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Research and Application on Industrial Internet Ecosystem Model

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Abstract: Industrial Internet can drive the high-quality development of industries, and accelerating the development of industrial Internet is conducive to the transformation and upgrading of China's manufacturing industry and to the improvement of its international competitiveness. To build an industrial Internet model that is universally adapted to large, medium, small, and micro enterprises, this study analyzes the existing industrial Internet models in China and abroad, and proposes an industrial Internet ecosystem model (IIEM) composed of three dimensions and six layers. Additionally, the operation mechanism of IIEM is presented in terms of entity, resource, digital intelligence, and dynamic value flows. Digital intelligence flow exhibits the flow value of data—a new production factor—at different levels and dimensions of IIEM, which explains the basic logic for improving the intelligent level of enterprise production systems and delivered products and expounds on the basic paths of digital transformation. IIEM emphasizes industrial attributes. Furthermore, the effectiveness of IIEM in assisting enterprises to understand the evolution and realization paths of industrial Internet and to integrate into the industrial Internet platform is verified through case study.

Keywords: industrial Internet; ecosystem; model; digital-knowledge; dynamic value flow

1 Introduction

Industrial Internet is an important engine to empower enterprises and promote high-quality industrial development. In 2022, the *Government Work Report* released by the State Council emphasized the acceleration of the development of industrial Internet. As the pace of intelligent transformation and upgrading in China's manufacturing sector has continued to increase in recent years, industrial Internet has grown rapidly and has gradually become a significant research topic.

Currently, domestic research on industrial Internet, at the technical level, mainly focuses on the functional systems of network, platform, security, and data, including the design of platform architecture, standards system, security, and evaluation indexes. Related research includes the following: (1) proposing a framework of industrial Internet standards system for industrial development needs, covering basic commonality, network, data, platform, security, and other aspects [1]; (2) providing theoretical descriptions from the technical perspective of the elements involved in the construction of the industrial Internet platform, such as equipment, data, and network [2]; (3) technically proposing the basic concepts of industrial Internet, analyzing the industrial Internet architecture and key technologies involved [3,4]; (4) constructing evaluation indexes of the industrial Internet platform to guide its development through the establishment of evaluation indexes [5]; (5) proposing that enterprises should be the main body of industrial Internet and that the construction of industrial Internet standards system should be further improved, from the perspective of strengthening the independent research and development (R&D) and application

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of core technologies [6]. At the application level, relevant research mainly focuses on the development of consumer Internet integration. Relevant studies cover the following areas. Based on the analysis of domestic platform-based enterprises such as Haier COSMO Plat, Inspur Cloud, and Ali Cloud, the characteristics of industrial Internet platforms are summarized, and an in-depth study of the industrial end of industrial Internet is suggested [7,8]. Further, the industrial Internet system and model applicable to small- and medium-sized enterprises (SMEs) are constructed based on the analysis of the application of industrial Internet technology in the supply chain innovation structure and operation mode of agricultural machinery, complex collaborative manufacturing of aviation equipment, and intelligent manufacturing of process industry [9–11]. Moreover, the ecological governance logic of manufacturing transformation and upgrading from the perspective of industrial Internet are proposed while indicating that this is not an enterprise supply chain ecology but the ecological composition of transformation and upgrading interpreted from the perspectives of enterprises and government [12]. Additionally, the industrial Internet platform's ability to promote the optimization of capital allocation structure and realize value co-creation is proposed [13,14].

Overall, existing studies have generally explained the better functionality of industrial Internet platforms, but an in-depth study is needed to explain the gradual realization of such functions from the perspective of enterprises, especially SMEs. Further studies focusing on the industrial site and oriented to management upgrading are particularly needed to elucidate the basic principles and composition of industrial Internet technology applications in SMEs. Moreover, such studies would help investigate the development mechanism of grafting industrial Internet technology to promote industrial economy and industrial transformation and upgrading. Focusing on the industrial attributes of industrial Internet, this study aims to clarify the basic principles of industrial Internet to promote the upgrading of secondary industries by constructing a new industrial Internet model. The study also summarizes the methodology of its implementation and application and extends the research results to the integration process of primary and tertiary industries (such as agriculture, medical care, logistics, and transportation).

