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Method for Developing an Implementation Strategy of Cyber-Physical Production Systems for Small and Medium-sized Enterprises in China

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Abstract

Enabled by the development of internet technologies, cyber-physical production systems (CPPS) are expected to open up entirely new possibilities to improve the efficiency of existing assembly systems of industrial companies. Nevertheless, realizing the potential of CPPS still remains a difficult task for small and medium-sized enterprises (SME), given the high variety of improvement possibilities offered by CPPS enabling technologies and the limited resources for their deployment. Hence, it is necessary to develop an implementation strategy of CPPS. Meanwhile, the consideration of location factors could support industrial companies to identify the appropriate CPPS implementation strategy since the location factors highly effect assembly system environment. In this context, a new approach to analyse the influence of location factors on the implementation of CPPS is exposed in this paper, which aims at investigating and identifying of relationships in between. Firstly, an application map of CPPS is generated. Secondly, the manufacturing industry status analyzed and subsequently a catalog of currently important location factors for the assembly systems are identified. Then a qualitative model of a relational analysis is established by an agglomerative hierarchical clustering algorithm. An industrial case study is used to demonstrate the applicability and the validity of the proposed approach.

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Keywords: Assembly system; CPPS; implementation strategy; location factor

1. Introduction

The increasing digitalization of the manufacturing, hidden behind the term Industrie 4.0, aims at resolving challenges which industrial companies face in the current turbulent corporate environment. Enabled by the development of internet technologies, cyber-physical production systems (CPPS) are expected to substantially change the manufacturing industry by improving the efficiency of existing processes and thus making companies highly productive and more competitive [1]. Nevertheless, realizing the entire potential of Industrie 4.0 still remains a quite difficult task for the majority of industrial enterprises, given the high variety of improvement possibilities offered by CPPS enabling technologies and the limited resources for their deployment.

Location factors play an important role in the manufacturing context since they characterize the production environment and hence have a strong influence on company's development. Therefore, the consideration of their individual factors could support industrial companies to identify the most appropriate key improvement areas regarding application fields of CPPS.

It is, therefore, necessary to systematically investigate and identify possible relationships between location factors and application fields of CPPS. The focus of this paper is set on highly dynamic emerging countries. In particular, Chinese small and medium-sized industrial enterprises have to be exemplary considered. In section 2, the state of the art literature related to the research topic is reviewed. The proposed investigation methodology is presented in section 3. Section 4 summarizes the research findings. An exemplary case study is elaborated in section 5. Finally, a summary concludes the paper.

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2. State of the art

In the context of this research topic, various models and tools for application fields and maturity assessment of the implementation of CPPS are analyzed and evaluated. On the other hand, studies for the analysis of location factors are reviewed first in order to investigate the role location factors play for industrial enterprises.

In the field of Industrie 4.0, [2-6] provide models for the maturity assessment of CPPS implementation. The general purpose of as-it-is assessment and improvement measures to reach a higher stage of digitalization is similar among models. However there are different emphases regarding objectives such as providing guidance on how to overcome barriers, extending the dominating technology focus by including organizational aspects, and economically using Industrie 4.0. In each maturity model it is distinguished between several levels regarding the CPPS maturity. Additionally, the overall maturity results from the evaluation considering different dimensions. At the same time, several online tools are available for the Industrie 4.0 assessment [7-11]. The analysis of various existing CPPS studies shows, however, that the influence of location factors on the implementation of CPPS enabling technologies is hardly addressed. Only a few research approaches for the definition of CPPS application fields as well as models for assessment of the maturity in each field partly take location factors into consideration [2], [6]. However, a holistic approach, which considers the impact of location factors on the implementation of CPPS, is missing.

Location factors can be bundled into two groups. It can be distinguished between location factors with regard to plants, production systems and operational performance and location factors relevant for the allocation of Foreign Direct Investments (FDI).

