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The Realistic Pattern and Path Choice of the Development of Agricultural Software Industry

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Abstract: With the accelerated integration of information technology and agricultural development, the agricultural software industry has emerged to support the development of smart agriculture. In this article, we first examine the development status of and challenges faced by China's agricultural software industry by analyzing the development strategies of the industry in China and abroad using literature review and survey data. Subsequently, we propose strategic goals, major engineering projects, and policy measures for the development of China's agricultural software industry. China's agricultural software industry lags behind other developed countries in terms of technology development and promotion, enterprise operation, and user accumulation. Difficulty in development, weak innovation capabilities, low return on investment, and insufficient protection of intellectual property rights restrict the growth of China's agricultural software industry. China should, therefore, regard the development of agricultural software as the main strategic goal and focus on strengthening the innovative capabilities of its agricultural software industry by 2035. The major engineering projects we proposed involve the development of agricultural enabling software and platforms, promotion of precision agriculture management software application, establishment of agricultural software industry clusters, and cultivation of the agricultural software enterprise. Furthermore, China should improve its policy support system, strengthen the overall coordination mechanism, optimize the discipline system, and strengthen talent training for the agricultural software industry.

Keywords: agricultural software industry; feature classification; current pattern; path choice; suggestions for major projects

1 Introduction

Software is the soul of information technology, foundation of intelligent agriculture, and engine of the digital economy. With the expansion and application of information technology across the society at large, the agricultural software industry has gradually become a strategic highland for industrial competition worldwide. In recent years, the United States, Japan, and France have successively implemented the *US Government Cloud Computing Technology Roadmap*, *Agriculture, and Food Industry in the Social 5.0 Era* and *Agricultural Innovation 2025* initiatives, actively attempting to lay out a plan for the agricultural software industry while striving to consolidate existing advantages and seizing development opportunities to commanding heights. Compared to developed countries, the development process of China's agricultural software industry is relatively recent, but the state attaches great importance to it. For example, the *Action Plan for Revitalizing Software Industry (2002–2005)* issued by the

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State Council emphasizes the importance of software as a key strategic industry in national economic and social development. In recent years, China has implemented policy documents, including the *Big Data Industry Development Plan (2016–2020)*, *Notice of the State Council on Printing and Distributing the Development Plan of New-Generation Artificial Intelligence*, and *Digital Agricultural and Rural Development Plan (2019–2025)*, to support the technological innovation of agricultural software and improve the development environment of the agricultural software industry.

The emergence of agricultural software has attracted extensive attention in academic circles. The progress in relevant research includes the construction of an agricultural decision support system based on system engineering theory and methods exploring the practical applications of agricultural software to promote profitable agriculture through science and technology [1]. With the popularization of agricultural economic management software products in the agricultural field, software to computerize agricultural management, such as agricultural power remote report systems have been developed to realize remote reporting, file transmission, and data sharing of agricultural production management information [2]. Service software has been developed for modern agricultural production, including comprehensive agrometeorological services, agricultural management systems, rapid detection of pesticide residues, agricultural irrigation, agricultural condition monitoring, and farmers' training, to promote the extension of agricultural software applications from the management end to the production end [3–5]. Furthermore, by integrating new generations of information technologies such as big data, cloud computing, fifth-generation mobile communication, and artificial intelligence (AI), the scanning Raman spectrum imaging system for non-destructive testing of agricultural and livestock products and intelligent detection management systems of agricultural residue rapid testers based on personal computers have been developed to promote the intelligent, accurate, personalized, and multi-scene development of agricultural software [6–8]. It is worth noting that China attaches great importance to the development and application of agricultural software, systems, and platforms and supports the formulation of standards and software technology research and development (R&D) for agricultural early warning, agricultural information, and agricultural breeding in the form of national scientific research and international cooperation projects. China has developed the national grassroots agricultural technology extension information cloud platform and promotes agricultural product early warning, agricultural monitoring systems, online consultation system platform, and gold seed breeding platform (the first national Internet Plus commercial breeding platform with independent intellectual property rights), all providing effective means of department management to enable scientific decisions and macro control [9–11].

It should also be noted that there is still little academic literature on agricultural software, which is mostly at the stage of system development and promotion, and macro discussion on agricultural software industry is lacking. Furthermore, there is no consensus on the characteristics and categories of the agricultural software industry, and there has not been an objective evaluation on the level of development of China's agricultural software industry. Therefore, there is an urgent need to determine the current developmental status of China's agricultural software industry, clarify major challenges and key needs, and establish strategic objectives and path choices for the agricultural software industry, to put forward targeted and practical development suggestions.

2 Development characteristics and classification of agricultural software industry

2.1 Development characteristics of agricultural software industry

The term "agricultural software industry" refers to a broad suite of economic activities related to agricultural software products and services, including not only agricultural software technology, products, and services, but also the industrial environment, product market, industrial cluster, and industrial ecology. The agricultural software industry has the prominent characteristics of being knowledge-intensive, highly complementary and compatible, and concomitantly high risk and high income.

