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Development Strategy of Industrial Software for Iron and Steel Industry

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Abstract: Considering the urgent demand for industrial software by the iron and steel industry during its transformation, we viewed the current status, analyzed the bottlenecks, and herewith propose industrial software development strategies for the iron and steel industry. Compared with similar products abroad, the four categories of industrial software in China are currently being developed in an imbalanced manner. Specifically, research and development design software is the weakest among the four; production control and operation management software is strong enough for market competition, and service support software faces an opportunity for catching up with and even outpacing its international counterparts. Hence, targeted development strategies are required for each category of industrial software. Market operation should be combined with government guidance to mobilize various resources and implement targeted policies. The unique advantages of having a large scale, rich knowledge, and numerous scenarios for the domestic steel industry should be maximized to provide more practical scenarios and iterative optimization opportunities for domestic industrial software and thereby promote high-quality development of China's domestic steel industry.

Keywords: iron and steel industry; intelligent manufacturing; industrial software; enterprise informatization; automatic control; customized development

1 Introduction

After more than 40 years of development, China's domestic steel industry has built the world's largest production capacity (accounting for approximately 50% of world capacity), and it currently faces the urgent need to transform its manufacturing model from a traditional mode to one that is of excellent quality and high efficiency. The steel industry's large-scale investment stage has passed, and its further development will focus on the "soft power" of the industrial chain. Therefore, the importance of industrial software has become increasingly apparent. Meanwhile, China's industrial software currently faces a mature stock market, and industrial software of other countries have the first-mover advantage in both technology and brand. Compared with developing a new-demand incremental market, the current situation is even more difficult; thus, it is necessary to have a deep and accurate understanding of the difficulties in industrial software development from a subdivided industry perspective.

With regard to industrial software research, different types of documents [1–6] have been released, but most of them are aimed at the discrete manufacturing industry, mainly focusing on the status quo and exploring product design software tools. Some of them are special technical studies on the process manufacturing industry, or summary descriptions of relevant issues from an industrial development perspective. However, there are few comprehensive studies that summarize the current situation and analyze today's problems in industrial software for the process manufacturing industry, especially the steel industry. Therefore, this study focuses on the development status of the

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steel industry and the application characteristics of industrial software, aiming to put forward some strategic suggestions for software development in the steel industry.

2 Classification of steel industrial software and the demands of the steel industry

2.1 Classification of industrial software in the steel industry

There are different ways to classify industrial software. Owing to the differences among various industries or the inconsistent focus of discussion, there is currently no standard classification method that is generally adopted by the industry. Because the embedded industrial software is usually closely related to the equipment, which has strong attributes and personalized characteristics, the discussion and analysis here focus only on industrial software related to the manufacturing management business instead of embedded software. Manufacturing management business-related software is divided into the following four categories, according to the functional use of industrial software and the characteristics of the steel industry.

The first category is research and development (R&D) design software tools, which mainly include three subcategories: (1) material design and R&D software, which is used for thermodynamic calculation, material performance calculation, molecular dynamics calculation, phase field calculation, metal material database, and so on, (2) manufacturing process design and optimization software, which solves the design problems and conducts the optimized simulation of iron and steel metallurgical process, the core of which is the finite element analysis software, and (3) factory design and delivery tool software, which is used in the design of steel plants and delivers design results in digital forms.

The second category is industrial software for production control. It includes the following types of software: (1) control software for various objects (such as equipment and process) that are composed of process control models (e.g., model base, rule base, and parameter base) and adopts distributed control system (DCS)/ programmable logic controller (PLC) as carriers; (2) data acquisition, monitoring, and analysis software based on supervisory control and data acquisition (SCADA) configuration; (3) production process execution management system (MES) software; and (4) various professional optimization control algorithms and software packages that aim at the dynamic optimization of control strategies based on models, online diagnosis of equipment, and prediction and early warning of production processes. Given that DCS/PLC, SCADA, real-time database, and so on can be applied across industries, they are not a special topic for steel industry software and will not be the focus of discussion here.

The third is operation management software, which is adopted to meet management needs concerning production, supply, marketing, R&D, human resource, finance, organization, and key performance indicators in steel enterprises by means of information. The software systems developed according to specific processes optimize and reconstruct the organizational structures, operation modes, and business processes, and support the flattening of management, efficient operation, and maximization of the profitability of steel enterprises.

The last category is called service support industrial software, which involves wide-ranging and updated business areas of the steel industry/enterprises. Inside group enterprises, software systems with specific forms and functions are used to support industrial interconnection and integration, and improve the collaborative efficiency among business units within the group. Moreover, outside the group, there is also a wide demand for collaboration across enterprises and even across industries, for example, steel product deep processing, e-commerce, precision distribution service, and so on. The whole steel industry also faces the urgent need to construct upstream and downstream supply chains to promote the cooperation and coordination among enterprises and innovate the in-between business model—concerning carbon measurement, management, and trading—to a higher level.

2.2 Steel industry's demand for industrial software

The steel industry is a typical process manufacturing industry, which has the characteristics of long processes consisting of many procedures, numerous equipment, complex processes, wide professional coverage, and huge uncertainty caused by different disturbances. The quality, manufacturing efficiency, and cost controllability of steel products can be ensured by using industrial software in whole-process business scenarios, involving new steel product design, production, sale, and management of steel enterprises. Therefore, the application of industrial software is crucial for a comprehensive improvement of the operation efficiency of the steel industry/enterprises, equipment performance, and steel products value chain, to achieve the core competitive advantage of the industry.

