Intelligent Manufacturing Promotes the Comprehensive Upgrading and Innovative Growth of China's Manufacturing Industry

Zhong Zhihua [1], Zang Jiyuan [2], Yan Jianlin [2], Miao Zhongzhen [3], Yang Xiaoying [2], Gu Yishana [2]

1. Chinese Academy of Engineering, Beijing 100088, China
2. Center for Strategic Studies, Chinese Academy of Engineering, Beijing 100088, China
3. School of Public Policy & Management, Tsinghua University, Beijing 100084, China

Abstract: Recently, China has aimed to expedite the development of intelligent manufacturing through novel scientific and technological advancements and industrial transformation. However, the intelligent manufacturing in China remains in its infancy. Issues pertaining to the unbalanced and inadequate development of intelligent manufacturing remain prominent in China; these could pose significant challenges to development of intelligent manufacturing. Hence, in the future, China should focus on the comprehensive development of intelligent manufacturing to cultivate a manufacturing industry that is both large in terms of scale and strong in terms of its capabilities. To this end, research should focus on promoting parallel progress and the integrated development of "digitalized manufacturing," "digitalized and networked manufacturing," and "digitalized, networked, and intelligent manufacturing." It is, thus, essential to integrate digitalized, networked, and intelligent enabling technologies with advanced manufacturing technologies when adopting intelligent manufacturing. Moreover, organizations should aim for comprehensive breakthroughs in product and process innovation and for advances in business models and integrated manufacturing systems. Consequently, advances in intelligent manufacturing are expected to facilitate pioneering developments and an intelligent upgrade of manufacturing organizations.

Keywords: China Manufacturing; intelligent manufacturing; digitalized manufacturing; digitalized and networked manufacturing; digitalized, networked, and intelligent manufacturing

1 Introduction

Currently, the global manufacturing industry is undergoing a significant transformation toward becoming increasingly digitalized, networked, and intelligent. Intelligent manufacturing, which is defined by the deep integration of new-generation information technology and advanced manufacturing technology, is the main driving force of this global industrial revolution [1]. The manufacturing industry in China, a global manufacturing center, is at a critical juncture of innovation and upgrading; China needs to leverage this opportunity afforded by the global manufacturing revolution, adopt the new scientific and technological advancements and industrial transformation, and expedite the development of intelligent manufacturing in order to realize a large-scale and highly capable manufacturing industry through innovation [2].

1.1 Development needs of China's manufacturing industry

Over recent years, the Chinese economy has shifted from high-speed growth to high-quality developments, while

new social dilemmas have also emerged. Meanwhile, the demands and business environments in which China's manufacturing industry operates are also undergoing significant transformations. The shortage of overall supply in the manufacturing industry has shifted to a shortage of effective supply, which implies that the existing manufacturing products and services can no longer satisfy the demands of an upgraded consumption structure. There remains a considerable difference between China and other developed countries in terms of the technological innovation capacity, resource utilization efficiency, and quality of development in the manufacturing industry. Consequently, China's manufacturing industry falls in the middle to the lower end of the global value chain. Therefore, it is imperative for China's manufacturing industry to pursue all-round transformation, upgrades, and innovation to achieve high-quality developments [3].

The fundamental approach to transform, upgrade, and innovate China's manufacturing industry is as follows. First, the structural changes on the supply side should be improved. Second, the urgent demands of businesses should be met to facilitate innovation, transformation, and upgrades through technological progress. Third, the digitalized, networked, and intelligent development of manufacturing should be promoted. Fourth, the overall technological and operational performances of the manufacturing industry should be improved. Fifth, the quality of manufacturing products and services should be enhanced. Sixth, the labor productivity and economic efficiency of the manufacturing industry should be increased. Furthermore, the technology, production, and operating models of the traditional manufacturing industry must be reshaped to ensure that the manufacturing supply chain is better prepared for changes in the consumption network and market environment and also to promote transformation in the quality, efficiency, and driving forces of the manufacturing industry [4].