2.1.1 The agricultural software industry is knowledge-intensive

The agricultural software industry is based primarily on technology and knowledge, with intellectual investment and technological innovation being key elements in its promotion. During the early stages of industrial development, agricultural software primarily involves agriculture-related data transmission and processing. As modern agriculture develops and progresses, there will be an explosion in the amount of available agricultural data; computing models of agricultural environments will become more complex and diverse; and the demand for computing power in all directions of agricultural production, operation, and management will significantly increase (e.g., computing hardware represented by chips) [12]. This has driven the gradual evolution of agricultural software into a system

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that integrates perception, transmission, computing, and exchange, and the industry has become more knowledge- and technology-intensive. In addition, the proportion of technological R&D and intellectual investment in the agricultural software industry is much higher than that in other agricultural industries while innovation and creativity are core elements that enhance the competitiveness of the agricultural software industry.

2.1.2 The agricultural software industry is highly complementary and compatible

The products and services of the agricultural software industry are highly complementary and compatible with computers, mobile devices, and wearable device terminals. To better meet the personalized and diversified needs of agricultural production and operation, technology and R&D enterprises formulate unified standards, carry out R&D cooperation through patents and technologies, and overcome the disadvantages of product compatibility and intelligent interconnection caused by the relatively closed R&D process. To weaken the price competition of homogeneous software products among enterprises, sales and service enterprises also need to strengthen compatibility, cooperation, and information-sharing, forming effective barriers to the harm caused by the vicious competition between enterprises and industrial chains [13].

2.1.3 High risk and high income coexist in the agricultural software industry

As with other information technology industries, the agricultural software industry faces risks, including technology iteration, low input–output ratio, achievement transformation, and macro decision-making, among others. In terms of technology iteration, the production conditions of planting and animal husbandry are significantly different, which makes the development of agricultural information technology exploratory and uncertain. In terms of input and output, the agricultural software industry has invested huge amounts of fixed assets, technology, management of human resources, and R&D expenses in the initial stage of its development. Further, investment in future industrialization is also expected to be large, and hence, there is a risk of poor actual output after such a high input. Finally, in terms of macro decision making, the speed at which the technology related to the agricultural software industry is updated is significantly high. Improper innovation decision-making makes it difficult for technology updates to match the needs of economic and social development and can cause the failure of commercial transformation of technology R&D, which may bring huge losses to businesses. Nevertheless, the agricultural software industry is still a “sunrise industry,” with a relatively high rate of return on investment and significant returns for relevant enterprises.

2.2 Classification of agricultural software industry

The essence of the development of the agricultural software industry is to consider information as an important element of productivity and promote in-depth integration of information technology and agriculture. In other words, it is a process of full penetration of information technology in the field of agriculture. The agricultural software industry can be divided into several sectors.

First, the agricultural software industry is categorized into basic software platforms, agricultural application software platforms, and practical agricultural software systems [14]. The basic agricultural software platforms are the basic platforms for software operation, including Windows, Linux, and other operating system software, such as SEQ servers, Oracle, Sybase, and other database software. The agricultural application software platform is a software development and execution environment for applications in specific agricultural fields, including development tools such as MyEclipse, Eclipse, and NetBeans, and integrated development environments such as Visual Studio, C + + Builder, and Delphi. Practical agricultural software systems include a variety of software developed for specific agricultural problems, including agricultural expert systems, agricultural production decision support systems, agricultural database systems, agricultural information consulting systems, and agricultural market information analysis and release systems [15].

Second, based on different service links, the agricultural software industry is categorized into agricultural production, operation, circulation, management, and socialized services. The software applied in the field of agricultural production is mainly for agricultural production personnel, including agricultural multimedia software, practical agricultural information consulting system, agricultural expert systems for production management, agricultural vocational education software, audio information service software based on network technology, agricultural distance education software as well as agricultural handheld mobile terminals, agricultural e-books, and electronic dictionaries. The software applied in the field of operation and circulation is mainly for agricultural operators, including market information collection software, market analysis and prediction software, online market information release software, e-commerce application software, enterprise resource planning management software,

sales management systems based on Internet technology, and logistics distribution management system software. The software applied in the field of agricultural management is mainly for agricultural administrators, including agricultural database software, agricultural macro-decision-making systems based on geographic information systems, e-government security software, internal administrative business application software, public supervision and service software, government intelligent decision-making software (such as emergency command, disaster prevention and reduction, social linkage, and daily decision-making), government information resource management software, e-government data exchange and application systems, government bidding, procurement, major project management, and supervision software. The software applied in the field of socialized services is mainly for agricultural technology extension personnel, including agricultural information collection software, agricultural expert systems, agricultural decision support systems, agricultural information management systems, agricultural database systems, mobile agricultural information systems, automatic generation and maintenance software of agricultural websites as well as consultation, diagnosis, prediction and analysis, detection, monitoring, evaluation, optimization, design, and control system software [16,17].