Discrete manufacturing is considered to be design-driven manufacturing, which means that it deeply depends on design software tools. The product functions, performance, and manufacturability are mainly solved in the design stage. The steel industry is manfuacturing-driven and the vast majority of orders are for the production of mature

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steel grades. In steel production, being manufacturing-driven means that the top priority is the effective control of the manufacturing process (aimed at ensuring product quality, cost control, and delivery schedule), and new steel grades R&D is only a small part. This is correspondingly reflected in the development and application of industrial software, that is, production control and operation management software has been prioritized for development and thus, has gained a better development space by being directly related to enterprise efficiency. Such characteristics of the whole steel industry have significantly increased the attention paid to the industrial software of production manufacturing and operation management, distracting from the level of attention and discussion that R&D software deserves. Therefore, R&D design industrial software in the steel industry has received much less attention than that in the discrete manufacturing industry, and the level of application has also lagged behind.

With the acceleration of the industrial structure adjustment, the demand for high-quality development continues to rise in the steel industry. Based on the 14th Five-Year Plan, great effort is expected be made continuously to improve and stabilize raw material support capability, strictly restrict new production capacity, accelerate merger and reorganization of enterprises, adjust and optimize process structure, promote intelligent manufacturing, and strengthen green and low-carbon manufacturing. The higher demand for R&D industrial software is being proposed for process design and optimization related to the development of new materials, which has become a new driving force for the development of industrial software in the steel industry.

3 Development status and bottleneck analysis of industrial software in the steel industry

3.1 Development status

3.1.1 Industrial software of developed countries holds the first-mover advantage in both technology and brand

Developed countries have taken the lead in industrialization and established a complete industrial system that has both wide coverage and prominent priorities. Substantial industrial knowledge accumulation, advanced automatic control processes, and mature enterprise management systems formed in industrialization have provided a solid foundation for the steady development of industrial software, and the first-mover advantage is extremely obvious.

In the past 40 years, China's steel industry has been blooming; accompanied by scale expansion, almost all the advanced metallurgical equipment and manufacturing processes in the world have been introduced, and many new demands that have not been met because of the stagnation of the foreign steel industry have constantly emerged. International industrial software players are keenly aware of the market opportunity, and they use various market means to embed industrial software into many links and development processes of China's manufacturing industry, including the steel industry. For example, in engineering colleges and universities, almost all kinds of industrial software tools have been applied in teaching and experimental activities. Beginning from the university classroom, students are guided to accept and become familiar with their specific concepts, functions, and usage habits, which objectively expands the vision of students and paves the way for students to choose the corresponding industrial software after they become engineers. However, they spare no effort to promote industrial software to enter the working process of the design institutes, engineering companies, software agents, and manufacturing enterprises. The effort made is not simply for improving market share but also for gaining great benefits by accumulating domestic manufacturing application knowledge and solidifying it into the software system, which directly raises the technical threshold of the software and further strengthens the market monopoly position—by developing software standards, repackaging interface, forcing specificity and consistency of application programming interface calling, and so on.

3.1.2 The development of industrial software in China is extremely unbalanced

Similar to others, steel industrial software is gradually developed under the guidance of the development law of the steel industry. Over the years, the scale of the domestic steel industry has increased rapidly, but there are potential problems such as being busy with development and neglecting accumulation. Many advanced equipment, process techniques, and industrial software were imported, but steel enterprises have not taken enough time to carry out meticulous self-digestion, re-upgrading, and transformation into the stage of knowledge accumulation. The hidden danger of a weak foundation of industrial software is inevitable, as China lands in an "introduction–digestion–re-introduction" cycle.

The actual situation of the steel industrial software is vividly shown in Fig. 1, where the industrial software is likened to a table, and the four legs of which are the four categories of industrial software. The present situation of industrial software used in the steel industry is that all or most of the operation management, production control, and

service support software have been (or are) stably supported by domestic industrial software, while the R&D design software is still mainly supported by foreign products.

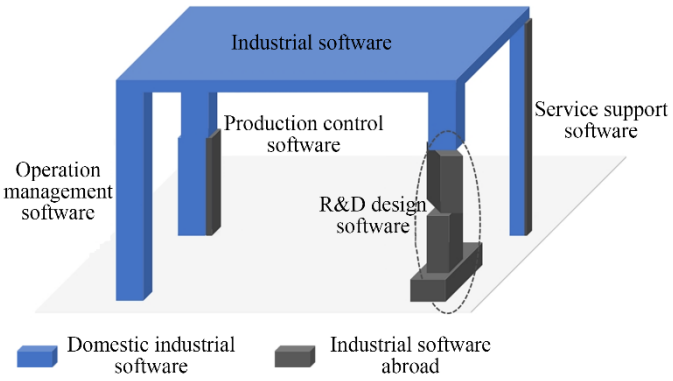

Fig. 1. Schematic of the support relationship of subclass software in the steel industry.