With respect to the first group, [12] examined international plant configuration strategies, in particular their dependence on various key competitive drivers. [13] investigated the influence of location-related factors on the establishment and ownership decision of multinational enterprises (MNEs). [14] studied the effect of road infrastructure on the location of new manufacturing facilities. [15] provided an interesting analysis on the location of manufacturing plants in relationship with pollution regulations. [16] examined the impact of agglomeration economies on companies' production subcontracting behavior. [17] investigated the influence of the geographical location on the evolution and the spatial concentration of the automotive industry. [18] provided insights on the process of spatial industrial variation putting the focus on both factors that determine location decisions of new industrial facilities and spatial factors with cost implications for firms.

Considering location factors related to Foreign Direct Investments (FDI), [19-22] provided an extensive overview of the most important determinants for the allocation of FDI. [23] contributed for better understanding of the influence of institutions and institutional development on the attracting of foreign investments. [24] evaluated the effects of taxation on FDI. The role of governance infrastructure on FDI flows is examined by [25]. [26] studied the importance of labor costs as a determinant of Foreign Direct Investments. [27] focused on the effects of corruption and market attractiveness on the FDI.

In summary, it can be stated that location factors can have a significant impact on the attractiveness of a certain location. Especially companies in the manufacturing industry should be aware of the effect of location factors, since they play a crucial role for determining the production environment and hence can be a key aspect for the future development and the success of a company. Hence, the knowledge of relationships between location factors and application fields of CPPS would help industrial companies to better prepare for the turbulent corporate environment and facilitate the definition of implementation strategies for CPPS enabling technologies.

3. Methodology

The presented methodology aims at overcoming this research gap in three steps. In the first step, an application map of CPPS is generated based on the study of state of the art literature as well as Industrie 4.0 use cases from the industry practice. A catalog of factors which are relevant for the location of production facilities in China is created in the second step. In the last step, a framework is developed for the investigation of the generated CPPS application fields and identified location factors on relationships.

3.1. Application map of CPPS

CPPS are enabled by various technologies, the so called enabling technologies, such as Internet of Things, embedded systems, cloud computing, etc. Depending on how these technologies are combined, it allows for the definition of various fields of application of CPPS. Currently, an explicit overview of such applications cannot be found in the literature. Thus, an application map of CPPS is generated in the first step of the proposed methodology. A starting point for the generation of an application map is the definition of Industrie 4.0 technology fields. In this regard it is distinguished between five Industrie 4.0 technology fields, namely cloud computing, smart factory, robust networks, IT security and cyber-physical systems (CPS)/embedded systems [28]. As a result of an extensive review of state of the art literature, key characteristics, features and enabling technologies are defined and assigned to each of the five technology fields. Additionally, the map of Industrie 4.0 use cases, provided by the platform Industrie 4.0, is primarily used for the study of exemplary cases for applications of CPPS from the industry [29].

On the basis of the research findings, application fields of CPPS are derived. The generated map consists of a total of 29 applications, see Fig. 1. Individual fields of application are assigned to a corresponding cluster, in which is improvements can be expected if an application field is implemented (Manufacturing process, Research and Development as well as Logistics and Supply Chain Management (SCM)). Certain application fields have a comprehensive improvement potential across the entire production system and hence their clear assignment to one of the three clusters above is arguable. Such fields of application are listed in two separate clusters (Big Data/Cloud and Information and Computing Technology

(ICT)). As the emphasis of the following paper is set on application fields related to production processes and production environment, the cluster Logistics and SCM was excluded for further consideration within the analysis.