3 Development status of agricultural software industry in China

China's software industry had a late start, but with the acceleration of social informatization, the agricultural software industry has developed rapidly in the last 20 years. In 2019, the output value of China's software service industry reached 7.2 trillion CNY, 121.8 times that of the year 2000. The total number of enterprises increased from 5624 in 2003 to approximately 37 000 in 2019 [18]. In this study, a combination of field and questionnaire-based investigations were conducted to study national agricultural software enterprises and relevant scientific research institutes to obtain basic data on industry development.

3.1 The agricultural software industry shows a trend of regional agglomeration, with government and agricultural enterprises

According to the survey data, enterprises headquartered in the eastern region account for 70% of the national agricultural software enterprises. The agricultural software industry shows a trend of agglomeration and development in the eastern region and has formed an interconnected agricultural software industry cluster with Beijing, Shanghai, and Zhejiang provinces as the key regions. The existing agricultural software industry primarily serves government agencies and agricultural enterprises (Fig. 1). The proportion of agricultural software enterprises serving government agencies is 65.9% and the proportion of agricultural software enterprises serving agricultural enterprises is 63.4%. Thus, the software service needs of new agricultural business entities such as family farms, cooperatives, and agricultural enterprises need to be further explored.

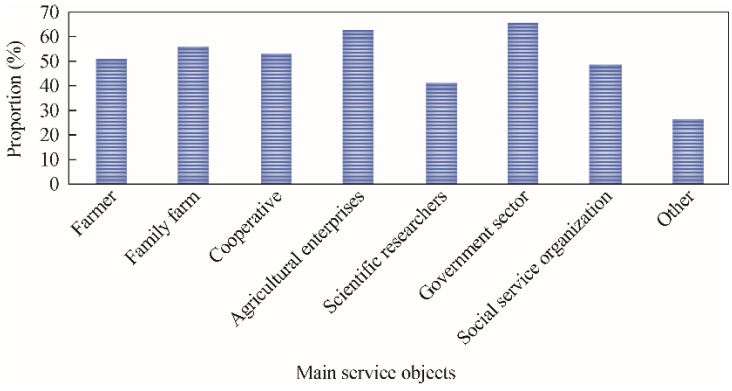

Fig. 1. Service objects of interviewed agricultural software enterprises.

3.2 The product type is mainly agricultural production software, which mainly provides users with information monitoring and software development services

Among the types of software products and services provided by relevant enterprises, agricultural production software accounts for the highest proportion, reaching 80.5% (Fig. 2), which shows that there is a great demand for it. In addition, the popularization of information technology and equipment can increase R&D, promotion and

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application of agricultural operations, management, and service software. Agricultural software enterprises focusing on providing information monitoring and system development services, account for 63.4% and 58.5%, respectively. However, agricultural software products, such as plant protection services, agricultural machinery dispatching services, and agricultural operation services, need to be further popularized (Fig. 3).

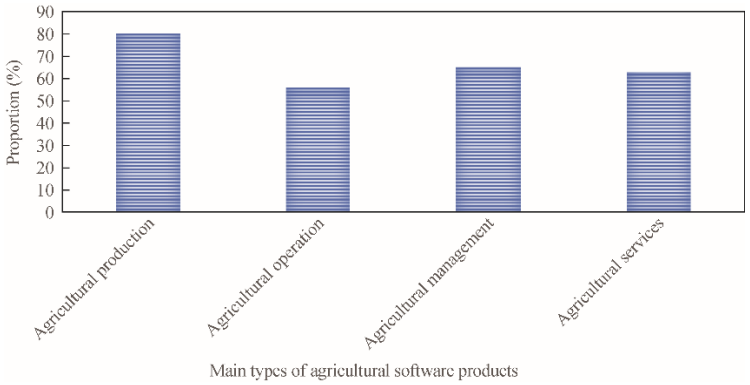

Fig. 2. Market product types of interviewed agricultural software enterprises.

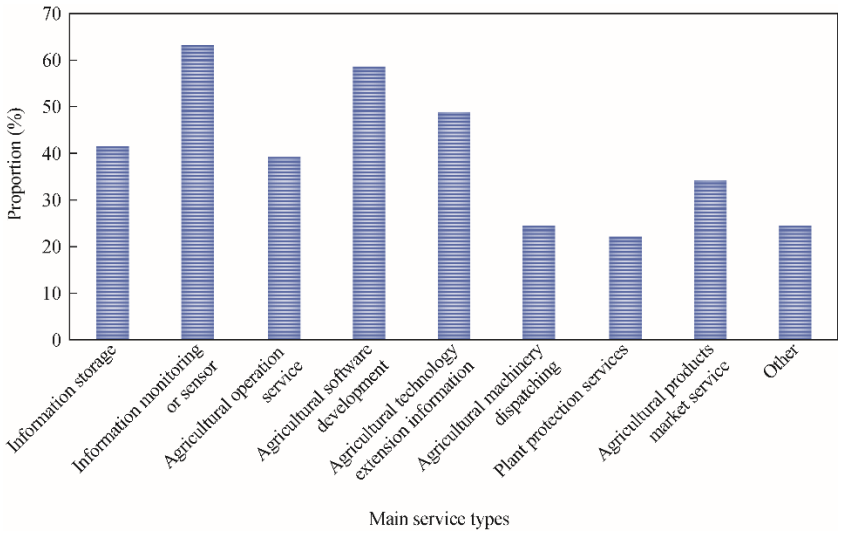

Fig. 3. Types of information services provided by agricultural software enterprises.