1.2 Role of intelligent manufacturing in the development of China's manufacturing industry

In the 21st century, the development of new-generation information technologies such as the mobile Internet, super-computing, big data, cloud computing, and artificial intelligence (AI) is advancing rapidly; clustered technological breakthroughs are also emerging. In particular, new-generation intelligent manufacturing technologies developed via the deep integration of AI and manufacturing technologies have become one of the main driving forces of the new industrial revolution [5]. This manufacturing revolution, with intelligent manufacturing at its core, has attracted widespread attention from countries worldwide. Major industrialized countries have made strategic choices to develop intelligent manufacturing to promote the transformation of their manufacturing industries and consolidate and reshape their competitive advantages in this field. The development of intelligent manufacturing has emerged as a key factor in enhancing national competitiveness and dominating future markets.

This new scientific and technological revolution and industrial transformation worldwide has introduced significant opportunities for the comprehensive innovation and upgrading of China's manufacturing industry. After years of continuous developments in the fields of manufacturing and modern information technology, China has established a large-scale and complete industrial system and implemented a well-structured and fully equipped supply chain network. Intelligent manufacturing plays a key role in leading and driving the new industrial revolution, serving as the intersection point of manufacturing and information technologies. In this manner, it is expected to induce the further integration of new-generation information and advanced manufacturing technologies; enhance the technological optimization and upgrading of traditional industries; accelerate the cultivation and development of new industries; enable the rapid development of new technologies, products, and equipment; generate new drivers of economic growth; facilitate the development of digitized, networked, and intelligent manufacturing industries; and promote China's manufacturing industry through substantive transformation [6].

2 Challenges in developing intelligent manufacturing

Recently, China has focused on intelligent manufacturing in order to realize manufacturing supremacy through innovative developments and the promotion of the transformation and upgrading of the manufacturing industry [6]. Through the joint efforts of the industrial and scientific communities, the transformation toward a digitalized, networked, and intelligent manufacturing industry has accelerated, and positive results have been achieved. However, owing to the uneven levels of manufacturing productivity across different localities and industries, the intelligent manufacturing in China remains in its infancy. These negative effects of unbalanced and inadequate development are evident, and they significantly hinder the further development of intelligent manufacturing.

2.1 Challenges in implementing intelligent manufacturing

In 2018, a research team from the Chinese Academy of Engineering conducted a survey on the building of

manufacturing power in 11 cities, 22 industries, and 1859 organizations in China. The results showed that China's manufacturing organizations strive to implement intelligent manufacturing and that a large number of them have begun to explore the implementation of intelligent transformation and upgrading. There also existed a significant demand for intelligent transformation in 73% of the organizations surveyed; furthermore, 24% of these organizations planned to transform to intelligent manufacturing; 52% were actively transforming to reduce manpower; 45% aimed to improve product quality; 28% planned to replace manpower using machines in certain sections; and 34% planned to establish fully digitalized and intelligent factories [7].

In general, the basic concept of intelligent manufacturing is now widely recognized by manufacturing organizations in all Chinese industries, and the development of intelligent manufacturing has gradually shifted from conceptual popularization toward practical applications. Intelligent manufacturing is a new method of manufacturing and production. However, the deep integration of new-generation information and manufacturing technologies is still undergoing rapid developments and changes [8]. As a result, the development progress of intelligent manufacturing varies across organizations, industries, and regions. Many organizations are still unsure regarding the concept, direction, focus, path, and implementation strategy of intelligent manufacturing, and have, therefore, made mistakes in implementation. The technological template for the implementation of intelligent manufacturing has not been developed thus far, and its progress still remains considerably inadequate for meeting the significant demands of the business world.