The assumption is that other factors can be put aside—the top of the table looks extremely solid and stable, but the four legs prop up the table in different ways. During the expansion period of the steel industry, the direct perception of practitioners is that the tabletop is flat and stable, and there is no time to consider (or care about) the state and changes under the table. However, when deeper demand for the reliability of industrial software for steel industry transformation emerged, practitioners suddenly find that the table that has been built for decades is not so solid after all, and the industrial software for R&D supported by foreign products is the most uncertain leg. At present, there is no complete domestic backup supply scheme to choose from; if this leg is accidentally broken, the table will overturn immediately.

3.2 Bottleneck analysis

3.2.1 No social consensus on software value

In the steel industry, there has been a common thinking pattern of emphasizing hardware but neglecting software. Enterprises usually attach great importance to the technical progressiveness of hardware equipment, but pay less attention to the software embedded in the equipment and control process. This is not only due to the invisible and untouchable characteristics of software, but also due to the lack of intuitive cognition and understanding of the role, value, and importance of industrial software. For example, in the bidding and procurement of engineering projects, the lowest price is required, and sometimes money pays for only hardware, with software being free. Such kind of business behavior has greatly depressed the price of software, and the value of software gets artificially discounted. The software embedded in hardware is trusted unconditionally and even blindly, but the constraint function of software definition on hardware features has been seriously neglected.

It may be difficult for domestic industrial software to fully meet the demand in the expansion stage of the rapidly developing steel industry, and it is reasonable for enterprises to introduce some critical industrial software technology, but the problem is the repeated import. On one hand, enterprises have no strong willingness to digest and absorb the introduced software technologies and have make no action for software re-innovation during software maintenance. On the other hand, there is insufficient software development, both in terms of the amount of development resources invested and the intensity of the development efforts (in addition, price demands are too harsh for software providers), which makes it rather difficult for enterprises to master the core industrial software technology, thus leading to a cycle of repeated introduction. Moreover, because of the repeated import of equipment, high-end equipment embedded with software is mostly in black or gray boxes, which restricts new product development and increases manufacturing costs constantly.

The value of industrial software is greatly underestimated even on the development side, which is manifested by the lack of awareness of software intellectual property protection, not only infringement but also the difficulty of rights protection. Failing to protect the intellectual property when using some software tools and open-source software may hinder the sustainable development of industrial software.

3.2.2 Inadequent innovation abilities of industrial software

Demand personalization refers to the materialization of enterprise-specific management concepts and processes in software. It is natural to pursue personalized demand, but overemphasizing personalization may restrict the

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improvement of software product quality and professional services. Domestic management software developed according to the specific needs of users often pays too much attention to customization and personalization, but neglects the condensation and extraction of common requirements and the ability training for systematic planning and software architecture design. Therefore, it is impossible to develop and improve industrial software products in view of continuous and effective accumulation and inheritance. The stability, scalability, replicability, and portability of the system structure are not good enough, and the related implementation cycle is also problematic.

Superimposing a customized development mode and insufficient R&D resources on each other results in weak capability for independent innovation, few core technologies, no ability to lead technological development, and finally, restrictions on process innovation. Substantial amounts of industrial knowledge, process parameters, and manufacturing know-how implied in user needs have failed to play their due role in enhancing the value of industrial software. In the long run, the only role for domestic industrial software to play in the international industrial division is just as a follower and user. By contrast, international software giants firmly occupy a relatively high market share in the large-scale, high-end, industrial software business, and have been leading the development of technology and application to the future.

Most of production process automation systems are built and delivered together with the production line equipment in steel enterprises, in which, many key technical devices are imported, including basic data acquisition and control equipment, intelligent sensing, special measurement, and the software embedded in the production process control. There is, in following-up, no sufficient attention being paid to application digestion, and not enough investment made for further development. Thus, it is difficult to constitute a complete industrial software system because of the failure of continuous innovation, and this also restricts the process transformation, product innovation, and structural upgrading of steel enterprises.

Mathematical models are the core technology of industrial process control and application informatization, which are mostly embedded in a “black box” manner in the construction of new production line projects and systems. A common phenomenon is that the accuracy of the model can reach or exceed the guaranteed value stipulated in the contract during the project acceptance assessment of foreign companies, but in the large-scale production followed-up—even for the same equipment and models—the control accuracy, product quality, and the status of the inspection and acceptance will also have a large deviation because of the change in working conditions and product adjustments. It often happens that some models change from being easy-to-use to unable-to-use, and from useful to useless. What should be recognized is that mathematical models are not always universally applicable, and industrial software in the form of process models is not a process of simple design–programming–delivery, but a process to discover problems continuously and improve in use. The quality of models and software used should be maintained and secondarily developed according to the equipment status and production conditions to ensure that the production process and product quality are stably controlled.

3.2.3 Bottlenecks in high-end R&D design tools

R&D design software is one of the most knowledge-intensive industrial software, which has deeply precipitated much engineering experience, several data models, and highly concentrated industry knowledge. The design of industrial products is greatly dependent upon this kind of software as tools. Without the support of professional design software, the design and development of any new products and new processes cannot be fulfilled. In fact, R&D industrial software is obviously the most inadequately developed software area for domestic manufacturing industries, including the steel industry, and even some of them have been in a “grabbed-by-the-throat” situation, which means that there is no other choice to make when uncertainties arise in software supply. Therefore, the bottleneck situation of R&D software has become a key problem that requires an urgent solution.

