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Development Path of China's Industrial Software Industry in the New Era

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Abstract: The industrial software industry is crucial for the high-quality development of the manufacturing industry. Against the backdrop of strengthening China's manufacturing industry in the new era, industrial software development is becoming a direct driving force for optimizing manufacturing and management processes, transforming production methods and relations, improving total factor productivity, and promoting the spillover and transformation of advanced industrial technologies. China is currently building an independent, controllable, safe, and efficient modern industrial system, which challenges the original "technology–production–market" division of labor and creates important opportunities for developing the industrial software industry. Considering the current international market structure, this study analyzes the basic characteristics and market share of industrial software products as well as the shortcomings and problems of China's industrial software industry development. Further, it summarizes two new development trends in the industrial software industry: platform-based and open-source development. Based on this, we propose the following three development paths: (1) improving weak links while strengthening basic research, (2) making technical breakthroughs to catch up with the international advanced level, and (3) leading the development with frontier technologies, thus hoping to address the industrial deficiencies and improve the industrial level. Furthermore, we propose several suggestions. First, the organizational model should be optimized to maximize the leading role of industrial enterprises. Second, the policy objective should be refined to promote the breakthrough of key technologies regarding industrial software at different levels. Third, the application market needs to be expanded to promote the innovation of industrial software products. Fourth, it is necessary to tap and support the cultivation of industrial software talents through multiple channels.

Keywords: industrial software; system integration; industrial bottlenecks; leading the development with frontier technologies

1 Introduction

Industrial software refers to the software applied in industry. As an important part of the basic industrial capacity and optimization of the manufacturing industry, software supports the high-quality development of China's manufacturing industry. The independent control of industrial software is an important foundation of industrial development and information security. Considering its development and long-term needs, the state has put industrial software on a par with petroleum and natural gas, basic raw materials, high-end chips, and crop seeds and called for the management of key and core technologies. The 14th Five-Year Plan clarifies the development

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goal of implementing a manufacturing power strategy in the new period and presents new and higher requirements for developing industrial software, which is an important basic tool of manufacturing power.

For a long time, the development of China's industrial software industry has faced pressure from two sides: it is hindered by its own development dilemma and is directly impacted by international industrial software products. Research on the development of the industrial software industry focuses on the interaction between various industries and the software industry. For example, the competitive advantage of industrial software enterprises comes from the distribution and location of innovation nodes in the innovation network [1], and the resource advantage of platform enterprises can significantly improve the efficiency and innovation ability of enterprises [2]. Considering the particularity of the industrial software industry, some studies have analyzed the development trend and influencing factors of the industrial software industry by focusing on topics such as information technology services [3], integration of the two industries [4], industrial Internet [5], and the intelligent factory [6]. The results of these studies indicate that intelligent manufacturing, industrial Internet [7], autonomous development [8], and the Internet of Things (IoT) [9] are closely related to industrial software. Other studies suggest that industrial software is reshaping manufacturing [10]. Owing to the fundamental and load-bearing properties of industrial software in design and manufacturing activities, once link and safety problems occur [11], the relevant shortcomings will negatively affect national industrial security [12]. As an important basic tool of manufacturing power, the development of industrial software has presented new and higher requirements.

Industrial software is the innovative driving force of manufacturing development, driving manufacturing and management process optimization, production mode and relation transformation, total factor productivity improvement, and advanced industrial technology spillover and transformation, thus promoting the industrial system from equipment-centered to software-defined. To accelerate the transformation of the manufacturing industry into intelligent, service-oriented, and ecological development and realize the optimization and upgrade of the industrial software industry, this study comprehensively analyzed the important position of industrial software in domestic strategy and international competition. It also expounded on the development status and trend of industrial software from two aspects: industrial scale and international manufacturers. Further, it clarified the main challenges and opportunities in developing China's industrial software industry and presented the development path of China's industrial software industry to provide a basic reference for industry development research.

2 Important role of industrial software industry in strengthening manufacturing power

2.1 Independent and controllable development in industry

Since the reform and opening up, China's export-driven economic development model has objectively made technology, markets, and other important links in industrial production depend on foreign economic entities. The comparative advantage of China's participation in the international division of labor gradually changes from factor price to the scale of the production network. The rapid change in the international market also has an unpredictable impact on the production network. In recent years, the world economy has undergone structural changes, and the COVID-19 pandemic has led to the shrinking of global markets and rising protectionism. To strengthen China's initiative in the reglobalization reform, it is necessary to form a new development pattern with domestic major cycles as the main body and domestic and international double cycles promoting each other. During the 14th Five-Year Plan period, it is necessary to strengthen the industrial infrastructure capacity and weak links of basic software and other bottlenecks through the reconstruction of industrial infrastructure.

