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Paths for the Digital Transformation and Intelligent Upgrade of China's Discrete Manufacturing Industry

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Abstract: The discrete manufacturing industry in China is currently being transformed and upgraded. Digital transformation and intelligent upgrade is an inevitable choice for China's discrete manufacturing industry, as intelligent manufacturing can promote the quality, efficiency, and competitiveness of discrete manufacturing. The sub-sectors of discrete manufacturing in China differ significantly and require diversified paths for digital transformation and intelligent upgrade. In this paper, we first summarize the typical characteristics of the discrete manufacturing industry, explore the challenges regarding the digital transformation and intelligent upgrade of the industry, and elaborate on common key technologies including advanced manufacturing, new-generation information, and new-generation artificial intelligence. Subsequently, we investigate four typical cases to present the frontier application progress in the field in China and propose the following key development tasks: (1) achieving breakthroughs in key enabling technologies for intelligent manufacturing, (2) developing intelligent manufacturing equipment, (3) building digital and intelligent workshops and factories, (4) providing digital and intelligent services, and (5) building standards and safety systems. Furthermore, it is necessary to accelerate pilot applications, highlight domestication, increase the reserve of high-tech talents, and formulate relevant laws and regulations in the future, to promote the high-quality development of China's discrete manufacturing industry.
Keywords: intelligent manufacturing; discrete manufacturing industry; digital transformation and intelligent upgrade; topological optimization; workshop scheduling; deep learning

1 Introduction

The manufacturing industry is an economic base, a key to the prosperity of China, and a basis of a strong country [1,2]. As the main body of China's real economy, the manufacturing industry is essential to the national economic system. According to the characteristics of product manufacturing processes, the manufacturing industry includes the following categories: discrete, process, and hybrid manufacturing. Discrete manufacturing covers sub-sectors, including home appliances, home furnishing, textiles, food, aerospace, aviation, national defense equipment, ships, electronic devices, machine tools, and vehicles. Discrete manufacturing has a large share in China's manufacturing industry, serves as an important industry to address livelihood issues such as employment, and has a considerable relevance to the lives of the residents. Although sub-sectors with advanced digitization and intelligentization, such as aviation, vehicles, and electronic devices, are included in discrete manufacturing, there are also sub-sectors with low-level automation and digitization, such as general and special equipment, facing realistic challenges of relatively low benefits and high costs. Overcapacity, plain profitability, fierce market competition, and so on inhibit China's traditional discrete manufacturing industry. There is an urgent need to accelerate transformation and upgrade to

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improve quality and efficiency, and go through digital transformation and intelligent upgrade [3,4].

Currently, scientific research and engineering practices regarding digital transformation and intelligent upgrading in the manufacturing industry are in the early stages of exploration. In scientific research, there is research aiming at the critical role that equipment revolution plays in intelligent upgrading of the manufacturing industry [5], remote collaborative intelligent upgrade methods for maintenance staff in small- and medium-sized enterprises [6], parallel and mixed upgrading pathways of intelligent manufacturing in China [7], key breakthrough directions and the implementation plan for intelligent factories in discrete manufacturing [8], and goals, characteristics, and paths of intelligentization of process manufacturing industries such as petrochemical and steel industries [9]. In engineering practices, MindSphere, presented by Siemens, supports companies in building intelligent factories. The aviation, medicine, and energy industries widely use General Electric's Predix. Schneider Electric built programmable logic controllers on the new EcoStruxure architecture and platform, enabling intelligent upgrades for production processes. The COSMOPlat industrial Internet platform developed by the Haier Group connects user needs with the entire intelligent manufacturing system, allowing users to participate in the entire process of product design and development, manufacturing, logistics, distribution, and iterative upgrading, thereby realizing cross-industry and cross-discipline expansion and services.

At present, the subsectors of discrete manufacturing in China differ significantly from each other in multiple dimensions and levels, such as application bases, market demands, and points of interest [10], so no path is set in stone for digital transformation and intelligent upgrade of China's discrete manufacturing industry. For specific implementations, actual situations in industries and enterprises must be considered. In this study, we first investigate the typical characteristics of the discrete manufacturing industry, based on which we analyze the challenges and common key technologies regarding digital transformation and intelligent upgrade of the industry. Subsequently, according to four typical transformation and upgrade cases: home appliances, home furnishing, textiles, and food, we propose technical paths for digital transformation and intelligent upgrade. We propose key development tasks for digital transformation and intelligent upgrades for discrete manufacturing enterprises and provide corresponding suggestions.

2 Typical characteristics of the discrete manufacturing industry

Developing intelligent manufacturing is essential for improving the quality and efficiency of discrete manufacturing and promoting the transformation of China's manufacturing industry from a large to a strong one. The traditional discrete manufacturing industry faces challenges, including low-level automation and digitalization, weak basic support technology, low value-added products, serious pollution, and high resources, costs, and energy consumption during manufacturing processes. Products in the discrete manufacturing industry are usually larger systems composed of multiple parts, which are processed in a series of discrete processes and then assembled [2]. The following nine dimensions summarize the typical characteristics of the discrete manufacturing industry:

Sub-sectors. There are many subsectors in the discrete manufacturing industry, and the characteristics of products and market demands of these subsectors differ, such as production lot, manufacturing mode, and process flow. The enterprise scales of the different subsectors vary. The digitalization, informatization, automation, and management operation levels of enterprises are also significantly different, as are the corresponding business needs and future development paths. Therefore, subsectors in the discrete manufacturing industry differ significantly in application bases, market demands, points of interest, knowledge barriers, business patterns, and so on.