2 Review of industrial Internet models

2.1 Existing domestic and foreign industrial Internet models and comparative analysis thereof

The development stages, goals, and the definition and implementation of the industrial Internet model vary among countries depending on the basic industrial conditions. The International Organization for Standardization classifies smart manufacturing and industrial Internet as similar. It places Germany's Reference Architecture Model Industrie 4.0 (RAMI4.0), the United States' Smart Manufacturing Systems (SMS) and Industrial Internet Reference Architecture (IIRA), and Japan's Industrial Value Chain Reference Architecture (IVRA) together for comparative studies. There are 13 common industrial Internet-related models (Table 1).

Among the existing domestic and foreign industrial Internet models, the construction ideas, standards constraints, and technology paths of the industrial Internet models of Germany, the United States, and Japan are worth studying. Table 2 lists the analysis of five industrial Internet reference models with a brief introduction.

Table 1. Relevant industrial Internet reference models.

Model name	Developer organization
Reference Architecture Model Industrie 4.0 (RAMI4.0)	German "Plattform Industrie 4.0"
Smart Manufacturing Systems (SMS)	US National Institute of Standards and Technology (NIST)
Industrial Internet Reference Architecture (IIRA)	Industrial Internet Consortium (IIC)
Intelligent Manufacturing System Architecture (IMSA)	China's National Intelligent Manufacturing Standardization Overall-Working Group
Internet of Things (IoT) Conceptual Reference Model	ISO/IEC JTC 1/WG 10 Working Group on Internet of Things
IEEE the IoT Reference Model	IEEE P2413 IoT Working Group
The International Telecommunication Union (ITU) IoT Reference Model	ITU-T SG20: IoT and its applications
IoT Architecture Reference Model	oneM2M IoT Protocol Alliance
Big Picture 3D diagram	ISO/TC184 Automation Systems and Integration
Standard roadmap for smart manufacturing framework	Alliance Industrie du Futur (AIF)
Industrial Value Chain Reference Architecture (IVRA)	Japan Industrial Value Chain Initiative (IVI)
Intelligent Manufacturing General Architecture (IMGA)	Chinese Academy of Engineering
Industrial Internet Architecture 2.0	China Academy of Information and Communications Technology

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Table 2. Comparison of industrial Internet reference models.

Model	Features	Conditions of Chinese enterprises
RAMI4.0	3D model; taking the digital factory as basic units and the administrative shell as the empowerment tool; achieving vertical, end-to-end, and horizontal integrations; requiring a strong industrial ecology base, a good digitalization, and standards base	Most enterprises do not have a good digital and standards foundation, with imperfect vertical integration, poor end-to-end integration, and difficult horizontal integration owing to the lack of uniform rules
SMS	3D model; focusing on digital management of the three life cycles; building a “manufacturing pyramid” based on ISA95, the international standard for integrating enterprise and control systems; requiring a high level of management standardization and emphasizing manufacturing ecology	Most enterprises do not have a high level of management standardization, with inadequate management of the three life cycles of product, production, and order
IIRA	3D model; taking the enterprise as a unit; requiring enterprises to have good standards and information technology base and platforms to have cross-industry capabilities	Most enterprises have poor management standardization and information technology, and enterprise platforms do not have cross-industry capabilities or have not yet established platforms
IVRA	3D model; advocating putting people first and highly identifying with lean management ideas; emphasizing factory ecology	Most enterprises have weak industrial engineering management skills, and lean management is yet to become common
Industrial Internet Architecture 2.0	3D model; requiring the enterprise to have a good functional architecture and technical system, more data accumulation, and strong data modeling abilities	Most enterprises do not embrace the concept of enterprise architecture, with a weak or no technical system, and with insufficient data accumulation and modeling capabilities

