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ORIGINAL PAPER

SMART FACTORY WITHIN SUSTAINABLE DEVELOPMENT AND GREEN GROWTH CONCEPTS

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ABSTRACT. **Background:** The authors' motivation was the growing popularity and interest in both aspects as well as the attempt to identify the relationship between the intelligent factory and other models and concepts. This paper was developed to assess the state-of-the-art in the Smart Factory concept, and in particular its analysis in the context of the concept of sustainable development and green growth policy. The aim of the study was to identify a research gap as a lack of publications linking the concept of a Smart Factory with such management concepts as: lean or agile, as well as green growth policy and sustainable development.

Methods: In the literature review, publications from the Web of Science and Scopus databases were analyzed. The identification of the gap was possible due to the analysis of the occurrence of the key concepts in the scientific papers which were selected by the authors. During the research, a sheet was created. It was the database of articles meeting the established criteria.

Results and conclusions: There are no articles which cover the Smart Factory topic relating to lean or agile management at the same time. The systematic literature review and the analysis show that other authors rarely see lean and agile as a chance considering the Smart Factory and they do not combine these concepts. On the basis of the review it is impossible to state if the combination is possible and what the relations are. However, this topic is interesting and worth further analyses. This should be considered as a research gap. According to authors, there is a chance or even a need to use a lean and agile approach in production, resources and processes management.

Key words: Smart Factory, Sustainable development, Green growth, Systematic literature review, Industry 4.0.

INTRODUCTION

The concept of a Smart Factory in literature appeared already at the end of the twentieth century, that is, a dozen or so years before the dynamic growth of interest on the canvas of the fourth industrial revolution [Elliott, Hyduk 1989]. In the following years, at the turn of the century, there was a noticeably growing interest in sensors [Robert et al. 1993, Yen 1999, Schilp et al. 2003], production automation [Biros, Sadowski 2000, Wucherer 2003, Colombo et al. 2004], supply chains [Noori, Lee 2002], followed by wireless technologies [Lee et al. 2007, Secrist 1997, Zhuang, Goh, Zhang 2007, Bag, Anand, Pandey, 2017]. All these elements began to connect with the concepts of the Smart Factory and smart production (also called as smart manufacturing). This is because the technological advancement became a natural catalyst for development, as well as the evolution of the definition of intelligence in industry. A few years before the postulated fourth industrial revolution, the intelligence of production and factories was associated with digitalization [Gehman 2002, Lake 2003, Schott et. al. 2018] and the vision of the creation of an independent Smart Factory was announced at the beginning of the 21st century [Teresko 2004]. The concept of the fourth industrial revolution, called in Germany as 'Industry 4.0', can be understood as a significant change in the organization and management of the 21st century industry,

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using a number of tools and technologies. The most important ones include RFID, CPS, IoT, IoS and the Big Data concept [Odważny, Szymańska, Cyplik 2017]. The Industry 4.0 concept was presented as an element of High-Tech Strategy 2020 - an action plan implemented by the German government. It is worth noting that similar concepts were also created in the United States (under the name 'Industrial Internet') and Internet + in China. In subsequent years, the number of definitions increased thanks to numerous organizations and entities that began to deal with the subject. This is exemplified by the Smart Manufacturing Leadership Coalition (SMLC), which indicates the essential features of smart manufacturing. According to it, smart manufacturing is the ability to solve current and upcoming problems through open infrastructure, which allows for faster implementation of solutions, building advantage and additional value in the process [Leiva 2017]. The National Institute of Standards and Technology (NIST) defines smart manufacturing as fully integrated and interoperable systems that are able to react in real time to variable demand and conditions not only in the factory, but also in the supply chain, with an emphasis on customer needs [Carolis et al. 2017].

The concept of Smart Factory within Industry 4.0 was presented for the first time in Germany in 2011 and it is closely related to the fourth industrial revolution [Kagermann, Wahlster, Helbring]. This was the moment when the diversity of definitions and understanding of the concept of an intelligent factory began to decrease. The authors of articles about the Smart Factory began to point out the common features of the concept, which were also presented in this paper. Undoubtedly, the smart approach to production is a wide set of tools used to optimize manufacturing processes. The implementation of the 'smart' assumptions and concepts created an important competitive advantage with the use of advanced information and production technologies, gaining flexibility in the physical process at the same time despite the dynamically changing global market.