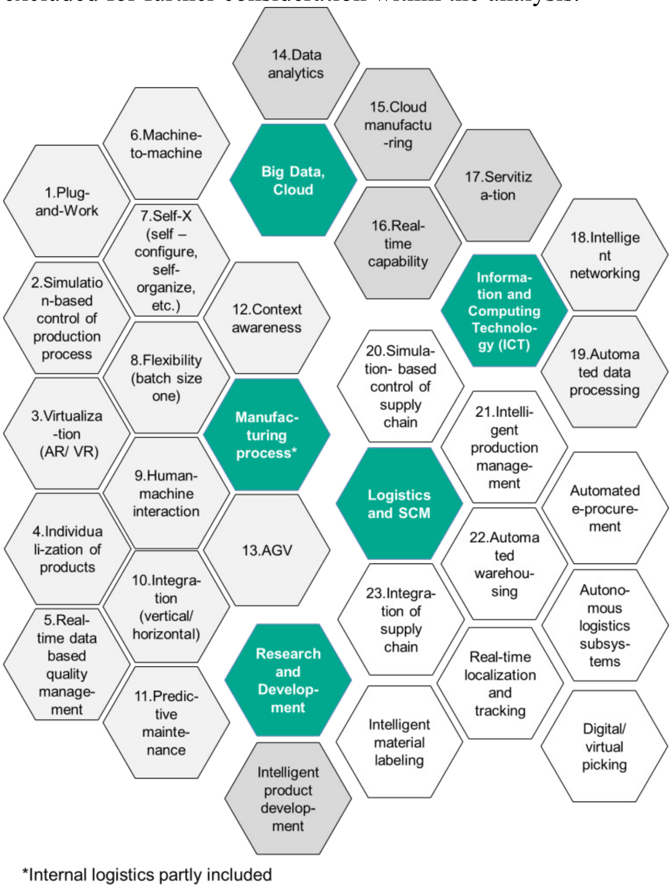

Fig. 1. Application map of Cyber-Physical Production System

3.2. Catalog of relevant location factors

Despite rising labor costs and slowing economic growth during the last years, China is the most competitive manufacturing nation in 2016 and still remains a preferred offshoring destination [31][32]. Thus, for better understanding of the determinants of China's attractiveness as manufacturing location, a funnel approach is applied.

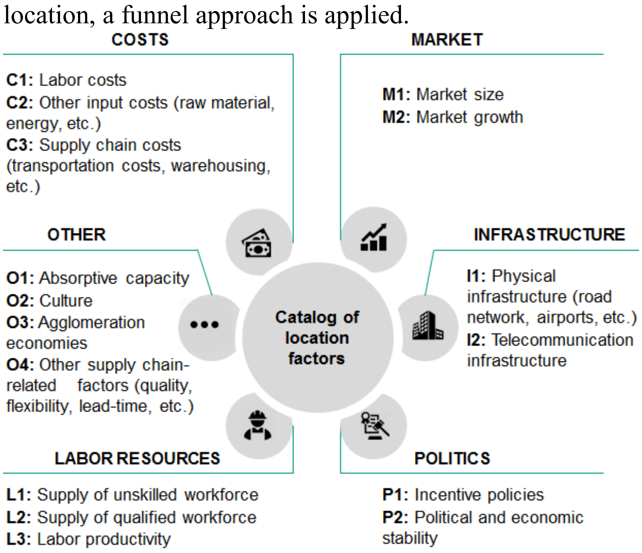

Fig. 2. Catalog of selected location factors relevant for China

The purpose is to identify determinants, which characterize the advantages of the country as manufacturing location. First, currently important factors for industrial location were studied (a long list). The long list of location factors is then filtered focusing on those factors which represent the advantages of the country as manufacturing location (a short list). Finally, the filtered list is extended and completed with additional location factors which are not included in the short list, but still describe important reasons for China to be an attractive manufacturing location.

As a result, the created catalog comprises sixteen location factors, grouped into six categories, see Fig. 2.

3.3. Investigation of relationships between application fields of CPPS and location factors

The investigation of relationships between application fields of CPPS and location factors includes data gathering via online survey and expert interviews from industrial companies located in China and their analysis using an appropriate assessment methodology. Basis for the gathering of data and evaluation of the results is a questionnaire which is designed specifically for the purpose of the research methodology. The questionnaire comprises three parts. In the first part of the questionnaire multiple choice questions were defined with respect to some basic information related to a company (company's size, industry sector, annual turnover, etc.).

