

# Research on Intelligent Manufacturing Development Strategy in China

The Research Group for *Research on Intelligent Manufacturing Development Strategy*

**Abstract:** Intelligent manufacturing is the basis for transforming China into a manufacturing power. Intelligent manufacturing is a general concept under continuous development. In this paper, the features of intelligent manufacturing are discussed. Intelligent manufacturing is categorized into three basic paradigms: digital manufacturing, intelligent manufacturing, and new-generation intelligent manufacturing. It is proposed that China should push forward the intelligent transformation of its manufacturing industry by adopting a technology roadmap of “parallel promotion and integrated development.” The strategic objectives, strategic guidelines, and development paths for the future development of intelligent manufacturing are outlined. Then, preliminary suggestions with regard to mechanism guarantees and policies in China are proposed, which include strengthening and implementing the intelligent manufacturing promotion mechanism, increasing fiscal and financial support, and deepening international exchanges and cooperation.

**Keywords:** new-generation intelligent manufacturing; basic paradigms; parallel promotion and integrated development

## 1 Introduction

In the 19th National Congress of the Communist Party of China, General Secretary Xi Jinping called for the acceleration of efforts to establish China as a major manufacturing power and to develop an advanced manufacturing industry. General Secretary Xi Jinping further noted the importance of integrating informatization and industrialization, as well as the need to drive the development of intelligent manufacturing, thus accelerating the development of digital, networked, and intelligent manufacturing industries. The *China Manufacturing 2025* plan has, at the national level, defined a strategy for establishing China as a major manufacturing power. Furthermore, it has been clearly stated that the historical transformation of China from a gigantic manufacturer into a world power in manufacturing will be achieved through the comprehensive integration of new-generation information technologies in manufacturing industries, with a focus on the promotion of intelligent manufacturing.

## 2 Intelligent manufacturing is the primary approach for establishing China as a major manufacturing power

Intelligent manufacturing is of utmost importance for the transformation and upgrading of China’s manufacturing industries. The Chinese economy is currently transitioning from a stage of rapid growth to a stage of high-quality development. The manufacturing sector is one of the most important components of the real economy and is the primary focus of supply-side structural reforms. Therefore, the optimization of industrial structures, transformation of development modes, and enhancement of quality and efficiency in manufacturing industries must be accelerated. The development of intelligent manufacturing has made significant headway since the implementation of *China Manufacturing 2025*. According to a sampling survey involving 1 815 enterprises in 10 cities around China, 73% of all industries have shown a strong interest in implementing intelligent manu-

**Received date:** August 20, 2018; **Revised date:** August 27, 2018

**Corresponding author:** Zang Jiyuan, E-mail: zangjiyuan@126.com

**Funding program:** CAE Advisory Project “Research on Intelligent Manufacturing Led by New-Generation Artificial Intelligence” (2017-ZD-08-03)

**Chinese version:** Strategic Study of CAE 2018, 20 (4): 001–008

**Cited item:** The Research Group for *Research on Intelligent Manufacturing Development Strategy*. Research on Intelligent Manufacturing Development Strategy in China. *Strategic Study of CAE*, <https://doi.org/10.15302/J-SSCAE-2018.04.001>

facturing. In another survey concerning intelligent manufacturing, it was found that the intelligentization of 308 projects in the period of 2015–2017 has, on average, improved productivity by 34%, enhanced energy efficiency by 17.2%, decreased overhead costs by 22%, shortened the research and development (R&D) period by 32.4%, and reduced product defect rates by 29.4%. Statistics have shown that investments in intelligentization upgrades in Guangdong, Jiangsu, and Zhejiang now account for over 70% of all industrial investment in these regions. This demonstrates that the enterprises of China have a strong need for intelligent manufacturing and possess the foundations to achieve greater heights of intelligentization.

Intelligent manufacturing has provided a historical opportunity to leapfrog developments in China's manufacturing sector. General Secretary Xi Jinping noted that this new round of technological and industrial revolution has formed a historical intersection with the acceleration and transformation of China's mode of economic development and has provided a rare and important opportunity for the implementation of innovation-driven development strategies. General Secretary Xi Jinping also noted that China will aim for the integration of internet technologies, big data, and artificial intelligence (AI) in the real economy, to create a large and powerful digital economy. Intelligent manufacturing will be the primary approach for driving the transformation and upgrading of China's industrial technologies, which will fundamentally transform the business models of the manufacturing sector. Old practices will be replaced with new practices, and stock reforms will be driven by incremental reforms, thus advancing China toward the high end of the global value chain.

Intelligent manufacturing is the path by which innovation-driven development and industrial transformation will be realized in the Chinese manufacturing sector. China must persist in making intelligent manufacturing the primary line-of-attack in establishing itself as a major manufacturing power and must drive the development of intelligent manufacturing to accelerate the realization of this national objective.