One technical trend is that new material R&D will be based on material database. In the construction of material database, developed countries have formed obvious advantages owing to their early start. Although China has built some similar databases for scientific experiments and engineering applications, the accuracy, completeness, integration, uniformity, and availability of them are still behind.

R&D industrial software is indispensable tools for model construction, calculation analysis, and result delivery for metallurgy process design and simulation optimization in the steel industry. It requires the accumulation of many libraries of methods and models, and it supports mutual coupling, which requires relatively high completeness of simulation calculation. Domestically, it obviously lags behind the internationally advanced level, in terms of systematic development.

Process factory design consists of many stages, including plant design, construction, operation, reconstruction and expansion, and is a process of multi-professional collaborative work. The effective transmission of relevant

design data is required to support the continuous expansion and extended integration of design functions in a cross-professional way. In this field, the software products abroad have already been in a business monopoly position for quite some time.

Some industrial software are still monopolized by international software giants and show more specialization and configurability in terms of process optimization, production planning, energy scheduling, and so on, which all have the characteristics of knowledge intensiveness, complex technology, and a long development cycle. The demand for data analysis tools and advanced control software continues to rise, and the dependence of steel enterprises on tool software has further increased. Industrial software products abroad dominate the technological development and high-end market.

3.2.4 Lack of brand influence of industrial software

Industrial software is a product in which technology and brand elements are integrated, and where technology supports the brand, and in turn, the brand assists users to gain an intuitive feeling and cognition. Therefore, the brand influence of industrial software can provide users with strong confidence in use.

Software development in a customized way is a competitive strategy for local software suppliers to gain relative market advantages by being closer to user management habits, which can make up for their own technology shortcomings and brand deficiencies. Moreover, to a certain extent, it guarantees the latecomer advantage of the domestic industrial software industry. However, the drawbacks of customized development cannot be ignored, especially customized software development in an overly narrow sense that it only focuses on meeting the minimum functional requirements, often ignoring the continuous accumulation of knowledge in the process and referring to mature product design techniques. As such, it is impossible to cultivate or incubate large-scale software architecture techniques.

The project-based business model has been adopted by a considerable number or even the majority of industrial software companies domestically, which is not a sustainable way to develop industrial software. Succumbing to the survival pressure from the market, companies following this approach have failed to adhere to the original intention of developing industrial software products, and gradually became project-centric companies engaged in the integration business. The software quality pursued by these companies is flexible, shallow, and often discounted because of the cost pressure, that is, to meet the delivery and acceptance requirements and realize the minimum function at the lowest cost in the shortest time possible. This is the normal state of the domestic industrial software market, and continuous improvement on product quality has become a secondary (passive) choice.

China’s MES software for steel is one of the few large-scale industrial software with both brand appeal and quality advantages, which has strong competitiveness and occupies a large market share. Although some business management software has been widely used, there is no comparative advantage in management concepts, technical architecture, user experience, and brand promotion. The current domestic industrial software situation has shown the constraints on the process optimization, products upgrading, and structure adjustment of the steel industry.

4 Development opportunities of industrial software in the steel industry

The industrialization process in China has entered a new stage marked by high-quality development, and this stage will take a long time to come to fruition. In the past few decades, the rapid industrialization process has formed the unique advantages of having a large scale and many scenarios, but the insufficient accumulation of industrial technologies and knowledge remains a weakness. This weakness is manifested in that industrial knowledge is highly fragmented and decentralized; the basic conditions and talent reserve of industrial technology software are not solid enough, and the resource elements and social environment for the success of industrial software are not perfect.Because of all these factors, the rise of domestic industrial software is not expected to happen for quite some time.

The good news is that intelligent manufacturing has become a national strategy. By promoting the industrial Internet strategy, the comprehensive interconnection of people, machines, and things will be realized, such that the connection is ubiquitous, supply is flexible, and manufacturing resources are efficiently allocated, and the transformation and upgrading of the manufacturing industry will be solidly supported. As a basic industry of the national economy, the steel industry will also benefit from this process, and the corresponding industrial software will get a rare chance to develop.

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4.1 Maximizing the existing advantages

4.1.1 The scale of the steel industry has great advantages

The market will always be the driving force behind industrial software development. The huge scale of the domestic manufacturing industry, which consists of many industrial enterprises, complete industry categories, and rich practical scenarios, will provide real demand for whatever is needed. This means that there are extremely rich manufacturing resources feeding the industrial knowledge back to software, which, from a global perspective, is a unique advantage of domestic industrial software development. The existing scale of the steel industry provides a broad market space, and the latecomer advantage enables almost all new processes and new demands to find scenarios that can provide solid support for expanding the industrial software industry.

With the transformation and development of the steel industry, new practice scenarios with wide-ranging needs are emerging, constituting a powerful driving force for industrial software upgrading. This will provide valuable opportunities for industrial software to transform from being weak to strong. At present, there is a consensus and active action for the whole steel industry to build the chain master of industrial software, and it is necessary to seize rare opportunities and make breakthroughs the soonest possible.

4.1.2 There is a strong desire to compete in the industrial software industry

From an industrial software supply perspective, it is an objective reality that domestic industrial software enterprises are generally small in scale, start relatively late, and face high survival pressure. Among the four types of industrial software in the steel industry, production control software has formed a considerable scale and a good foundation, and some of them have been able to compete with similar foreign products. For example, domestic software can compete fairly well with similar foreign products in the construction of high-speed and large-scale cold rolling mill control projects. Some software products have also shown comparative advantages, and it is not surprising that in some cases, domestic enterprise resource planning (ERP) systems are used to replace well-known foreign products.