An intelligent factory is therefore a flexible and independent unit, which is characterized by high technological advancement, presenting features related to the fourth industrial revolution. It is a highly flexible factory with a high level of vertical and horizontal integration. Machines, devices and people are connected on the network thanks to numerous sensors and the control system is managed remotely, using applications and mobile tools. The intelligent factory is also a unit capable of effectively aggregating and using data. These data can be the basis not only for the management of current production, but also for planning processes or preventive management.

The Smart Factory is a factory that should be identified with a smooth flow of information, ease of adaptation to a changing market environment, as well as a high level of data security. The factory's intelligence results not only in the available technologies, but also a close relationship with the customer who is, inter alia, able to change features of an ordered product.

On the basis of the literature study, it is possible to point out a number of the Smart Factory features [Hermann, Pentek and Otto 2015]. These are among others:

- Appropriate network infrastructure, control systems, analytical software and integrated information system.
- Access to modern technologies - primarily technologies that enable the analysis and processing of large amounts of data (Big Data) and artificial intelligence.
- Interoperability achievable through the operation of the Internet of Things.
- Virtualization applied to support both real-time management and operational management. This can be achieved thanks to sophisticated simulation models.
- Technological decentralization, which supports an independent decision making process in cyber-physical systems for the production of highly customized products (in practice the products are designed directly by the customer).

Real-Time capabilities, understood as the ability to aggregate and analyze specific and current data in real time. As a result, the factory can react immediately to any changes on the market, but also machine errors, producing on parallel devices (or production lines) [Schlick 2014].

The implementation of the above should lead to the construction of a flexible unit identified with the Smart Factory concept. Such a defined factory has features of high adaptability to dynamically changing demand and is able to optimize production on a large scale, but also in small production batches - products with high diversity [Jäger 2016].

The concept of sustainable development seems to be a much broader issue, comparing it to the Industry 4.0 concept. It is also a concept that has been defined many times since the 1970s. Sustainable development is the result of changes in the production and socio-economic environment that began to pay attention in the 1960s to the natural environment and its relationship with it. In addition, the authors more and more often paid attention to the level of environmental degradation, and the idea of 'quality of life' was gaining in popularity. It is worth noting that sustainable development concerns not only the area of industry, but is a much broader concept, also taking into account its scope that also embraces construction, architecture, business (including services), urban transport, but also consumption. In relation to the above, we are dealing with a mature concept, in contrast to the Industry 4.0 concept, which in fact is still being developed and is not yet clearly and precisely defined or described. In this paper, sustainable development will be defined as a concept which takes into consideration all aspects of human life: it is based on three pillars: social, economic and environmental. After the publication of the Brundtland Commission's report 'Our Common Future', the idea of sustainable development started to function as a way of satisfying the growing needs of the population while preserving the environment at the same time [Zaman, Goschin 2014].

It is worth underlining that despite the relatively long functioning of the term 'sustainable development', the authors still point out that the term is much more developed in theory than in practice [Skowroński 2006]. It is therefore one of the elements that can be analogous to the Industry 4.0 concept. In the literature since 2000, links between science, technology and sustainable development can be noticed. The authors even argue that science and technology should play a central role in the implementation of the sustainable development concept [Cash et al. 2003]. Unfortunately, in most cases, the development of technology is carried out at without green trends that would prevent the degradation of human life and the Earth's system. In connection with the above, the essence of the hypotheses and questions posed in this work seems accurate and justified.

METHODOLOGY AND PURPOSES OF ANALYSIS

Literature review criteria

A systematic literature review is a method for analyzing literature, using a specific range of tools to analyze data, identify, select and critically evaluate literature in the chosen research areas. The main purpose of the method is to find answers to defined and developed questions stated at the beginning of the thesis or to pertain to the previously stated hypothesis using research which was assumed within the literature review [Okoli, Schabram 2017]. Qualifying literature is usually done on the basis of the primarily set criteria.