The formulation and implementation of strategies for the development of intelligent manufacturing in China must be accelerated. At present, China's efforts to establish itself as a major manufacturing power are moving ahead at full speed, and the realization of industrial intelligentization and transformation is urgently required in Chinese enterprises [1]. Although the importance of intelligent manufacturing in China's plans is well-established, a clear strategy for the development of intelligent manufacturing has yet to be formulated. A suitable technological roadmap is a core aspect that has yet to be addressed, and additional research and planning must be performed on the "whys, whats, and hows" of intelligent manufacturing. The understanding, direction of development, operational focal points, path selection, and implementation strategies of China's major industries in intelligent manufacturing are still plagued with ambiguities and misunderstandings. To drive the sustainable,

healthy, and rapid development of intelligent manufacturing in China, it will be necessary to gain an understanding of global technology trends and propose a strategy for the development of intelligent manufacturing that is suited to the domestic conditions of China. In the technological roadmap, it is necessary to clarify the strategic goals, directions, and priorities pertaining to intelligent manufacturing. This will accelerate the intelligentization and transformation of Chinese manufacturing, thus realizing the transformation of China from a large manufacturing nation into a power in the global manufacturing industry.

### 3 Basic paradigms, technological pathways, and systems of intelligent manufacturing

Intelligent manufacturing is an overarching concept and system that is continuously evolving. It represents the comprehensive integration of new-generation information technologies with advanced manufacturing techniques and is a form of optimization and integration that involves every process and system in the product, manufacturing, and service life cycles. This concept is the key for achieving the digitalization, networkization, and intelligentization of the manufacturing sector, which will drive further improvements in product quality, efficiency, and service levels in this sector and open a path toward innovative, green, cooperative, open, and mutually beneficial development [2, 3].

According to a review of the evolution and development of intelligent manufacturing, there exist three basic paradigms in the development of intelligent manufacturing: (1) digital manufacturing, i.e., first-generation intelligent manufacturing; (2) smart manufacturing, i.e., "Internet plus" manufacturing or second-generation intelligent manufacturing; and (3) digital-networked intelligent manufacturing, i.e., new-generation intelligent manufacturing (Fig. 1).

#### 3.1 Digital manufacturing

Digital manufacturing is the first basic paradigm of intelligent manufacturing, and it can also be called the first generation of intelligent manufacturing.

In the 1950s, digitalization led to the application of information technology in manufacturing industries, which gradually caused the focus of the manufacturing sector to shift from automation to digitalization. Digital manufacturing is the use of digital data to describe, analyze, and control product, process, and resource information through the integration of digitalization and manufacturing technologies to rapidly produce products that satisfy user requirements.

The primary features of digital manufacturing are as follows: (1) digital techniques are widely used to produce "digital era" products such as computer numerical control machines; (2) digital equipment, digital design, and digital modeling and simulation are used broadly in production processes, along with

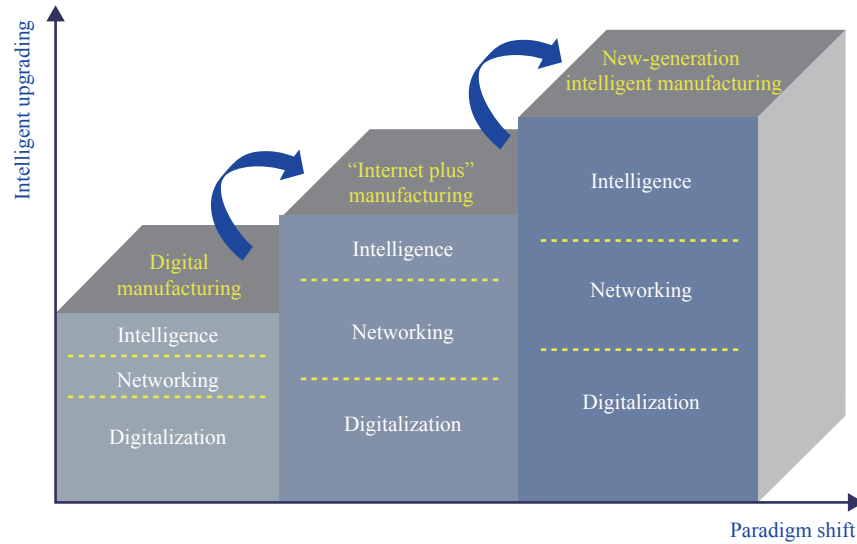


Fig. 1. Evolution of the basic paradigms in intelligent manufacturing

information management; (3) the production processes strongly feature integration and optimized operation.

