A Review Of Smart Factories In The Context Of Industrial 4.0

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***Abstract*—Since the theory of Industrial 4.0 was put forward, building smart factories has become the main path for the upgrading of manufacturing industries in various countries. Academic research on smart factories has been accelerated, but there is a lack of inductive research on the literature. Based on the relevant literatures about smart factories in CNKI, Web of science, SCI, EI and other databases from 2014 to 2020, this paper summarizes the definition of smart factory and classifies and compares the selected literatures from the aspects of research content and research direction. It is concluded that there are six research perspectives and research trends at home and abroad about the smart factories in recent years. The results of this study have enlightening value for the theoretical research and practical exploration of smart factories.**

Keywords—Industry 4.0; Smart Factory; Research Trends; literature review

I. INTRODUCTION

Smart Factory is a manufacturing system based on Industry 4.0, which describes the link of the future manufacturing industry chain. It is a factory that uses intelligent interconnection technology to produce products through data generation, data transmission, data acceptance and processing. Under the background of fierce global competition, loose innovation environment and shortened and customized product life cycle, manufacturers must design their factory production systems to be more flexible and adaptive to face the current situation. Therefore, the major manufacturing countries in the world have introduced corresponding measures one after another. For example, the German government issued the "Industrial 4.0" plan and the "Smart factory" plan in 2014, which provided new ideas for the development of German manufacturing. In 2016, the National Institute of Standards and Technology issued a report entitled "current Standard system of Intelligent Manufacturing system", which intends to promote the establishment of the future standard system of intelligent manufacturing system in the United States. In order to break down the technical barriers, the world's top technology enterprises such as AT&T, Cisco, General Electric, IBM and Intel have jointly established the Industrial Internet Alliance, which aims to promote the deep integration of physical technology and digital technology in the field of industrial manufacturing. In 2017, at the information and communications exhibition conference held in Hanover, Germany, the then Japanese Prime Minister Shinzo Abe also put forward the concept of "connected industry". Its main cores are: First, build a new digital society in which people interact with devices and systems. Second, addressing new industrial challenges through cooperation and coordination Third, actively promote the training of senior talents to adapt to digital technology. Soon after, the relevant departments of Germany and Japan jointly issued the Hanover Declaration, the main content of which is to promote "interconnected industries that realize value creation by connecting people, equipment, technology and so on." In the early stage of economic globalization, Europe, the United States and other developed countries are at the top of the global value chain because of their core technologies in many industrial fields. Emerging economies represented by China are mostly engaged in low value-added processing, assembly and other services in the global manufacturing field, facing the problem of "tragic growth". At the present stage, under the influence of anti-globalization and trade protectionism, the global market of China's export products is greatly squeezed. At present, the development of China's manufacturing industry is facing many constraints, such as low added value of products, technical barriers and so on. These are the core problems that China urgently needs to solve at present. With the rapid development of artificial intelligence technology, Internet of things and communication technology in China, the transformation of manufacturing enterprises to smart factories is the only way for the development of China's manufacturing industry. To this end, the then Premier of the State Council Keqiang Li put forward the "Made in China 2025" plan in the 2015 Government work report. "Made in China 2025" focuses on promoting the deep integration of informatization and industrialization in China, accelerating the integration and development of a new generation of information technology and manufacturing technology and taking intelligent manufacturing as the main direction of the deep integration of the two modernizations. Focus on the development of intelligent equipment and intelligent products, promote the intelligent production process, cultivate a new mode of production, and comprehensively improve the intelligent level of enterprise research and development, production, management and service. To sum up, the smart factory has become a sharp weapon to solve the problem of global manufacturing development, and it has also become the focus of global academic research and industry attention.