In taking the opportunity to transform and upgrade the manufacturing industry, there is great possibility for steel industrial software to stand out and partially overtake others, through its application in as many scenarios as possible.

4.1.3 A sense of social crisis in industrial software facilitates breakthroughs

The topic of developing industrial software has often appeared in various national industrial policies. This gives a strong message that the guiding role of the state will play a part in developing industrial software and cultivating the market environment, and this will deepen the whole society's understanding of the value of industrial software.

Facing changes in the domestic and international economic situation, the urgent sense that industrial software must become independent and self-controllable will help promote the recognition of domestic industrial software throughout society, provide more application scenarios to verify, iterate industrial software products, quickly improve the functions, and steadily build software brands.

4.2 Local enterprises actively seek improvement and development

4.2.1 Automatic control software for production lines

Benefitting from the implementation of large-scale steel construction projects in China, numerous representative steel industry software companies have emerged, with representative enterprises including Shanghai Baosight Software Co., Ltd., Beijing Aritime Intelligent Control Co., Ltd., and CISDI Engineering Co., Ltd. in Chongqing. They all have strong, independent integration capabilities and can self-sufficiently develop whole-process production lines for plate, coil, pipe, wire, bar, profile, and other varieties. An automatic control system software can be totally developed independently, with software functions similar to those from abroad.

In line with the development capabilities of software for steel manufacturing line control, domestic brand software tools have developed rapidly, such as SCADA, large-scale real-time databases, communication middleware, high-frequency data acquisition, and implementation process analysis, which have been widely verified and become the core components of the platform. There are many cases of large-scale centralized control centers that have been built based on the aforementioned software and achieved business integration with breadth, height, and depth by breaking the boundaries of traditional automation control and information management.

The next task is to implement the commercialization of the technical achievements of production control software to accumulate successful application cases. For example, Baosight Software has worked on what is now a high-performance PLC controller with a backplane frame based on an open standard bus, which has been successfully applied in the control of a seven-stand, high-speed, cold rolling mill. The corresponding control performance and

reliability have reached the same level as those of internationally renowned brands. It is an important experience for the progress of domestic industrial software to form gradually some controllable and available domestic backups or alternative solutions and moderately reduce the dependence on foreign DCS/PLC, SCADA and other basic software and hardware systems. Although there exists considerable development workload, doing so is valuable from the perspective of safety, self-controllability, knowledge accumulation, industrial improvement, and market competition.

4.2.2 Process model and optimization control software

Universities represented by Northeast University and some research institutes have condensed many scientific issues through cooperation with steel enterprises. Many achievements have been made in basic theoretical research and engineering technology development methods, which have promoted the application level of digital twin modeling, intelligent optimization technology, and data analysis methods and tools. Relying on the rich resources of China Iron & Steel Research Institute Group, the Automation Research and Design Institute of Metallurgical Industry has accumulated a certain competitive advantage in material design, R&D, process optimization, and integration of whole-process models.

Much progress has been made in developing production simulation systems that incorporate expert experience, establishing a virtual environment of manufacturing, and applying it to the simulation operation of production scheduling, so as to predict the production workload, order delivery, and product quality performance, and thereby propose optimization and adjustment plans. An intelligent management system has been developed with the intelligent integration of design, predicting, scheduling, diagnosing, and decision-making, which has significantly improved the manufacturing level of products for the whole manufacturing life cycle. Adopting on-site process monitoring and real-time big data analysis helps revise and optimize manufacturing process specifications, and the manufacturing process level of steel plants is improved substantially.

4.2.3 Manufacturing execution system software

The development of steel MES system needs large investment in a lengthy development cycle because of its industrial diversity, functional complexity, and poor universality, which is fiercely competitive with lower market concentration in the domestic market. In recent years, the complete MES solutions for the steel industry provided by Baosight Software have been widely used during the internal business restructuring of China Baowu Steel Group Corporation, as well as in Ansteel Group, Shougang Group, Maanshan Iron & Steel Company Ltd., and Taiyuan Iron & Steel (Group) Co., Ltd. With the leading position enhanced, the domestic MES software in the steel industry has shown strong competitiveness, and comparative advantages have also been formed in both technical business and brand image over similar foreign products.

4.2.4 Operation management industrial software

Compared with R&D design and production control software, operation management software not only involves software technology, but also incorporates the corresponding management connotations, as it is necessary to consider the influence of the market, policies, and management concepts. Baosight Software has constantly focused on the contribution to informatization construction of the steel industry for quite a while and has delivered information development and service to Baosteel for more than 40 years. At present, Baosight Software is going all out to provide a series of complete solutions for intensive management in Baowu Group. The industrial software functions and services provided by Baosight covers whole-process, multi-level, and full-lifecycle processes of steel manufacturing. In recent years, ERP developers represented by UFIDA, Kingdee, and Inspur have rapidly promoted the domestic ERP market's transformation to implement cloud strategy. Many large steel groups have established professional R&D teams dedicated to serving the parent body and the industry, and have accumulated considerable technological achievements and industrial software products.