Digital manufacturing has been gradually adopted by Chinese enterprises since the 1980s. This has led to the digitalization of design, production, and management processes, the popularization of digital control systems and manufacturing equipment, and the introduction of enterprise informatization. Tremendous technological advancements have been realized in this manner [4]. In recent years, “robotization” and “digital renovation” have been strongly promoted in various regions, which have led to the construction of many digital production lines, workshops, and factories. Numerous industries have been upgraded to digital manufacturing, and digital manufacturing in China is now entering a new stage of development. However, most Chinese enterprises (especially small and medium-sized enterprises) have yet to complete their transition to digital manufacturing. Thus, China must take a pragmatic approach to promoting intelligent manufacturing and take the necessary steps to close the gap in digitalization, thus establishing a strong foundation for further developments in intelligent manufacturing [5].

### 3.2 “Internet plus” manufacturing – smart manufacturing

Smart manufacturing is the second basic paradigm of intelligent manufacturing and is also known as “Internet plus” manufacturing or second-generation intelligent manufacturing.

Internet technologies have progressively matured since the end of the 1990s. In China, “Internet plus” is promoting a deep level of integration between the Internet and the manufacturing sector; previously independent “nodes” (e.g., people, processes, data, and objects) are now linked together through the Internet. Through intra- and inter-enterprise cooperation, many societal resources have been integrated and optimized. The “Internet plus” manufacturing paradigm has also reformed the value chain

of the manufacturing sector, and it is driving the transition of this sector from digital manufacturing to smart manufacturing.

The primary manifestations of the “Internet plus” manufacturing paradigm are as follows. (1) According to the application of digital technologies, Internet technologies have become ubiquitous, leading to the production of networked products. Collaboration and sharing in design and R&D are also common. (2) In manufacturing, supply chain, value chain, and end-to-end integration has been achieved through intra-factory integration. Additionally, the data and information flows of manufacturing systems have become interconnected. (3) Internet platforms facilitate connections and interactions between users and enterprises in every stage of the product/service life cycle (i.e., design, manufacturing, logistics, sales, and maintenance), and manufacturing models have transitioned from product-centered models to user-centered models.

The industrial world of China is taking advantage of the strategic opportunities afforded by the development of the Internet to promote the “Internet plus” paradigm. This has resulted in the widespread deployment of new technologies such as the Industrial Internet and cloud computing in the manufacturing sector by leading Chinese manufacturing industries and internet enterprises. The foundations laid by digital manufacturing have therefore facilitated the successful transition of many enterprises to smart manufacturing, and these enterprises are now pioneers in intelligent manufacturing. In addition, many of the enterprises that have not completed their transition to digital manufacturing have taken a technological pathway where digital manufacturing and “Internet plus” manufacturing are being developed in parallel. That is, the enterprises of China are closing the gap in digital manufacturing and leapfrogging into the “Internet plus” stage through an integrated form of development, where advanced technologies are used to solve problems in conventional manufacturing, thus improving their overall level of development.

In the “Industrie 4.0” initiative of Germany and the Industrial Internet of the United States, the smart paradigm in manufacturing is clearly explained, and these plans provide well-defined technological roadmaps for the implementation of smart manufacturing. However, as these plans were proposed before strategic breakthroughs had been achieved in new-generation AI, they are not true manifestations of the “fourth industrial revolution,” as they do not account for new-generation intelligent manufacturing. The application of the aforementioned plans is therefore limited to the smart manufacturing paradigm. A tremendous historic opportunity has therefore been presented for the Chinese manufacturing industry to surpass the traditional leaders of the global manufacturing industry.

### 3.3 New-generation intelligent manufacturing – digital-networked intelligent manufacturing

Digital-networked intelligent manufacturing, i.e., new-generation intelligent manufacturing, is the third basic paradigm of intelligent manufacturing and is internationally referred to as “intelligent manufacturing.”

In recent years, the Internet, cloud computing, big data, and the Internet of Things have developed at a breakneck pace, leading to numerous breakthroughs that have driven the rapid development of new-generation AI technologies (e.g., big data intelligence, cross-media intelligence, human-machine hybrid-augmented intelligence, and crowd intelligence), leading to a strategic breakthrough [6]. The holistic fusion of new-generation AI technologies and advanced manufacturing technologies will lead to a new generation of intelligent manufacturing, i.e., digital-networked intelligent manufacturing. The defining feature of new-generation AI is the capability to learn, generate knowledge, and use knowledge with an unprecedented level of efficacy, which will undoubtedly lead to tremendous advances. New-generation intelligent manufacturing will cause fundamental changes in the integration of manufacturing and its design, as well as related service processes. New technologies, products, business models, and operational models will begin to emerge, which will irreversibly change the products, production modes, service models of society and even the ways in which people live and think. These changes will subsequently drive significant developments in societal productivity. New-generation intelligent manufacturing is therefore a revolutionary step forward for the manufacturing sector and will become a key driver in the development of China’s manufacturing industries [1].

