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Parallel Promotion and Integrated Development: A Technology Roadmap for Promoting New-Generation Intelligent Manufacturing

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Abstract: This paper discusses the history of intelligent manufacturing development in western developed countries and the status quo of intelligent manufacturing development in China. It proposes that intelligent manufacturing development in China should not follow a sequential development process, as was the case in the western developed countries. China should adopt the technical route of parallel promotion and integrated development and promote the simultaneous development of the three paradigms of intelligent manufacturing: digital manufacturing, smart manufacturing, and new-generation intelligent manufacturing. While vigorously promoting, applying, and popularizing smart manufacturing, China should accelerate the exploration and research of new-generation intelligent manufacturing to lead and promote the upgrading and development of the country's manufacturing industry.
Keywords: parallel promotion; integrated development; new-generation intelligent manufacturing

1 Introduction

Intelligent manufacturing is a large system that undergoes constant evolution and has formed several paradigms through practice and evolution in the long term. Overall, three basic paradigms have been formed: digital manufacturing, which is also known as first-generation intelligent manufacturing; smart manufacturing, which is also known as "Internet plus" manufacturing or second-generation intelligent manufacturing; and digital-networked intelligent manufacturing, which is also known as new-generation intelligent manufacturing [1].

2 Development of intelligent manufacturing in developed countries

The development of intelligent manufacturing in western developed countries also underwent three paradigms, although they were "in-series." Digitalization, networkization, and intelligentization are, in that order, the three stages of intelligent manufacturing development in the west. Owing to the limitations in technological development, the network technology at the digitalization stage has yet to achieve universal application. Meanwhile, at the networkization stage, artificial intelligence (AI) has yet to achieve a breakthrough. This is why it required a long time of approximately 50 years for intelligent manufacturing in the west to develop into its current state.

2.1 Digitalization stage

From the 1950s until the mid-1990s, informatization was at the digitalization stage, mainly manifesting through applications of computation, communication, and controls. Some developed countries had started research on applications of computer technology in company operations, management, design, and

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manufacturing departments, forming a number of discrete, single-application systems. In the 1950s, the first computer drawing program was created in the United States. As the first computer-aided drawing system, it hastened the development of computer-aided engineering design in the 1960s. In the late 1960s, research and development of computer-aided engineering design was started in Norway. In 1971, the French car manufacturer Groupe Renault was the first to succeed in computer-aided manufacturing (car body design and manufacturing). In 1974, the fifth-generation computer numerical control (CNC) device, which utilized microprocessor chips and semiconductor memory, was successfully developed. This enabled the mass application of CNC machine tools in the manufacturing industry, which had an evolutionary influence over industrial upgrading. In 1993, 24 000 companies in the U.S. were already using electronic data interchange, which was the precursor to e-commerce. Of these, the largest 100 enterprises had reached 97% usage. All major U.S. corporations had achieved office automation, and some multinational corporations had even realized virtual offices. The transformation that digitalization has brought to the conventional industry starts with obtaining the order, product design, industrial design, major manufacturing planning, material preparation, product processing assembly, and delivery. All of these stages are computerized.

2.2 Networkization stage

Since the mid-1990s, the Internet was widely applied on a large scale, and informatization had entered the stage of networkization, the main characteristic of which is the Internet of Everything. Following the application of Internet at a global scale, manufacturing companies continuously attempted to achieve networkization of enterprise information system, i.e., "Internet plus". Internet plus resulted in significant benefits to companies in the late 1990s. Ford Motor Company from the U.S. had an intranet that connected 120 000 computer workstations around the globe, while Hitachi Ltd. possessed an external network that connected it to its 2 100 partner companies around the world in 1997. In addition, with regard to utilizing the Internet for e-commerce, Dell Inc. and Cisco Systems Inc. were the most successful enterprises at the time, having increased their revenue by a large margin through the usage of the external network. Germany's "Industrie 4.0" and the U.S.'s industrial Internet completed the definition of "Internet plus" and proposed a technical route. Germany's "Industrie 4.0" selected Cyber Physical Systems as its core, digitalizing and integrating the product, manufacturing, and services, thus achieving integration and interconnection within and between corporations. The U.S.'s industrial Internet proposed a high-level fusion among the global industrial system; the advanced computational, analytical, and sensing technologies; and the Internet, in order to reconstruct the global industry.