3.3 Agricultural software is popularized and applied to agricultural production, circulation, and other links to promote the high-quality development of modern agriculture

In recent years, with the support of the National Key R&D Plan and National Science and Technology Support Plan, relevant research institutions, universities, and enterprises have made substantial advancements in software development with independent intellectual property rights in agricultural information technology. Agricultural software is widely used in production management, business circulation, and socialized services, which improves the information perception, quantitative decision-making, intelligent control, precision investment, and personalized service ability of modern agriculture. In the production process, systems such as environmental monitoring and precision agriculture have been developed for different industrial types, including field planting, facility cultivation, livestock and poultry breeding, and aquaculture. Currently, the most widely developed and applied agricultural software are e-commerce platforms along with agricultural product quality and safety management traceability platforms. This effectively promotes brand construction and assists in market-oriented promotion of agricultural products while also assisting with agricultural management changes toward order, network, individualization, and monitoring of the planting, agricultural product processing, and testing management processes.

3.4 Agricultural big data analysis has become a hot demand for agricultural software, and AI enables the agricultural software industry

According to the survey data, approximately two-thirds of the agricultural software companies surveyed have established big data intelligent technology R&D teams; 74% of agricultural software products are equipped with big data intelligent analysis and application systems; and 46% of agricultural software products can provide cloud services. This indicates that big data and cloud service technology have gradually become research and application hotspots in the field of agricultural informatization. With the development and application of AI and other emerging information technologies, based on the operation of existing agricultural software, intelligent positioning is adopted to capture more valuable data and information while improving the application value of the obtained information, the efficiency of data acquisition in building a more intelligent data identification system to endow agricultural software with incremental functions.

3.5 Improving comprehensive agricultural benefits through development and promotion of agricultural software

Currently, China's agricultural software has been widely used in production management, agricultural management, business circulation, and socialized services. (1) The production management sector includes systems designed for production environment monitoring, variable-rate fertilization control, precision pesticide application control, agricultural water-saving irrigation, water–fertilizer integrated intelligent irrigation, and pest control. These systems were developed to realize automatic information sensing, precision management, and intelligent control in agricultural production. (2) In the agricultural management sector, the industry has developed systems that focus on remote monitoring and control of agricultural machinery operations, cooperative operation services, production data information management, and intelligent management of modern agricultural ecological parks. These not only reduce operational costs and improve labor productivity but also demonstrate the advantages of modern agricultural brand development. (3) In the business circulation sector, the systems developed focus on operation and circulation, quality and safety traceability of agricultural products, intelligent warehouse comprehensive management systems, intelligent detection and management systems for warehouse environments, operation and management decision-making systems, and transparent supervision. These systems break the space–time and geographical constraints of the agricultural market to solve the problem of information asymmetry and reduce the cost of each circulation link. (4) In the socialized services sector, the "agricultural nanny" management system and "12316" comprehensive information service platform have been designed and developed to efficiently extend the agricultural information resource service to villages and farmers, playing a positive role in coordinating the balanced development of urban and rural areas and narrowing the digital divide.

4 Main difficulties in the development of China's agricultural software industry

4.1 Gap between China and foreign countries in the development of agricultural software industry

Although China has achieved significant success in the development of the agricultural software industry, which plays an increasingly prominent role in supporting and serving the agricultural real and digital economies, there is still an overall gap in the development of the agricultural software industry between China and agriculturally developed countries.

4.1.1 The technology R&D and promotion mode of foreign agricultural software are relatively advanced

Promoting the integration of informatization and modern agriculture has become an important trend in agricultural development. Developed agricultural countries carried out agricultural informatization construction long before China, which meant that they transitioned rapidly from policy and financial support to scientific and technological R&D and innovation, product promotion, and application with a wide range of agricultural software types. Furthermore, developed countries have attached importance to the functional combination of sensors, satellite navigation systems, and machine control technology, which has contributed to the in-depth development of agricultural software products and applications. In recent years, China has issued a series of smart agricultural policies to promote the development of the agricultural software industry. However, because of the late start of the industry, low product quality, decentralized agricultural production, and imperfect service systems, the core technology and theoretical bottlenecks need to be overcome, and the radiation scope of the agricultural software industry needs to be widened.