The systematic literature review thanks to its form can be used as a method which fills the gap within methodologies designed for analyzing problems in the specific research or literature area [Tranfield, Denyer, Smart 2003, Adams 2016].

The main criterion for doing searches in both analyzed databases was the keyword 'Smart Factory'. In the next stage, the authors limited results using additional filters. In the Web of Science database the authors limited 'Research Areas' and included areas as follows: Engineering; Automation Control Systems; Business Economics; Robotics; Operations Research Management Sciences; Metallurgy, Metallurgical Engineering; Mechanics; Social Sciences, Other Topics; Social Issues; Social Work.

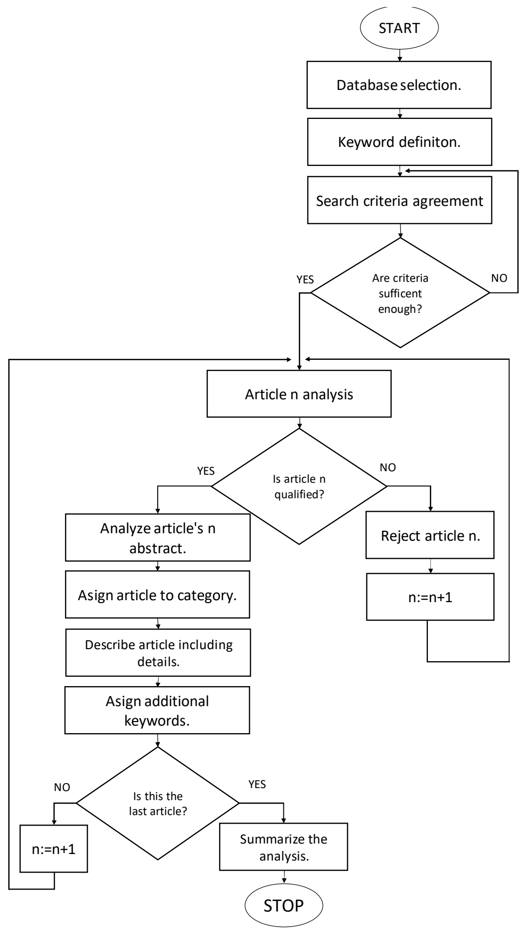
In the first search of the key word (without limiting results), there were 1371 results in Web of Science including all component databases. After limiting 'Research Areas' the number of results decreased to 1193. Such a number of results required further limitations. In the next stage, the authors limited results using a language filter. By choosing only English publications, the authors received 1145 results. In the final stage of preliminary research, the authors decided to limit the publications' type. Considering the fact that in this paper the focus of the authors was to analyze not only specific technological solutions but mainly scientific articles which consider extensively the topic, the authors excluded all patents from the final results. This limited the list to 603 publications.

The authors decided to limit the results from the Scopus database similarly. The first filter set was related to 'Subject area'. The criteria in both databases (Scopus and Web of Science) are not identical, however, they have convergent ranges and this was the reason for choosing the following areas in the Scopus database: Engineering; Business, Management and Accounting; Decision Sciences; Social Sciences; Environmental Sciences; Multidisciplinary; Economics, Econometrics and Finance. In the first search of the key word (without limiting results), there were 1437 results in Scopus including all component databases. Analogical language limitations (only English publications) resulted in 997 publications. The research as described above was done in October 2017.

Study selection

In this paper, the authors decided to prepare a systematic literature review which is based on two different databases: Scopus and Web of Science. Articles were analyzed using a previously prepared Excel spreadsheet. This spreadsheet includes all qualified articles and publications on the basis of the chosen criteria. The list allowed the authors to assign to publications the following keywords: sustainability, green growth, lean, agile, automation, Internet of Things, CPS (Cyber-physical system), Industry 4.0, Big Data. The keywords should be treated as a brief description of the publication and were the base for further analysis. First four keywords (sustainability, green growth, lean, agile) were chosen specifically because of their popularity within the management area. The authors wanted to find and understand possible relations between concepts and models. What is more, the purpose was to check the hypothesis that the number of articles which cover more than one concept is close to zero. Other keywords (automation, Internet of Things, CPS, Industry 4.0, Big Data) are commonly used terms within considerations of the Smart Factory after the fourth industry revolution.