2.2 Demonstration of intelligent manufacturing and challenges faced by small- and medium-size enterprises

Recently, several Chinese localities have vigorously implemented pilot applications of intelligent manufacturing to focus on promoting demonstration projects and successful experiences. Several world-leading digitalized workshops as well as digitalized and networked factories have been put into operation, and many manufacturing plants have increased their levels of automation, mechanization, and intelligent operation substantially, leading to significant improvements in the efficiency and quality of production. According to the results of a nationwide survey [9], organizations that launched pilot intelligent manufacturing demonstration programs reported that their production efficiency increased by an average of 45%, energy utilization rate increased by 20%, operating costs reduced by 25%, product development cycles were shortened by 35%, and product defect rates were reduced by 35%; this highlights the strong catalytic effect of pilot applications of intelligent manufacturing.

It must also be recognized that most organizations in China, especially small- and medium-size enterprises (SMEs), face many practical difficulties in implementing intelligent manufacturing. On one hand, most SMEs have extremely low profit margins; weak profitability; and inadequate reserves of technology, capital, and talent. The implementation of intelligent manufacturing involves significant investment costs and the risks of trial and error. On the other hand, sub-sector solutions are not integrated sufficiently with the needs of SMEs, and low-cost, reliable, and easy-to-maintain solutions are particularly scarce. According to a survey of 280 manufacturing organizations across 12 counties (cities and districts) in Zhejiang province conducted by the Zhejiang Intelligent Manufacturing Expert Committee in 2018, there were six major difficulties in promoting intelligent manufacturing in SMEs: transforming organizations, obtaining leadership approval for intelligent upgrading, finding reliable contractors, securing sustained upgrading, managing the health of the production system, and forming a synergy among multiple entities. Therefore, SMEs still face considerable challenges in promoting the application of intelligent manufacturing in practice.

2.3 Lack of resources for widespread implementation of intelligent manufacturing

While promoting intelligent manufacturing, China attaches great importance to strengthening the collaborative innovation of industries, universities, research institutes, and end users. Vigorous efforts have been devoted toward helping organizations increase the innovative use of key technical equipment and core industrial software and solutions and also toward strengthening the basic support capabilities for intelligent manufacturing. Recently, organizations and industrial parks related to intelligent manufacturing equipment, software, and system integration services have emerged rapidly across the country, serving as incubators and boosters for the expansion of the intelligent manufacturing industry. Breakthroughs have also been achieved in a host of intelligent manufacturing equipment areas; national standards for intelligent manufacturing have been released, and international cooperation in intelligent manufacturing standards has been successful. Thus, the industrial ecosystem of intelligent manufacturing is taking shape, and the trillion CNY intelligent manufacturing market is steadily expanding.

Compared to the significant domestic demands for intelligent manufacturing, the overall supply capacity in China

remains inadequate. The self-reliance on key intelligent manufacturing technologies and equipment is low. Many high-grade computerized numerical control (CNC) machine tools, special intelligent manufacturing equipment, and core components are still dependent on imports, and the risk of "hollowing out" remains. In most regions, the supply capacity for intelligent manufacturing systems is still insufficient, and providers of integrated intelligent manufacturing solutions with integrated hardware and software systems and deep industrial foundations are often scarce. Therefore, the difference between leading Chinese organizations and advanced manufacturers from other countries in terms of technologies, products, and services remains substantial. The development of public platforms that support innovation in intelligent manufacturing is progressing slowly, and personnel training for intelligent manufacturing is unable to meet the needs of organizations in many industries. China still requires considerable efforts to achieve an all-round application of intelligent manufacturing.

3 Parallel progress and integrated development

Intelligent manufacturing is the result of the deep integration of advanced manufacturing and information technologies. Through this iterative integration and evolution, three basic paradigms have gradually formed: digitalized manufacturing; digitalized and networked manufacturing; and digitalized, networked, and intelligent manufacturing [5]. In developed industrialized countries, these three basic paradigms evolve in sequence and together form a series-based technological pathway. However, in China, a latecomer in industrialization, challenges pertaining to these three basic paradigms coexist simultaneously. Therefore, the parallel progress and integrated development of all three basic paradigms is the only viable technology route for promoting intelligent manufacturing in China [9,10].