Cloud computing, IoT, next-generation mobile communications, artificial intelligence (AI), blockchain, and other new-generation information technologies are developing rapidly and becoming applications. The manufacturing industry is moving in the direction of digitization, networking, and intelligence, and the industrial system is transforming from equipment-centered to software-defined. Industrial software, referred to as "the wisdom of industry," is the software of industrial basic knowledge and the basic resource for implementing industrial activities. It is fundamental and has a carrying capacity in design and manufacturing activities. Industrial software involves the deep cross and integration of advanced industrial manufacturing technology, engineering management, computers, software, etc. Meanwhile, the innovation of the software industry has a significant network effect, and its development depends on the interaction between industries and the software industry. The competitive advantage of industrial software enterprises comes from the distribution and location of innovation nodes in the innovation network [1], and the advantages of platform enterprise resources can greatly improve enterprise efficiency and innovation ability. In general, the development of industrial software is intended to develop the industrial foundation and strengthen the construction of industrial basic capacity. The independent

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control of industrial software is the basic guarantee of industrial security and information security, which is of great significance to the in-depth implementation of manufacturing strategic power.

The high-quality development of the manufacturing industry has presented new requirements for China's industrial system, and the original technology–production–market division of labor is facing new challenges. The international supply risk of industrial software in China's industrial system is increasing, and the domestic and foreign division structure of scientific and technological innovation activities (represented by industrial software) is undergoing a functional transformation. The emergence of these situations provides a valuable window of opportunity for optimizing and upgrading China's industrial software industry. Recently, globalization has encountered countercurrents: the World Trade Organization and other multilateral trading systems are facing challenges, and individual countries have conducted malicious attacks on China's high-tech fields (industrial software has become an important means of repression). This indirectly reflects the potential role and influence of industrial software in the national economy and industrial security.

2.2 Important growth point for a strong manufacturing country

International brands or large enterprises divide their businesses in the international consumer market according to the characteristics of product demand: large multinational enterprises integrate global supply chains; leading technology enterprises focus on research and development (R&D) and design while providing supporting industrial software and services; and domestic enterprises import raw materials and high-end parts, complete parts manufacturing and system integration in China, and then realize whole or partial sales and circulation into overseas consumer markets. As far as China is concerned, the entire cycle is manifested as an international dependence structure. Therefore, China needs to ensure a smooth domestic major cycle, realize the industrial loop of the industrial cycle, perceive the demand of the international market, absorb international raw materials, and provide products and services to the international cycle through the construction of digital infrastructures such as industrial software to make up for the lack of capacity in R&D, design, intelligent manufacturing, and other links to strengthen its manufacturing power under double-cycle conditions.

Manufacturing powers emphasize fostering a sound industrial ecology and giving full play to the advantages of super-large markets and the potential of domestic demand. In 2020, China's industry-added value exceeded 38 trillion CNY [13], and the huge industrial scale created a considerable demand for industrial software. However, compared with developed countries, there is a large gap in the size of China's industrial software market, which is less than 10% of the global total, and the industrial software sales volume is far lower than that of developed countries. For example, in 2018, China's industry-added value accounted for nearly 30% of the world total, while the industrial software market size accounted for only approximately 6% of the world total; there is a clear mismatch. In the medium and long terms, China will stride steadily from a large to a strong manufacturing power. The rapid industrial transformation and upgrade will certainly bring broad growth space for the industrial software industry, and China's industrial software industry is expected to usher in a huge "blue ocean" market. The industrial software industry has a clear scale market advantage and domestic demand potential, and its importance is expected to be further manifested.

3 Development status and technology trend of international industrial software

3.1 Development status

In the *Guidance Catalogue for Key Products and Services of Strategic Emerging Industries* (2016 edition), industrial software is divided into four categories: R&D design, production control, operation management, and industrial Internet platform and industrial application. From the perspective of the global industrial software market pattern, US and European enterprises are in the leading position, steering the development direction of technology and industry. The most critical R&D and design software in the field of discrete manufacturing is mainly controlled by Dassault Systems Group (France), Siemens Industrial Software Co., Ltd. (Germany), ANSYS Co., Ltd. (USA), and Hexagon Group (USA). The high-end market for production control software is mainly occupied by Siemens Industrial Software Co., Ltd., Omron Group (Japan), Honeywell International (USA), and Aspen Technology Co., Ltd. (USA). The high-end market for management and operations software is mainly occupied by SAP (Germany) and Oracle (USA). In addition, in computer-aided design (CAD) software, international manufacturers have mature technology and obvious advantages, represented by Dassault Systems Group, Siemens Industrial Software Co., Ltd., and Parameter Technology Company (USA); in terms of computer-aided engineering (CAE) software, international manufacturers have perfect product lines and are in a monopoly

position, while there is no large-scale software for sustainable development and maintenance in China. In terms of electronic design automation (EDA) software, Simus Technology Co., Ltd. (USA), Kaideng Electronics Co., Ltd. (USA), and Mingdao International Co., Ltd. (USA) have monopolized the market, and Chinese enterprises cannot provide digital full-process solutions to meet the needs of high-end chip design.