Product lifecycle. The discrete manufacturing industry involves many aspects (e.g., R&D, manufacturing, sales, operation and maintenance services, and recycling), which greatly vary in application scenarios, domain knowledge complexity, and management methods. Each aspect is independent and strongly correlated with the other aspects [11].

Process flow. Multi-variety, small-batch, or single-piece production [1] is adopted according to orders and inventories. The importance is attached to both production and research. Mixed-line production was used. Production equipment layouts are designed based on processes rather than products.

Automation level. The automation level mainly refers to the unit-level automation level. The automation level in the discrete manufacturing industry is relatively low, requiring inspection of each part's processing quality and process. The technical skills of operators largely determine product quality and production efficiency.

Production planning management. Product processes change significantly, which requires the support of good planning abilities and production systems.

Batch number management and tracking. The management and tracking of batch numbers are in the process of

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refinement.

Job planning and scheduling. Process-level and equipment-level job plans are scheduled according to priority, work center capacity, equipment capacity, and so on.

Data acquisition. Basic information (e.g., personnel, equipment, material, and quality) is acquired mainly with manual reporting, combined with semi-automated information collection technology (e.g., bar code collection).

Equipment management. Generally, multiple machines can perform the same machining process. Failure of a single machine does not seriously impact the process of the entire product line.

3 Challenges for digital transformation and intelligent upgrade of the discrete manufacturing industry

3.1 Weak application bases

Strengthening application bases is the premise of digital transformation and intelligent upgrades. The imbalance and insufficiency of digitalization and informatization are the main contradictions in China's discrete manufacturing industry. Advanced information technologies, like 5th generation mobile communication technology (5G), provide technical support for transforming and upgrading the discrete manufacturing industry. However, industrial technology development is deficient, and the foundation is weak. The development of high-end manufacturing technologies has also been constrained. Despite the large scale and wide range of discrete manufacturing industries, low-level automation, high cost, and difficult conversion impede the transformation and upgrade of the discrete manufacturing industry. In response to the needs and pain points of the discrete manufacturing industry, strengthening the application bases and platform promotion of intelligent manufacturing is a challenge for the transformation and upgrading of China's discrete manufacturing industry.

3.2 Lack of key technologies

Improving key technologies is the basis of digital transformation and intelligent upgrading in the discrete manufacturing industry. China's industrial development is lagging, with less time, accumulation, and, generally, less controllable technologies compared to developed countries. Currently, digital transformation and intelligent upgrades are dependent on imported industrial equipment and software. Developing key technologies requires enterprises' long-term accumulation and exploration in the industry. It is also a prerequisite for external collaborators to understand enterprises' production and operation methods and perform efficient collaboration. The controllability of key technologies is also a challenge as it is an essential basis for China's discrete manufacturing industry to leapfrog and improve quality and efficiency.

3.3 Shortage of talents and cultural resources

Developing talent is crucial to the digital transformation and intelligent upgrade of the discrete manufacturing industry. Technological innovation is ultimately an innovation of talent. The shortage of talent is a major shortcoming in the process of transforming and upgrading discrete manufacturing industries. Digital transformation and intelligent upgrades are also processes of cultural reshaping, with new cultures of flexibility, trial and error, reflection, learning, respect, equality, and user-driven, which are more suitable for the era of intelligence. A consensus of top–down, people-oriented, service to people, and stimulation of the whole staff is an important guarantee for transforming and upgrading the discrete manufacturing industry. It is necessary to strengthen the development of talent and culture in the industry and activate the inner motivation to innovate talent.

3.4 Difficulty in data accumulation and utilization

The key aspects of digital transformation and intelligent upgrade include the accumulation and utilization of data loads, thus making structured, complete, accurate, reliable, and real-time data accumulation and utilization a premise of the transformation and upgrade. Data acquisition is incomplete and inaccurate owing to the variety of protocol types of the industrial equipment and sensors of enterprises. Sensitive issues, such as data security and ownership, make companies reluctant to use intelligent platforms. The low accuracy and utilization rate, together with the lack of application scenarios, affect the motivation of enterprises to transform and upgrade, bringing little benefit to creating value. Thus, ensuring that the data are accumulated and used accurately and safely is another challenge.