3.1 Digitalized manufacturing

Digitalized manufacturing is the first generation of intelligent manufacturing; it is based on the widespread application of digital technology in manufacturing, mainly to optimize the production process, shorten the product development cycle, reduce manufacturing costs, enhance product quality control, and improve the labor productivity of organizations. Since the 1980s, Chinese organizations have gradually expanded the application of digital control systems and manufacturing equipment, digitizing the design, manufacturing, and management processes by adopting information technologies. These efforts have yielded positive results. Over recent years, various localities have devoted tremendous efforts toward promoting the replacement of humans with machines and digital transformation. Furthermore, many digitalized production lines, workshops, and factories have been established. Thus, digitalized manufacturing in China has entered a new phase.

Nevertheless, it must be noted that the development of the manufacturing industry varies across the different regions in China. Many manufacturing organizations, especially SMEs, are still in the initial stages of this transition from mechanization to digitalization. Owing to the weak foundation of IT applications and automation as well as the constraints of technology, human resources, capital, and other factors, these organizations are yet to accomplish this transformation into digitalized manufacturing; such organizations require considerable efforts for the development of intelligent manufacturing. These organizations account for a large proportion of the manufacturing organizations in China. Therefore, this is a problem that needs to be resolved before actual progress can be achieved in advancing intelligent manufacturing, both now and in the future. It is imperative for these organizations to complete the groundwork of digitalized manufacturing based on their actual needs and lay a solid foundation for promoting intelligent manufacturing at higher levels.

3.2 Digitalized and networked manufacturing

Digitalized and networked manufacturing represents the second generation of intelligent manufacturing, which is based on the extensive application of network technology in manufacturing. It is a combination of the Internet and digitalized manufacturing. Over recent years, leveraging the strategic opportunity afforded by the advances in Internet technology in the manufacturing industry, Chinese industries have promoted the development of digitalized and networked manufacturing. As a result, many manufacturing organizations have completed digitalized and networked transformations and upgrades.

Certain organizations with a solid digital foundation have extensively applied networked technology and have undergone rapid transformations into digitalized and networked manufacturing organizations. For example, Sany Heavy Industries began exploring the digital design, manufacture, operation, and maintenance of engineering machinery and equipment in 2008, taking the first step toward digital transformation. Over recent years, exploiting

the opportunity presented by the development of the industrial Internet, this company has built an Internet of Things (IoT) supply platform based on the global connection of equipment and established the linkage of equipment, materials, and personnel. In addition, the company has launched an industrial Internet platform encompassing the industrial chain of multiple industries and constructed a general platform for the industrial Internet across industries and domains. In this manner, Sany Heavy Industries has rapidly grown into a leading company in the construction machinery manufacturing industry, driven by the advances in digitalized and networked manufacturing [11].

Certain organizations with a weak digital foundation have also implemented vigorous steps to overcome the shortcomings in digitalization and undergo rapid transformations into digitalized and networked manufacturing organizations through the active application of network technology. For example, CFMOTO, a motorcycle manufacturing company, possessed a weak digital foundation. However, since 2012, in an attempt to address its shortcomings in digitalization, the company has formulated plans to build a manufacturing cloud, e-commerce cloud, logistics cloud, design cloud, and process cloud and also developed a car connection platform and consumer customization system. The realization of data-driven management through the entire industrial chain (which includes customer demand, R&D and design, order management, supply chain collaboration, sales and distribution, and after-sales services) has notably enhanced the company's market demand discovery and rapid response capabilities as well as its ability to quickly deliver large amounts of personalized and customized products, while maintaining control over its production costs. In this manner, the company has successfully transformed into a globally competitive high-end motorcycle manufacturer and a post-market supplier.

