different in case of cooperation or collaboration. Cooperation means that human and a machine work together to achieve a common determined goal. Human and machine pursue different tasks, which are independent. The last stage is described as full collaboration between human and machine to achieve a common goal. This means that all subtasks have to be adjusted and the interaction has to be aligned to current situation [Onnasch et al. 2016]. Three types of interaction are presented in Figure 11.

The fourth type of interaction is substitution. It can be defined as complete replacement of humans through machine or robot. This type can be found in 11% of the given applications.

Then, effects on work organization and long-term effects, for instance work place substitution and ergonomics, are evaluated by the total amount of cited opportunities and challenges of the application examples. Figure 12 and Figure 13 display the results.



Source: Bauer et al. 2016

Fig. 11. Cooperation between man and robot

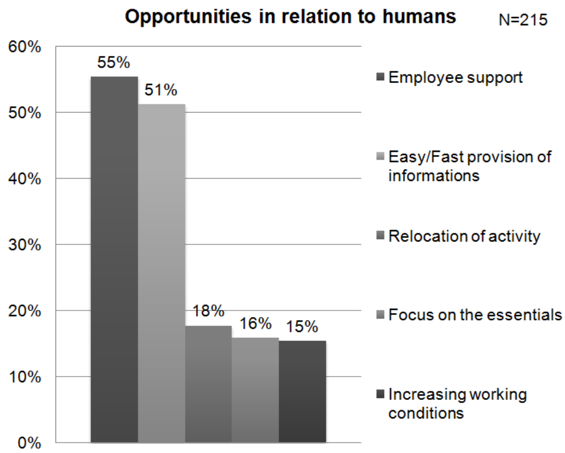


Fig. 12. Opportunities in relation to humans

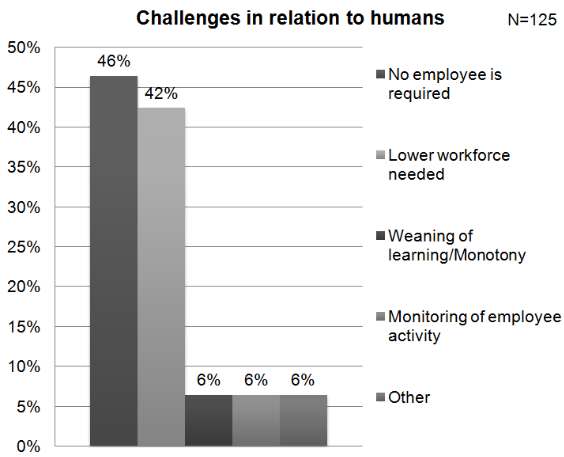


Fig. 13. Challenges in relation to humans

Support of the workers and fast information delivery are the main opportunities for humans in industry 4.0 applications. Context sensitive information provisioning, intelligent objects, and worker assistance systems could be also integrated to this result.

As Figure 13 shows the number of employees required for task fulfillment is smaller than in current use-cases. This total number of respondents (Fig.13) is smaller than the number of respondents in other categories. Due to the topic of increasing thoughts, fear and questions of employee substitutions through the information process, it does not affect the entire scope of Industry 4.0 application. Nevertheless it remains as a significant part.

CONCLUSION

This paper presents the overview of over 300 applications from the field "Industry 4.0". This analysis and evaluation criteria involve fields of activity and affected stakeholders, reasons for use-case implementation and following benefits, industry 4.0 aspects and development stages, opportunities and challenges of humans in integrated industry. These topics are also represented in research and development project MyCPS. Due to analysis and evaluation results the role of employee can be emphasized: the analyzed data shows that the majority of the applications are not using the substitution through robots or other technical environments. There is a very high speed trend development in industry 4.0 field to observe. The future progress of human centered cyber physical systems should be a focus of analysis and discussion of in following research.

ACKNOWLEDGMENTS AND FUNDING SOURCE DECLARATION

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DIGITALIZACJA ŁAŃCUCHA WARTOŚCI W PRZEMYŚLE – PRZEGLĄD I OCENA ISTNIEJĄCYCH ZASTOSOWAŃ INDUSTRY 4.0 W NIEMCZECH

STRESZCZENIE. Wstęp: Praca przedstawia wyniki prac w ramach projektu badawczego "MyCPS" (Human-centered development and application of Cyber-Physical Systems).
Metody: W ramach projektu, 14 partnerów, w tym siedmiu będących przedstawicielami przemysłu, opracowało metody i narzędzia do zastosowania aplikacji dla inteligentnej digitalizacji i automatyzacji procesów przemysłowych.
Wyniki: Poddano ocenie porównawczej 385 przypadków. Zostały one sklasyfikowane według poziomu rozwoju celów Industry 4.0. Trójpoziomową „informację", „połączenie" oraz „inteligencję" użyto dla rozróżnienia aplikacji według poziomu ich dojrzałości w ujęciu Industry 4.0.
Wnioski: W projekcie MyCPS specjalną uwagę zwrócono na rolę siły roboczej oraz interakcji rozwiązań technologicznych z pracownikami. Dzięki temu, analiza pomaga przedsiębiorstwom oraz badaczom na ocenę kluczowych aspektów w rozwoju Industry 4.0.

Słowa kluczowe: Industry 4.0, zastosowanie praktyczne, zarządzanie technologią, Smart Factory.

Część tej pracy została zaprezentowana w formie referatu podczas konferencji "24th International Conference on Production Research (ICPR 2017)", która odbywała się w Poznaniu między 30 lipca, a 3 sierpnia 2017 roku.

DIGITALISIERUNG VON INDUSTRIELLEN WERTSCHÖPFUNGS-KETTEN - EINE ÜBERPRÜFUNG UND EVALUIERUNG BESTEHENDER ANWENDUNGSFÄLLEN VON INDUSTRIE 4.0 IN DEUTSCHLAND

ZUSAMMENFASSUNG. Einleitung: Das Paper stellt aktuelle Ergebnisse des BMBF Forschungsprojektes „MyCPS" (Migrationsunterstützung für die Umsetzung menschzentrierter Cyber-Physical Systems) vor.
Methoden: Im Rahmen des Projekts entwickeln 14 Partner, darunter sieben Industriepartner, Methoden und Werkzeuge, um Anwendungen intelligenter Digitalisierung und Automatisierung von industriellen Prozessen zu entwickeln. Innerhalb des Papers wurden über 385 Anwendungsfälle nach Vergleichskriterien bewertet. Darüber hinaus wurden Use Cases aufgrund ihrer Entwicklungsphase von Industrie 4.0-Zielen und Versprechungen klassifiziert. Die drei Ebenen "Information", "Interaktion" und "Intelligenz" dienen dazu, Anwendungen nach ihrem Reifegrad nach Industrie 4.0 zu differenzieren.

Fazit: In MyCPS wird besonderer Wert auf die Rolle der Mitarbeiter und die Interaktion der technologiegeführten Use Cases mit den Mitarbeitern gelegt. Die Analyse hilft Unternehmen und Forschern dabei, Schlüsselaspekte der Entwicklung von Industrie 4.0-Anwendungsfällen selbst zu bewerten.

Codewörter: Industrie 4.0, Anwendungsfall, Technologiemanagement, Smart Factory, Digitalisierung

Der Teil dieser Arbeit wurde in Form des Vortrag während der Konferenz "24th International Conference on Production Research (ICPR 2017)", die in Poznan am 30 Juli-3 Aug 2017 stattfand, präsentiert.

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