### 3.4 Technological roadmap for the “parallel promotion and integrated development” of intelligent manufacturing in China

The three basic paradigms of intelligent manufacturing are manifestations of the staged and integrated nature of

intelligent manufacturing development. These basic paradigms develop one after another, in chronological order. That is, each level of technological development and industrial integration will exhibit its own set of characteristics and key challenges owing to the staged nature intrinsic to the integrated development of advanced information technologies and manufacturing techniques. However, the three basic paradigms of intelligent manufacturing are not clearly distinct from a technological aspect, as the technologies of each paradigm are intertwined and interconnected by iterative improvements, such that the development of one paradigm is inevitably linked to the development of another. This embodies the integrated nature of intelligent manufacturing development [1].

China should leverage its late arrival advantage and concurrently develop all three basic paradigms in an integrated manner. China will therefore tread a new path toward intelligent manufacturing, where digital, networked, and intelligent manufacturing are developed in parallel, thus driving Chinese manufacturing industries toward high-quality development. First, China must persist with an “innovation-led approach” where advanced technologies such as the Internet, big data, and AI are used to drive the comprehensive integration of advanced information technologies and manufacturing techniques. Second, China should aim for high-end manufacturing and accelerate the development and application of new-generation intelligent manufacturing technologies. Third, a pragmatic and adaptable approach should be taken to gradually drive technological reforms and intelligentization upgrades in Chinese enterprises. The experiences gained from the successful implementation of “Internet plus” manufacturing in China should be thoroughly utilized. Chinese enterprises should, according to the needs of their development, use advanced technologies to solve difficulties encountered in conventional manufacturing and complete their digital “remediation” in a pragmatic manner while aiming for greater heights in intelligent manufacturing.

In the next stage, the promotion of intelligent manufacturing in China should focus on the large-scale promotion and application of “Internet plus” manufacturing, i.e., smart manufacturing. Beyond 2025, with the generalization of the “Internet plus” paradigm and the maturation of new-generation intelligent manufacturing technologies, the focus of China’s drive toward intelligent manufacturing will shift to the large-scale popularization and application of new-generation intelligent manufacturing.

### 3.5 New-generation intelligent manufacturing system

The new-generation intelligent manufacturing system is an overarching system formed by the combination of two major support systems (the industrial Internet of Intelligence and the intelligent manufacturing cloud) and three major functional sys-

tems (intelligent products, intelligent production, and intelligent services), as shown in Fig. 2.

Intelligent products and intelligent manufacturing equipment are the main embodiments of the new-generation intelligent manufacturing system. Intelligent products are the value carriers of intelligent manufacturing and services, while intelligent manufacturing equipment forms the technological premise and material basis for the implementation of intelligent manufacturing. New-generation intelligent manufacturing will create a limitless space for innovations in product and manufacturing equipment design and lead to revolutionary changes in these aspects.

Smartphones and smart vehicles are classic examples of intelligent products: the recently launched iPhone X and Huawei Mate10 are already equipped with dedicated AI chips that have learning capabilities. In the near future, new-generation AI will become widely utilized in smartphones and will thus revolutionize these products. Cars, for example, have developed from petrol cars into electric cars (digitalization) and then into connected cars (networkization); car development is now moving rapidly toward self-driving cars (intelligentization).

New-generation intelligent manufacturing technologies will allow innovations in products and equipment to take flight and create greater space for growth and development. By 2035, the products and manufacturing equipment of China will transition from the “digital era” to the “smart era” through their intelligentization. This will lead to the appearance of advanced intelligent products such as smart terminals, smart appliances, intelligent service robotics, and smart toys, which will further improve quality of life. In addition, by driving the intelligentization and upgrading of heavy equipment in key industries (e.g., computer-manufacturing equipment, aerospace equipment, ship and marine equipment, vehicular and rail transportation equipment, agricultural equipment, medical equipment, and energy production

equipment) and developing intelligent manufacturing equipment (e.g., intelligent robots and intelligent machine tools), the “pillars of China” will become even more advanced and powerful owing to the incorporation of “industrial brains.”

In the short-term, China should focus on achieving breakthroughs in the following intelligent products: intelligent industrial robots, intelligent machining centers, autonomous drones, intelligent ships, intelligent cars, intelligent trains, intelligent excavators, smart medical devices, smartphones, and smart appliances.