3.5 Insignificant economic benefits

The fundamental goal of digital transformation and intelligent upgrades is to increase economic benefits. Currently, some large enterprises in the discrete manufacturing industry conduct transformations and upgrades driven by their business development needs, policy support, and financial investment. However, the transformation and upgrade of small- and medium-sized enterprises still face many challenges, such as unclear application scenarios, high transformation costs, low benefits, difficulty in offsetting transformation costs, and in exploitation of market-based business models, resulting in a lack of motivation for transformation and upgrade. For small- and medium-sized enterprises, it is a long-term task for discrete manufacturing industry transformation and upgrades to continue to improve the efficiency and benefits of transformation and upgrade, exploit practicable business patterns, dive deep into application scenarios, and build high-performance systems and platforms to solve the problem of insignificant benefits and unclear prospects.

4 Common key technologies

Digital transformation and intelligent upgrade of the discrete manufacturing industry will deeply integrate common key technologies (Fig. 1), such as advanced manufacturing technologies, new-generation information technologies, and new-generation artificial intelligence (AI) technologies, to improve the efficiency of R&D and production, optimize resource configuration, innovate business patterns, and generate new businesses and technologies. Advanced manufacturing technologies are the core foundation of industrial technology production and the most important aspect of digital transformation and intelligent upgraded technological systems in the discrete manufacturing industry. New-generation information technologies exploit a virtual world parallel to the physical world, providing technical methods for interacting and collaborating with humans, machines, materials, methods, and environments. New-generation AI technologies will drive the social economy from a digital economy to an intelligent one, generating new patterns, businesses, and technologies.

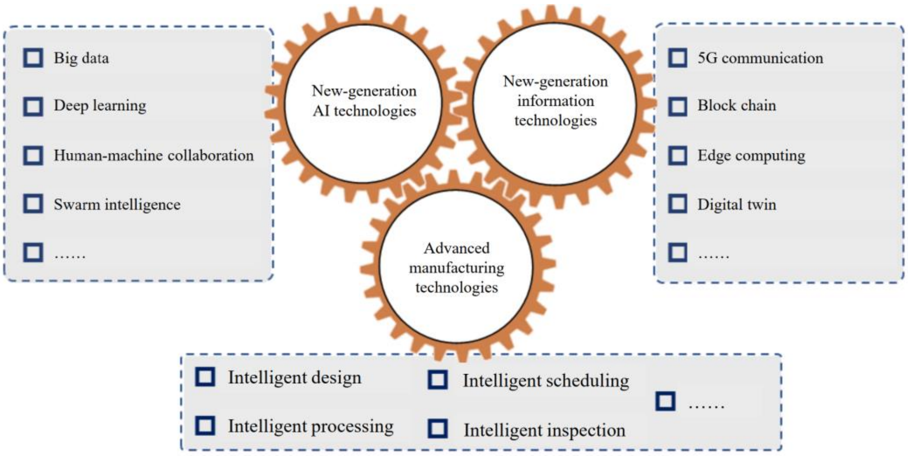

Fig. 1. Common key technologies for digital transformation and intelligent upgrade of discrete manufacturing industry.

4.1 Advanced manufacturing technologies

Advanced manufacturing technologies are the keystone and core for digital transformation and intelligent upgrading of the discrete manufacturing industry [12], covering every aspect of the product lifecycle, including intelligent design, intelligent processing [13], intelligent scheduling, intelligent inspection, and other technologies. The core of the digitalization of product materials (e.g., production equipment, assembly plants, and logistics systems in the discrete manufacturing industry) is industrial knowledge and its digital models (e.g., manufacturing mechanism, data-driven, design optimization, and management scheduling models). With the help of AI technologies, advanced manufacturing technologies can fully meet the needs of flexible mass production and product scale customization in the discrete manufacturing industry and better support high-quality products and services.

Topology optimization has become one of the core technologies in intelligent design based on a solid theoretical foundation and integration with large-scale, high-efficiency computer technologies. Topology optimization aims to obtain the best form of material distribution to achieve the optimal target performance of the structure, given the boundary conditions and various constraints. Various engineering design problems can be solved using it (Fig. 2).

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Using traditional macrostructure topology optimization design techniques, engineering structures can be intelligently designed, thus significantly reducing the structural weight, improving the carrying capacity, and maximizing the material utilization rate. Multiple physical properties, such as the structural fundamental frequency, strength, and thermal deformation, can be considered. Multiscale design techniques in topology optimization can realize intelligent metamaterial design, such as developing metamaterials with negative Poisson's ratios by designing microstructures of materials [14] and developing thermal metamaterials with thermal cloaking functionalities by considering the influence of material microscopic properties on the flow of heat in the structure [15]. These metamaterials have wide-ranging prospects for application.