On the whole, domestic developing bodies in operation management industrial software already possess good technical capabilities and have demonstrated market competitive advantages. It is optimistic to make such types of domestic industrial software to substitute similar foreign products, as long as they focus on the future, keep close to user service, carry forward the cost advantage, pay attention to market segments, and simultaneously make good use of the national industrial policy support. The point is to improve the coverage and attractiveness of steel enterprises.

4.3 Data application ushers in new opportunities for development

4.3.1 Narrowing the gap between China and other countries based on industrial Internet

In the process of promoting industrial Internet, it is advisable to be fully aware of the objective reality of the small gap between domestic industrial software and abroad, which is China's comparative advantage. On one hand, such

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comparative advantage must be capitalized on as soon as possible to make up for the insufficient accumulation of industrial software, by transforming gradually from an offline to an online mode to promote knowledge accumulation and technical iteration. Although this cannot fundamentally solve the bottleneck problem faced by R&D design software, it might significantly narrow the gap and strengthen competitiveness in the market. On the other hand, through industrial Internet, data applications can tap the value of emerging businesses and develop incremental market segments from the existing mature business competition. In particular, the flexible business model advantages of domestic suppliers can be exploited to develop a new form of industrial software for the steel industry in the future.

Innovative business scenarios have emerged, driven by the demands of management reform and innovation during the transformation of the steel industry, where typical examples are standardized and unified application software environments for factories that could also be production lines, manufacturing processes, business unit bases, or enterprises; the interface between sophisticated management in factories or at the workshop level and the operation process at the enterprise level; real-time visualization, with product quality and cost as the main line and enterprise decision support; integration of single or multiple plants (bases) in manufacturing collaborations based on economic and value-based business processes to optimize plant operations; achievement of cross-regional and distributed equipment maintenance management, and management penetration of outsourced service-based production operations. These scenarios have become development opportunities for the upgrading of steel industrial software.

4.3.2 New application technology promotes new business models of industrial software

The new-generation information technology represented by industrial Internet emphasizes interconnection and data application, which provides—from the aspects of industrial ecological construction, sophisticated management, and offline and online business integration—a new development idea for the operation management software and solid technical support for cultivating the architecture design ability of large-scale industrial software.

The development digital twins are helpful in building a data-based simulation platform for R&D design to support product performance forecasting and industrial process optimization. Moreover, the application of artificial intelligence technologies is valuable for rapidly integrating product design, production, service, and other links such as applying machine learning technology in the determination of scrap steel grading, supply chain network management, and so on.

By integrating cloud computing, mobile internet, 5G mobile communication, digital twin, augmented reality/virtual reality, and other technologies, large-scale centralized control centers can realize real-time monitoring of equipment status, as well as prediction and visualization of production change trends and abnormal event inducement, to improve the certainty and accuracy of production process control.

5G technology is particularly helpful, as it provides fairly new means to solve many technical problems such as the collection of sensor data on deterministic time slices and real-time transmission and identification of massive high-resolution videos/images. The application of 5G can also accelerate the interconnection of massive people–machines–things data and make factory environment monitoring more accurate. There is a wide range of fields in which 5G can be used, to detect product defects timely, identify raw materials precisely, monitor equipment working status remotely throughout its life, and so on. 5G technology allows conducting equipment fault diagnoses and repair jobs remotely, outside the limits of factory boundaries.

At present, some cloud-style simulation service platforms have emerged domestically. Although they still integrate many or part of the industrial software tools from abroad, the new platform and technology will play a catalytic role in the technical development and commercial promotion of R&D design software, which is conducive to shortening the development cycle of basic software and makes it possible to substitute those from abroad.

As open-source concept is gradually accepted by software developers and practitioners, the development of industrial software has received greater support from open-source technology. Benefitting from the increasingly rich algorithms, components, engines, and tools of open-source platforms, self-integrated industrial software increasingly adopt open standards, thereby greatly reducing the comprehensive development cost.

4.3.3 The reconstruction of information-based system opens up new development opportunities

Industrial Internet will inevitably have a significant impact on the development and service models of traditional industrial software. The traditional business models of software product license and customized development still exist, but the new cloud service model will impact and even subvert the traditional practices. This means that opportunities and challenges coexist. The cloud–edge–end flat architecture of industrial Internet has attracted

widespread attention in the industries, and is expected to solve the "data islet" problem brought about by the traditional five-tier architecture and meet the urgent need of enterprises for data-value mining.

In the coming days, changes in steel industrial software systems will happen in two main aspects. The first is a functional evolution, where, in combination with big data, artificial intelligence, information physical system, and other technologies under the industrial Internet layout, an intelligent optimization decision-making system platform consisting of various special industrial software will be established to realize intelligent applications such as real-time monitoring remotely and in mobile form, real-time self-adjustment of planned tasks, self-regulation of process flow, and self-optimization of operating conditions for key equipment. The second is function assignment, where all functions and applications of enterprise business, such as global, platform, collaborative sharing, and general-purpose applications, will be horizontally integrated in the cloud, and the edge side will undertake the job of online monitoring, real-time calculation, accurate control, and regional applications, and will strengthen the intelligence at the process and basic levels while the traditional enterprise informatization functions gradually migrate, after being reconstructed, to the cloud or the edge.