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4.1.2 Foreign agricultural software enterprises have mature operations and rich products

Famous agricultural software enterprises, including AgSense, Agrian, and Cropin, are concentrated in Europe and the United States. Relying on technical advantages, they highlight personalized and differentiated services to continuously meet the personalized needs of users. They also focus on segmentation, have rich product types and stable performance, and occupy a large global market share. Some agricultural software enterprises in China specialize in agricultural informatization, whereas others are software subsidiary/departments of agricultural enterprises, and agricultural-related subsidiaries/ departments of large information technology companies. Although some R&D has been achieved and applied, competitiveness in the international market is weak, and there is a lack of core backbone enterprises.

4.1.3 The foreign agricultural software industry focuses more on accumulating user groups

The foreign agricultural software industry pays more attention to user intentions and satisfaction during the development process. Facing the current situation in which agricultural software users have conservative thinking and low sensitivity to new technologies, various methods have been actively adopted to widen the user base. First, users have been provided with “cloud, network, end” and other hardware equipment that support their own software system free of charge to help improve the level of infrastructure and gain the users’ trust. Second, customer feedback, complaints, and consultation are recorded in a timely manner, providing users with proper after-sales service to improve service quality and customer retention. Finally, the system must pay attention to resource integration; use intelligent and digital management modes to connect the upstream and downstream of the agricultural industrial chain, improve the efficiency of agricultural production, operation, and circulation, and reduce agricultural production and transaction costs. In China, as a result of the aging of agricultural business leaders and low education levels, agricultural software enterprises pay insufficient attention to users and suffer from low-quality after-sales services.

4.2 Bottlenecks in the development of China’s agricultural software industry

The weak industrial foundation, scattered data resources, huge amounts of collected but untapped data for the entire industrial chain of important agricultural products, and imperfect agricultural and rural basic data resource systems are practical challenges for the development of China’s agricultural software industry. Furthermore, the development potential of the agricultural software industry is restricted by problems such as the poor application of agricultural software, low return on investment of agricultural software enterprises, weak core competitiveness of the agricultural software industry, and insufficient protection of intellectual property rights.

4.2.1 Agricultural software development is difficult and practical applications are poor

In contrast to manufacturing or heavy industries, agriculture relies on biological organisms for production, which is greatly affected by the production environment, season, and degree of standardization. Agricultural production systems are often large and diverse, covering many subdivided industries such as field planting, protected horticulture, animal husbandry, and aquaculture. At the same time, there are great differences among different production varieties, which create difficulties in the planning, model construction, development, and design of agricultural industry software. In the process of popularizing and applying agricultural software, farmers participating in agricultural production, processing, and transportation have limited ability for operating information software. In addition, the low degree of standardization and small-scale agricultural industry have significantly affected the application of agricultural software in the process of agricultural production, management, circulation, and service. This also hinders the spillover effect of information technology to the agricultural software industry.

4.2.2 The high operating costs of agricultural software enterprises restrict enterprise development

The agricultural software industry is knowledge-intensive, and the prices of production factors such as fixed assets, human capital, and R&D funds are much higher than those of other segments of agriculture. Considering high input costs, the financing capacity of the agricultural software industry is limited. At present, the customer groups of agricultural software enterprises, such as farmers and rural cooperatives, are mainly agricultural production subjects with relatively limited income and payment abilities. In recent years, the living standards of rural residents have improved significantly, but an income gap still exists between urban and rural areas. Some agricultural production subjects are unable to bear the high transformation costs of agricultural informatization and digitization. These factors limit the profit and the development levels of agricultural software enterprises.

4.2.3 The independent innovation ability and core competitiveness of the agricultural software industry are weak

Technical conditions for the basic development of agricultural software in China are weak. The development of agricultural software in China is primarily based on the application of foreign software development tools or technical architecture, and the development of third-party intermediate products is only secondary. Agricultural software development enterprises have weak independent innovation ability and high external dependence. Product exports in the application software are concentrated at the lowest end of the industrial chain with low product added value and serious homogenization. Competition in the international agricultural software market has become increasingly fierce. The types of agricultural software in developed countries are highly advanced and cover all types of industries and production links. Many well-known agricultural software enterprises, such as Trax View, Farm Logic, Grain Trac, and Ag Expert have been cultivated, and related products occupy most of the global agricultural software market, creating a technology generation gap for the application of these products in developing countries. In contrast, the scale of China's agricultural software industry is generally small, and there is a gap in delivery capacity, human resources, and service level. Core competitiveness is not strong; the driving force for sustainable development is lacking; and competitiveness in the international market is insufficient.

4.2.4 Intellectual property protection must also be improved

In terms of software development, considering the unique replicability of computer software, developers can easily obtain software source code through reverse engineering and other technologies. Although the rate of software piracy in China is decreasing annually, piracy and infringement still exist. This behavior makes the user experience of the industry worse, substantially affecting normal agricultural production, management, and circulation business. Moreover, piracy infringes on the brand reputation of software, indirectly restrict the sustainable development of China's agricultural software industry and damage its international image in the global agricultural software market. At present, China mainly protects the copyright of agricultural software through copyright law, and relevant academic fields are constantly exploring the use of patent law or trade secrets to protect the legitimate rights and interests of enterprises. However, compared to developed agricultural countries, the protection of intellectual property rights in China is still insufficient and lacks a proper system of laws and regulations.