In the field of academic research, the related research of smart factories is growing rapidly. Scholars have different views on the definition of the concept. For example, scholars such as Jin (2016) and Hongzhao Dong(2004) described the concept of smart factory from the production process and manufacturing process of smart factory. Osterrieder (2020) and others put forward the concept of smart factory from the composition of production units of smart factory. In terms of research perspective, it is relatively divergent. For example, Li(2010), Zhang(2016) and others focused on the business model and construction standards of smart factories. Park (2019), Chongwatpol (2015) and others focused on the technical composition of smart factories. Thoben (2017) and O'donovan (2015) mainly from the perspective of issues related to the construction of smart factories under the background of Industrial 4.0. In terms of research trends, some scholars generally predict the future research of wisdom factories from the combination of Internet of things digital factory and smart factory, while other scholars generally believe that smart factory should not only stay at the technical level, but should turn their research perspective to management and should focus on the construction of smart factory in small and medium-sized enterprises. The above research shows that scholars have different definitions of the concept of smart factory, many research perspectives and the research trend is divergent. For this reason, this paper will summarize and analyze the relevant research of smart factory and try to define the concept of smart factory and reveal the research perspective and research trend of smart factory.

II. The Formulation Of Literature Collection Strategy

Considering the authority of the literature database and the pertinence of the literature, this paper makes a cross-database search based on the CNKI database, which has included relevant articles about the smart factory in Web of science, SCI, EI and other databases. In September 2013, the German government put forward the concept of Industrial 4.0, which defines the core content of Industrial 4.0 as smart factories and intelligent manufacturing. In the same year, the academic circles set off an upsurge of research on smart factories. Therefore, this paper sets the search time interval from 2013 to 2020. In view of the fact that scholars may put forward concepts such as smart factory and intelligent manufacturing before 2013, this paper will analyze and summarize this part of the literature separately and add it to the research of this paper.

III. Research Results

A. *The concept of smart factory*

Although smart factory is the main development direction of the upgrading of global manufacturing enterprises, it is still in the initial stage of its development. At this stage, the academic research on this cutting-edge topic has just started. At present, many scholars have defined the smart factory. In this paper, the representative definition of the selected smart factory is as follows: Park (2019) proposed that smart factory is a distributed manufacturing system, which uses the industrial Internet of things to interconnect with the application of the production unit. According to Kusiak (2018), the smart factory is a digital factory that sublimates wisdom in factory manufacturing, discovers rules and provides coordination of intelligent services on the basis of manufacturing couplets, so as to improve production efficiency. Osterrieder (2020) believes that smart factory is a factory with enterprise intelligent decision-making and specialized production using network physical systems, data processing, and IT infrastructure. Comprehensive scholars have put forward many concepts of smart factory and the above concepts are summarized as follows: smart factory uses manufacturing IoT technology, information physics technology, big data technology, virtual simulation technology, network communication technology and so on and has the analysis and optimization ability, cooperation ability, prediction ability, perception ability, information-based and intelligent manufacturing, production and management of the factory.

B. *The research perspective of smart factory*

Through the collection, reading and collation of the relevant literature, it is found that there are many perspectives in the current research on the smart factory, which is summarized in this paper based on the different perspectives of previous studies.

- Value chain perspective

In the research of smart factory, some scholars have conducted in-depth research on how to upgrade the manufacturing value chain. For example, Li(2015), Ouyang(2016) and others mainly discussed the impact of Chinese manufacturing enterprises on the upgrading of their own value chain after realizing their own intelligence. Lv(2019) also takes Haier as the main body of research and concludes that Haier realizes the transformation of intelligent production, intelligent service and intelligent products by building smart factory system, so as to upgrade Haier's own value chain. It was mentioned in the 2014 World Trade report that smart services provided by smart factories can enable manufacturing factories to participate in the upper reaches of the global value chain by providing external R&D services, design services, and financial leasing services, etc., thus helping traditional manufacturing enterprises to upgrade the global value chain.

- Perspective of technology application

Schuh (2014) and others proposed that smart factories should focus on new sensors and data processing and data analysis capabilities and provide producers with solutions to cope with external individual needs, so as to reduce the negative impact of demand uncertainty. Hsu (2014) and others systematically expounded that smart factories should adopt data analysis methods to predict the performance of manufacturing systems and solve the problem of the decline of modern manufacturing capacity of traditional factories by allocating resources in advance. Wü nsch (2010) demonstrated the importance of flexible manufacturing systems, computer integrated manufacturing systems, omnipotent manufacturing systems, virtual manufacturing systems, agile manufacturing, networked manufacturing and intelligent manufacturing systems used by manufacturing enterprises in the construction of smart factories. Barbosa (2013) proposed that the manufacturing model of smart factory should mainly focus on distributed, networked and virtual production framework. At the same time, in order to improve the autonomy and cooperation of production system, multi-agent technology and artificial intelligence technology should be introduced into the design and research of smart factory.