5 Development strategy and suggestion for industrial software in the steel industry

5.1 Development strategy

5.1.1 Returning to the origin of industrial software development with knowledge as the core

Industrial knowledge is the core of industrial software, and it is critical to construct the knowledge base for developing the software. It is an arduous task to make industrial knowledge explicit while developing industrial software. It is also a long process to convert knowledge into technical solutions and iteratively optimize them in application. The thinking of "overtaking on a curve" and the campaign-style development mode must be eliminated, and the pursuit of numerous industrial software achievements that can be quantitatively evaluated and are marketable should be the steady focus. For example, based on industrial Internet, the production-line-oriented digital twin systems can be designed and developed, which will drive the deep integration of industrial mechanism models and data models, so that the dynamic optimization of manufacturing processes can be achieved intelligently and real time decision-making of enterprise operation can be performed smartly, thereby achieving the goal of operation efficiency improvement for steel enterprises and the whole steel industry.

5.1.2 Exploiting the multiplier effect of the existing advantages

One of the most important points for the success of the industrial software industry is transforming the scale advantage of domestic manufacturing industry into incremental support for the development of industrial software. In the background of the transformation from traditional manufacturing to high-quality development, it is critical to seize the opportunity of pattern transformation and explore huge market potential, so that the revitalization of industrial software industry can be achieved in the future. To respond to the common needs in the steel industry, the priority is to select the direction of certain segments with broad market prospects that are both still better in existing technical value and large value-added space, and develop industrial software products that can significantly contribute to the improvement of manufacturing efficiency and product quality.

5.1.3 Developing high-end R&D design software

In all aspects of the steel life cycle, the importance of software design tools being able to support steel grade design, process optimization, and prediction decisions is prominent. R&D design software involves model completeness, knowledge depth accumulated, data transmission effectiveness in design chain, cross-discipline extension and integration, new function design expansion, and so on. Its strong exclusivity also determines that it is impossible to participate effectively in the competition by compensating for and strengthening only partial functions, and there is no room at all for any software with low prices and simple functions to survive in the market.

Industrial software at the high end refers to advanced architecture, powerful functions, profound accumulation and better user experience. Regarding high-end tool software, a big gap exists between domestic products and international advanced-level products, especially since there are few original technologies required to compete on an equal footing with market first-movers. In spite of the severe situation, domestic industrial software should still be committed to high-end development. Concretely speaking, it is a must to pursue high-end functions from the beginning of the design process, focus on accumulation, and avoid seeking quick success and instant benefits. Low-end industrial software will not be favored by users. Homogeneous competition that is always at a low level will only aggravate the deterioration of the market environment, not win the market or achieve sustainable development.

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5.1.4 Implementing the dual strategy of technology and brand development

Industrial software typically has the dual attributes of technology and brand. Users' trust in a brand derives from the recognition of the function, which determines the market position to a certain extent. Pure technical development ability is not the only source of competitiveness for industrial software enterprises. It is necessary to promote the construction of quality engineering and brand engineering actively by starting substitutions through services, and exploit the advantages of building a long board, innovate numerous core technologies belonging to oneself, and be committed to industrialization, productization, and service. This is the right way to cope with harsh market competition challenges in technology upgrades and brand creation.

5.1.5 Cultivating industrial ecology to build an orderly market

Industrial software are products in which various experiences of the whole industry have been integrated, and the developed functions have been repeatedly optimized. Continuous application iteration is an inevitable process for industrial software to mature, and it is a necessary step for the development of the domestic industrial software industry.

What must be done is to cultivate a benign market environment, invest necessary policy resources, and develop a suitable mechanism of fault tolerance and fair competition, as well as implement support policies for the application side, so as to provide more application scenarios and opportunities for domestic industrial software and drive the improvement and iteration of software functions. It is also necessary to build a supply–demand cooperation relationship covering the upstream and downstream of the industrial chain, provide more market opportunities for domestic industrial software, and build an alliance system that is oriented to the industrial ecology. Specifically, attention must be paid to cross-industry and cross-profession collaboration and industry–university–research-application cooperation by, for example, forming a joint force between the upstream mechanical equipment and engineering design of the steel industry and the downstream steel product user industries/enterprises.

5.2 Suggestions

5.2.1 R&D design tools are the primary issue in developing industrial software

There are few market opportunities for domestic software providers to develop R&D design industrial software by their own efforts without industrial policy support and a corresponding new development mechanism design. It is urgent to solve this predicament, and this cannot be done simply on some industrial policies and plans from just a specific management perspective. The top priority is to identify the responsible developing bodies and how they can be organized for a dedicated R&D design software, and to promote the design of a top-level structure. The integration of various resources is also necessary for all national parties to formulate related policies and form a joint force, so that the targeted reinforcement of resource support can be provided from all aspects: fiscal, financial, human resource, taxation, and so on.

5.2.2 Fostering an industrial environment that is conducive to the development of domestic software

It is particularly important to combine an effective market with a promising government to coordinate a variety of policy resources, implement comprehensive measures, and mobilize the huge domestic manufacturing market resources in order to establish a development pattern that has internal circulation as the pillar and internal and external double circulation as the supplement.

The key direction of industrial software development should first be clarified as aiming to "fill in weaknesses, promote substitution, and build long boards," and then promote implementation according to different situations (Fig. 2).

Production control industrial software has the potential for building competitiveness through market mechanism. Because of brand disadvantages, the improvement of the industrial environment should be prioritized to achieve a benign social and market environment through the combination of an effective market and a promising government, so as to stimulate the endogenous power of domestic software enterprises and give play to deeper and broader substitution effects.