3.3 Digitalized, networked, and intelligent manufacturing

Digitalized, networked, and intelligent manufacturing is a new generation of intelligent manufacturing based on the breakthroughs in AI and its in-depth application in manufacturing. It is a combination of intelligent technology, the Internet, and digitalized manufacturing, and it currently represents the most recent direction and the highest level of intelligent manufacturing. Under this new phase of intelligent manufacturing, systems are capable of learning and possess the ability to model and optimize complex systems, thus introducing intelligent manufacturing to the manufacturing industry.

Recently, China has accelerated the deployment of new-generation intelligent manufacturing. The scientific and technological community has actively implemented "intelligent manufacturing and robotics" projects and promoted theoretical research, technological breakthroughs, and product development for new-generation intelligent manufacturing. Currently, in China, the new generation of intelligent manufacturing technology is applied mainly for the quality control of products, remote operation and maintenance of equipment, production optimization and scheduling, and other similar fields; nevertheless, more diverse application scenarios are expected in the future. In China, although the new generation of intelligent manufacturing technology remains at the stages of exploration and experimentation, it shows considerable promise.

The next five years are expected to be an important period for the all-round innovation and upgrading of the manufacturing industry in China. The Chinese manufacturing industry should pursue the technology route involving parallel progress and integrated development. To establish a solid foundation for future developments, efforts should be devoted toward assisting organizations, particularly SMEs, in addressing their shortcomings in digitalization and also toward completing digitalized transformation and upgrading projects. Furthermore, to leverage the impetus of innovation, the opportunities afforded by the advances in the Internet, big data, AI, and other new-generation information technologies need to be exploited. Innovations in new-generation intelligent manufacturing can be achieved by pursuing breakthroughs in manufacturing development in order to promote "Internet + digitalized manufacturing" as well as digitalized and networked manufacturing.

4 Importance of intelligent manufacturing in innovation and upgrading of manufacturing organizations

Intelligent manufacturing represents a large system that covers the entire lifecycle of products, including manufacturing and services; it can be optimized and integrated with manufacturing systems. This helps realize digitalized, networked, and intelligent manufacturing [4]. To promote the intelligent transformation and upgrading of manufacturing organizations in China, an innovation-driven tailored approach should be adopted; furthermore, systematic plans should be established and coordinated implementation should be attempted [9]. On one hand, considerable importance should be attached to the accumulation of innovations in manufacturing technology, and this should also be promoted continuously. Such innovations are of fundamental importance and vital for the survival

of manufacturing organizations. On the other hand, it is also necessary to exploit revolutionary empowerment technology—digital, networked, and intelligent technologies—to upgrade, integrate, and innovate manufacturing technologies. Such innovations are ground-breaking, beneficial to all, and applicable to all types of manufacturing organizations across industries and sectors. This is key for manufacturing organizations to prevail in competitive markets.

4.1 Innovation of intelligent products

Products and equipment are the main agents of intelligent manufacturing. Products realize the value of intelligent manufacturing, whereas equipment serve as the precondition and foundation for the implementation of intelligent manufacturing. Breakthroughs in new-generation intelligent manufacturing technology are expected to introduce revolutionary changes in products and equipment, transforming them from the digital generation to the intelligent generation. This would also enhance the functions, performance, and market competitiveness of these products [9].

The high-speed rail (HSR) in China is an example of the extensive application of latest technologies such as next-generation communication, the BeiDou Navigation Satellite System, cloud computing, IoT, big data, and AI. The HSR makes efficient and comprehensive use of all available space, time, manpower, and other resources in the railway system. This can be attributed to the comprehensive perception, ubiquitous interconnection, convergent processing, and optimal decision making of the trains as well as the fixed infrastructure and traffic environment information systems, which optimize the processes of transportation, operation management, and decision making [12,13].

