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Smart factories: Literature review and development prospects

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Abstract:

Smart factories have demonstrated the effectiveness in leading technological trends and enhancing social production efficiency. Consequently, smart factories have attracted the attention of not only business owners and policymakers but also scholars in many fields of research. However, the conception of a smart factory varies significantly depending on the approaches. This discrepancy translates into a notable divergence in creating a development strategy for a smart factory, encompassing aspects such as technology selection for investment, the enhancement of human resource strategies, and the overall development strategy for the entire enterprise. Furthermore, this disparity poses challenges in proposing a consistent science and technology policy to promote the trend of intelligent production. To address these shortcomings, the authors conducted an exhaustive literature review of published works on smart factories to establish a comprehensive concept and delineate the primary characteristics of smart factories, providing a fundamental framework for strategic planning and investment policies. This research offers a foundation for formulating a set of criteria to assess the intelligence of manufacturing factories.

Keywords: **cyber-physical systems, industrial internet of things, intelligent manufacturing, smart factory.**

Classification number: **2.2**

1. Introduction

The creation and development of the smart factory have fundamentally transformed the production method of goods and services and created a revolution in industrial production, also known as the Fourth Industrial Revolution. In other words, the smart factory is the embodiment of the Fourth Industrial Revolution. Indeed, thanks to information technologies such as the Internet of Things (IoT), cyber-physical systems (CPS), and the integration of microprocessors for the processing centers (production cells), industrial production has transitioned from mass production methods and standard products to a mode that meets individual needs, with optimal output achieved automatically and requiring minimal or no human intervention.

Industrial production has made significant strides since the Third Industrial Revolution, characterised by digitisation and automation. However, automation has previously been applied at the level of individual devices, with separate analysis and decision-making systems. The production system is not optimised, causing long response time and therefore can not be customised to meet the requirements. These shortcomings have spurred the advent of the Fourth Industrial Revolution and the emergence of the smart factory. That presents both a challenge and an opportunity for developing countries to keep up with future developmental trends.

A smart factory, when compared to today's factories, as displayed at the Hannover Fair, can be conceptualised as a facility that attains the level of digitisation and automation of the Third Industrial Revolution and has incorporated sensors, microprocessors, artificial intelligence (AI), and other modern technologies such as the industrial IoT and a management and monitoring system via CPS. This configuration enables the factory to self-collect data, self-analyse, and self-configure to meet flexible demands optimally in real time.

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Investing in a smart factory requires significant resources and time commitment, but it has become an investment trend for not only businesses but also national target programs in many developed countries. The primary advantages of investing in a smart factory include:

- Maintaining the leading position of developed countries and large enterprises or performing as a catalyst for the development of developing countries and enterprises.

- Assisting factories in lowering costs and improving product quality.

- Meeting the diverse needs of customers and adapting to changing environmental factors in real time.

Given the numerous benefits provided by smart factories, this article explores the scientific foundations of smart factories by searching and synthesising recently published scientific articles. The findings aim to offer policymakers and investors an overview and in-depth insights to inform their decision-making processes.

To gain an in-depth understanding of the current state of smart factories, the authors conducted searches in databases such as ScienceDirect.com, Web of Science, IEEE Xplore, and Springer. This search provided more than 100 publications, which were subsequently filtered and selected. Out of these, 49 publications were identified as closely related to smart factories and intelligent manufacturing. The publications were categorised based on their publication year and type (Figs. 1 and 2).

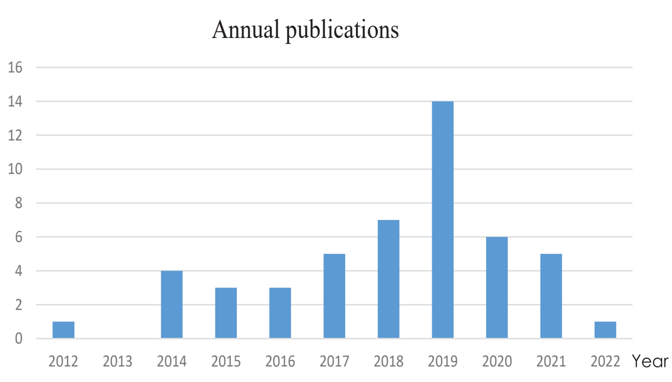

Fig. 1. Time distribution of smart factory publications.

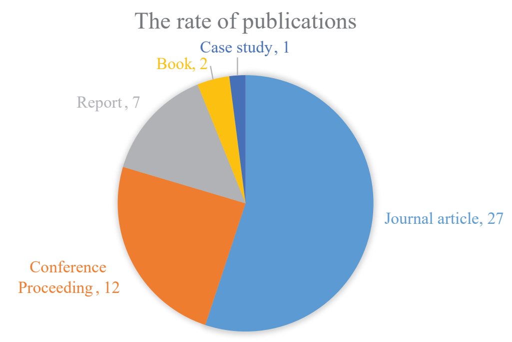

Fig. 2. Classification based on type of publication.