(1) Germany’s RAMI4.0 is a model using the digital factory at its core, with a rigorous hierarchical management structure. However, it requires a strong base of industrial ecology, a digitalization level at about industry 3.0, and many standards (approximately 700) constraints at its starting point of implementation. As Chinese enterprises have not yet completed industrialization, their digitalization levels vary, and the quality awareness is generally weak; most of them, particularly SMEs, are not ready to adopt the model.

(2) The SMS model developed by the US National Institute of Science and Technology takes the product, production, and order life cycles as three dimensions, with the intersection point on the “manufacturing pyramid,” emphasizing the establishment of a “smart manufacturing ecosystem” based on standards. The model is suitable for large enterprises with more complete standards and requires a good foundation of industrial software for lifecycle management. As many enterprises in China, especially SMEs, do not have relevant standards or do not follow them, and the information technology foundation is weak, it is difficult to adopt the model.

(3) The IIRA model is an industrial Internet reference architecture proposed by the US Industrial Internet Consortium (IIC), once benchmarked to RAMI 4.0. IIRA emphasizes architecture and depends on IIC members and IIoT community architects for operation. The model’s implementation requires enterprises to have good standards and an information technology foundation, which is not practicable for most Chinese enterprises.

(4) Japan’s IVRA model is the only one that includes people as a special resource in the asset dimension and incorporates the management methodology of Plan, Do, Check, Act or the Deming cycle. This is because of the long-standing human-centered employment culture, in-depth understanding of human–machine relationships, and the ubiquitous lean thinking of Japanese companies. Chinese companies generally have management shortcomings and an extensive management style, making it impossible to apply the model directly.

(5) The Industrial Internet System Architecture 2.0 proposed by China provides the functional framework, technical system, and implementation framework of industrial Internet and illustrates the Industrial Internet System Architecture from a technical perspective. However, the architecture is slightly complex and difficult to understand for large enterprises, as well as for SMEs, who generally lack the concept of architecture.

A model is a map for enterprises to implement the industrial Internet. An industrial Internet model suitable for China’s national and enterprise conditions can enable enterprises to orient themselves clearly and quickly identify implementation entry points and paths. To this end, using top-level design ideas of the world’s advanced industrial Internet models, such as those from Germany, the United States, and Japan, drawing on their technical essence and common elements (three-dimensional model, emphasis on ecology, etc.), and eliminating their inapplicable parts build the foundation for constructing a new industrial Internet model.

2.2 Analysis of the misconceptions concerning industrial Internet

2.2.1 Industrial Internet is not merely about information infrastructure

Industrial Internet entails the connection of techniques at industrial ends such as product–man–machine–material–method–environment–measurement or the mapping of their operation mechanisms and contains the mapping of relational networks of these industrial ends, such as the management relationship, process relationship, production organization, and upstream and downstream entity supply chain. Industrial site data intimately interact with its industrial end, mapping a more complex industrial site relationship network with complicated data types. The data are passed, penetrated, and loaded according to the mapped industrial site relationship network and calculated, analyzed, and reasoned according to the given industrial mechanism model and algorithm. Finally, business decisions/predictions are made to solve the actual industrial site problems.

From the previously mentioned industrial attributes of industrial Internet, it is regarded as not only a new type of "information infrastructure" similar to the new generation of information and communications technology (ICT), such as big data, artificial intelligence (AI) and fifth-generation mobile communication (5G), but also as new "industrial infrastructure."