4.2 Innovation in intelligent production

Intelligent production is the main component of intelligent manufacturing, and intelligent factories are the main carriers of intelligent production. Using digital, networked, and intelligent technologies, intelligent factories have achieved optimized production processes, thus significantly improving the performance, functionality, quality, and efficiency of their production systems. The optimization and upgrading of production systems, including intelligent equipment, intelligent production lines, intelligent workshops, and intelligent factories, is expected to become a major battleground for promoting intelligent manufacturing [9].

Through the application of digital, networked, and intelligent technologies, discrete intelligent factories have achieved an upgrade in processing quality, the optimization of processing technology, the maintenance of processing equipment, the intelligent scheduling and management of production, and improved manufacturing standards and market responsiveness. For example, Shaanxi Fast Gear Co., Ltd., underwent a digitalized and networked transformation in 2006, with a focus on upgrading high-grade CNC machine tools and industrial robots, intelligent sensing and control equipment, intelligent testing and assembly equipment, and other core technologies and equipment. They achieved connectivity and a high degree of integration between different pieces of equipment and also between the equipment and management systems. As a result, the company has realized significant improvements in product quality and production efficiency and has also achieved notable progress in controllable costs per 10 000 CNY output, occupied inventory funds, product development cycles, and other indicators. Thus, it has emerged as one of the world's top manufacturers of commercial vehicle gears.

Process-based industries possess a concentrated production capacity; a high degree of automation in their production techniques, equipment, and production processes; and strong digital and network foundations. Accelerating the exploration and application of new-generation intelligent manufacturing technology could help organizations in realizing safe, reliable, efficient, and green production and operation. For example, through the establishment of a digital monitoring and optimization system covering the entire production process, Jiujiang Petrochemical Corporation constructed a whole-process monitoring system for energy supply, production, transportation, transmission, and consumption. It launched digitalized and networked applications with the features of automation, real-time processing, visualization, modeling, and integration in planning and scheduling, safety and environmental protection, device operation, energy management, IT control, and other business areas. Furthermore, it developed implementation methods and industrial solutions for building digitalized and networked factories in the process-based industry; this resulted in a clear enhancement in quality and efficiency [14].

4.3 Innovation in intelligent services and new models and formats

Intelligent manufacturing is expected to result in significant structural changes on the supply side. With the support of intelligent manufacturing technologies, the production, organization, and industrial models of the

manufacturing industry will undergo revolutionary changes and eventually complete the fundamental shift from product-centric manufacturing to user-centric manufacturing [9].

To this end, the production model should first shift from large-scale assembly lines to large-scale customized production [1]. Using the Internet, manufacturing organizations can be linked more closely with their customers and the market and thus directly alter their production process in accordance with the demands of customers. The optimized allocation of production resources enables organizations to meet user demands in a more efficient, economical, and personalized manner. For example, Foshan Wision Furniture Manufacturing Co. provides users with customized product solutions through its online platform; this has transformed the company from a traditional furniture factory into a large-scale manufacturer of customized products, thereby significantly improving its market competitiveness [15].

Second, the industrial model should shift from a production-based approach to service-based manufacturing. The widespread application of digital, networked, and intelligent technologies has afforded considerable opportunities for value addition in different links of the industrial chains of companies; it has also accelerated the extension of high value-added industrial chains, both upstream and downstream, and promoted a shift from product-centered operations to user-centered operations. For example, the ShaanGu Group has established a remote monitoring system for operating equipment in order to provide users with personalized, customized, and systematic solutions for energy conversion [16]. Through the deep application of the IoT, big data, cloud computing, and other information technologies in key networks of the wind power industry, Xinjiang Goldwind Science & Technology Co., Ltd., developed an intelligent operation and maintenance service system for large wind farms, providing customers with intelligent monitoring, intelligent operation and maintenance, intelligent fault diagnosis, and early warning services for wind turbines [17]. By combining digital, networked, and intelligent technologies with traditional businesses, both these companies have transitioned from a single-product manufacturer to a system solution provider and a service-oriented manufacturing organization.