Algorithm of analysis



Source: own study

Fig. 1. Algorithm of work preparation - a systematic review of literature

In both databases, the authors were searching for the 'Smart Factory' keyword. In the next stage, results were limited as described in the previous chapters of this paper. After preparing the list of publications and using chosen filters articles' titles were checked and specific publications were qualified for abstract's analysis. The articles devoted to the topic of Smart Factor within Industry 4.0 were chosen for further analysis and included in the Excel spreadsheet. All publications in the spreadsheet were described by filling names of the authors, date of publication, place of publication. What is more, the authors prepared an additional, short description of each article and assigned specific keywords to them which were chosen during the analysis and were considered as crucial for further analysis. Such an approach allowed the authors to prepare two separate spreadsheets (for both databases separately), which were merged. The articles, which appeared in both bases, were marked to avoid doubling the results. Figure 1 presents an algorithm which is a simplified presentation of steps taken by the authors in order to complete the analysis.

The above algorithm performance results are presented in the consecutive chapter.

ANALYSIS RESULTS

In accordance to the assumptions described in the previous chapters, the authors analyzed a group of 603 articles from the Web of Science database. This number was obtained from 1372 articles which were limited by filters (language limitation, scientific areas and type of publication, i.e. excluding patents).

Tables 1 and 2 present the percentage share of articles based on their origin. The main difference between results from Scopus and Web of Science is a high position of articles from Italy. What is similar, is a fact that in both databases the top positions are successively held by articles from Germany and the United States. In both databases, articles from Poland stand for only 1% of the analyzed group, which makes them classified as 'Others'.

Table 1. Percentage of articles due to their origin – Scopus

Scopus	
Germany	17%
United States	12%
Italy	8%
China	6%
South Korea	5%
Austria	5%
Others	47%

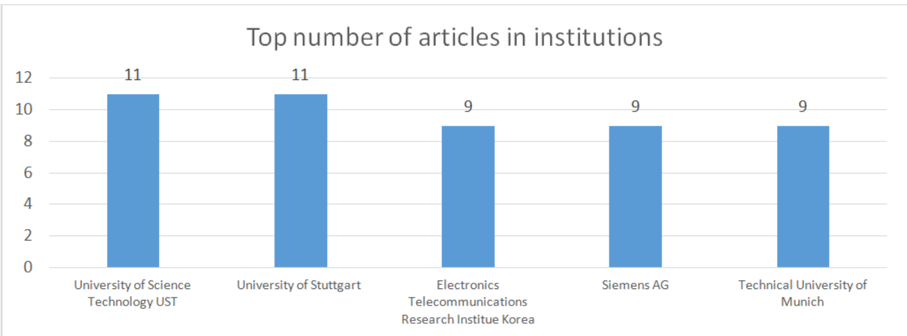
Source: own study

Table 2. Percentage of articles due to their origin – Web of Science

Scopus	
Germany	19%
United States	14%
China	12%
South Korea	7%
Italy	6%
Taiwan	5%
Others	37%

Source: own study

As part of the analysis, one might indicate leading research units with researchers most active in publishing articles related to the Smart Factory concept. These units are shown in the Figure 2.