2.2.2 Industrial Internet is not merely the Internet of Things

Since the beginning of the 21st century, the IoT industry has flourished, and physical entities have been interconnected on an increasingly large scale. Industrial Internet is a native industrial interconnection network based on industrial Ethernet/industrial control network and industrial IoT. "Industrial site + Industrial end" is both the root of problems and the resource and impetus for solutions. Industrial IoT focuses on the industrial field, taking the on-site industrial ends of product–man–machine–material–method–environment–measurement as the basic resource and connection, the object of empowerment, with strong industrial properties. Conversely, the IoT has a wider range of connection, mainly connecting physical ends without industrial properties. There is a significant difference between the two.

2.2.3 Industrial Internet is not merely a technology network

Technology is an artificial product. The native interconnected network is an objective existence in nature beyond technology, such as the existence of the gravitational network between planets, ecological network between organisms, relationship network between people, and collaboration network between enterprises. These networks are not established after the development of the technological network. Rather, the technological network constantly learns and imitates the objective existence of the native network, continuously superimposing and integrating with it, to reach the current technological heights. Data analysis of industries that have implemented the industrial Internet in recent years has revealed that industries with a more developed network of business relationships have a higher level of industrial Internet application (e.g., the electric power and light industry, which have highly developed business networks, topped the national list). Therefore, a study on the industrial Internet model should focus on the technical network from a technical perspective and the relationship networks such as the geographical collaboration, family relationship, and vernacular cooperation networks possessed by SMEs. However, no research has yet been conducted on the entitative relationship networks of enterprises in the existing industrial Internet models in China or abroad.

2.2.4 Industrial Internet is not merely the domain of large companies

Currently, China's industrial Internet has mainly adopted a development path in which large enterprises build their platforms, while SMEs depend on the cloud. Large enterprises have innate advantages such as capital, talents, and business networks. However, SMEs can also build their industrial Internet according to their needs, and their unique network of entities collaborative relationship in niche areas makes it easier to implement the large-scale application of industrial Internet.

In sum, China urgently needs to explore an independent model of industrial Internet that reflects advanced industrial thinking at home and abroad while conforming to national and enterprise conditions to form an ecosystem framework to guide the development, integration, and operation of industrial Internet. The model needs to provide a basis for large enterprises and SMEs to build a simple and practical industrial Internet. It must promote different types of enterprises to build an industrial Internet successfully to meet their specific needs.

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3 Industrial Internet ecosystem model construction and mechanism

3.1 Industrial Internet ecosystem

Industrial Internet ecosystem refers to the new industrial network formed by the interaction of all industrial elements (industrial entities, resources, data, knowledge, etc.) in industry-related fields and the dynamic organic whole formed by many stakeholders in its value chain based on digital-knowledge technology and the rules of integration, symbiosis, and win-win. By comparing and analyzing several industrial Internet reference models, this study extracts the common features of "3D+ecology" and introduces the concept of the industrial Internet ecosystem model (IIEM). With "data + knowledge" as the value driver, a universal industrial Internet model—IIEM—is constructed (Fig 1). By identifying the positive effect of industrial Internet overlapping with the entities enterprise relationship network and taking "entity + resource" as the connecting element, the widespread data and information "isolated islands" of enterprises are eliminated.