Third, the organization model should shift from competition and monopoly among organizations to competition and collaboration among organizations. A ubiquitous information network and convenient and speedy logistics systems make it easier for organizations to optimize resource allocation throughout the industry chain. The material, energy, capital, and information flow required for production have become more convenient and more transparent. Organizations may soon have the choice to decompose, outsource, or crowdsource their R&D, design, production, sales, and service activities to the entirety of society and even the world. By enabling collaboration and sharing for production, manufacturing, design, innovation, and manufacturing services, an ecosystem of win–win co-competition will be created among the manufacturing organizations.

4.4 Intelligent manufacturing support systems and integration

An intelligent manufacturing support system is a technical infrastructure for the development of intelligent manufacturing; it is an important cornerstone for the advancement of manufacturing organizations from digitalization to networked and intelligent production. Innovations in intelligent manufacturing system integration promote the integration of various functional manufacturing systems with new-generation intelligent manufacturing systems. This is essential for improving the overall performance of intelligent manufacturing. To accelerate the intelligent transformation of Chinese organizations, it is imperative to vigorously develop the industrial Internet and intelligent manufacturing cloud platforms, while also emphasizing on innovations in intelligent manufacturing system integration.

The industrial Internet network is a key network infrastructure for intelligent manufacturing, featuring low latency, high reliability, and wide coverage [18]. It mainly provides basic information support services for organizations. Recently, China has accelerated the implementation of the Industrial Internet Project and advanced the upgrading of intelligent manufacturing infrastructure and technology in networks, platforms, and security. This has supported intelligent manufacturing considerably and yielded positive results. The cloud-based platform of intelligent manufacturing is based on ubiquitous network technology and is focused on the users. Through the deep integration of humans, machines, and objects, the platform provides technical support for manufacturing organizations. Over recent years, many intelligent manufacturing cloud platforms, such as Alibaba Cloud (also known as Aliyun), Huawei Cloud, RootCloud, and CASI Cloud, have emerged in China and delivered excellent performances.

Innovations in intelligent manufacturing system integration involve the integration and optimization of various functional subsystems under a support system and expand the optimization of certain aspects of intelligent manufacturing to the optimization of the entire system. For example, Anhui Conch Group Co., Ltd., has established

system-wide intelligent optimized control covering the entire cement production process and realized automated factory operation, fault pre-control, visualized management, total-factor collaboration, and intelligent decision making [18]. They achieved this using advanced technologies such as the Narrowband Internet of Things, data sensing and monitoring, information interaction and integration, and adaptive control. Furthermore, they have emerged as a leading global cement producer through business transformation and upgrading. The Haier Group Corporation has constructed a COSMOPlat industrial Internet platform featuring the direct interconnection of users, the supply chain, and equipment. This platform provides organizations with diversified intelligent services, such as the construction of connected factories, mass customization, big data-empowered value addition, supply chain finance, collaborative manufacturing, knowledge sharing, testing and certification, and equipment maintenance, based on the integration and optimization of all relevant resources in the industrial chain. Being a world-leading home appliance manufacturer, Haier now stands at the forefront of the global industrial chain for home appliances [19].

5 Conclusion

Since the 13th Five-Year Plan period, China has promoted the transformation and upgrading of manufacturing by focusing on intelligent manufacturing; thus far, these efforts have yielded good results. Nevertheless, the development of China's intelligent manufacturing is expected to require a long time for completion. The application and promotion of intelligent manufacturing in China can be further accelerated by adopting digital, networked, and intelligent upgrades; moreover, differentiated implementation with respect to industries and regions combined with industrial characteristics and a focus on R&D, production, operations, and maintenance are expected to be helpful. Intelligent manufacturing can accelerate the in-depth integration of new-generation information technologies such as fifth-generation mobile communication, big data, and AI with the manufacturing industry. It can also promote an emphasis on innovation pertaining to products, production, models, and manufacturing system integration, thus improving quality and efficiency. This would help shift China's manufacturing capability toward the high end of the industrial chain.