2. The driving forces of factory smartisation

Smart factories contribute to the enhancement of human resources quality. Indeed, with the systems being automated from data analysis to production operations, unskilled jobs will disappear. People who want to work in such systems must improve their skills to meet the increasing requirements of knowledge and strengthening proficiency. Additionally, smart factories play an important role in maintaining and strengthening a factory's competitive position within the industry by increasing its reputation with consumers, supplier partners, and society. However, deploying a smart factory is far from straightforward, particularly for developing countries. The main barrier currently is the scarcity of financial and human resources.

Firstly, investing in a smart factory creates long-term benefits rather than immediate returns. Given the substantial investment required, the payback period extends considerably. Moreover, the benefits are sometimes not shown in revenue but rather in intangible assets such as prestige and competitive position.

Secondly, in terms of personnel, the operation of a smart factory necessitates a highly skilled workforce, spanning from leadership to employees. As a result, this is a costly and time-consuming process because the existing human resources of traditional factories need to be retrained.

3. The concept of smart factories

The concept of smart factories plays an extremely important role as a framework for further research. After reviewing the gathered publications, it is evident that several perspectives exist regarding the concept of a smart factory, depending on one's point of view. Based on the scope of influence and the level of conceptual detail, these viewpoints can be categorised into three major groups: the macro approach, the operational approach, and the technique and technology approach.

According to the technique and technology approach, a smart factory is defined as a factory equipped with smart devices and modern technologies, such as the IoT, CPS, sensors, and more. These components facilitate communication and data sharing, establishing a virtual system alongside the physical one, often referred to as the "twin towers". This approach offers the advantage of pointing out specific technologies and production facilities for smart factories. However, it tends to overlook considerations of investment efficiency as well as the macro and micro impacts associated with smart factories. B. Chen, et al. (2017) [1]. assert that a smart factory combines physical and cyber technologies, deeply integrating previously independent discrete systems, thereby increasing the complexity and precision of involved technologies. In their article, the authors propose a smart factory architecture comprising four layers: the physical layer, network layer, application layer, and data layer. They also present a case study involving a candy food factory to substantiate their perspective on smart factories. Navid Shariatsadeh and colleagues define a smart factory as a digital factory combined with IoT, asserting that it represents a step towards a factory-of-things closely aligned with IoT. They emphasise that IoT not only handles intelligent connections among physical objects but also encompasses interactions with diverse IT tools deployed within the digital factory [2]. While their perspective underscores the technological aspect of smart factories, it overlooks the primary function of these factories, which is self-reconfiguration to adapt to changing customer demands and maximise factory profits. C.Y. Yoon (2019) [3] proposes a measurement scale for smart factories, assessing smart levels based on internal and external connectivity. Like other studies within the technique and technology approach, the focus lies on the necessary technologies for a factory to attain smart status without considering investment capital and its associated benefits [3-21].

The operational approach focused on operational efficiency, encompassing aspects like product quality, response time, and production organisational flexibility. This group contends that a smart factory establishes comprehensive internal connectivity within the factory and links with customers and external partners. By autonomously gathering and analysing data, the system can engage in reconfiguration to optimally align with customer requirements and environmental parameters. The advantage of this approach is that it aims to satisfy the specific requirements of customers while simultaneously reducing production costs, maximising factory profits, minimising investment return time, and enhancing the factory's reputation. However, this approach does not specify where to allocate investments or consider the macroeconomic impact. J.W. Kyun, et al. (2021) [22] corroborate this perspective by stating, "In the manufacturing industry, the smart factory is considered the final stage of the Fourth Industrial Revolution. Manufacturing companies are pursuing breakthroughs by introducing various advanced technologies to ensure their competitiveness". Their study analysed data from diverse Korean SMEs and concluded that SMEs could enhance their competitiveness by investing in 4.0 technologies such as IOT and big data, thereby gaining the advantages of a smart factory, which fosters flexible manufacturing to compete with the economies of scale of larger enterprises. M. Mohammed, et al. (2018) [23] defines a smart factory as one that "integrates 4.0 technologies to improve performance, quality, controllability, and transparency of manufacturing processes.

In the smart factory, the system is context-aware and helps people and machines execute their tasks based on information from both physical and virtual worlds. Components of the system can negotiate with each other and with other factory components to either request or offer functions". According to scholars, a smart factory encompasses multiple 4.0 technologies that facilitate the connection of people, machines, and context-aware systems. The emphasis is on improving factory operational parameters regardless of the specific technologies employed, as long as the system can be context-aware across all operational facets, rendering the factory "smart". This approach assists enterprises in adjusting their investments to align with available resources and updating suitable technologies [24-33].