Smart production represents the front line of new-generation intelligent manufacturing systems, while smart factories are the main vehicles for smart production. Smart factories are generally categorized either as discrete manufacturing or process manufacturing factories, depending on the industry in question. In all cases, the objective of smart factories is to optimize production processes and greatly improve the performance, functionality, quality, and efficiency of their production systems. The most important directions for development in this respect are intelligent production lines, smart workshops, and smart factories.

The fusion of new-generation AI technology and advanced manufacturing technologies will revolutionize production lines, workshops, and factories, and the relevant enterprises will advance toward self-learning, self-adaptive, and autonomously controlled new-generation smart factories. Technological improvements and intelligentization-based upgrades in enterprise productivity through “robotic replacements” will solve shortages in labor and increases in labor costs and fundamentally improve the quality, efficiency, and competitiveness of the manufacturing sector. In the coming period, improvements in the production capacity of Chinese enterprises through the intelligentization and upgrading of production lines, workshops, and factories will be the main arena for the promotion of intelligent manufacturing.

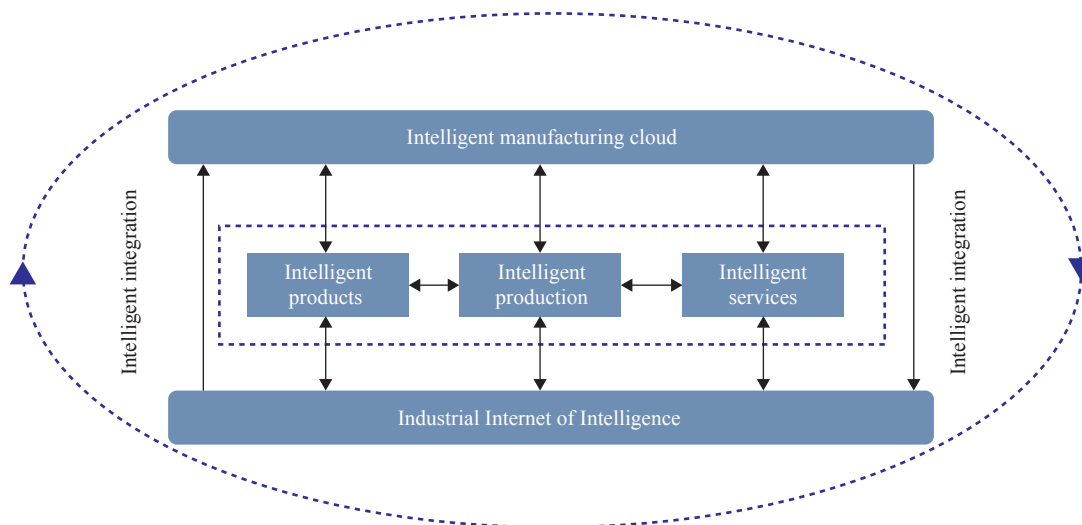


Fig. 2. New-generation intelligent manufacturing system

Process industries are of fundamental strategic importance in the Chinese economy, as they have highly concentrated production systems and strong digital and network foundations; these are the most likely industries to make a breakthrough in new-generation intelligent manufacturing. For example, the establishment of digital, networked, and intelligent production and operations management systems in smart petrochemical factories can greatly improve the optimization of production processes, safety, and environmental compliance.

Intelligent discrete manufacturing factories will use new-generation AI technologies to enhance machining quality, machining process optimization, machining equipment maintenance, and the intelligent adjustment and management of production, thus establishing intelligent factories in the true sense.

In the short-term, China should focus on the establishment of smart factories in the following 10 industries: steel; electrolytic aluminum; petrochemicals; coal chemicals; wine, vinegar, and soy sauce brewing; 3C machining; thin-film transistor manufacturing; automotive panel stamping; three-dimensional printing-based casting; and household appliance manufacturing.

Production models and business transformations based on intelligent services represent an important theme in the new-generation intelligent manufacturing system. The use of new-generation AI technologies will lead to a fundamental shift in the manufacturing sector, from a product-centered approach to a user-centered approach. Production models will change from large-scale assembly line production to large-scale customized production, while industries will shift from production-oriented manufacturing to production and service-oriented manufacturing, thus completing the transformation of supply-side structures.

In the short-term, the promotion of large-scale custom production should be prioritized in the home appliances, furniture, and clothing industries, while the introduction of remote operations and services should be prioritized in the aircraft engine, high-speed rail equipment, general rotating machine, power generation equipment, construction machinery, lifts, and utility monitoring and control system industries.

The intelligent manufacturing cloud and the industrial Internet of Intelligence are important support systems for the new-generation intelligent manufacturing system. Internet and cloud technologies will drive the transformation of the manufacturing sector from digital manufacturing toward networked and intelligent manufacturing, and the focal points for this development are the “Internet of Intelligence,” “cloud platforms,” and “network security.”