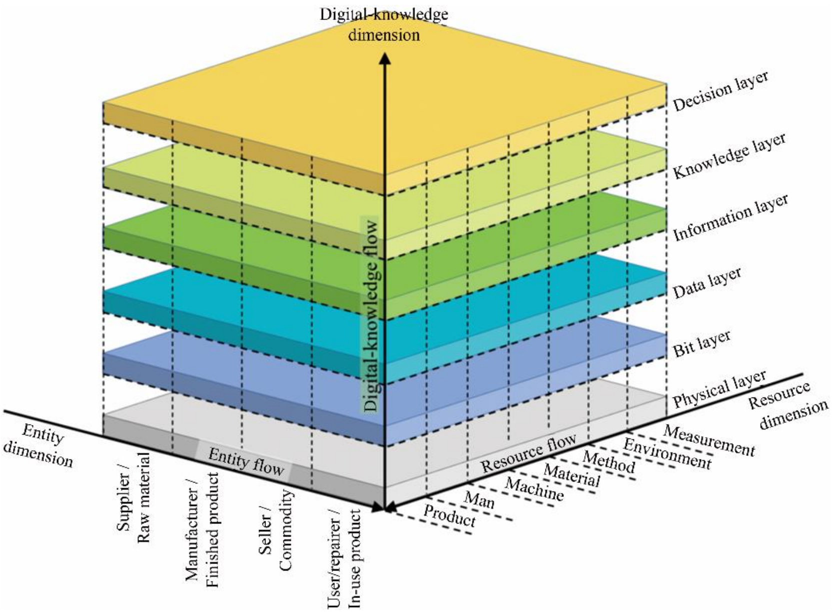

Fig. 1. Structure of IIEM.

3.2 Components of the industrial Internet ecosystem model

3.2.1 Industrial entities

Industrial entities are composed of corporate and product entities, which constitute the first category of core elements in the industrial Internet ecosystem. These entities exist as independent enterprise entities in the network system of enterprise entities operating in a market economy and reflect corporate values by delivering quality product entities on time. The intangible and rigid product demands in the form of orders drive and connect upstream and downstream enterprise entities in series, forming an entity flow, as described by the entity dimension.

3.2.2 Resources

Resources are the second category of core elements in the industrial Internet ecosystem, and product–man–machine–material–method–environment–measurement constitutes the resource network system of an enterprise. The process of manufacturing products with high quality and efficiency include resource gathering, process realization, and continuous improvement of product and enterprise values. During the process, orders drive the dynamic flow of resources and change their properties to form the resource flow, as described by the resource dimension.

3.2.3 Data

Data is the third category of core elements in industrial Internet ecosystem. As a value carrier, a product interacts with the enterprise entity and resource networks through a value-added process using data, mapping and deconstructing industrial entities, and fusing product value streams loaded with resources. The mapping, transfer, and application of data in different life cycle stages and at different levels constitute a data network system, thus forming a digital-knowledge flow, as described by the digital-knowledge dimension.

3.2.4 Knowledge

Knowledge is the fourth category of core elements that constitute an industrial Internet ecosystem. Knowledge constitutes the logic and method of human interaction with the objective world to build mechanism and data models and support human and machine decision-making and solve specific problems. Knowledge is produced by the reconstruction and dimensional increase of data and information, and digitized knowledge and data flow coexist in the same stream. Data flow penetrates the barriers of enterprise entities, while knowledge guides people and machines to act correctly. The digital-knowledge flow is the data flow that carries digital knowledge.

3.3 Structure of the industrial Internet ecosystem model

IIEM comprises "three dimensions, four flows, and six layers", emphasizing that the industrial Internet ecosystem should be planned, constructed, and operated by centering on industrial entities, as shown in Fig 1.

Three dimensions—entity, resource, and digital-knowledge dimensions—analyze the ecosystem formed by the superposition of the entity, resource, and data network systems of industrial Internet in three directions. The entity dimension is a comprehensive dimension comprising enterprise and product entities. It reflects the actual situation of internal production operation and external business cooperation and the change of product attributes at different stages and in different enterprises; for example, the end products of upstream enterprises are the raw materials or components of downstream enterprises. The establishment of an entity dimension goes beyond the conventional practice of considering only the interconnections within enterprises and directly leads them to focus on the interconnections between enterprise entities.

Four flows include entity, resource, digital-knowledge, and dynamic value flows. Each of the "three dimensions" have a flow to represent the business characteristics of this dimension, and the three flows unite to form the dynamic value flow. The flux of "four flows" reflects the mechanism of a multi-dimensional value flow. The resource flow is composed of the most common elements of product–man–machine–material–method–environment–measurement in industrial sites, which is suitable for the context of Chinese enterprises and is a common connecting element of industrial Internet. According to the basic logic of manufacturing, as shown in the direction of the arrows of entity and resource dimensions in Fig 1, the entity and resource flows move, converge, and accrue value toward the final product.