The global industrial software market is relatively stable. US companies are numerous and have a strong comprehensive strength, and German, French, UK, Swedish, Dutch, Swiss, Italian, and other countries' enterprises are quite prominent. Some companies from Japan, South Korea, and India cannot be ignored. With the development of AI and the popularization of IoT technology, the industrial software application field is also expanding, with the emergence of several industrial IoT platforms (such as Predix, Mindsphere, Thingworx, Cumulocity, Uptake, and ADAMOS). Further, mergers and acquisitions and the integration of industrial software enterprises are extremely dynamic. Mainstream companies that used to focus on segmented fields constantly acquire cross-professional software companies and pay equal attention to mergers and acquisitions as well as independent development. For example, Siemens Industrial Software Co., Ltd. has invested over 10 billion USD overseas in the past decade, acquired many industrial software companies (involving UGS, Mentor, LMS, CD-Adapco, Mendix, and other products), and become a comprehensive industrial software enterprise.

Industrial manufacturing has become an important field of international industrial competition and cooperation. The R&D and manufacturing of industrial products are inseparable from industrial software; therefore, industrial software is one of the important links in the advanced industrial foundation and modernization of the industrial chain [14]. The development of the industrial software industry can be divided into three stages: the software development itself, collaborative application of software (i.e., the stage of colluding and optimizing business processes), and industrial cloud, that is, software companies change from providing customers with a single tool to providing customers with a "software + services" overall solution. At present, international manufacturers have entered the third stage. Taking R&D and design software as an example, they have realized the technology accumulation of the software itself, realized the application collaboration of software in industrial practice, and are focusing on developing the overall solution of "software + service." In contrast, the overall solution capability of domestic enterprises is still obviously insufficient, and there are only a handful of domestic enterprises with industry advantages. The overall state can be summarized as strong management software, weak engineering software, more low-end software, and less high-end software.

3.2 Technology trends

3.2.1 Accelerating the realization of industrial software platforms

The manufacturing industry is in the transition stage from digitization to networking, and the industrial software platform is the core of innovation and development in this stage. Traditional independent industrial software is gradually turning to platforms and will become a part of the software platform service in the future. It is necessary to exploit the resources and advantages of platforms, drive the innovative development and ecological construction of the software itself, and support the integration, interconnection, and social collaboration of production, operation, management, service, and other activities and processes.

The integration platform represented by the design and simulation integration platform can start from demand, cover the whole process of product design, planning, manufacturing, and service, realize model-based design functions, fully enhance the integration ability of design and manufacturing, and improve efficiency and reduce the cost accordingly. As an application and service platform based on the industrial Internet, Siemens Teamcenter, for example, realizes the comprehensive perception, dynamic transmission, and real-time analysis of industrial data, supports accurate decision-making and intelligent control, and improves the allocation efficiency of manufacturing resources by building a basic network connecting machines, materials, people, and information systems. For the low-code development platform, the complex information technology stack is encapsulated by the configuration-type low-code development technology. In terms of interaction and data, the development efficiency of terminal engineers can be improved through configurable methods. It is necessary to reduce the labor cost of enterprise application development, lower the threshold for industrial software development, and alleviate the current situation of a talent shortage in the industry.

With the development of platformization, industrial software is migrating to the cloud and gradually moving to cloud deployment. The development of new-generation mobile communication, big data, and cloud computing technologies provides solid support for the industrial software cloud. The trend of industrial software migration to the cloud is obvious. The deployment mode has changed from within enterprise to private, public, and hybrid

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clouds. The software architecture has changed from tight to loose coupling and focuses on componentization, platformization, and services. The operating platforms support various mobile computing devices instead of merely personal computers.