Source: own study

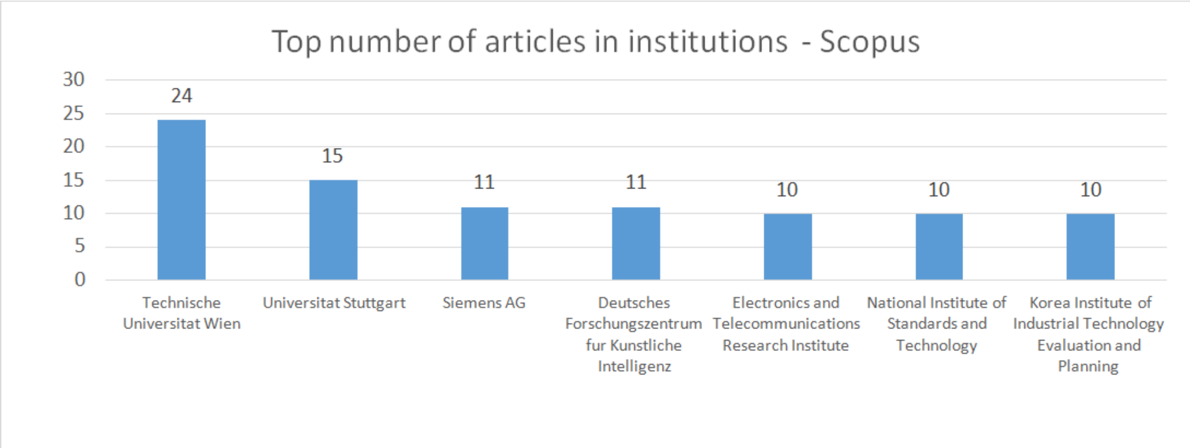
Fig. 2. Number of articles in institutions – Web of Science

Interestingly, 3 out of 5 top institutions are from Germany which is compatible with the data from tables 1 and 2.

In the next step of analysis, the authors took a look at the review work based on information from the titles and content of abstracts. Thanks to this, 293 articles from Web of Science were qualified for further analysis.

The second source of data used by the authors was the Scopus database, which offers 1437 articles before filtration and 997 after.

As in the case of the Web of Science results analysis, the same analysis was performed in the case of Scopus. The leading research units with researchers most active in publishing articles related to the Smart Factory concept. These units are stated in Figure 3.



Source: own study

Fig. 3. Number of articles in institutions – Scopus

Similarly to chart in Figure 2, most of articles come from Germany which confirms their very strong participation in the development of this field.

Summing up the analysis from both databases, 293 and 202 articles which could be assigned to or refer to one or more criteria (i.e. sustainability, green growth, lean, agile, automation, Internet of Things, Cyber Physical System – CPS, Industry 4.0 and Big Data) were selected. In total, 495 articles were obtained of which about 15% appeared in both databases. Finally, 419 unique articles which match authors' criteria were prepared in the list.

During the analysis, attention was also paid to the aspect related with the number of articles appearing over time. Table 3 presents the number of articles that meet the authors requirements published in subsequent years. Based on the data, it can be seen that in the last two years the interest in this subject was definitely bigger than before.

Table 3. Summary of the number of articles and analysis of Web of Science and Scopus databases for the Smart Factory

Year	Before filtration	After filtration	After abstract analysis
1970-2007	397	303	34
2008	30	25	6
2009	47	35	2
2010	68	30	3
2011	68	43	5
2012	153	82	14
2013	210	93	17
2014	297	129	35
2015	384	207	70
2016	635	384	134
2017	520	269	99
Total	**2809**	**1600**	**419**

Source: own study

Analyzing the summary of the collected articles in the context of keywords related to the Smart Factory topic, it can be seen that the least articles refer to the framework of sustainable development and green growth as well as Lean and Agile Production. The list for all keywords is presented in Tables 4 and 5.

For the purposes of this article, a summary of the concepts occurrence over the years has been prepared. Detailed information can be found in Table 5.

Table 4. List of the number of articles with keywords in the analysed set of articles

	Web of science	**Scopus**	**Total**
Industry 4.0	80	105	**185**
Internet of things	42	75	**117**
CPS	31	65	**97**
Automation	38	25	**63**
Big Data	10	22	**32**
Sustainability	9	11	**20**
Lean	8	8	**16**
Agile	3	5	**8**
Green growth	1	4	**5**

Source: own study

Based on the data from tables 3 and 5 it can be concluded that the greatest interest in the analyzed topics was in the years 2016-2017. In turn, the beginning of interest can be considered to be in 2012 because of the number of publications. It may be directly related to the Industry 4.0 concept which began to operate in 2011 in Germany.