The second part of the questionnaire refers to the evaluation of location factors. On the one hand, respondents should estimate the current importance of each location factor, included in the catalog, for their company. The importance of location factors is measured using a five-point Likert scale: from 1 (not important at all) to 5 (very important). On the other hand, one question for each category allows the respondents to express their opinions about expected future trends in the importance of location factors.

The last part of the questionnaire contains questions in relationship to the application fields of CPPS. For the application fields in the map, multiple choice questions with four answer possibilities were formulated. The four answer possibilities describe adequate levels of maturity with respect to Industrie 4.0 which could be achieved regarding a certain application field. The answer possibilities of each question are arranged in ascending order, i.e. the 4th answer alternative corresponds to the highest maturity level (achievement of Industrie 4.0). The aim is to gain insights on the application fields of CPPS which are deployed in the company at their current maturity level. Besides the estimation of the current Industrie 4.0 maturity of their company, respondents should assess future trends of various CPPS enabling technologies considering their importance for their company. For this, a four-point Likert scale was defined for a list of CPPS enabling technologies: from 1 (less important than now) to 4 (will be the main focus).

In summary, the developed questionnaire consists of a total of forty questions.

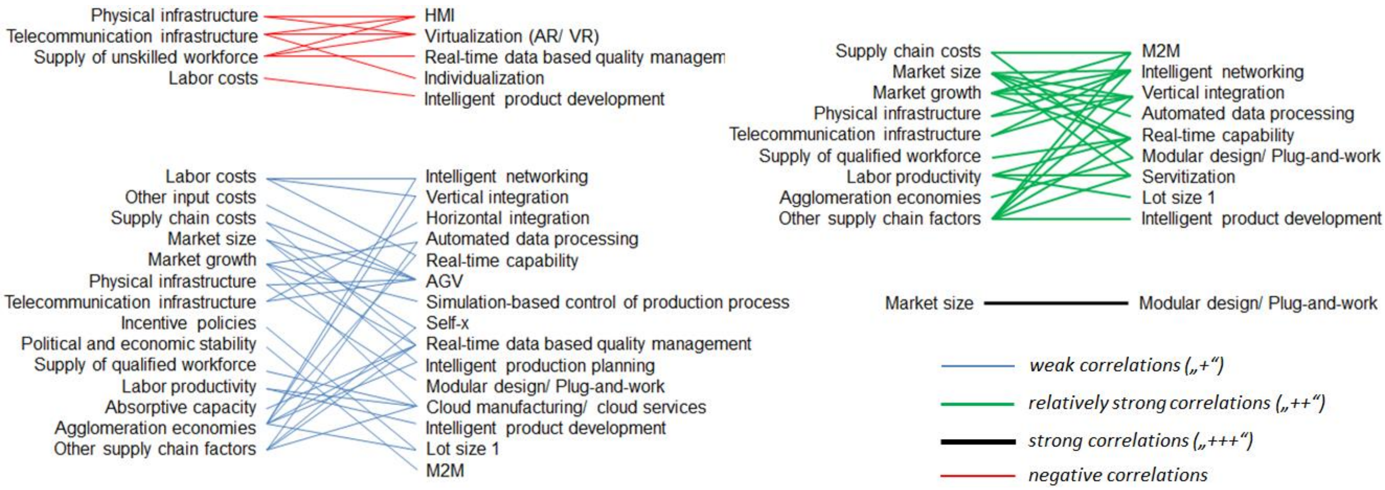

Fig. 3. Relations between location factors and CPPS application fields

4. Survey Results

Overall, twenty four respondents from different companies participated in the online survey and 3 expert interviews both face-to-face and via telephone conference were carried out. The gathered data were analyzed and evaluated using Microsoft Excel. The logic analysis based on expert interview partly validated the statistical robustness of the analysis of online survey.

Identified correlations are standardized on the interval [0, 1] and, based on that, qualitative evaluated. That is, standardized correlations with a value on the interval (0, 0.33] are weak and, therefore, are marked with one plus sign ("+"). Those with a value on the interval (0.33, 0.66] are relatively strong and thus marked with two plus signs ("++"). Standardized correlations with a value on the interval (0.66, 1] are strong and thus marked with three plus signs ("+++"). Figure 3 provides an overview of the identified correlations.