3.2.2 Industrial software is gradually becoming open-source

Open-source software and the open-source community have strong creativity and vitality and have gradually developed into an important mode of technological innovation and industrial development. For example, for big data, cloud computing, AI, and other technologies, the international community generally adopts the open-source development mode, relying on the open-source community for rapid iteration. The complexity of open-source software and the barriers formed by years of technological accumulation make it difficult to achieve a comprehensive breakthrough by relying on the independent R&D of a single vendor. Accordingly, the development environment for industrial software has changed from a closed and dedicated platform to an open and open-source platform. Through open-source software, more development and user resources will enter the industrial software product innovation system to gather wisdom, make good use of talents, and accelerate the innovative development and distributed verification of industrial software modules, components, and toolboxes.

In China, the development environment for open-source software is improving significantly. First, the continuous development of higher education and rapid evolution of the Internet industry have created numerous potential developers, and the human advantage has gradually shifted from workers to engineers. Open, easy-to-use development tools and technologies were quickly mastered (and actively participated in) by numerous developers, which facilitated the formation and expansion of the user base of open-source industrial software. Second, the manufacturing industry has a large volume and variety of application scenarios, resulting in a large amount of industrial data. Data resources have become an important driving force for industrial transformation and upgrading. As competition intensifies in the international market, open-source software provides a new choice for Chinese industrial enterprises to avoid potential bottleneck problems and also gives new impetus to the growth of the domestic software industry.

4 Development trend and challenges for China's industrial software industry

4.1 Development trend

The rapid development of the industrial economy and the deep implementation of the integration of industrialization and modernization have brought valuable development opportunities for China's industrial software industry. Under the precise support of relevant industrial policies and the direct support of a series of projects represented by major national science and technology projects, China's industrial software industry has been rapidly developing. China initially formed a domestic industrial software product system covering automotive, construction machinery, aerospace, electronics, home appliances, and marine equipment. The industry has certain industrial technology R&D and service support capabilities and has begun to shift from introduction to independent R&D and characteristic development.

From the perspective of market size, China's industrial software products achieved revenue of 194.4 billion CNY in 2020, with a compound annual growth rate of 20.3% from 2012 to 2020 (Fig. 1). However, the global market size is still not large, which indirectly shows the great potential for development.

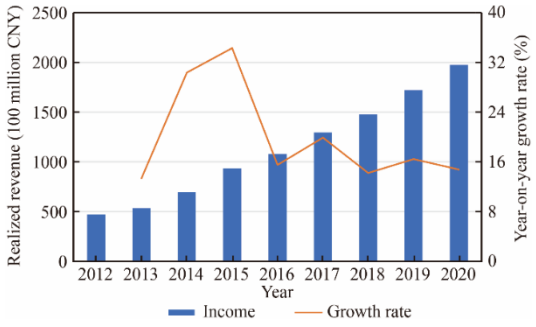

Fig. 1. Evolution of China's industrial software market scale (2012–2020).

Note: Data are from the announcement of the Ministry of Industry and Information Technology and the Statistical Yearbook of China's Electronic Information Industry (electronic).

From the perspective of industrial layout, China's industrial software industry shows the basic characteristics of strong management software, weak engineering software, and insufficient high-end software. Domestic industrial software development in the field of operation management (such as production management, customer service, and integrated management) is better; however, the R&D and design software represented by CAE and EDA lags. Contrastingly, the share of domestic industrial software in the low-end market is high but still non-existent in many high-end areas.

From the perspective of supply capacity, China is emerging with several industrial software enterprises with good R&D capabilities. For example, the two-dimensional CAD and three-dimensional CAD/computer-aided manufacturing software of Guangzhou Zhongwang Longteng Software Co., Ltd. has a certain influence in the international market. Anshi Asia Pacific Technology Co., Ltd. has sustained progress in the direction of simulation software; independently developed products have been recognized by the application industry; enterprise resource planning (ERP) software of UFIDA, Kingdee, Inspur, and other brands have become the main force in the domestic market; and the strategic cloud transformation of related products is being implemented.

From the perspective of the development trend, the driving role of the industrial Internet is increasingly emerging, and domestic enterprises are taking measures such as strengthening platform construction, pooling development resources, and cultivating and deploying industrial applications to actively transform to cloud services. Notably, in the area of digital software for manufacturing product innovation, the scale of relevant development enterprises is small, and there is no company listed yet.