2.3 Intelligentization stage

As the world entered the 21st century, a new technological and industrial revolution occurred. On a foundation where big data, cloud computing, mobile Internet, and industrial Internet had achieved clustered breakthroughs and integrated applications, AI realized a strategic breakthrough and ushered in a new era, in which deep learning, interdisciplinary crossover, human–machine collaboration, collective intelligence, open source, autonomous control, etc. are the new characteristics. Currently, the overall advancement of AI-related disciplinary development, theoretical modeling, technological innovation, and software and hardware upgrading are triggering chain breakthroughs, expediting the leap from digitalization and networkization toward intelligentization in various economic and social fields. The deep fusion between advanced manufacturing technology and new-generation AI technology forms new-generation intelligent manufacturing, which will cause a fundamental revolution in the manufacturing industry and become the major driving force for its future development [2].

3 Status quo of intelligent manufacturing development in China

3.1 Intelligent manufacturing with favorable development conditions

China has a full-range, independent manufacturing industrial system. This has enabled China to become the largest producer in the world of more than 220 out of over 500 kinds of major industrial products and to be aptly called the global manufacturing powerhouse. At the same time, China's information industry has undergone rapid development recently, and four out of the 10 top-ranked Internet companies in the world are Chinese. The Chinese State Council issued the *Next-Generation Artificial Intelligence Development Plan* on July 20, 2017, laying out AI in advance and seizing a significant strategic opportunity. Therefore, China has prepared favorable conditions for the development of products of deep fusion between the manufacturing industry and information technology, which is intelligent manufacturing.

3.2 Discrepancy in level of development of intelligent manufacturing

3.2.1 Unbalanced industrial development

Currently, China's intelligent manufacturing has entered a period of rapid development. While a series of policies and measures have been successively introduced by the central government and the local governments at all levels, some regions have failed to combine their industrial characteristics and levels of development. Instead, they are blindly pursuing the high-

end industrial layout. Fields such as industrial robots, additive manufacturing, and industries related to "Internet plus" have become development priorities in several regions, leading to the serious problem of similar industrial layouts across the country. The number of robotics industrial parks already built or under construction has exceeded 40. In a few years, the number of robot manufacturing companies has exceeded 800. China is now facing the risk of high-end industries becoming low-end, with excess manufacturing capacity for low-end products.

3.2.2 Unbalanced regional development

Between 2015 and 2017, the Ministry of Industry and Information Technology had selected a total of 208 National Intelligent Manufacturing Pilot Demonstration Projects and 428 National Intelligent Manufacturing Special Projects. With regard to the former, the National Intelligent Manufacturing Pilot Demonstration Projects from East China comprise nearly 60% of all selected projects, which is significantly more than those from Central and Western China. The reason for this is closely related to the fact that East China had a relatively well-established intelligent manufacturing foundation. With regard to the latter, East China had the highest number of selected National Intelligent Manufacturing Special Projects, at nearly 60% of all projects. Beijing, Shanghai, Shandong province, Guangdong province, Zhejiang province, and Jiangsu province topped the chart, with a combined percentage of over 45% of all 428 selected projects [3].