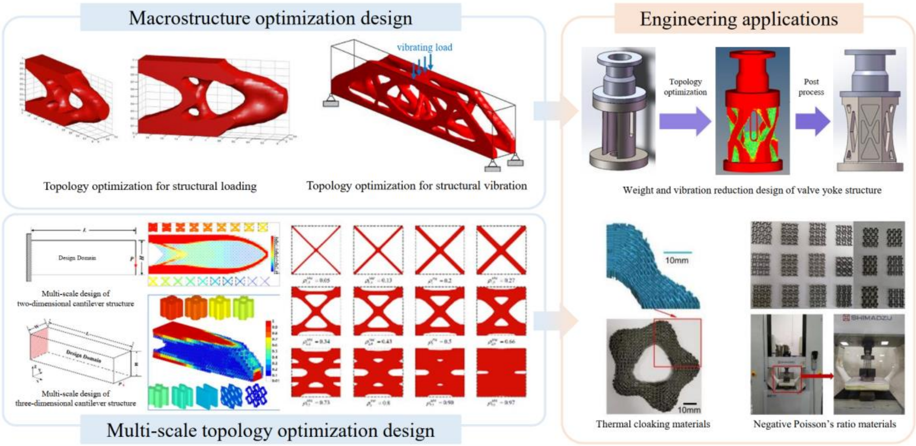

Fig. 2. Intelligent design applications based on topology optimization.

4.2 New-generation information technologies

New-generation information technologies such as 5G, edge computing, and blockchain are the engine and impetus for digital transformation and intelligent upgrades. New-generation information technologies are developing at a high speed and have a strong penetration capability, connecting the previous "digital islands" and expanding space for controlling production resources and processes. New-generation information technologies provide methods for interacting and collaborating with humans, machines, materials, methods, and environments. Blockchain technology is a reliable, trustworthy, secure, and efficient means to connect intelligences in a discrete manufacturing system, with features such as decentralization, autonomy, transparency, prevention of tampering, and traceability.

5G technology has the advantages of high bandwidth, low latency, high reliability, and large-scale nodes. 5G and key technologies such as network slicing and edge computing provide an important guarantee for the interconnection of sensory data of key elements in manufacturing workshops and accurate analysis and prediction, thereby promoting the development of intelligent workshop scheduling technology (Fig. 3). Based on 5G technology, perception systems with collaborating clouds, edges, and ends can be designed, thus realizing the interconnection of multi-source heterogeneous data. Based on perception data, AI technologies can accurately predict uncertain anomalies, turning uncertain anomalies into predictable, avoidable events [16]. According to the prediction results, the scheduling models can be adjusted, turning passive response into active regulation, reducing the impact of anomalies on the production processes and ensuring the effective and stable implementation of production plans [17].

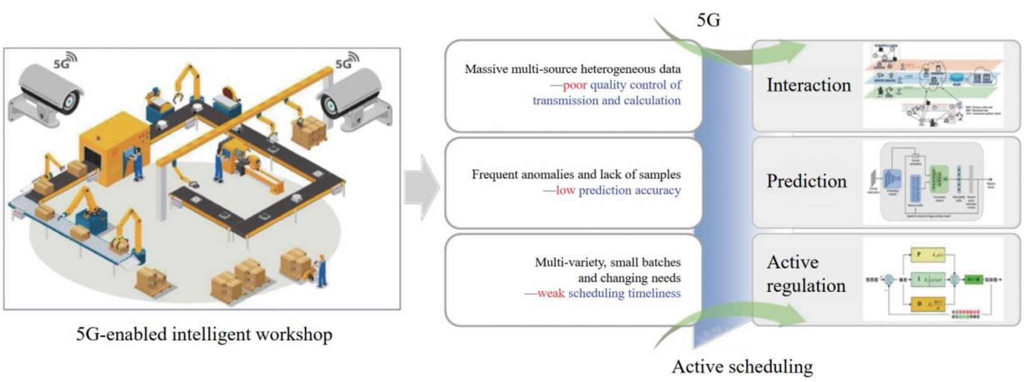

Fig. 3. Manufacturing workshop scheduling technologies based on 5G.

4.3 New-generation AI technologies

New-generation AI technologies are superstructures of digital transformation and intelligent upgrades. The rapid development of AI technologies has driven the social economy from digital to intelligent. Large changes in social formation and production patterns also occur [18–20]. For example, integration with technologies such as big data, deep learning, reinforcement learning, intelligent human–machine collaboration, swarm intelligence based on networks, and cross-media reasoning will ultimately bring a qualitative leap to the transformation and upgrade of discrete manufacturing. Real-time processing and visualization technologies of massive data based on AI technologies and the construction of a digital twin manufacturing process and a hybrid model of the mechanism are the keys to realizing high-efficiency digital intelligence in discrete manufacturing processes.

In the domain of AI, deep learning is a research hotspot in machine learning that has developed rapidly in recent years. Fault diagnosis methods based on deep learning automatically extract features without requiring complicated signal processing [21]. Deep-learning-based methods allow for surface defect feature extraction and localization [22]. A multi-representation-based domain adaptation network for fault diagnosis [23] saves time for feature engineering and improves diagnosis generalization. A semi-supervised convolutional neural network-based method for surface defect recognition reduces the cost of data labeling [24], realizing surface defect recognition with limited data (Fig. 4).