4.2 Challenges

4.2.1 High technical barriers in R&D and design and obvious international dependence of core technologies

Countries with a more developed industrial software industry are industrial powers that have completed the process of industrialization, and the corresponding industrial software support system is flawless. In contrast, the basic capacity of China's industrial software industry is weak, and there is a shortage of forward-looking research and design capabilities. Industrial software R&D involves the cross-integration of industrial manufacturing technology, engineering management, applied mathematics, computer and software, and other disciplines [15]. Only the joint participation of multiple types of innovation subjects (and disciplines) can promote the technological progress and product innovation of industrial software [16]. Although China's industrial system covers all industrial categories, the supply and demand of key links are controlled by a few international enterprises in many subdivisions. From the perspective of a coarse-grained industrial cycle, China's industrial system is complete and has comprehensive industrial demand. However, on the supply side, there are large gaps in several areas and a strong dependence on international supply. For example, China's R&D and design industrial software localization rate is low (less than 10%), and the three-dimensional geometry engine (CAD software core), the CAE solver, and other industrial software foundations and core technologies are still far from being independent. Most of them purchase authorization from foreign products or directly use open-source kernels to develop software products, which, under special circumstances, leads to the risk of a bottleneck in the foundation and core technology of industrial software.

4.2.2 Scale of enterprises in the system integration link is small and the industrial ecology is incomplete

In terms of volume, China's industrial added value (24.5%) and R&D investment (23.8%) are among the top in the world. The *Whitepaper on China's Industrial Software Industry (2020)* points out that China's industrial software industry revenue accounts for only 6% of the world's total, which indicates that the industrial ecology is not complete enough to match the transformation and upgrading needs of industrial enterprises. At present, the coverage of China's industrial software enterprises is wide, but the scale is generally small, the profitability is not strong, and the product system degree is not high. Almost no enterprises are approaching the world-class level of technology and scale, and large and strong enterprises that play a leading role in the economic cycle and unblocking the market are lacking. As noted, the drive and incubation effect of key industrial enterprises to independent industrial software is absent; product innovation design, simulation, and process control in fields such as aviation, aerospace, shipbuilding, electronics, and rail transportation mostly use foreign industrial software, and the R&D processes of new models and products are increasingly dependent on foreign industrial software. This situation affects the positive design ability of China's industrial products and widens the gap between domestic industrial software and foreign technology and applications, indirectly promoting the formation of application ecological barriers.

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The project selection mechanism supported by government special projects can no longer guarantee that enterprises gain sustained support, and those with social capital are more willing to invest in projects with little investment but quick result. The deficient investment of enterprises leads to the weak sustainable development of industrial software. The mature industrial software development process is generally long, and the current guidelines issued every 3–5 years to select a batch of enterprises are not conducive to the formation of a stable, long-term core work team. In the process of formulating the national scientific research plan, there still exists disengagement regarding research, and the principle and focus of project approval are not clear, leading to homogenization and repeated investment among various types of funding projects. There is a structural contradiction between the current fund management method and the personnel cost. This should be the main part of the industrial software support project rather than the purchase of a large amount of equipment. The efficiency of capital management has not reached a high level, and an input-output relationship with a higher efficiency and quality needs to be formed.

4.2.3 Gap between compound software R&D personnel is large, and talent cultivation needs to be improved

China's software industry development is weak and the wages of industrial software developers are not competitive in the market. However, some of the emerging information industries are developing rapidly and software talents in these industries have higher wages, which leads to a lack of high-end talent in the industrial software industry. Industrial software R&D personnel should master software development skills and have a deep understanding and cognition of complex industrial mechanisms, product objects, business scenarios, operation procedures, and so on. The training of compound leading talent is time-consuming and difficult. The core talent loss in universities and scientific research institutions is serious owing to the lack of continuity of state support, and the education and training force in the industrial software industry is insufficient and results in research fault.

5 Development path of China's industrial software industry

The influence of industrial software usually exceeds that in its own field, and it has a leverage effect on the development of many industrial fields. The industrial software industry is a typical high-technology barrier industry. International enterprises use technological innovation and intellectual property rights to build a high industry entry barrier. Under the original market pattern, domestic industrial software enterprises are reluctant to invest more resources in technological R&D owing to the limited future market size, making it difficult for them to enter the high-end industrial software market. In recent years, the anti-globalization trend has posed a challenge to the international cooperation in industrial software. However, under the new pattern of double circulation, China's industrial software industry is faced with supply problems but also has new development opportunities for domestic industrial software enterprises. For example, import substitution will bring significant incremental market space to the industrial software industry, which is conducive to accelerating the realization of an independent and controllable industrial software field.

The key manufacturing fields relate highly to the national economy, and people's livelihoods cannot be separated from industrial software support. The independent control of industrial software is an important guarantee of China's industrial and information security. The industrial software industry, as a potential inferior field, urgently needs to achieve rapid development through independent innovation. Because of its basic, platform-based role and because it constitutes a single industry's digital innovation environment, the potential radiation effect is prominent. China's industrial software industry is facing a relatively mature market, which is more difficult to enter than is developing a new demand market. Industrial software enterprises should not pursue a comprehensive approach but rather specialize and refine in a segmented industry or field to create unique advantages. We should remain open to the world and deepen cooperation in cutting-edge technologies and applications. As such, this paper discusses and presents three development paths: strengthening the base, catching up and making breakthroughs, and leading by excellence.