3.2.3 Unbalanced corporate development

In recent years, China's manufacturing industry has put significant emphasis on developing "Internet plus" manufacturing. Several corporations that had a relatively well-established digital manufacturing foundation have successively undergone a transformation and achieved smart manufacturing. One example is Sany Heavy Industry Co., Ltd., which accelerated the networkization process by self-deploying an Internet of Things (IoT) and big data platform that is based on globally interconnected devices, thus providing users with new services, including Predictive Maintenance (PdM) and IoT Finance. Another example is Qingdao Haier Co., Ltd., which developed an interconnected factory centered around an entire course order execution and management system, allowing real-time simultaneous response to global user needs and rapid delivery of smart personalized plans. Another example is Foshan Weishang Furniture Manufacturing Co., Ltd., which built an interactive open design platform called "New Home Net," digging deeply into the personalized needs of each consumer, thus realizing manufacturing driven by consumption. It also created the "large-scale furniture design customization manufacturing system," effectively solving the conflict between personalized customization and standardized mass production. However, the foundation of China's intelligent manufacturing is very weak, with the majority of companies—especially the numerous small and medium enterprises—yet to complete the transformation into digital manufacturing. Therefore, the unbalanced development of intelligent manufacturing among various corporations requires great attention.

As a result, China cannot blindly follow the technical route of the western developed countries in order to develop intelligent manufacturing. Instead, to satisfy the different needs of intelligent manufacturing, China must implement the technical route of "parallel promotion." Currently, given its well-established manufacturing and information technology system, China does not need to follow the sequential technical route. Instead, it should adopt the method of "integrated development."

4 "Parallel promotion and integrated development" is necessary technical route to achieve leapfrog development

China's manufacturing industry should not follow the sequential development route of the west in order to achieve transformation, upgrading, and leapfrog development, as this would require several decades to completely develop digital manufacturing, followed by developing smart manufacturing and eventually developing new-generation intelligent manufacturing. Instead, China's manufacturing industry must seize the new opportunities offered by the integrated development of the new-generation AI technology and manufacturing industry, using innovation to realize new transcendence, thereby driving China's manufacturing industry from merely following to parallel development, leading, and striding forward and achieving "lane changing and overtaking," i.e., leapfrog development.

To advance intelligent manufacturing, China must exploit its late-development advantage and follow the "parallel promotion and integrated development" technical route, developing in parallel the three paradigms of digital manufacturing, smart manufacturing, and new-generation intelligent manufacturing simultaneously. This will enable China to fully utilize the fast-developing integrated innovations of information and manufacturing technology in a timely manner in order to lead and propel the intelligent transformation of China's manufacturing industry [1].

4.1 Innovation-driven, simultaneous development

China must insist on "innovation-driven" development, directly using the most advanced technology, such as the Internet, big data, AI, etc. and aiming for high-end quality. China should expedite the research, development, promotion, and application of new-generation intelligent manufacturing technology, driving the deep integration between advanced information and manufacturing technology, in order to pave the way for intelligent manufacturing, thus realizing the "lane changing and overtaking" of China's manufacturing industry. Sinopec Zhenhai Refining & Chemical Co., Ltd., which is a subsidiary of the China

Petroleum & Chemical Corporation (Sinopec), is the largest integrated refining chemical manufacturer in China. It has utilized the Internet, big data, AI, automation, and other similar modern information technologies to construct a pilot integrated refining and petrochemical complex with intelligently optimized manufacturing processes. It is driven by the coordinated optimization of the supply chain, industry chain, and value chain. Thus, China has taken the lead in creating an internationally advanced, domestically leading intelligent factory in the petrochemical industry.

4.2 Integrated development through use of advanced technologies in low-tech industries

The successful practice of energetically promoting "Internet plus" manufacturing for important insights and experience must be fully exploited. A majority of the corporations that are yet to achieve digital manufacturing should take the advanced technical route to realize integrated development through the use of advanced technologies in low-tech industries, while completing the "make-up lesson" for digital manufacturing, simultaneously leapfrogging towards an even higher intelligent manufacturing level. For example, Zhejiang CFMOTO Power Co., Ltd. was previously a motorcycle parts factory with limited digitalization. Through "Internet + Innovation + Manufacturing", it successfully completed the "make-up lesson" for digitalization, building "manufacturing cloud, e-commerce cloud, logistics cloud, design cloud, and process cloud" across the board and improving its product quality to the highest international standard. Currently, it has developed into an "invisible champion" corporation satisfying the international standard in the special motorcycle industry.