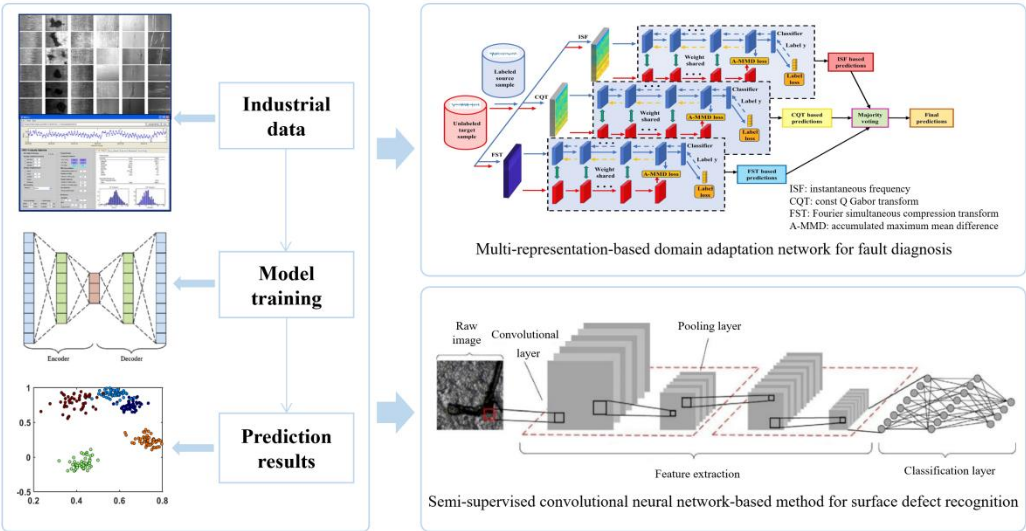

Fig. 4. Intelligent diagnosis technologies based on deep learning

5 Typical case analysis and technical path

China’s manufacturing industry has entered a stage of steady development. The discrete manufacturing industry is generally at a late stage of Industry 2.0, while the level of intelligent manufacturing is relatively weak. The manufacturing industry needs to be transformed and upgraded, with an all-round digital transformation and intelligent upgrade of the discrete manufacturing industry. The deepening application of digital and intelligent technologies will promote transformation and upgrades in six aspects: business pattern, service pattern, R&D pattern, operation pattern, manufacturing pattern, and decision-making pattern (Fig. 5). The industry is in the stage of applying different patterns and most of them are in the early stage. Some enterprises attempt to implement the transformation and upgrade of operational and decision-making patterns. The transformation and upgrade of the remaining three patterns demand higher requirements, and only a small number of companies are exploring and applying them. Four typical enterprises in the discrete manufacturing industry are taken as examples to analyze the technical paths for digital transformation and intelligent upgrades.

5.1 Transformation and upgrade of R&D pattern

The Haier Group implemented digital transformation and strived to become a leader of smart homes in the Internet era. The group has transformed from a traditional manufacturing home appliance enterprise to a platform for incubating makers for the whole society, providing solutions to intelligent manufacturing and personal customization for small- and medium-sized enterprises. Haier’s digital transformation and intelligent upgrades have undergone

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three main stages (Table 1). (1) Upgrade stages of customization and informatization. With the planning of a large e-commerce platform, the integration of all e-commerce businesses has been realized, including business-to-business, business-to-consumer, and cross-border e-commerce. The user's front-end acquisition, purchase, distribution, and receipt of the entire process of interactive experience have been opened, and value-added services other than home applications are provided for users. (2) Construction stages of automation and networking. Haier's interconnected factory has accomplished a cluster of precision assembly robots, introduced enterprise resource planning (ERP), manufacturing execution system (MES), and warehouse management system (WMS), and realized multiple interconnections among products and equipment, products and modules, as well as products and human beings. The interconnections subvert traditional serial operation patterns and realize parallel production. (3) Stages of comprehensive networking, digital transformation, and intelligent exploration. COSMOPlat, an industrial Internet of Things (IoT) platform, has been established to provide path references for digital transformation practices in the industry by aggregating high-level award-winning cases, showing the innovative value of digital transformation in the industrial Internet field. Overall, the Haier Group has actively introduced advanced technologies to realize automated and intelligent transformation and upgrade of home appliance manufacturing production lines, shortening the product development cycle by 30%, increasing the per capita output value by 30%, and nearly doubling the production capacity. COSMOPlat provides platform support for industrial Internet applications in practical scenarios and has become a valuable benchmark for innovation in the digital transformation of discrete manufacturing.