- Business model perspective

Luo (2013) believes that with the technical support of the smart factory, the intelligent service provided by the smart factory is to provide customers with personalized, intelligent and accurate services based on the needs of users through intelligent analysis of users' information, preferences, behavior, needs and habits of big data. Based on the fact that 99.5% of Japanese manufacturers are small and medium-sized enterprises and the average labor productivity is only 43% of large manufacturers. Weng (2020) proposes to use the intelligent production operating system of smart factories to achieve the commercial goal of on-demand production in micro-factories, thus activating the market potential. Brown (2016) believes that production information data is the core element of the enterprise, and highly smart factories will intelligentize the production data, so that the factory itself will become more adaptable and automated and will better provide a good guarantee for the development of the enterprise itself. Taking the speech of Dirk Sefer, an associate professor of design engineering at the University of Bath in the UK, as an example, Professor Dirk Sefer's prediction is described in detail. "Highly connected factories will one day sell their time using machines as a service. This is also the trend of business model innovation of smart factories in the future. It also needs to improve the technical and management capabilities of manufacturing enterprises to meet the needs of the majority of customers".

- Supply chain perspective

Gunasekaran (2017) and others described that the construction of smart factories will improve the data analysis and predictive analysis capabilities of manufacturing enterprises, and then improve the level of supply chain management and the overall efficiency of the industrial chain. Kristin (2019) proposed that due to the highly intelligent interconnection of production data, smart factories may simplify production processes, operations, enterprises and supply chains into a single network system in the future to improve production coherence within manufacturing enterprises.

- Data processing perspective

La (2011) and others adopted the method of case study to illustrate that the production activities of manufacturing enterprises can use the method of data analysis to transform the original data into programming sentences and on this basis to make decisions on the future production behavior. O'Donovan (2015) and others described that the existing big data application architecture is suitable for large-scale production systems and the ability of the smart factory to collect and analyze information data should not only rely on the existing big data technology, but should improve the data processing ability according to the needs of the smart factory.

- Perspective of factory construction

In view of the fact that the smart factory is a new research topic, its production standard is not consistent with the conditions of safe production. Park (2020) elaborated that the complexity and uncertainty of the smart factory is relatively high and it is prone to unexpected production accidents. As a result, smart factories may end manufacturing tasks ahead of schedule, trigger failures, and leak important information in the production process. Wang (2020) demonstrated that even if smart factories have intelligent means of information sharing, complete information sharing in intelligent manufacturing is not necessarily the best choice for decision makers. Jerman (2020) also emphasizes that the construction of smart factories should not only focus on technological research and development and application, but also improve the "intelligent soft ability" of business leaders, that is the ability of continuous learning, flexibility, creativity, problem solving, critical and analytical thinking. Bü chi (2020) proposed that investment cost, technological innovation and opportunity cost in order to make better strategic decisions must be considered in the construction of smart factories. Napoleone (2020) pointed out that the network physical system is one of the most transformative technologies in the construction of smart factories, but in the process of transformation from traditional manufacturing enterprises to smart factories. We should not only pay attention to equipment and technology, but also study the operation and management characteristics of the enterprise. Walia (2019) predicted that the next generation mobile communication 5G will increase its flexibility and quality of service through network slicing technology. However, at present, there is still a lack of research on network slice management technology, which also makes the current smart factory's ability to play a limited. Osterrieder (2020) pointed out that most of the current literatures about smart factories are generally described by a single case with low generalization. In these literatures, they are usually based on equipment experimental data, have technical characteristics and rarely include impact assessment. Strozzi (2017) proposed that the current research on smart factory pays attention to the development of technology, which will lead to deviation in the research of smart factory. Dynamic analysis should be used to explain the research direction and field of smart factory, and the external factors existing in the construction of smart factory should be analyzed mainly from the perspective of government, industrial chain and enterprise competition.