Table 5. List of number of articles with keywords in the analysed collection of articles over the years

	Industry 4.0	Internet of things	CPS	Automation	Big Data	Sustainability	Lean	Agile	Green growth
1997				1					
1998				1					
1999									
2000				1					
2002									
2003				1			1		
2004				3					
2005				2					
2006									
2007				1					
2008									
2009									
2010		1							
2011						1			
2012		4		4	1	1	2	2	
2013		2	2	4		1			
2014	12	7	6	5	2	3			
2015	25	16	19	10	5	3	2	1	1
2016	83	44	40	18	12	6	4	3	3
2017	65	43	29	12	12	5	7	2	1
Total	**185**	**117**	**96**	**63**	**32**	**20**	**16**	**8**	**5**

Source: own study

CONCLUSIONS

The systematic literature review is a great base for analyzing a specific and scientific problem or understanding a term or a group of terms. The executed analysis let the authors to point out interesting facts and observations in the area of the Industry 4.0 concept. It was especially interesting to investigate relations between sustainable development and green growth trends with the Smart Factory idea.

The first remark that the authors would like to outline is that there are no articles which cover the Smart Factory topic relating to lean or agile management at the same time. This is interesting especially considering the popularity of lean and agile in the 20th century. Tools used in these two concepts were very often implemented and used within the Industry and it seems that they could improve the factory shape towards the Smart Factory. Nevertheless, the systematic literature review and the analysis show that other authors rarely see lean and agile as a chance considering the Smart Factory and they do not combine these concepts. On the basis of the review it is impossible to state if the combination is possible and what the relations are. However, the authors find this topic interesting and worth further analyses. This should be considered as a research gap. What is more, authors suggest that there is a chance or even a need to use a lean and agile approach in production, resources and processes management.

Considering the purposes of this paper, it is important to also mention that there are no articles which cover the topic of Smart Factory within Industry 4.0 and sustainable development or green growth. Green growth and sustainable development should be defined as much wider terms than the Smart Factory itself. Following this statement, the authors suggest that the Smart Factory concept implementation should be performed in the alignment with sustainable development requirements and should constantly question the correctness of implemented solutions green wise. It is crucial that the Smart Factory wisely manages all resources including wastes and knowledge. Unfortunately, the number of articles which describe these aspects is close to zero. Such articles mostly consider technological aspects and specific solutions. Most popular amongst them are: RFID, wireless, cloud computing, automation and common use of robots. Therefore, the authors suggest to investigate more widely the topic of sustainable development and green growth within Industry 4.0 and Smart Factory. The authors interpret this as the second scientific gap, even more important considering current requirements and laws within environmental protection and work safety regulations.

In the introduction of this paper, the authors stated that Smart Factory appeared already in late 1980s. Obviously, the term used almost 30 years ago did not relate to the fourth industry revolution and had a different scope. However, the publications show that at the time there was already interest in automation and robots. What is more, this interest expressly increased which was also predicted in prime publications.

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SMART FACTORY W POŁĄCZENIU ZE ZRÓWNOWAŻONYM ROZWOJEM I KONCEPCJAMI ZIELONEGO WZROSTU

STRESZCZENIE. **Wstęp:** Wzrost popularności i zainteresowania w obu omawianych aspektach oraz próba identyfikacji relacji pomiędzy inteligentnym zakładem produkcyjnym i innymi modelami i koncepcjami był główną motywacją dla autorów dla pracy nad tym zagadnieniem. W prezentowanej pracy przedstawiono rozszerzoną ocenę koncepcji Smart Factory, w szczególności jej analizę w kontekście koncepcji zrównoważonego rozwoju oraz zielonego wzrostu. Celem pracy była identyfikacja luki naukowej powstającej na skutek braku publikacji naukowych poświęconych połączeniu koncepcji Smart Factory z takimi koncepcjami zarządzania jak: Lean lub agile, jak również zielonym wzrostem i zrównoważonym rozwojem.

Metody: Na podstawie przeglądu literatury, dokonano analizy publikacji pochodzących z baz Web of Science oraz Scopus. Identyfikacji luki była możliwa dzięki analizie występowania kluczowych koncepcji w pracach naukowych, wybranych przez autorów. Dane następnie zostały uporządkowane tabelarycznie, tworząc bazę artykułów spełniających określone kryteria.