5 Development path choice of agricultural software industry in China

The world is currently in a new stage of intelligent development in the digital world. Agricultural software and information services are expected to integrate, support, and serve all fields of rural revitalization, and their role in enabling the agricultural industry will become increasingly obvious during the fourteenth Five-Year Plan period. To promote the high-quality development of China's agricultural software industry, a new development concept should be implemented to face key fields, accelerate the deployment of agricultural software industry innovation strategies, and provide support for the development of smart agriculture.

5.1 Development objectives

Taking the promotion of agricultural technology software as the main line, the objectives are to strengthen the innovation and development ability of the agricultural software industry, to aim for future agricultural intelligent reform, to implement information security guarantees, and to develop the agricultural software industry as the core driving force of comprehensive digitization, informatization, and intellectualization of agriculture. The principles of data-driven innovation, integrated application, safety and controllability, and industry chain coordination should guide this development. Other objectives include focusing on the high-end links and key areas of the agricultural software industry and innovation chain, accelerating the breakthrough of key technologies and short-board technology, building an information security system, and significantly improving the supply and information security capacity of the agricultural software industry while broadening its application field. The cultivation of backbone enterprises in the agricultural software industry should further be accelerated to actively develop information security technologies and industries.

By 2025, the agricultural software industry must promote the extension of agricultural software to platforms, networks, and mobility. Promoting the deep integration of agricultural software with agricultural equipment manufacturing and agricultural service innovation as well as improving the integration and innovation ability of agricultural software are essential to realize the reconstruction of the value chain of the agricultural software industry. By 2035, China intends to build an all-encompassing agricultural software industry ecology, striving to cultivate innovative, leading, and backbone enterprises for the integration of software and hardware, services, and data to

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build a number of agricultural software industry clusters that support and ensure agricultural production management, circulation, and sales and operation services.

5.2 Major engineering suggestions

5.2.1 Project for agriculture-enabling software and platform development

To implement the agricultural-enabling software and platform development project, China must focus on the intelligent construction needs of leading agricultural industries and breakthrough cloud platform technology of intelligent agricultural software development, to establish a component library system and architecture, including basic components and business components. The industry must also build an agricultural Internet of Things enabled software development platform, focusing on supporting a number of enterprises with agricultural software as a service (SaaS) as the leading business to cultivate and promote information collection, video monitoring, data analysis, system management, interface monitoring, PEST model, crop growth model, expert judgment, equipment management, user management, machine-to-machine (M2M) card management linkage control, and other basic software systems. There must be R&D solutions suitable for planting, aquaculture, e-commerce, big data services, farm management systems, and smart agriculture. This research must aim to develop enabling tools for intelligent agricultural technology and equipment applications (such as the agricultural product supply chain). The code of intelligent agricultural software must be standardized to make intelligent agricultural software available, affordable, and well used, to support the intelligent transformation of agriculture. Furthermore, timely building of the National Agricultural Software Development and Innovation Center is crucial, along with tackling the bottleneck technologies restricting the development of agricultural software systems to solve the problems of repeated development and weak pertinence of agricultural software systems and to improve the comprehensive competitiveness of the agricultural software industry.

5.2.2 Project for the application and promotion of precision agriculture management software

Projects are required to build for promoting precision agriculture management software with the aim of solving the problems of inaccurate investment in agricultural production, large resource consumption, unscientific agricultural operations, and serious agricultural non-point source pollution. These projects must also focus on the promotion and application of precision agriculture technology and breakthroughs to address the technical bottlenecks and institutional constraints on the application of precision agriculture management software. To promote precision agriculture management software, the projects must build a regional application demonstration base for precision agriculture technology and cultivate precision agriculture management software development enterprises. They must also create a new development model for the precision agriculture management software industry, for the upgrade of precision agriculture technology, considering economic and environmental benefits [19]. The industry should gradually apply precision agriculture software across the entire industry, the entire process, and all links of agricultural production. Building a software application demonstration base for precision operation technologies such as precision planting, precision irrigation, and precision spraying would promote the typical application mode of precision agriculture and ensure synchronous improvement of the output and quality of agricultural products [20,21].