The macro approach defines a smart factory as one capable of swiftly and optimally meeting customer needs, thereby conserving societal resources, safeguarding the environment, maintaining a competitive edge, and enhancing the industry and the nation's competitiveness. This approach is characterised by its focus on long-term objectives and broad scope, but it poses challenges for small and medium enterprises (SMEs), especially those with limited potential. As described by J. Lee (2015) [33], in a smart factory, manufacturers have the capability to meet customer specifications at any production rate, accommodating last-minute production changes and offering flexibilities far beyond the reach of traditional factories. The author also analyses the benefits of a smart factory for related stakeholders and its socioeconomic impact. Some developed country governments have recognised the advantages of smart factories and have initiated strategies to foster their growth. "German and US governments have established separate initiatives to accelerate the use of the IoT and smart analytics technologies in the manufacturing industries and, consequently, to improve the overall performance, quality, and controllability of manufacturing process. The smart factory is the integration of all recent IoT technological advances in computer networks, data integration, and analytics to bring transparency to all manufacturing factories" [34-38].

While authors may hold varying views on smart factories, each offers their unique perspective and definition. After carefully analysing their interpretations and definitions, we have inferred a comprehensive definition of a smart factory as follows: "A smart factory is a factory equipped with automatic machines, facilities, sensors, and experienced people. The human-machine system is interconnected, as well as connected to external entities, so that the factory can automatically or semi-automatically collect and analyse information about the environment, customers, and partners. The system has the ability to self-configure or self-reconfigure accordingly to optimise the production process, save resources, protect the environment, and improve the competitiveness of the factory as well as the industry and the country".

4. The symbols of a smart factory

Smart factories deliver daily benefits to enterprises and contribute to their long-term development, as well as the advancement of industries and nations. However, the utilisation of smart factories is a challenging progress that demands substantial resources, including human, financial, and temporal investments. J. Stamper (2019) [39] conducted a survey involving 204 European manufacturing enterprises, revealing that only 28% of manufacturers had integrated smart factory practices, with an additional 29% planning to do so within the next three years. This survey also concluded that one of the major challenges with smart factory projects is the significant level of investment required. Initially, smart factories may progress relatively slowly for large global manufacturers, due to the substantial initial investment. Consequently, it is critical to identify the key characteristics of smart factories, as these will serve as an analytical framework for building smartisation metrics and making utilisation smart factory strategy.

Based on reviewed papers, smart factory recognition symbols are affirmed as follows:

- *Production facility and technology:* Machinery, processing units, and production facilities (including conveyor belts and vehicles for transporting materials and work-in-progress) must be digitised and computer-controlled (often using embedded computers). This empowers these devices to collect and process data, make optimal decisions, and communicate with other production units and the factory's central system to acquire and share information.

- *Modularisation:* Unlike conventional factories, the smart production system is composed of small modules (or processing centers), each of which can work independently or in combination with others to form a complete production line. Modularisation facilitates flexible manufacturing because these modules can be rearranged and reconfigured to make a fast and efficient production for new products.

- *Connectivity:* Every piece of equipment in a smart factory is linked to sensor systems and the factory's network. Each device has an identifier within the network, enabling it to exchange data with other equipment and the factory's operating system. Devices can also self-configure based on received information or be remotely configured through a CPS network. CPS can be illustrated as a physical device, object, or equipment translated into cyberspace as a virtual model. This virtual model, with networking capabilities, can monitor and control its physical counterpart, while the physical aspect sends data to update its virtual counterpart.

- *Operation:* An integrated production management system, including planning, implementation monitoring, data collection, processing, and automatic and semi-automatic decision-making, must be implemented in the factory. This system must also be interconnected with partners and customers to respond promptly and efficiently to changing working environments.

- *Human resources:* A smart factory requires well-trained employees with the capacity to work and make decisions within highly automated systems. These employees should also possess skills in operating and handling situations involving automation and remote-control programming.

- *Performance:* In a smart factory, the manufacturing system can configure itself to customise the operation of each individual product based on the current status of all machines involved in the production line. This ensures high-quality production with optimal operational costs. Such smart factories enable manufacturers to meet customer specifications at any production rate, accommodating last-minute production changes and offering flexibilities beyond what traditional factories can achieve. Additionally, a smart factory can autonomously respond to changes in internal and external factors to optimally meet the demands of all stakeholders.

5. Conclusions

This article has provided a general concept and the principal characteristics of a smart factory after conducting an extensive review of published and synthesised works. These are foundational prerequisites that can assist managers in crafting investment and development strategies while aiding policy-makers in designing policies to advance regional and national science and technology, and resource optimisation. However, the scope of this article is insufficient to comprehensively address this research problem, given its broad and interconnected nature. Issues such as the impact of smart factories on the integration of SMEs into the global supply chain, investment priorities, and the sequencing of investments for resource optimisation will be addressed in forthcoming articles.

CRediT author statement

Tran Son Ninh: Conceptualisation and Methodology, Data analysis and Reviewing; Tran Doan Hieu: Data collection and Analysis, Editing; Pham Thi Hoai Thu: Data collection, Writing.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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