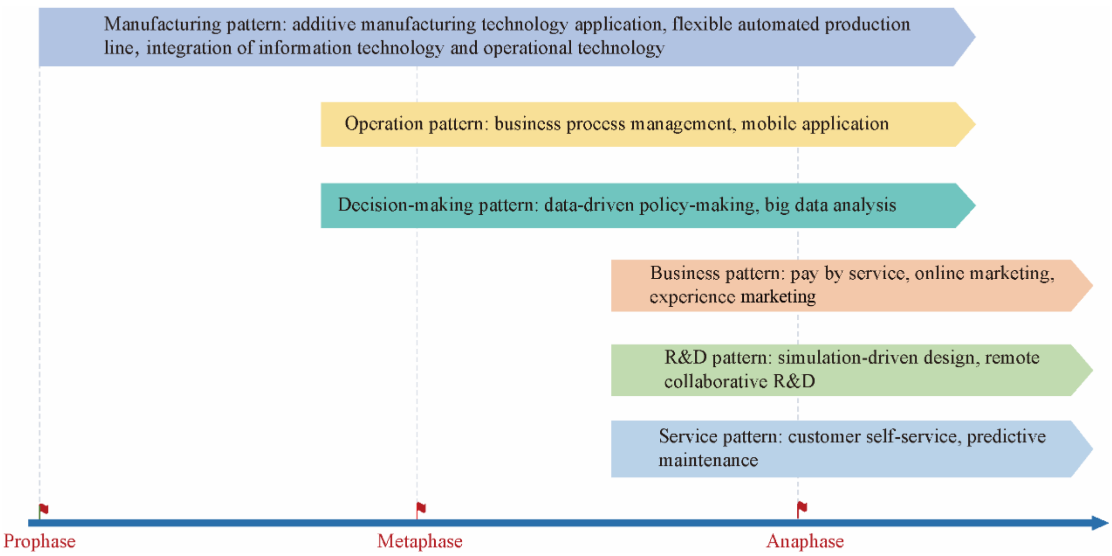

Fig. 5. The patterns of transformation and upgrade under different stages in the discrete manufacturing industry.

Table 1. Timetable for digital transformation and intelligent upgrade of Haier Group

Year	Stage	Technologies of digital transformation and intelligent upgrade
2000–2003	Customization and informatization	B2C e-commerce platform, flexible manufacturing and customization, "U-Home U-Life" platform, ERP improvement
2004–2015	Automation and networking	Digital sharing and collaboration, MES, intelligent robot assembly line, big data, and cloud computing
2016–2020	Comprehensive networking, digital transformation, and intelligent exploration	COSMOPlat, 5G mass machine communication & IoT communication, AI vision & virtual reality, edge computing & cloud control

5.2 Transformation and upgrade of operation pattern

Suofeiya Home Collection Co., Ltd. (hereinafter referred to as Suofeiya) uses a unified manufacturing operation management platform to realize digital transformation through production site visualization, manufacturing process transparency, and performance management standardization across factories. Suofeiya's digital transformation and intelligent upgrades have undergone four main stages (Table 2). (1) Management stage of informatization. Computer-aided design (CAD) drawing software replaced traditional manual drawing, whereas barcode and production management systems were applied to achieve information management. (2) Parallel stages of informatization and automation. A flexible production line was introduced to improve production efficiency while adopting the ERP system. Furthermore, an information and digitalization center was established to achieve full coverage of the information system and comprehensively promote flexible production lines. (3) Stages of digital transformation and intelligent exploration. "Project X" was implemented. MES, WMS, and supplier management systems were launched to realize intelligent warehousing and sorting automation and to plan and build intelligent factories. (4) Stages of networking and intelligent exploration. "Future Factory" 4.0 Workshop was put into production. Relying on the Internet and advanced technologies, such as big data and AI, commodity production, circulation, and sales processes have been upgraded and transformed, reshaping the business structure and ecosystem. Overall, with the related applications of informatization, automation, and intelligence, Suofeiya has realized the intelligentization of production processes and the digitization of production management and completed the transformation and upgrade of manufacturing and management patterns, which has increased the production efficiency by 50% and reduced the labor cost by 30%–50%. The comprehensive applications of Internet-based big data and AI technology have accomplished the transformation and upgrade of the process of commodity production, circulation, and sales, becoming a typical case of digital transformation and intelligent upgrade of the discrete manufacturing industry.

Table 2. Timetable for digital transformation and intelligent upgrade of Suofeiya Home Collection Co., Ltd.

Year	Stage	Technologies of digital transformation and intelligent upgrade
2005–2012	Informatization	CAD drawing software, barcode system, production management system
2012–2015	Informatization and automation	ERP system, comprehensively carried-out flexible production lines, packaging automation, full coverage of information system
2015–2018	Digital transformation and intelligent exploration	MES, WMS, supplier management systems, intelligent automation of warehousing and sorting
2018–2020	Networking and intelligent exploration	"Future Factory" 4.0 workshop, Internet Plus, big data platform

5.3 Transformation and upgrade of business pattern

Qingdao Kute Smart Co., Ltd. (hereinafter referred to as Kute) is an intelligent clothing manufacturing enterprise that has formed a KUTE intelligent pattern with mass customization as the core. They proposed a personalized customization mode and customer-to-manufacturer (C2M) pattern and built a Kute C2M industrial ecosystem to better meet the individual needs of consumers [7]. Kute's digital transformation and intelligent upgrades have undergone four main stages (Table 3). (1) Information management and automated production. Kute selected mass personalization as the main business pattern, upgraded the production plant with automated equipment, and launched an e-commerce system. (2) Parallel stages of informatization and automation. New technologies, such as automated design, MES, and WMS, were introduced, and a new business pattern of C2M was initially formed. (3) Stages of digital transformation and intelligent exploration. A digital production planning system was introduced, and efforts were made to promote the construction of data standardization and form a new pattern of data-driven large-scale personalized customization. (4) Stages of networking and intelligent exploration. After the introduction of intelligent logistics and automated warehousing systems, the labor consumption of the logistics department was reduced by 80%. With the IoT, Internet Plus, and other technologies, an Internet ecosystem has been formed, and an intelligent factory has been built. Overall, Kute realized the transformation of the new business pattern of C2M and established an intelligent factory where people, events, and things are interconnected. Compared to the traditional pattern, the production efficiency is increased by 25%, the cost is reduced by 50%, and the profit is increased by 20%, which has become a typical case of quality improvement and supply-side structural reform.