5.2.3 Project for establishing an agricultural software industry cluster

To address the problems of small overall scale, low ecological construction ability, and weak international competitiveness of China's agricultural software industry, a few agricultural software industry clusters should be built with global influence relying on urban clusters such as Beijing Tianjin Hebei, Yangtze River Delta, Pearl River Delta, Chengdu Chongqing, and Wuhan metropolitan area to focus on the national new-generation AI innovation and development pilot zone. The industry should also set up an intellectual property layout design center to develop the agricultural software industry cluster into a fusion area of China's industrial and innovation chains, making it a commanding point of industrial competition and a regional economic growth pole. For example, Guiyang should develop an agricultural software and information service industry that relies on the advantages of big data industry; and the advantages of agricultural machinery equipment manufacturing clusters in Shandong Province and Northeast China should be maximized to develop special software industry clusters for the intelligent transformation of agricultural machinery equipment while strengthening the upstream and downstream cooperation between agricultural machinery equipment manufacturers, software developers, and system integrators to promote the development of intelligent agricultural machinery manufacturing. Through the establishment and promotion of industrial clusters, China must build the agricultural software industry ecology and cultivate leading enterprises in

the agricultural software sector with international competitiveness, to realize the intelligent manufacturing of management software, engineering software, and R&D and design software, to promote the development of a high-quality national agricultural software industry and enhance international competitiveness.

5.2.4 Agricultural software enterprise echelon cultivation project

Focusing on the strategic objectives of manufacturing power and network power, the localization of basic software as well as agricultural enabling and application software should be promoted by reasonably increasing the investment in agricultural software and information service industry to accelerate the construction of the entire lifecycle echelon cultivation mechanism—cultivation, support, and promotion—of agricultural software enterprises. Moreover, the industry must formulate a cultivation plan to lead enterprises in the agricultural software industry to implement the strategy of large software enterprises and groups, to strengthen the interaction between upstream and downstream projects in the industrial chain. The establishment of a leading enterprise cultivation library and the provision of preferential support to warehousing enterprises in terms of project support, talent introduction, and product promotion would advance larger scale and stronger main businesses to have a driving role in regional agricultural software enterprise clusters. The industry must address and support the major achievements and industrialization projects of technological innovation of special agricultural software to cultivate and attract excellent talent and innovation teams, accelerate the incubation of start-ups and unicorn enterprises, promote integration into the global innovation network, and form an emerging agricultural software R&D cluster, leading to changes in agricultural technology. Through the construction of the echelon cultivation project, an enterprise support policy support system covering finance and taxation, investment and financing, technology R&D, import and export, talent, intellectual property rights, market application, and international cooperation will be fully established to cultivate an agricultural software enterprise cluster of a certain scale, high technology content, good efficiency, and strong competitiveness. Essentially, the industry must build an industrial echelon in the field of agricultural software.

6 Countermeasures and suggestions

6.1 Improvement of the construction of policy support system

First, the agricultural software industry policy must be improved further. Policy support for the agricultural software industry must be reasonably increased to establish a special government procurement mechanism for agricultural software products highlighting independent innovation, to set up a special project for the localization and substitution of key information infrastructure in the agricultural software industry, and to support the improvement of the market share of independent and controllable agricultural software products. Promotion of the collaborative development model of the agricultural software industry and modern agriculture, such as the Zhongguancun Software Industrial Park and Guizhou Agricultural Big Data Center, and active exploration of new models and formats for the development of the agricultural software industry will support the growth of the industry. Policy layout must be achieved to fill in the gaps and weak links of agricultural software and promote the comprehensive pilot of expanding the opening of the agricultural software service industry.

Second, support for the agricultural software industry must be increased. In accordance with the national strategic plan of the digital rural development strategy, digital agriculture and rural development plan and the Internet Plus action plan, the financial and government procurement policies and measures must be formulated to support the development of agricultural industry. The industry must follow market law, formulate a list of government procurement software and information service products and services, improve the supporting service measures of government procurement, drive social capital investment through government procurement, reduce the costs of enterprise innovation and entrepreneurship, and improve the vitality of industrial innovation. Furthermore, the industry should provide policy support for national science and technology plan funds, establish a special fund for the development of the agricultural software industry, clarify the tilt to key regions and directions, and ensure efficient demonstration and application of agricultural software products and services.

Third, China must increase financial support for the agricultural software industry and guide financial institutions to give priority credit support to small- and medium-sized agricultural software enterprises, encourage Angel funds, venture capital institutions, and guarantee institutions to innovate the mode of cooperation with agricultural software enterprises, support qualified agricultural software enterprises to enjoy preferential tax policies, encourage enterprises to strengthen technology R&D, and improve their overall technical level.

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6.2 Strengthening the overall planning and coordination mechanism

First, China must optimize the innovation and entrepreneurship environment of the agricultural software industry. In combination with the development needs of national digital agriculture, plans to build an agricultural software industry base, incubation base, and training base along with other innovation and entrepreneurship efforts to provide management guidance, skill training, market development, standards consultation, inspection and certification, and other services for relevant participants are required. Support for telecom enterprises is also needed to upgrade the communication infrastructure, conduct pilot work on universal telecommunications services, build broadband network infrastructure and service systems with high quality, high speed, smooth flow, low price, convenient urban and rural coverage to lay a solid foundation for agricultural software technology and services. China must also actively implement science and technology commissioners and agricultural technology extension workers to carry out rural science and technology entrepreneurship; create an application environment for the transformation of agricultural software products and service achievements; build a comprehensive information service platform for rural science and technology entrepreneurship; and direct the accelerated flow of agricultural software, talent, scientific and technological achievements, knowledge, and other elements to rural areas.

