Accelerating the Formulation of a Technology Strategy for Intelligent Manufacturing Suited to the National Conditions of China

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Abstract: There is currently a new phase of accelerated scientific and technological revolution as well as industrial transformation, and global manufacturing has entered a new stage of development. Developed countries such as the United States, Germany, and Japan have formulated their own development strategies for intelligent manufacturing technology. In addition, intelligent manufacturing in China is currently going through a critical period of accelerated development. However, there remains the important problem of insufficient and imbalanced development. In this context, a development strategy should be developed to determine the intelligent manufacturing technology suitable for China's national conditions based on the principle of combining progressiveness, staged approach, practicality, and openness. This will guide and promote the scientific and intelligent upgrading of the manufacturing industry in China.

Keywords: China's national conditions; intelligent manufacturing; technological strategy

The *China Manufacturing 2025* strategic plan states that the historical transformation of China from a large manufacturing country into a top-tier manufacturing powerhouse will be driven by the holistic integration of next-generation information technology and the manufacturing industry, with a focus on the promotion of intelligent manufacturing. As the current period is critical for the intelligentization, transformation, and upgrading of China's manufacturing industries, it is necessary to accelerate the formulation and implementation of technological strategies for intelligent manufacturing technologies that are suited to the domestic conditions in China. This is expected to drive and accelerate the development of digital, networked, and intelligent manufacturing in China, and should provide the progressive leadership and scientific guidance necessary to achieve this endeavor.

1 Intelligent manufacturing is the strategic approach in this new round of competition in the global manufacturing industry

Since the beginning of the 21st century, numerous breakthroughs have been achieved in Internet technologies, big data, cloud computing, the Internet of Things (IoT), and artificial intelligence, which have been rapidly integrated into the manufacturing industry. These advances have ushered in a completely new stage of development for the global intelligent manufacturing industry [1]. This new stage of development has been manifested in the following aspects: (1) the external information environment of the manufacturing industry has undergone extensive and long-lasting changes. Furthermore, the generation, storage, acquisition, transmission, and utilization of information

have become more efficient than ever before. (2) Innovations related to the integration of advanced information technologies and advanced manufacturing technologies are currently undergoing an accelerated rate of development. (3) Breakthroughs in artificial intelligence and the widespread usage of this technology have increased the prospects for machine learning and automated knowledge generation in the manufacturing industry. (4) The manufacturing industry is entering a stage of rapid deconstruction and reconstruction, which has accelerated the transformation of concepts for new development and paradigms in the manufacturing industry; manufacturing technologies, production models, production factors, and value chains are now constantly being remodeled. In summary, intelligent manufacturing is leading and driving a new phase of industrial revolution and transformation on a global scale [2].

Meanwhile, the global manufacturing industry has undergone a comprehensive readjustment since the global financial crisis. Based on the need to reinvigorate their national economies, the manufacturing powerhouses globally have accelerated the formulation and implementation of technological strategies for the digitalization, networkization, and intelligentization of their national manufacturing industries. In 2012, the American industrial world was the first to propose the "Industrial Internet," whose focus is the facilitation of real-time interconnections and intelligent interactions between machines, controller platforms, and upstream/downstream industries through software control applications and software-defined machines. The ultimate goal of the Industrial Internet is to form a data-driven, open, and intelligent industrial system that is based on modeling and high-level analyses [3]. In 2013, "Industrie 4.0" was launched through a collaboration between the technological and industrial circles of Germany. The focus of Industrie 4.0 is the use of embedded machine and equipment intelligence to devise an intelligent manufacturing model that is highly automated, digitalized, and networked, based on cyber−physical systems (CPS), thus enabling mass customization and shorter product launch timescales [4]. In 2016, the Japanese industrial world launched the "Industrial Value Chain Initiative" (IVI), which is based on a framework for intelligent manufacturing units and industrial interconnections. The aim of IVI is to establish a mutually connected industrial value chain through the collaboration of different industries in a "loosely-coupled" setting via a "loosely-defined standard" defined by upper-level committees, thus improving the overall productivity and competitiveness of the Japanese manufacturing industry [5].

Here, we briefly examine the technological strategies adopted by the United States, Germany, and Japan to advance their intelligent manufacturing capabilities. The technological strategy of the United States makes complete use of its immense capabilities in information technology and innovation services, and it emphasizes the use of "soft" advanced information technologies to enhance the efficacy and efficiency of "hard" manufacturing

processes. The German strategy utilizes Germany's cumulative advantages in mechatronics and manufacturing, and the focus of this strategy is the integration and incorporation of "soft" advanced information technologies in "hard" manufacturing processes, in order to achieve the integration of manufacturing, computing, communications, and control in an organic manner. The technological strategy adopted by Japan reflects on the pragmatism of the Japanese manufacturing industry and its focus on refinement; this strategy is a bottom-up approach for process optimization and information integration that begins from the most basic manufacturing elements. In summary, the first and second tier industrial nations of the world are formulating technological strategies that highlight their technological advantages and the features of their manufacturing industries to drive the digitalization, networkization, and intelligentization of their manufacturing industries. The objective of these strategies is twofold. First, they seek to enhance the competitiveness of their manufacturing industries on the global stage. Second, they aim to seize the immense market space that will be created by the transformation and upgrading of the global manufacturing industry, by seeking to implement a strategic approach in this new round of competition in the global manufacturing industry.