Through system integration, the functional and support systems of intelligent manufacturing will be combined to form the new-generation intelligent manufacturing systems. System integration is the most fundamental aspect and advantage of new-generation intelligent manufacturing, as it features prominently in its internal and external structures. The characteristics

of new-generation intelligent manufacturing will therefore include concentration and distribution, coordination and precision, and tolerance and sharing.

## 4 Strategy for development of intelligent manufacturing in China

The next 20 years will be a crucial period for the transformation of the Chinese manufacturing sector into a major manufacturing power and for the sector to undergo changes in quality, efficiency, and growth drivers. We must seize the strategic opportunity introduced by this new round of scientific and industrial revolution to establish China as a major manufacturing power. This will be achieved by transforming supply-side structures through intelligent manufacturing. A strategy for the development of intelligent manufacturing in China must be formulated through scientific research, and China must stay on the path of “parallel promotion and integrated development.” By establishing an innovation chain in the industry chain and refining capital chains according to the needs of the innovation chain, a deep level of integration and a mutually beneficial feedback cycle will be established between the economy and the fields of technology and finance. In this way, intelligentization and leap-frog development will be achieved in the Chinese manufacturing sector.

### 4.1 Strategic goals

Over the next 20 years, the development of intelligent manufacturing in China will be realized in two stages.

In the first stage (up to 2025), “Internet plus” manufacturing (smart manufacturing) will be deployed on a large scale throughout the country and will become generalized in developed regions and key industries. Meanwhile, new-generation intelligent manufacturing projects will be piloted in various key areas and promoted in some industries.

In the second stage (up to 2035), new-generation intelligent manufacturing will be deployed on a large scale in manufacturing industries around China. China will lead the world in intelligent manufacturing technologies and their application, and the transformation and upgrading of the Chinese manufacturing sector will be realized. The overall level of the manufacturing sector will reach the advanced world standard, with some industries being at the world-leading level. This will establish a robust foundation for China to become a world leader in the global manufacturing industry by 2045.

### 4.2 Strategic approach

Over the next 20 years, the development of intelligent manufacturing in China must adhere to a “needs-guided, innova-

tion-driven, adaptable, and industry upgrade-focused” strategic approach to achieve the transformation and intelligentization of Chinese manufacturing industries.

**Needs-guided development:** Needs represent the greatest driver of development. High-quality development and supply-side transformation in the manufacturing sector have created an intense need for intelligentization and upgrading. Intelligent manufacturing should therefore serve the strategic needs of China by servicing the transformation and upgrade needs of the manufacturing sector. As Chinese enterprises are the main embodiment of economic development and intelligent manufacturing, the development of intelligent manufacturing must satisfy enterprise needs with regard to product digitalization, networkization, and intelligentization, manufacturing processes, and services, as well as enterprise needs for quality and efficiency improvement and sustainable development.

**Innovation-driven development:** To achieve the intelligentization and transformation of the Chinese manufacturing sector, we must seize the opportunities introduced by the integration of new-generation AI technologies in the manufacturing sector. The development of intelligent manufacturing should be used as the main approach for transforming and upgrading China’s manufacturing sector, and innovations should be applied to continuously create new breakthroughs and pull the Chinese manufacturing sector in tow, until it reaches the forefront of the manufacturing world. This is the key to overtaking other countries in the global manufacturing industry and achieving leapfrog development.

**Adaptable development:** The enterprises of China must be the focus of China’s drive to promote intelligent manufacturing, and the realization of enterprise transformation and upgrading must be the primary objective of this endeavor. However, the development of China’s enterprises is highly heterogeneous, and it is not possible to use a “one size fits all” approach in the intelligentization and transformation of these industries. It is also inadvisable to forcefully push for intelligent manufacturing or adhere to foreign approaches. Regarding China’s enterprises (especially the small-and-medium enterprises (SMEs), which constitute the majority), intelligent manufacturing development must be based on the actual state of development of each enterprise, and each enterprise must search for a technological pathway toward transformation and upgrading that suits its requirements. China must seek to inspire its enterprises to undertake intelligentization and assist them in this endeavor, especially the SMEs.

**Industry upgrade-focused development:** The goal of China’s efforts to promote intelligent manufacturing is to upgrade its industries. This effort must focus on all enterprises and industries, especially the manufacturing sector. Government, technological, academic, and financial sectors must work together to create a healthy ecosystem for promoting changes in the quality, efficiency, and growth drivers of the Chinese manufacturing sector to achieve the holistic modernization, transformation, and upgrading of China’s manufacturing sector.

### 4.3 Development pathway

At the strategic level, the development pathway for intelligent manufacturing is as follows: overall planning – breakthroughs in key areas – staged implementation – comprehensive advancement.