The operation management industrial software has shown certain comparative advantages, and it can still rely on the market mechanism for development, subject to the spillover effect brought by the existing systems and late-mover advantages, and further enhance the long-board function and expand the long-board field.

5.2.3 Supporting the formulation of industrial software standards

The proposal to speed up the formulation of China's industrial software standards is critical. At present, the factual standards adopted domestically in the production control industrial software market are dominated by foreign

manufacturing enterprises, and it is difficult to unify, which results in problems in product program compatibility and interconnection in the domestic market. To make up for the shortcomings, it is necessary to speed up the standardization job and promote the comprehensive and integrated application of industrial software in the steel industry.

5.2.4 Pooling resources to form efficiency advantages

It is also suggested that in the relevant industrial development planning, the implementation strategies be studied by classification, and the relative resources be reasonably gathered to focus on key points and pursue long-term breakthroughs. The support strategies of R&D design software should be in the form of "targeted poverty alleviation" to make up for its shortcomings as effectively as possible. Taking the following steps is important and will help tremendously. The first is to establish an industrial software research think tank by putting together the experts and talents in various fields such as steel enterprises, scientific research institutes, universities, system integration service providers, and so on, to provide high-level consulting services. The second is to promote technical innovation cases systematically and provide targeted support to successful business models. The third is to formulate policies on funds, talents, and management, to support steel enterprises in promoting the development of industrial software.

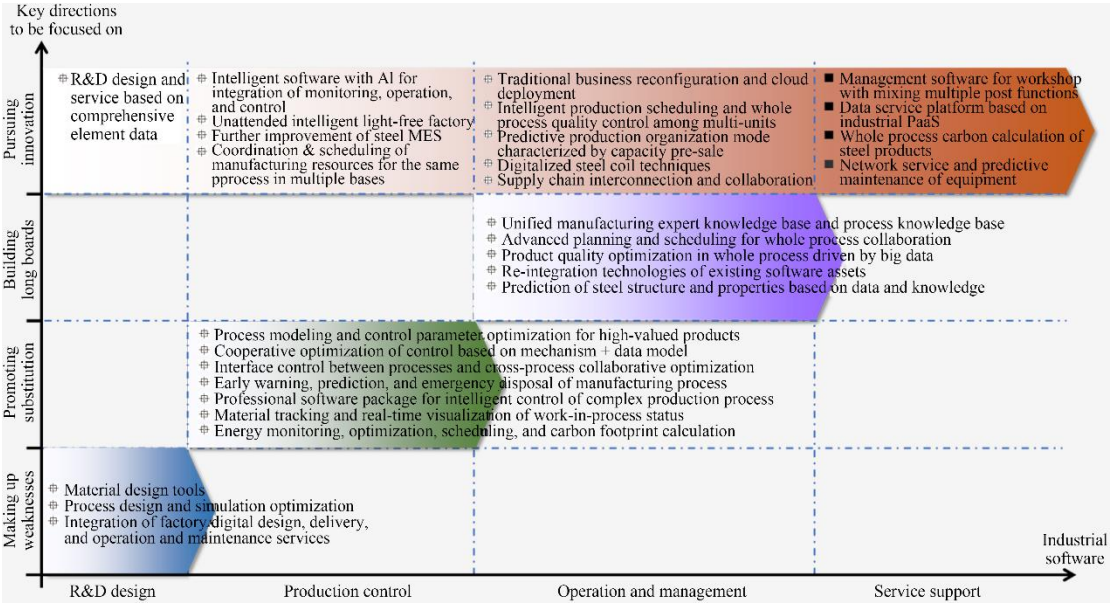

Fig. 2. The key directions for "making up for the weaknesses, promoting substitution, building long boards, and pursuing innovation" in the development of steel industrial software.

Note: PaaS means platform as a service.

6 Conclusion

The steel industry is a basic industry of the national economy; it is deeply involved in the development level and competitiveness of many manufacturing industries. Thus, it is critical to study systematically the development situation of industrial software in the steel industry, and then strategize the design and development of industrial software in a targeted manner. With the rapid development of China's steel industry, it is moving toward the forefront of the world, which not only shows the strong independent integration ability of the steel industry, but also provides an opportunity for the development of industrial software. However, the contradiction that the industrial software does not adapt to the development of the steel industry remains; in particular, the shortcomings of R&D design software are prominent. It is in a similar situation as most manufacturing industries that face the risk of being stuck in a situation where they have no control of.

Focusing on the current, medium-, and even long-term development, it is critical to integrate market effectiveness with active government participation and give full play to the scale advantages and transformation needs of the domestic steel industry. It is also of practical significance to implement precise policies and allocate specific resources (e.g., policies, markets, scenes, and talents) according to the classification of the industrial software industry. That is, actions to promote substitution and build long boards should be taken while making up for the targeted weaknesses, so that an orderly market can be gradually created, and the industrial software ecology can be

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steadily cultivated in the steel industry. At the present limited window period of high-quality development of manufacturing and innovative application of industrial Internet, the issue of developing industrial software should be prioritized in government work and social agenda to create a good situation for the coordination of industrial software, both in terms of technical development and brand creation, and thereby support the transformation and upgrading of the steel industry in China.

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