C. The research trend of smart factories

Walia (2019) proposed that the construction of smart factories in the future should rely on 5G technology and improve flexibility and quality of service through network slicing. Chongwatpol J (2015) elaborated that smart factories should conduct more in-depth research on the data in the production process in order to improve the level of intelligence in the manufacturing industry. Evjemo (2020) emphasized that smart factories will need new solutions in their future development to create an open robotic system that automatically transitions between multiple safety modes, that is from machine automation to secure task sharing and direct collaboration in the robot's workspace, in order to ensure stability in production. Kim (2020) proposed that the future smart factory research should be based on the physical model of the smart factory and mainly study the factors that affect the technological innovation of the smart factory, such as CEO leadership, organizational learning, etc. Syberfeldt (2016) expected that the research of smart factory should not only focus on technological innovation, but also expand the understanding of practice and the exploration of business model. Jerman (2017) proposed that the research direction of smart factories should turn to management disciplines. In addition to emphasizing technical skills and knowledge, soft abilities are also considered important, as well as continuous learning, flexibility, creativity, problem-solving skills, critical and analytical thinking skills. Won (2020) believed that small and medium-sized manufacturing enterprises were the main body of the manufacturing industry, but at present, the construction of smart factories mainly focuses on large-scale manufacturing enterprises and there was little research on the technological research and implementation of small and medium-sized enterprises. The future research direction should be turned to small and medium-sized enterprises. Park (2020) emphasizes that due to the high complexity and uncertainty of smart factories, unexpected problems are easy to occur in the production process. Although there has been literature on the necessity of analyzing the threat of smart factory and system management in academic circles, the content of the research is not comprehensive. In the future, corresponding intelligent systems should be established to improve the detection rate of abnormal signals.

To sum up, the current research trend of smart factory is mainly in the field of data processing, technology application, management and technology improvement. First, with regard to the data processing of smart factories, many scholars have identified the combination of 5G technology, the Internet of things and the construction of smart factories as the research direction, which is also the main trend of smart factory research. Second, some scholars define the research trend of smart factory as technological R&D and innovation. Third, some scholars conduct interdisciplinary research on the construction and management of smart factories, such as Syberfeldt (2016). It is concluded that the construction of smart factories will more affect the business model of China's manufacturing industry in the future.

Finally, some scholars believe that the technology of the smart factory is still in the immature stage and there are too many uncontrollable factors, so we should focus on the technological improvement of the smart factory.

IV. CONCLUSIONS AND PROSPECTS

By connecting and summarizing the similar research fields of smart factories, this paper finds that the existing literatures of smart factories are weak in their business processes, information management, and the construction and maintenance costs of related machines, products and remaining equipment. At the same time, the relevant literature seldom describes in detail the industrial chain evaluation, business model and capital application of smart factories. Through the research and classification of the selected literature, it can be roughly summarized into three research directions. First, the innovative application of smart interconnection technology in smart factories. Its main research content is to rely on the Internet of things perception technology for information-based manufacturing, committed to the deep integration and integration of information technology and manufacturing technology, in order to achieve the intelligent interconnection of manufacturing enterprises. Second, the significance of the construction of wisdom factories. The main research content is the thinking of supply chain, business model innovation and China's value chain upgrading after the construction of smart factory model. Third, the related problems in the construction of smart factory. The main research content is to think about and solve the problems encountered in the construction of smart factory.

This paper has some deficiencies in the selection of literature. As the related concepts of Industrial 4.0 were put forward in September 2013 and the search limit of this paper is set in 2013, we don't rule out the possibility that early scholars have done research on the topic of smart factory. There may also be a small amount of missing literature. At the same time, the literature selected in this paper may be understood and subjective by the researchers. Through the research of this paper, the construction of smart factories is mainly based on large-scale advanced manufacturing enterprises, while small and medium-sized manufacturing enterprises due to the limitations of their own scale, funds and other conditions, how to join the ranks of smart factories is a question worth pondering. Therefore, in the future research, we will focus on how small and medium-sized manufacturing enterprises achieve their own intelligence, and conduct in-depth research on the construction plan of smart factories.

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