4.3 Standardization and compatible upgrading

While promoting the integrated development of the three paradigms, i.e., digital manufacturing, smart manufacturing, and new-generation intelligent manufacturing, China must adopt a uniform standard, which is crucial to China's intelligent manufacturing development. During the "parallel promotion" of the three aforementioned paradigms in the next 20 years, Chinese corporations will face multiple technological upgrading and paradigm shifts. Therefore, China must emphasize establishing and executing relevant standards for intelligent manufacturing. These standards must allow compatible upgrading, such that corporations will not need to start over afresh during a paradigm shift, thus avoiding low-level repetitive construction and creating a conducive environment for various corporations to start technical transformation and intelligent upgrading.

5 Feasibility of parallel promotion and integrated development and a few typical examples

Currently, China has relatively well-developed technological integration and application of manufacturing, information, AI technology, etc. in the fields of process manufacturing, large-scale individual customization, remote operation, maintenance services, etc., offering appropriate conditions for developing new-generation intelligent manufacturing.

5.1 Process manufacturing field

Overall, the process manufacturing industry has a high degree of automation, which provides a good foundation for implementing new-generation intelligent manufacturing. It is related to the petrochemical, chemical engineering, metallurgical, building material, food, and pharmaceutical industries. For example, intelligent manufacturing can be applied to the food fermentation industry, which produces conventional Chinese liquor, table vinegar, soy sauce, etc. Targeting the entire industry chain of fermentation, according to the fermentation system theory, digitalized data processing and mining methods can be applied to analyze conventional fermentation models. Moreover, technologies such as intelligent automation, IoT, and big data can be used to realize the mechanization, automation, informatization, and digitalization of fermentation, ultimately achieving optimized operation, control, and management of the fermentation systems. Examples can be drawn from Chinese liquor companies such as Luzhou Laojiao Group Ltd. and Hebei Hengshui Laobaigan Liquor Co., Ltd., which have started technical transformation aimed at intelligent upgrading and transformation, thus tremendously improving the liquor processing technology, creativity, and liquor quality.

5.2 Large-scale individual customization

Large-scale individual customization is already being practiced in several consumer manufacturing fields, such as clothing, home appliances, and furniture. Exemplary corporations include Qingdao Red Collar Apparels Co., Ltd. (Red Collar, in short), Qingdao Haier Co., Ltd., and Foshan Weishang Furniture Manufacturing Co., Ltd. Red Collar's Kutesmart intelligent customization platform can be used as a typical case study. The company has developed a global user autonomic design expert system by combining new-generation AI technology and achieved the intelligentization of research development and design, gaining an absolute advantage compared with individual customization of clothing manufacturing. However, Red Collar's clothing production line has not been fully automated. Steps such as cutting and sewing continue to be dependent on manual labor. The fusion and application of conventional manufacturing technology and AI technology have helped Red Collar achieve upgrading and transformation of the conventional industry, and it has transitioned from a traditional clothing corporation to a platform ecological corporation [4].

5.3 Remote operation and maintenance services

Remote operation and maintenance services collect data on the operational states of intelligent equipment/products and use methods such as data analysis/mining and expert system to provide users with services such as remote online detection, failure warning, failure diagnosis and restoration, PdM, operation optimization, and remote upgrading. For example, Xinjiang Goldwind Science & Technology Co., Ltd. created a wind turbine failure warning platform, installing detection sensors in the core components of each wind turbine, which return operational state data. It also set up a team of experts to analyze each core component of the wind turbines and created data models for smooth operation. With the parameters inserted, the surveillance system can provide advance warning of a wind turbine failure [4].

6 Conclusion

At present, new-generation intelligent manufacturing has only begun to take shape. It is showing great potential and is expected to transform into real productivity at an unprecedented rate. China needs to expedite the exploration and research of new-generation intelligent manufacturing, while vigorously promoting, applying, and popularizing smart manufacturing, in order to conduct a batch of pilot demonstrations successfully and achieve large-scale promotion and application.

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