5.1 Path of strengthening the base of industrial software industry

5.1.1 Development goals

Our goal for R&D and design of underdeveloped industrial software is to develop core and key technologies, break foreign product monopolies, and break the technology blockade, focusing on CAD, CAE, EDA, and other software categories, aiming at the 3D geometry engine, solver, and other common key technologies to carry out research. Relevant research resources are heavily invested, application barriers are high when industry income is low, and there is an obvious technology gap, which makes industry users lack confidence in investment and is

difficult to solve through market mechanisms. It is necessary to establish a long-term collaborative mechanism to concentrate the superior strength of universities and research institutions to carry out joint research, striving to form usable independent technology within five years and steadily narrowing the gap with the international advanced level within ten years. In addition, the system architecture of complex industrial software, industrial software integration, modeling of complex engineering problems, and human–computer interaction of engineering are also key elements that determine whether commercial industrial software can be formed and should become key breakthrough directions.

By 2025, software enterprises will take the lead in making breakthroughs in key core technologies such as the 3D display engine, constraint solving, 3D geometric modeling engine, universal pre-processor/solver/post-processor, and production control process package and apply self-developed core technologies in high-end R&D and design industrial software products. Trials and demonstrations will be carried out in key industries to form industrial software technology standards and an ecosystem and alleviate the bottleneck problem. By 2030, safe and reliable industrial software and its standards system will be established, and breakthroughs will be made in core industrial software products such as CAD, CAE, and EDA to meet the application needs of key industries. By 2035, a system of industrial software products for R&D and design with fully independent intellectual property rights will be formed.

5.1.2 Basic steps

First, we should strengthen industrial basic R&D and the industrial software connection. Industrial software is the product of industrial knowledge, so we should deeply understand that there is no advanced industrial software without advanced industry. For aviation, aerospace, shipbuilding, electronics, rail transit, and other key industries, a comprehensive sorting of the existing gaps in basic materials, components, processes, equipment, and other aspects of the use of industrial software categories and pedigrees will be conducted; the technical gaps and causes in domestic industrial software products will be analyzed; the shortcomings in the basic theory of manufacturing science and industrial knowledge will be clarified; and a close connection will be made with the general basic research results of the National Natural Science Foundation of China and other scientific and technological channels and industrial foundation strengthening projects. We will strengthen the connection with the applications of major industrial projects and high-end equipment and systematically build the forward design and knowledge accumulation capacity of industrial enterprises.

Second, we should establish a multi-form, open-source, and coordinated nationwide system. Because generic key technologies are difficult to develop in the market, we will achieve long-term scientific and technological breakthroughs by organizing collective efforts by the state, coordinating the efforts of enterprises, universities, research institutes, and users, and ensuring the continuous investment of special funds. Basic and core technology research should be organized in the form of state-key laboratories, engineering technology innovation centers, and independent open-source software communities. Within a certain period, we must pay attention to direct economic benefits for China's industrial software-independent sustainable development to lay a solid foundation. We must rely on the major equipment products of key industries to form industry/field industrial software product solutions.

Third, we should explore the development path of innovations in principles and architecture. We should explore new technologies and modes that are based on geometric topology optimization and integrate geometric modeling, structural analysis, and optimization design and create a second development road in the direction of CAD and CAE. Combined with the technological innovation opportunities brought by the new-generation information technology, industrial software is decoupled from industrial knowledge and processes, and cloud-based, micro-service, and distributed software architectures are reconstructed. To give full play to the inherent advantages of the relative integrity of China's industrial system, we should encourage industrial enterprises, industrial software enterprises, scientific research institutions, and other application subjects to develop industrial mechanism models and software in accordance with certain standards and form a large-scale knowledge base and overflow development trend.