2 China must formulate a technological strategy for intelligent manufacturing suited to its domestic conditions

The People's Republic of China has developed at an extremely rapid pace since its establishment almost 70 years ago, especially in the last 40 years since the Chinese economic reform. China is now a major manufacturing nation with global influence, and the Chinese manufacturing industry now holds a remarkable position as it begins its transition to emerge as a top-tier player in the global manufacturing industry. The *China Manufacturing 2025* plan that was announced in 2015 clearly stated that the establishment of China as a major manufacturing powerhouse is a strategic goal, and it has also clarified the overall direction of the "three-step development" strategy. This plan also confirms that intelligent manufacturing will be the primary focus of China's efforts to transform and upgrade its manufacturing industries. In recent years, intelligent manufacturing industries in China have made significant progress owing to the governmental policies and market forces. Currently, a large batch of new applications, industries, and business models that are based on intelligent manufacturing are driving the rapid growth of emerging industries, and are also acting as a powerful driver of economic growth and sustainable development. However, it should be noted that Chinese intelligent manufacturing is still in its adolescence, and the problems caused by developmental imbalances and inadequacies are still clearly evident [6].

The domestic conditions faced by the development of intelligent manufacturing in China are generally manifested in the

following ways: First, the demand for intelligent manufacturing varies widely from one industry to another in each region of China. China currently has the world's most complete industrial system, with 41 industrial sectors, 201 divisions, and 581 groups. China is also the only country in the world that possesses all the classes specified in the industrial classification of the United Nations. However, because of this completeness, each industry and field can have very different market environments and technological levels, which is why the demand for intelligent manufacturing varies significantly from one industry to another. Second, the development of intelligent manufacturing in China's various industries is nonuniform in terms of their present level of development and foundations that have been laid for further development. Although intelligent manufacturing is highly developed in major enterprises, the majority of small- and medium-sized enterprises (SMEs) have yet to embrace digital manufacturing. Some industries (such as the automotive industry) have reached an internationally advanced level in intelligent manufacturing, whereas many of the remaining industries (e.g., rubber and plastic products) are still only beginning to develop intelligent manufacturing capabilities. At present, only 16% of China's industries have begun to implement intelligent manufacturing. The revenue and profit contribution of intelligent manufacturing is less than 10% in 52% and 60% of all Chinese industries, respectively, and costs have limited the implementation of intelligent manufacturing to a basic level in 90% of all SMEs [7]. Third, the development of China's modern manufacturing industry is less than 100 years old, which is why China continues to lag behind the developed nations of the world in terms of its accumulation of industrial knowledge and basic technological research. This shortcoming is manifested by its strong reliance on imports for many crucial components and high-end equipment, a lack of mastery in numerous key technologies, and the wide gap between China and the developed nations in economic indicators such as product quality, labor productivity, and energy efficiency. The intelligentization and transformation of China's manufacturing industries will be a historical undertaking as this effort will be confronted by the challenges of industrial revolution and the need to alleviate the industry's shortcomings through "supplementary classes."

At present, the Chinese economy is transitioning from high-speed growth into high-quality development. The endeavor to establish China as a major player on the global stage is now being pursued with full effort; the enterprises of China have shown strong enthusiasm for the impending industrial revolution, and there is a great sense of urgency for the transformation and upgrading of China's industries. Although China has defined intelligent manufacturing as its primary approach for achieving its strategic goals, there is still a lack of preparation at the technological and strategic levels. The industrial community of China is yet to formulate a clear strategy for the development of intelligent manufacturing, and the absence of a technical roadmap for

development is clear evidence of this fact. The understanding, development, operational focus, approach, and implementation of intelligent manufacturing by major enterprises are still riddled with numerous misconceptions. To drive the development of intelligent manufacturing in China in a satisfactory, sustainable, and rapid manner, it is necessary to formulate a development strategy for intelligent manufacturing that is suitable for the domestic conditions of China based on global technology trends. The formulation of a technological roadmap that defines the strategic goals, direction, and path of intelligent manufacturing development in China will be especially important for accelerating the intelligentization and transformation of Chinese manufacturing, which will drive the transition of China from a manufacturing giant into a major player in the global manufacturing industry.