Wyniki i wnioski: Nie stwierdzono istnienia artykułu, które jednocześnie poruszałby tematykę Smart Factory w relacji do zarządzania typu lean lub agile. Przegląd literatury wraz z jego analizą wykazał, że autorzy prac naukowych rzadko widzą metody lean lub agile jako szansę dla Smart Factory i nie łączą tych koncepcji. Na podstawie przeprowadzonego przeglądu nie jest możliwym określenie czy takie połączenie jest możliwe i jakie relacji zachodzą pomiędzy nimi. Jednak sama tematyka jest interesująca i warta dalszych analiz. Powinno to być potraktowania jako luka naukowa. Według autorów, istnieje szansa i potrzeba stosowania metod lean oraz agile w zarządzaniu produkcją, zasobami i procesami.

Słowa kluczowe: Smart Factory, rozwój zrównoważony, zielony wzrost, systematyczny przegląd literatury, Industry 4.0

DAS KONZEPT VON SMART FACTORY IM ZUSAMMENHANG MIT DER NACHHALTIGEN ENTWICKLUNG UND DEN MODELLEN DES GRÜNEN WACHSTUMS

ZUSAMMENFASSUNG. Einleitung: Der Anstieg von Popularität und Interesse für die beiden betreffenden Aspekte sowie der Versuch einer Ermittlung von Zusammenhängen zwischen einem intelligenten Produktionsbetrieb und anderen Konzepten und Modellen stellten einen Ansporn für die Autoren der vorliegenden Arbeit dar, sich mit diesem Forschungsanliegen auseinanderzusetzen. Im Rahmen des dargebotenen Beitrags wurde also eine eingehende Beurteilung des Konzeptes von Smart Factory, insbesondere dessen Analyse im Kontext des Konzeptes der nachhaltigen Entwicklung und des grünen Wachstums projiziert. Das Ziel der Arbeit war es, die Erkenntnislücke, die wegen des Mangels an betreffenden Forschungsarbeiten entsteht, zu identifizieren. Das bezieht sich hauptsächlich auf die Forschungsvorhaben, die der Anbindung des Konzeptes von Smart Factory an die Konzepten des Lean- oder Agile-Managements sowie dem grünen Wachstum und der nachhaltigen Entwicklung gewidmet sind.

Methoden: Aufgrund einer Fachliteraturübersicht wurde eine Analyse von in den Datenbasen Web of Science oder Scopus enthaltenen Veröffentlichungen durchgeführt. Die Identifizierung der betreffenden Erkenntnislücke war dank der Analyse des Auftretens der schlüsselhaften Konzepten in den von den Autoren ausgewählten Forschungsarbeiten möglich. Die gewonnenen Beiträge und Daten wurden demzufolge in Form von Tabellen aufgelistet, wodurch eine Datenbank mit den die bestimmten Kriterien erfüllenden Veröffentlichungen entstanden ist.

Ergebnisse und Fazit: Es wurde kein Beitrag, der sich gleichzeitig mit der Thematik von Smart Factory im Zusammenhang mit den Konzepten des Lean- oder Agile-Managements auseinandergesetzt hätte, wahrgenommen. Die Fachliteraturübersicht samt deren Analyse wies darauf hin, dass die Autoren von Forschungsarbeiten die Methoden des Lean- oder Agile-Managements kaum wahrnehmen und nur sehr selten sie als eine Chance für das Konzept von Smart Factory ansehen, indem sie diese Konzepte nicht miteinander verbinden. Auf Grund der durchgeführten Übersicht der betreffenden Forschungsarbeiten war jedoch die Feststellung nicht möglich, ob eine solche Verbindung überhaupt in Frage kommt und in welchem Zusammenhang gegebenenfalls die Konzepte zueinander stehen würden. Die angeführte Fragenstellung scheint aber durchaus interessant zu sein und für weitere Erforschungen empfehlenswert. Sie sollte als eine wichtige Forschungslücke angesehen werden. Laut der Aussage der Autoren bestehen die Chance und der Bedarf, die Lean- und Agile-Methoden im Management von Produktion, Beständen und Prozessen anzuwenden..

Codewörter: Smart Factory, nachhaltige Entwicklung, grüner Wachstum, systematische Fachliteraturübersicht, Industry 4.0

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