5.2 Path of catching up and making breakthroughs

5.2.1 Development goals

For production control, management operation, and service guarantee industrial software with a certain foundation, it is necessary to accelerate the localization replacement process, promote independent products to the high-end market, and establish a perfect ecological system. For software products with certain foundations in production control, operation management, and service guarantee, it is essential to encourage management

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departments, software enterprises, and application enterprises to reach a consensus and promote the deep integration of industrial software development and manufacturing businesses. In the manufacturing process, key process and industrial technical data should be continuously accumulated to promote the efficient combination of software products and engineering practices and finally realize the two-way feedback situation wherein industry demand drives technology development, thereby promoting enterprise innovation. We should encourage industrial enterprises to use domestic industrial software and maintain reasonable feedback to promote the iterative improvement of the software. To promote domestic industrial software products to the high end, it is necessary to break the market monopoly of imported products, optimize the development environment of the industrial software industry, and build an independent, controllable, and healthy ecological system. By 2025, an industrial software ecosystem with good marketization application results will be formed. By 2030, a new generation of digital platforms for large enterprises based on container cloud and micro-service architecture will be initially formed, and all kinds of industrial software will gradually turn to componentization, platformization, and service-orientation. By 2035, the replacement of industrial software products by localization will be complete, and independent products will reasonably occupy the domestic market and have first-class competitiveness in the international market.

5.2.2 Basic steps

First, industrial software should be deeply integrated with industry-leading enterprises to break the bottlenecks of China's industrial software enterprises. We should encourage the backbone industrial software and leading industrial enterprises to jointly build a platform for collaborative development with close business connections through equity investment and other means. With the help of funds, orders, and industrial enterprise knowledge, the two ends of demand acquisition and product procurement for industrial software should be grasped to form a market-oriented community of interests and accelerate the application, promotion, and evolution of industrial software.

Second, it is suggested to maintain a moderate scale of market segments with the help of capital and market forces. Industrial software enterprises should be encouraged to face the shortage of funds, talents, technology, and other practical problems and carry out a targeted layout for market segmentation. Instead of pursuing a large and complete development model, the company should focus on enhancing profitability and maintaining sustainability and form several industrial software product patterns in the form of "little giants" with limited resources. It is necessary to set up practical and effective financial policies, encourage social capital to participate in the investment, financing, and merger and acquisition activities of domestic and foreign industrial software enterprises, and support China's industrial software enterprises to become more refined, stronger, and more stable in their development.

Third, industrial software products should be cultivated through industrial applications. We should highlight the interaction between industrial and industrial software enterprises in demand and application practice, promote the spillover of advanced industrial technological innovation achievements of industrial enterprises to industrial software enterprises, and form a new model of industrial software technology research and product collaborative development driven by the integration of industrial and industrial software enterprises. Industrial enterprises formulate their information technology development strategies, take the application of domestic industrial software as the operating indicators of large state-owned enterprises to examine, actively try out and use domestic industrial software, and support industrial software enterprises to iteratively improve related products. It is necessary to establish an industrial software innovation center through continuous investment to build a solid foundation, seek breakthroughs, undertake product R&D, application, and promotion work, and promote the domestic industrial software application and promotion work of enterprises in the industry.

Fourth, the leading role of major projects in the original innovation of industrial technology should be exploited. Leading enterprises in key industries strive to realize original industrial technology innovation through the organization of industry–university–research–application forces, the development of industrial/professional industrial software technology and products, and the achievement of an international leading level by relying on major project R&D tasks. Industry-leading enterprises should be encouraged to set up their own industrial software R&D departments and seek the separation and listing of an industrial software business.

5.3 Path of leading by excellence

5.3.1 Development goals

To meet the needs of new industrial software, we should intensify the research on cutting-edge technology and realize the simultaneous layout of China's industrial software industry and international progress. We should also focus on the development of cloud computing, industrial big data, an industrial Internet platform, industrial applications, low-code development environments, smart enterprises, smart factories, and other new software technologies. With new industrial software as the breakthrough point, we should accelerate the industrial software cloud, platform, and intelligent transformation processes to identify and grasp industry leapfrog development opportunities. We will fully exploit China's advantages in industrial application scenarios and the application potential of new technologies, strengthen the construction of industrial Internet infrastructure and platforms, and promote the sustainable development capacity of new industrial software and the technological industrial system to become world-class.

By 2025, a batch of industrial Internet platforms will be built to provide direct support for big data, AI, and other applications in key industries. We should form a variety of industrial big data system products to support the comprehensive improvement of resource control, technical support, and value mining abilities and cultivate a large number of high-value and high-quality industrial applications. By 2030, the industrial Internet based on intelligent interconnection products will be built, and three to five industrial Internet platforms will reach international standards. Industrial big data systems and industrial Internet platforms cover key industries. By 2035, an internationally leading industrial Internet infrastructure and platform will be fully built.

5.3.2 Basic steps

First, production and application should be integrated and guided by demand. In the process of deepening the development of the manufacturing industry, industrial enterprises will gradually realize digital transformation and upgradation, and the partial technology accumulation effect will gradually appear and will drive the high-quality development of domestic new industrial software in reverse. Combined with the actual needs of key industries and major projects, we should form all kinds of professional industrial models and achieve integration in new industrial software in the process of promoting engineering task development. It is necessary to focus on the deep integration of new industrial software with engineering requirements, manufacturing technology, and business processes and coordinate and promote the application of domestic industrial software in various enterprises.