3 Basic principles and proposed actions for the formulation of a technological strategy for intelligent manufacturing in China

The next 30 years is a crucial period for the global development of intelligent manufacturing. The manufacturing industries of China are fully capable of seizing this historical opportunity to achieve strategic breakthroughs that will allow China to be on par with or surpass the developed nations of the west, and to achieve leapfrog development. The formulation of a technological strategy for intelligent manufacturing that is suited to China's domestic conditions is therefore an urgent task. However, this endeavor should adhere to the following principles.

The first principle is "progressiveness," that is, to keep up with current trends in technology. Technological innovation is the foundation on which the development of intelligent manufacturing is built. This new phase of technological and industrial revolution is thus the greatest strategic opportunity for China's drive towards intelligent manufacturing. It is therefore important to aim for cutting-edge technological innovations in engineering. To accelerate the deployment of this technology and facilitate pilot demonstrations, special attention should be paid to the integration of new-generation artificial intelligence with manufacturing technologies. It is necessary to rapidly master this core technology and take control of the technological initiative in intelligent manufacturing development.

The second principle is "a staged approach." In other words, the actual level of intelligent manufacturing development in each industry and region of China must be accounted for in the technological strategy. As the manufacturing industries of China vary widely in terms of their levels of development, it is not possible to use a naive "one size fits all" strategy to implement the intelligentization and transformation of China's manufacturing industries. In the national-level plan, it will be necessary to identify strategic targets and priority tasks for each stage of development. In economically developed regions, key

industries, and key enterprises, priority should be given to the acceleration of key breakthroughs; these industries and enterprises should take the lead in piloting new technologies, thus setting an example for other industries. A step-by-step approach should be followed to gradually expand the "area-of-effect" of key breakthroughs, i.e., from enterprises (points) to cities (lines) and finally, regions (surfaces). Following this approach, the development of intelligent manufacturing should be the focus on the national scale according to the conditions of each industry and region, and this should be maintained until generalization has been achieved.

The third principle is "practicality," which means that the implementation of intelligent manufacturing should be performed pragmatically, taking one step at a time. The government should use pilot enterprises as a template to guide the digitalization of other industries and showcase the benefits of digital manufacturing, and this will serve as an internal source of motivation for the implementation of industrial transformations. The digitalization of manufacturing industries should be based on market demands and the internal motivation of the enterprises themselves, and the maximization of economic benefits should be the aim of this exercise. Appropriate development goals should be proposed for each level of development, and it is important not to blindly pursue high levels of digitalization, automation, and intelligentization. Furthermore, unmanned operation should not be pursued. The foundations for digital manufacturing should be established in a step-by-step manner (i.e., from "points" to "surfaces"), following a "unit−production line−workshop−factory" technical pathway. This graded form of development will be beneficial for the satisfactory development of China's intelligent manufacturing capabilities. All enterprises, especially large, medium, and small ones, should seek a technical pathway towards industrial transformation that suits their needs, and which is based on the practical aspects of industrial development.

The fourth principle is "openness," i.e., international collaboration in intelligent manufacturing should be wholeheartedly pursued and strengthened with an open approach. Intelligent manufacturing is a general trend and common challenge in the development of manufacturing industries around the world. As a nation that has undergone a significant delay in its industrialization, China should maintain its openness towards the outside world throughout its drive towards intelligent manufacturing, and should tread the path of open communication and mutual benefit. China should learn from advanced industrialized nations and gain knowledge from their experience with intelligent manufacturing. It is also important for China to improve its links with manufacturing industries around the world, and to strengthen international collaborations in the formulation of technical standards for intelligent manufacturing. China may then jointly confront the challenges associated with intelligent manufacturing (information safety, intellectual rights, etc.) with the rest of the world, and share knowledge and information resources about

intelligent manufacturing. It will also be important for China to take the initiative in establishing a new framework for the global development of intelligent manufacturing, and to construct a space for mutually beneficial international collaborations, thus building a global community for intelligent manufacturing. This will allow China's manufacturing industries and the world as a whole to maximize the benefits provided by intelligent manufacturing.

4 Conclusions

A historical intersection has formed between the current phase of technological and industrial revolution and the transition of China's manufacturing industries from high-speed development into high-quality development. This represents a strategic opportunity for China to upgrade its manufacturing industries from low-end manufacturing to middle-to-high-end manufacturing, and it is also a golden opportunity for the major manufacturing enterprises of China to usher in innovation-based development and transformation of its industries. The Chinese manufacturing industry should seize this rare opportunity and take the initiative to formulate and plan a technological roadmap for the development of intelligent manufacturing. At the national level, it is necessary to clarify the technological direction and implementation pathway for the overall development of intelligent manufacturing by China's manufacturing industries. At the industry level, the technological direction and implementation pathway for intelligent manufacturing in each industry should be clarified. At the enterprise level, the overarching plan and implementation pathway for the realization of intelligent manufacturing by China's enterprises should be clarified. This will ensure that intelligent manufacturing in China will be developed in a sustainable and scientific manner, thus setting China on a path towards industrial transformation that is suitable for the domestic conditions of China.

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