Table 3. Timetable for digital transformation and intelligent upgrade of Qingdao Kute Smart Co., Ltd.

Year	Stage	Technologies of Digital Transformation and Intelligent Upgrade
2005–2012	Information management and automated production	Personalized customization, e-commerce system, automated production line
2012–2015	Informatization and automation	Information system of factory network and each single module, information management system, automation design, ERP, WMS
2015–2018	Digital transformation and intelligent exploration	Digital equipment, digital sewing and cutting, WMS, data-driven apparel mass personalization pattern
2018–2020	Networking and intelligent exploration	Intelligent logistics, IoT construction, Internet Plus, C2M business pattern, industrial Internet ecosystem

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5.4 Transformation and upgrade of manufacturing pattern

Inner Mongolia Yili Industrial Group Co., Ltd. (hereinafter referred to as Yili) is the only dairy enterprise in China's first intelligent manufacturing pilot demonstration project batch. It develops the smart dairy industry and leads the entire industry to actively explore informatization and intelligence. Yili's digital transformation and intelligent upgrades have undergone three main stages (Table 4). (1) Construction stage of automation. Automation construction has been implemented in the connection platform, site, online automatic packaging system, and Swisslog warehouse, realizing automation of the entire process of dairy production. (2) Transformation stage of digitalization and networking. Yili built an intelligent manufacturing system, acquired equipment status and data in real time, conducted unified data interaction, and formed online platforms such as product lifecycle management systems, policy, and regulation database systems, and food safety risk assessment systems. (3) Stages of networking and intelligent exploration. The production plan execution and lifecycle quality traceability systems were used, while safe and controllable core software, such as a formula management system, was independently researched. Yili has realized intelligent construction of manufacturing equipment upgrades and information interconnections, promoting an obvious improvement in production efficiency and a significant reduction in operation costs. Overall, Yili applies digital and intelligent technologies to the entire industry chain, promotes the construction of the smart dairy industry, realizes industry digitization and intelligentization, and helps steadily improve business performance. Moreover, it provides consumers with diversified and high-quality products and services and explores a new path for the high-quality development of China's dairy industry.

Table 4. Timetable for digital transformation and intelligent upgrade of Inner Mongolia Yili Industrial Group Co., Ltd.

Year	Stage	Technologies of digital transformation and intelligent upgrade
2005–2010	Construction of automation	Product automatic filling, packaging production line, barcode system, automatic production management system
2010–2015	Transformation of digitalization and networking	MES, Y-iLMILK intelligent workshop general model standards, iICIC interconnection network architecture & information model standards, iTTS product quality control standards
2015–2020	Networking and intelligent exploration	5G & AI, data sharing, standards unification, platform construction to break the Digital Island, digital platform for lifecycle industry chain

6 Key tasks

6.1 Achieving breakthroughs in key enabling technologies for manufacturing intelligence

Intelligent reasoning is the soul of intelligent manufacturing, focusing on breakthroughs in intelligent modeling and simulation technologies, holographic human–machine collaborative systems, complex object intelligent control system technologies, and digital twin technologies [25,26]. Intelligent sensors and the industrial Internet are the foundation of intelligent manufacturing, focusing on breakthroughs in intelligent sensors and sensor networks as well as intelligent terminals, plug-and-play technologies, real-time network operating system technologies, machine-to-machine technologies, and manufacturing IoT technologies. Big data and knowledge bases form the core of intelligent manufacturing, focusing on breakthroughs in manufacturing big data mining technologies, big data intelligent analysis and management technologies, and comprehensive reasoning technologies for manufacturing big data.

6.2 Developing intelligent manufacturing equipment

Intelligent manufacturing equipment with key research and development includes intelligent machine tools, intelligent forming equipment, special intelligent manufacturing equipment, intelligent robots, and intelligent flexible manufacturing production lines. Intelligent machine tools should have the characteristics of real-time perception and interaction of processing status, independent decision-making and optimization of production processes, and a lasting ability to maintain processing accuracy [27]. Intelligent forming equipment should have information acquisition, model prediction, and decision-making control functions. Special intelligent manufacturing equipment should have extraordinary working environment adaptabilities, such as ultra-high temperature, ultra-high pressure, and extraordinary process adaptabilities (e.g., ultra-precision and high-energy beams). Intelligent robots must be capable of welding, grinding, meticulous assembly, machining, and compliance control. Intelligent, flexible manufacturing production lines should have highly flexible and intelligent capabilities, combined with multimanufacturing functional units and manufacturing islands.