Second, we need to build an ecological environment through multi-party cooperation. For emerging technologies such as big data, cloud computing, and AI, the open-source development model is widely adopted around the world, and iteration is carried out by the open-source community. It is difficult to achieve the same efficiency by relying on the self-development of a single vendor for relevant technology models. Adhering to the concept of open-source development, it is essential to establish a community ecology of industrial software developers and integrate numerous development and user resources into the corresponding product innovation system with an open, innovative, and flexible mechanism. Enterprises can focus on the innovation and industrial chains of new industrial software, focus on the key points, division of labor, and cooperation, establish an open-source software community adapted to the national conditions, and form an ecological system covering industry, universities, research institutes, and applications.

6 Suggestions for the development of China's industrial software industry

6.1 Optimizing the organizational model to exploit the leading role of industrial enterprises

It is necessary to take the industrial enterprise as the main body and explore the innovation organization mode combining single-point and industry breakthroughs. It is suggested that leading enterprises in key industries should take the lead to integrate the strength of the industrial software industry, comprehensively sort out the technological situation in theory, mechanism, technology, and application, and identify the weak links that need to be prioritized and key breakthroughs. Relying on the support of national key R&D programs and major project R&D tasks, we will carry out technological breakthroughs and joint R&D and strive to build an independent and controllable industrial software technology system. We will transform actual demand and technology spillover into goal-oriented activities, break through the conventional way of project contract cooperation, and explore a new organizational model in which industrial enterprises take the lead and multiple innovation subjects jointly participate in R&D. Several industrial software innovation centers will be established to support the application of domestic industrial software by small and medium-sized enterprises in various forms.

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6.2 Promoting key technological breakthroughs in industrial software at different levels

Key technologies and products of industrial software facing different industries, levels, and characteristics should be treated differently, promoted hierarchically, and adopted simultaneously. Aiming at the key technologies represented by the 3D geometry engine and solver, which have a large gap, high investment, low income, and long cycle, we should seek rapid breakthroughs through national organizations. For software products represented by ERP and production information management systems, China has certain technical reserves and application bases, supports industrial enterprises to try out and use domestic industrial software, and gradually iterates and steadily improves domestic industrial software. As represented by the industrial Internet and big data, China's new industrial software technologies and products that are synchronized with or even partially surpassed by those of foreign countries are simultaneously distributed with those of foreign countries, giving full play to the characteristics and advantages of industrial application scenarios and forming a leading position in world development.

6.3 Expanding application markets and promoting innovation of industrial software products

We should strengthen the application demonstration of domestic industrial software, formulate a classification catalog that can be replaced by domestic industrial software, encourage enterprises to use domestic industrial software, and form a two-way feedback channel for industrial demand and technological development. We should support both large and small enterprises and pay attention to the positive cycle and sustainable development of the industry. We should break through the original supporting methods of project application and evaluation, reconstruct the evaluation system and reward mechanism, and adopt mechanisms such as replacing evaluation with application and replacing subsidy with an award to effectively enhance the driving force of enterprise product innovation. We will issue tax incentives, tax reductions, and other supportive policies to reasonably reduce the R&D burden of enterprises and support them in improving their viability and resilience to risks. We will strengthen the protection of intellectual property rights, crack down on piracy and other undesirable activities, and create a favorable environment for industrial development.

6.4 Tapping talent potential to support industrial software talent training through multiple channels

It is necessary to give full play to the "open" attribute of the open source community, gather talents based on the national states, promote industrial software open source ecosystem structures, technology community construction, open source project training, open source community standards development, open source technology popularization and application, and personnel training, and explore the formation of a new industrial software open source development model under the Internet environment. We should provide policy guidance, intellectual property protection, open source community construction, relevant standards formulation, data asset protection, and other services for talents at all levels. We should also improve the distribution system and incentive mechanism for industrial innovation, improve the development evaluation system in line with the characteristics of all talent types, and fully stimulate the motivation for talent innovation. It is essential to respect human input and wisdom output, reasonably guarantee the treatment of personnel, and increase the proportion of personnel costs in project implementation. It is necessary to promote the industry–university–research–application coordination mechanism and encourage industrial software enterprises, universities, and research institutions to train industrial talents jointly. More industrial software courses should be set up in colleges and universities, the construction of domestic industrial software training systems should be strengthened, and the application level of industrial software related to people should be improved.

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