The strongest positive relationship was identified between market size and modular design/ plug-and-work (0.74). The weakest positive correlation was identified between supply chain factors, such as quality, flexibility, etc. and real-time data based quality management (0.09). Several negative correlations were found, as well. All of them are weak though.

Among the studied location factors, supply chain related factors, such as quality, flexibility, lead time, etc., resulted to have the highest number of correlations, as 10 relationships with application fields were identified. On the other hand, culture is the only location factor for which no correlation with any application field was discovered.

With regard to the application fields of CPPS, both intelligent networking and real-time capability are found to have the most relationships, since each one builds correlations with seven location factors. On the contrary, context awareness, data analytics and predictive maintenance do not correlate with any of the examined location factors.

5. Case Study

A case study at a Chinese small-sized company, located in Suzhou, is carried out. A key feature of the company is an intelligent assembly line, equipped with state-of-the-art Industrie 4.0 solutions. Thus, the case study which should serve both as a validation of the results obtained prior and to demonstrate how they could be applied in the industry practice. For this, the company's individual situation is evaluated and presented in the form of a catalog of location factors. Taking the identified relationships into account, corresponding application fields of CPPS which would be suitable for implementation in the company are then identified.

The analysis showed that, indeed, the majority of the application fields which are found to be appropriate for the studied company are already deployed within the intelligent assembly line. This finding supports the research findings since the majority of the surveyed companies which also assessed the same location factors as highly important already have deployed the considered application fields. On the other hand, the elaborated research methodology allows for recommendations regarding the implementation strategy of CPPS technologies. In the case of the studied company, "Servitization" is the only application field of CPPS which resulted to be suitable for the intelligent assembly line and is not deployed yet. Thus, if the intelligent assembly line is to be upgraded towards further implementation of CPPS, it is recommended to concentrate on "Servitization" as next application field to be deployed.

6. Summary

Cyber-physical production systems (CPPS) are expected to substantially change the manufacturing industry and lead to the 4th Industrial Revolution. A methodology was elaborated in order to examine the relationships between location factors and application fields of CPPS. The proposed methodology comprises three steps: generation of an application map of CPPS, creation of a catalog of relevant location factors and identification of correlations between CPPS application fields and location factors. The research findings suggest the existence of such relationships.

However, one major limitation is the small size of the data set what implies an incomplete coverage of the research topic and it allows for subjective estimations and views to significantly affect the quality of the results. Future research activities should, therefore, aim at providing a methodology which considers issues such as adequate size and composition of the data set in order to cover diverse aspects and characteristics as better as possible.

Besides appropriate data set, efforts should be directed to the investigation of alternative methodology for derivation of relationships. The latter emerges from the assumption that industrial enterprises would be always strived to achieve the highest possible maturity level in each application fields of CPPS. However, it is arguable whether a "perfect" maturity is required for each company [32]. That is, undergoing the entire process of digitalization and thus realizing the highest maturity level regarding CPPS might be neither necessary nor appropriate for a certain company. Instead of this, the individual optimum for a company could be somewhere "in between". As a result, specific companies might not be strived for the achievement of the highest maturity level considering some application fields regardless the importance of location factors. Such an issue was not taken into account in the applied evaluation methodology of the data. However, it could significantly influence the obtained results.

Furthermore, future research will be encouraged to investigate such interdependencies at a more detailed level. For instance, it can be studied whether a certain location factor affects an application field of CPPS only at a certain maturity level.

Last but not least, additional efforts would be necessary to widen the scope of location factors. A total of 16 location factors were studied what is far less than the number of existing location factors.

It is uncertain whether the consideration and improvement of the limitations listed above would lead to significantly different results. However, until this is done, the findings, reported in this paper, could provide a valuable guidance and support for Chinese SMEs when defining their own strategy for the implementation of CPPS.

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