6.3 Building digital and intelligent workshops

Manufacturing workshops on digitalization and networking are the primary forms of intelligent workshops [28]. Various equipment in the former should be digitally managed and controlled, while processing data should be digitally described, integrated, analyzed, and decided. The latter performs intelligent analysis and decision-making based on integrated data and intelligently optimizes the entire manufacturing process to enable the most reasonable allocation and optimization of resources.

6.4 Building digital and intelligent factories

Digital and intelligent factories are examples of intelligent manufacturing. Computer-aided accurate and reliable planning and design are executed with a three-dimensional simulation and optimization of the manufacturing processes and finished product performance. Concerning production and manufacturing, industrial robots, CNC machine tools are used to complete various production operations automatically, efficiently, and stably [8]. Regarding operation management, based on the industrial Internet, the growing needs of the entire value chain, including supply management, production and marketing, quality traceability, and after-sales operations and maintenance can be met through the effective organization and integration of knowledge in the manufacturing field.

6.5 Providing digital and intelligent services

Compared to traditional manufacturing services, digital and intelligent services are mainly reflected in improving the status and environment perception, service planning, decision-making and control levels, and service quality. In terms of industrial technology software services, integrated applications of networked intelligent industrial software are provided. In terms of intelligent services for industrial products, intelligent operation and maintenance services for major equipment are provided. In terms of production services, intelligent services such as tracking, scheduling, and optimal control of the production service processes are provided. For cloud services, integrated and shared services of manufacturing and service capabilities of the entire society are provided. Community-based intelligent manufacturing services provide seamless social networking, collaborative production among multiple enterprises, and intelligent product operation and maintenance services.

6.6 Building standards and safety systems

The system should focus on building as follows: (1) technical standards systems such as cloud computing, blockchain, and cyber-physical systems, which focus on the application and operation of technologies; (2) product standards systems such as industrial Internet platforms that focus on technical applications and products in terms of services; (3) process standards systems, such as the deep integration of industrialization and informatization, as well as intelligent manufacturing, which covers a wide range and types and should focus on analyzing the development and evolution process in multiple dimensions; and (4) safety standards systems that include building information security and physical security platforms in the discrete manufacturing industry, gathering security data, accumulating security knowledge and experience of offensive and defensive, and conducting big data analysis and early warning, identification, auditing, vulnerability management, defense, and antivirus.

7 Suggestions

7.1 Accelerating pilot applications

It is recommended to actively support and guide digital transformation, intelligent upgrades, and intelligent factory demonstrations in the discrete manufacturing industry. Based on the demonstration, large-scale implementation of digital transformation and intelligent upgrading of manufacturing equipment and enterprises will support the formation of an intelligent manufacturing ecological chain with regional advantages. Intelligent manufacturing demonstrative projects are implemented to select typical demonstrative enterprises and establish and disseminate benchmarking corporate images, focusing on key industries, such as high-end textiles, novel power equipment, construction machinery, home furnishing, and home appliances.

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7.2 Highlighting domestication

In the process of digital transformation and intelligent upgrade of the discrete manufacturing industry, it could be useful to highlight the domestication of core technologies, key equipment, and industrial software, while the phenomenon of "hollowing out" should be prevented. In terms of core technologies, key equipment, and industrial software, the industry–university–research–application integrated collaborative innovation pattern is pushed ahead to focus on solving the technical problems in the digital transformation process and intelligent upgrade of the discrete manufacturing industry.

7.3 Increasing the reserve of high-tech talents

Transformation and upgrade of discrete manufacturing industry requires strengthening the talent pool in terms of strategy, thought, technology, and execution. It is recommended to improve the vocational education and professional talent training pattern, focus on sustainable development, and cultivate professional technology and talent teams in intelligent factories in the discrete manufacturing industry. Furthermore, it is recommended to implement the construction of intelligent manufacturing talent teams and cultivate intelligent manufacturing talents [29] as follows: first, intelligent manufacturing high-tech talents, that is, cultivating intelligent manufacturing technology talents who are familiar with digital, networked, and intelligent technologies, proficient in intelligent manufacturing technologies, and good at solving practical engineering problems; second, intelligent manufacturing high-skilled talents, that is, cultivating intelligent manufacturing high-skilled talents with advanced knowledge, superb technologies, and skilled craftsmanship; third, high-level intelligent manufacturing management talents, especially entrepreneurial groups.

7.4 Formulating relevant laws and regulations

It is recommended to explore leading industrial development through legislation and continuously improve the supporting policies and regulations system for finance, taxation, finance, intellectual property rights, and personnel training to promote the long-term and stable development of the manufacturing industry. Furthermore, it is suggested to establish a digital asset intellectual property protection mechanism, introduce a digital asset licensing system, build a transparent digital asset use environment, increase government financial support, implement necessary tax incentive policies, and adopt diversified financial support methods. Information technologies can be used for digital assets for encrypting, labeling, tracing, and monitoring, strengthening legal constraints on violations.

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