References

[1] Zhou J. Fully promote the optimization and upgrading of traditional manufacturing industry and unswervingly build a strong manufacturing country [J]. China Industry and Information Technology, 2020 (1): 28–33. Chinese.

[2] Zhou J. Intelligent manufacturing——Main direction of "Made in China 2025" [J]. China Mechanical Engineering, 2015, 26(17): 2273–2284. Chinese.

[3] Zhu G F. From a large manufacturing country to a world manufacturing power [J]. Tsinghua Business Review, 2020 (3): 6–14. Chinese.

[4] Zhou J, Li P G, Zhou Y H, et al. Toward new-generation intelligent manufacturing [J]. Engineering, 2018, 4(1): 11–20.

[5] Zhou Y, Zang J Y, Miao Z, et al. Upgrading pathways of intelligent manufacturing in China: Transitioning across technological paradigms [J]. Engineering, 2019, 5(4): 691–701.

[6] The Research Group for Research on Intelligent Manufacturing Development Strategy. Research on intelligent manufacturing development strategy in China [J]. Strategic Study of CAE, 2018, 20(4): 1–8. Chinese.

[7] Zhou J. Promoting the manufacturing power strategy using innovation as the primary driving force and intelligent manufacturing as the main direction [J]. China Industry & Information Technology, 2018 (9): 16–25. Chinese.

[8] Zhou J, Zhou Y H, Wang B C, et al. Human-cyber-physical systems (HCPSs) in the context of new-generation intelligent manufacturing [J]. Engineering, 2019, 5(4): 624–636.

[9] Zang J Y, Wang B C, Meng L, et al. Brief analysis on three basic paradigms of intelligent manufacturing [J]. Strategic Study of CAE, 2018, 20(4): 13–18. Chinese.

[10] Ning Z B, Liu Z. The basis of intelligent manufacturing: Digitalization [J]. Metal Working, 2020 (7): 6–8. Chinese.

[11] He D. Sany Heavy Industry: Manufacturing as a service, data as value [J]. China Internet, 2017 (1): 23–25. Chinese.

[12] Editorial Department of Smart Factory. Digital twin: A new leader in information & intelligent manufacturing application [J]. Smart Factory, 2020 (4): 27–28. Chinese.

[13] Wang T J. Overall framework and development prospect of intelligent railway [J]. Railway Computer Application, 2018, 27(7): 1–8. Chinese.

[14] Wang H L. SINOPEC Jiujiang company: A sample of process intelligent manufacturing [J]. China Industry Review, 2016 (6): 72–77. Chinese.

[15] Wu Y S, Sheng Y, Cai N. Study on mass intelligent customization based on Internet Plus——Cases of Qingdao Redcollar and Foshan Weishang Furniture [J]. China Industrial Economics, 2016 (4): 127–143. Chinese.

[16] Fu X H. ShaanGu: Forging innovation and gathering development momentum [J]. China Industry and Information Technology, 2020 (5): 62–68. Chinese.

[17] Li F, Qiao H. Research on the business model evolution of digital technology driven industrial service——A case study of Goldwind [J]. Management Review, 2019, 31(8): 295–304. Chinese.

[18] Editorial Department of Ningbo Economy. Intelligent manufacturing is the key to cultivating new momentum for economic development: Interview with Miao Wei, Minister of the Ministry of Industry and Information Technology [J]. Ningbo Economy, 2017 (10): 3–5. Chinese.

[19] Lyu W J, Chen J, Liu J. Intelligent manufacturing and firm-level platform building in industrial Internet: A case study of Haier [J]. China Soft Science, 2019 (7): 1–13. Chinese.