The six layers include the physical, bit, data, information, knowledge, and decision layers. These layers analyze the value form of the digital-knowledge flow at different levels, revealing the essence and path of the digital transformation of an enterprise through the continuous digitization of the physical layer by bits, reconstruction/dimensionality increase, and decomposition/dimensionality reduction.

3.4 Operating mechanism of the industrial Internet ecosystem model

3.4.1 Operating mechanism of entity flow linked to market demand

Industrial Internet is not built and applied only within the enterprise. The collaborative relationships between enterprise entities are particularly important, as they constitute the ecosystem. Intangible and rigid demand in the form of orders holds the supply chain together, highlighting the close cooperation between an enterprise entity and external entities that constitute a digital economic relationship between entities.

The term entity has two meanings: (1) the enterprise entities and (2) the product entities in the supply chain. From the perspective of enterprise entities, with suppliers, manufacturers, sellers, and users/maintenance providers as different representatives, and with the support of digital-knowledge technology, a rich and diversified cooperation ecology is formed among enterprise entities, constituting an integrated and symbiotic "supply chain network" system. From the perspective of product entities, raw materials, finished products, commodities, and in-use products are the different forms of product entities, reflecting results in different phases in the product, production, and order life cycles. Product entities start from raw materials, are processed into finished products according to the process requirements, and are delivered to end users through the sales network to become in-use products and enter the daily use and maintenance phase. Regardless of whether they are representatives of enterprise entities or forms of product entities, these four types of business representatives and product forms move throughout the product, production, and order life cycles. Thus, they constitute the production process necessary for all enterprise entities and the flow of the value-added process of product entities.

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In the entity dimension, the future core competitiveness of enterprise entities includes the accurate match of supply and demand among enterprise entities, value-added change and smooth flow of product entities, and ability of enterprise entities to control the "supply chain network." Conversely, industrial Internet research in the past focused more on the connection of machine–material–method–environment–measurement while lacking the consideration of human connection, including how to connect human operation skills, human management status, and enterprise collaboration relationships formed by people.

3.4.2 Operation mechanism of resource flow as the value-adding process

The resource dimension describes the state of change and flow of resources concerning product–man–machine–material–method–environment–measurement required for R&D, production, operation, and management of an enterprise. A product entity, regardless of whether it is in the stage of raw material, development, manufacture, finished product, commodity, or usage, needs its owner (supplier, manufacturer, seller, user/ maintenance provider) to allocate various resources and support its R&D, production, selling, use, or maintenance functions.

Product–man–machine–material–method–environment–measurement, with an increasingly high level of technical content and management, constitutes a powerful resource flow to support production, ensure product quality, and allocate various resources. Additionally, these terms are highly adapted to the working context of Chinese enterprises.

As a special resource, "man" can be understood and integrated into the industrial Internet ecosystem network from four levels: "human body, human brain, human intelligence, and group intelligence." A "human body" as productivity is a carrier of human resources to complete the production process in collaboration with a machine. A "human brain" works with a human body to judge and optimize the results of manual labor and human–machine collaborative labor. "Human intelligence" integrates the intellectual thinking process of human beings into the knowledge layer of IIEM in the form of digital knowledge, supporting digital decision-making through knowledge reuse. "Group intelligence" maps the production organization composed of multiple people to achieve product value addition, as well as the management system and standard specifications to the industrial Internet ecosystem network, thereby introducing the control power of digital systems and releasing the creativity of people.