At the national level, a top-level design and overall plan for the development of intelligent manufacturing should be formulated to define the strategic goals and priority tasks of each level. Economically developed regions, key industries, and key enterprises should focus on accelerating breakthroughs in key areas and take the lead in piloting new technologies to lead other industries by example. The influence of key breakthroughs should be expanded through a staged implementation, from enterprises (points) to cities (lines) and finally to regions (surfaces). On this basis, key breakthroughs should be spread across the country according to the conditions of each region/city/enterprise at full speed, until their implementation is fully generalized.

At the tactical level, the development pathway for intelligent manufacturing is as follows: exploration – pilot tests – promotion – generalization. According to our experience in promoting digital manufacturing over the last few years, this is a rational and effective path for development. Exploration is necessary for confirming the viability of applying a new technology in industry. After the viability of a technology has been confirmed, the technology may be piloted in a few enterprises. Pilot tests allow for the detection of problems in the application phase and for the resolution of these problems. In addition, they allow other enterprises to observe the benefits of intelligentization and transformation and thus inspire an internal source of motivation. This is followed by popularization, which expands the range of applications of the technology. Additional problems can be found and resolved, which increases the maturity of technical, equipment, and system solutions. The full-scale deployment of the technology in all regions and industries of China is finally accomplished through generalization. This stepped and gradual form of implementation is highly adaptable and helps to minimize risk while ensuring high success rates. It is therefore a sustainable and effective path for the implementation of new technologies.

At the organizational level, a new ecosystem for growth should be created through the cooperation of industry, academic, financial, and government institutions, thus creating an organized form of innovation. The development of intelligent manufacturing must be driven by enterprise needs. Hence, manufacturing enterprises play a central role in intelligent manufacturing development. An industry cluster must be formed among system integrators, equipment and software suppliers, and technology and product development research institutes to ensure the technological success of intelligent manufacturing development and to satisfy the requirements of the Chinese enterprise world. New business models should be established by financial institutes to financially safeguard Chinese enterprises through finance leasing

or financing guarantees. The government should formulate policies to create a fertile entrepreneurial environment by forming industry clusters to invite investment, reduce the investment risks of financial institutions, and create favorable conditions for talent recruitment. In this way, the strength of all parties involved in intelligent manufacturing can be concentrated to implement an organized form of innovation.

## **5 Institutional safeguards and policy recommendations**

### **5.1 Enhance and implement mechanisms for promotion of intelligent manufacturing**

The role of the “Leading Group for Building China into a Manufacturing Power” in leading and coordinating the promotion of intelligent manufacturing should be strengthened and fully utilized to highlight the importance of intelligent manufacturing and to coordinate each government department in the promotion of intelligent manufacturing. The aim is to form a system consisting of the central government, local governments, and Chinese enterprises to lead, organize, and implement intelligent manufacturing in a systematic and pragmatic manner, according to the national strategy. Intelligent manufacturing should act as a point of convergence for the integrated development of the economy and for the technology and finance sectors, thus promoting the integration of these entities to form a mutually beneficial feedback cycle. In this way, an ecosystem for intelligent manufacturing will be formed through the alignment of industry, academic, financial, and government sectors.

### **5.2 Improve fiscal support for intelligent manufacturing development**

First, government investment in intelligent manufacturing should continue to increase. Several measures should be undertaken to support the key processes of intelligent manufacturing development, while various national-level science and technology projects and plans should be initiated to increase support for intelligent manufacturing. Support for key national projects should also be increased. Special incentives should be given to enterprises that have been awarded key projects (e.g., national intelligent manufacturing projects and “strong industrial base” projects) in the current year, according to the principles of territoriality.

Second, the “Incentive Funds for Technological Reform” should be used to drive the implementation of intelligent manufacturing. Intelligent manufacturing should represent the primary direction of technological reforms, while enterprise digitalization, networkization, and intelligentization reforms should be supported through equity investments, discounts, and compensation. In this way, investments in the technological reforms of

Chinese enterprises will represent the primary form of industrial investment.

Third, supportive policies such as tax incentives should be implemented. Enterprises that satisfy the prescribed conditions should be able to enjoy preferential corporate income tax rates and import duties. Policies for the accelerated depreciation of fixed assets should be implemented, and tax relief should be provided. Project investments in intelligentization-related technological reforms should be included in R&D tax deductions, and a tax refund system should be established. For intelligentization and technological reform projects, a portion of the increase in income tax resulting from the completion and deployment of these projects should be refunded to provide an additional financial incentive.

### **5.3 Improve financial support for intelligent manufacturing development**

The service capacity of modern financial services should be enhanced to ensure the harmonious development of the real economy, technological innovations, modern finance, and human resources. This is especially important for realizing the transformation of growth modes in the real economy, accelerating structural transformations, and improving industry and international competitiveness. In addition, this will resolve financing difficulties in the Chinese manufacturing sector and promote the return of financial capital to the real economy.