The second strategy is to cultivate competitive clusters in the agricultural software industry. Based on the needs of digital agriculture and rural development, combined with regional industrial foundation and resource endowment, industrial digitization and digital industrialization should be considered the main lines of development, China needs to promote the deep integration of software technology, products, services, and agriculture. In agricultural software high-end industry clusters, China needs to actively cultivate the agricultural software industry ecosystem, promote new business forms and models such as personalized customization and service extension, and promote the formation of an agricultural software industry cluster with distinctive characteristics, easy replication, and good diffusion, dominated by brand enterprises and guided by professional markets.

Third, the overall management of agricultural software industry-related organizations must be increased. The overall deployment of the development of China's agricultural software industry needs to be studied, and a work plan, special plan, and medium-and long-term technical roadmap need to be formulated for the development of the agricultural software industry in different periods and stages to form a systematic, comprehensive, and practical macro policy system reserve which would serve as the basis for specific policy formulation. To improve the coordination mechanism for the development of the agricultural software industry, the industry and partners need to formulate a working system with clear responsibilities and coordinated development, support the deep participation of third-party organizations such as agricultural software industry development alliances and industry organizations, and jointly promote the development of the agricultural software industry.

6.3 Optimization of discipline system construction

First, the industry must improve its disciplinary layout in intelligent agriculture. Guided by cutting-edge science, technology, and agricultural production applications, the dynamic coordination mechanism must be improved for a disciplined structure of intelligent agriculture. Independent pilots and trials should first be conducted, and then the cross-integrated disciplines of computer science and agricultural production management should be added to the curriculum of relevant colleges and universities, paying attention to the cross-integration and discipline design of computer science and agronomy, mathematics, physics, biology, meteorology, economic management, and perceptual neuroscience, to form a number of influential high-quality courses related to intelligent agriculture.

Second, the cultivation of postgraduates in intelligent agriculture should be strengthened. Focusing on key technologies such as AI, big data, and cloud computing, the interdisciplinary special task of intelligent agriculture development should be considered for the training carrier of master's and doctoral students to encourage pilot universities to independently set up interdisciplinary training plans and programs for intelligent agriculture, paying attention to the scientific research and innovation ability of master's and doctoral students in disciplines, such as intelligent agriculture and agricultural software. This will appropriately strengthen the engineering practice of postgraduate training, bringing much-needed attention to the joint training of universities and agricultural research institutes, smart agricultural leading enterprises, and agricultural science and technology parks, to encourage relevant application and research institutions to open experimental platforms and data for postgraduates.

Third, the evaluation mechanism for intelligent agriculture needs to be improved. Guided by technological innovation, application promotion, and talent training, the evaluation mechanism of intelligent agriculture should be optimized and evaluation methods conducive to the development of intelligent agriculture, agricultural software, AI,

and other disciplines should be explored to learn from international evaluation standards, encourage the combination of self-evaluation and social evaluation of pilot universities, integrate identified achievements in the form of papers, patents, software copyrights, and other forms, and build a review and evaluation mechanism for the dynamic flow of researchers.

6.4 Strengthening the training of talent team

First, the training of high-level innovative talent and teams should be strengthened. Industry-leading talent must be supported and cultivated to strengthen the training of professional and technical talents in basic research, applied research, operation, and maintenance, while developing vertical compound talents (who are proficient in theories, methods, technologies, products, and applications) and horizontal compound talents (who master agriculture, computer, biology, mathematics, physics, and management). Through major R&D tasks and base platform construction of smart agriculture and agricultural software, China needs to gather high-end talent, form a high-level innovation team in several key directions of agricultural software engineering, and encourage and guide cooperation and interaction with relevant global research institutions.

Second, the talent incentive mechanisms must be improved. China needs to establish and improve its personnel system, salary system, and talent evaluation mechanism to adapt to the development characteristics of smart agriculture and agricultural software. Similarly, it is necessary to break the institutional boundaries of talent flow, improve incentive methods such as technology shares and equity options, and promote the formation of a mechanism for the distribution of intellectual property rights of modern agricultural scientific and technological achievements; improve the performance salary system, to reasonably tilt key posts and business backbones to highlight contributions; improve the indirect cost management system of scientific research projects, arrange performance expenditure openly and fairly, and reasonably reflect the innovative value of scientific researchers.

Third, talent cooperation and exchange systems must be strengthened. Based on the Belt and Road initiative, the international market should be actively explored to strengthen the introduction of intelligent agriculture and agricultural software, and output superior agricultural software products and services. With platforms developed between China and other countries, cooperation with respect to smart agriculture and agricultural software development should be strengthened along the Belt and Road. China needs to strengthen academic exchanges with world-class research institutions and universities in the field of agriculture; invite top experts in the fields of agriculture, computers, and AI so that they can impart their experience, and domestic talent should be encouraged and supported to go to foreign universities for academic exchange and training.

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