The guiding effect of national financial investments should be utilized to attract capital from the enterprise world and society, and a diversified investment and financing system should be established for intelligent manufacturing. Credit support should be improved by guiding financial institutes to prioritize credit support for intelligent manufacturing projects that are technologically advanced, clearly superior, and have the potential to drive and support other forms of development. Support should be given to the creation of novel financing models and products through finance, investment, credit/finance guarantees, financial leasing, and microfinance institutions according to the needs of equipment manufacturing enterprises, systems solution providers, and users. Methods such as installment payments and financial leasing may be used to support the producers of intelligent manufacturing equipment, as well as the development of new forms of business, new operational models, and new applications. The establishment of various grants for intelligent manufacturing development based on a market-oriented mode of operation should be encouraged, and financial institutes should be actively guided to create products and services that suit the needs of intelligent manufacturing, in accordance with the law. Venture capital investments and stock investments in intelligent manufacturing by citizens should also be encouraged. The proportion of direct financing for manufacturing enterprises should be increased. The issuance of corpo-



rate bonds, short-term financing bills, and medium-term notes by enterprises in key areas of the manufacturing sector should be actively encouraged and supported if they fulfill the requisite conditions. The financing of manufacturing enterprises through initial public offering listings and National Equities Exchange and Quotations financing should be supported to expand the channels for corporate entity financing.

Under the premise of a controllable level of risk, financial institutes should offer intellectual property pledge loans related to intelligent manufacturing or portfolio loans and credit loans guaranteed by intellectual property pledges, as well as other innovative non-pledged loan products. This will expand the range of loan collateral available to intelligent manufacturing enterprises and other related enterprises.

#### 5.4 Improve international exchanges and collaborations

The establishment of a dialogue mechanism for high-level collaborations involving intelligent manufacturing with the cooperation of other governments should be accelerated. International exchanges and collaborations should be initiated to formulate standards and intellectual property rights in intelligent manufacturing. Exchanges and collaborations between domestic and international enterprises and industry associations in intelligent manufacturing technology should be supported to establish collaborations for attracting investment, technologies, and talent. Multinational companies and foreign institutes should be encouraged to establish R&D institutes and talent development centers in China and to construct pilot intelligent manufacturing factories and industrial parks. Additionally, domestic enterprises should be encouraged to participate in international mergers and acquisitions and to join cutting-edge foreign R&D endeavors. This will allow these enterprises to gain an understanding of key intelligent manufacturing technologies and gradually move toward independent development. The establishment of international alliances in intelligent manufacturing should be actively pursued, and academic exchanges should be initiated (through the World Intelligent Manufacturing Summit and International

Intelligent Manufacturing Conference, for example). A market and enterprise-oriented approach should be maintained during the development of intelligent manufacturing in China. In this way, a greater level of openness will be achieved in intelligent manufacturing.

#### 5.5 Introduce recommendations for development of intelligent manufacturing as soon as possible

The *Guiding Opinions about the Promotion of Intelligent Manufacturing to Accelerate the Transformation of China into a Major Manufacturing Nation* should be formulated as soon as possible to clarify the significance and basic position of intelligent manufacturing and to define the overall needs, development strategy, main objectives, and support and safeguards for intelligent manufacturing in China. This will allow for the implementation of priority actions in intelligent manufacturing and the mobilization of all citizens in driving the development of intelligent manufacturing, thus contributing toward efforts to establish China as a major manufacturing power.

#### References

- [1] Zhou J, Li P G, Zhou Y H, et al. Toward new-generation intelligent manufacturing [J]. *Engineering*, 2018, 4(1): 11–20.
- [2] Zhou J. Intelligent manufacturing—Main direction of “Made in China 2025” [J]. *China Mechanical Engineering*, 2015, 26(17): 2273–2284. Chinese.
- [3] National Manufacturing Strategy Advisory Committee, the CAE Center for Strategic Studies. *Intelligent manufacturing* [M]. Beijing: Publishing House of Electronics Industry, 2014. Chinese.
- [4] Wu C, Li B H. From computer integrated manufacturing to contemporary integrated manufacturing—Also about the systematic character of CIMS in China [J]. *Computer Integrated Manufacturing Systems*, 1998 (5): 1–6. Chinese.
- [5] Zhou J. Digitalization and intelligentization of manufacturing industry [J]. *Advances in Manufacturing*, 2013 (1): 1–7.
- [6] Pan Y H. Heading toward artificial intelligence 2.0 [J]. *Engineering*, 2016, 2(4): 409–413.