3.4.3 Operation mechanism of the BDIKW model supporting digital-knowledge flow

The data-information-knowledge-wisdom (DIKW) model is divided into four levels: data (D), information (I), knowledge (K), and wisdom (W). Based on the DIKW model, this study proposes a digital BDIKW model. Following the ASCII code, it deconstructs and reconstructs the traditional DIKW model by using the bit layer (B) as the "digitization base", forming the digital methodology of "everything comes from bits" and "digitize everything that can be digitized." The BDIKW model comprises a bit layer (B), digital data layer (D), digital information layer (I), digital knowledge layer (K), and digital decision-making layer (W). The digital decision-making layer is the layer in which human-like machine intelligence makes decisions/predictions or human beings and machines make decisions/predictions together. The physical layer comprises entity and resource dimensions, which represent industrial entities. The industrial entities are mapped to the BDIKW model, and the ICT elements such as big data, AI, 5G, and industrial software in the BDIKW model empower the industrial entities (Fig 2).

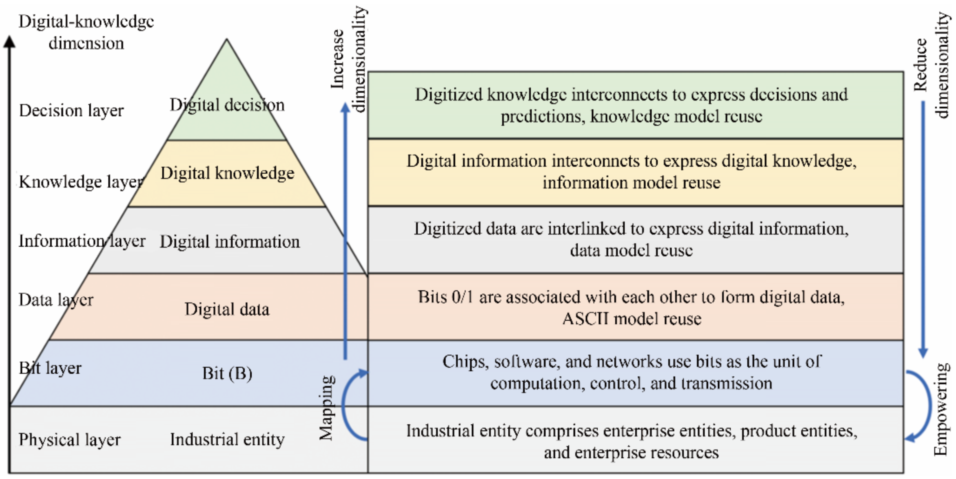

Fig. 2. The BDIKW model in the digital-knowledge dimension

Bits are digitally encoded symbols, and "the structure of the symbol is essentially a local mapping of semantic structures" [15]. For example, mechanical drive processes, CNC machines, and automated production lines are semantic from perception to processing, feedback, and control. "Symbols + semantics" constitute a human communication medium that operates in line with the BDIKW model and guides man-made systems toward intelligence. From symbols to semantics and knowledge to intelligence, the elements in the BDIKW model follow the digital cognitive process of bits ↔ data ↔ information ↔ knowledge ↔ decision-making. They are continuously reconstructed/dimensionally increased from the bottom up to achieve value upgrade or deconstructed/dimensionally reduced from the top down to achieve generalized retrieval. The BDIKW model explains and clarifies the working principle of digital transformation. Big data, AI, 5G, industrial software, digital twin, and other ICT elements also follow the BDIKW model.

3.4.4 Operation mechanism of the dynamic value flow combining three flows

Business transactions, demand transmission, order driving, and supply chain interaction between enterprise entities form an entity flow along the entity dimension. Products carrying market demand are accumulated according to the orders, driving the product–man–machine–material–method–environment–measurement resource flow along the resource dimension. The digital data/information/knowledge that penetrates the barriers of enterprise entities converges into the digital-knowledge flow, moving along the digital-knowledge dimension and continuously digitizing, deconstructing, and optimally reconstructing the physical layer. All three flows converge into the dynamic value flow, mapping the operational logic of entitative relationship, resource, and data networks (Fig 3).

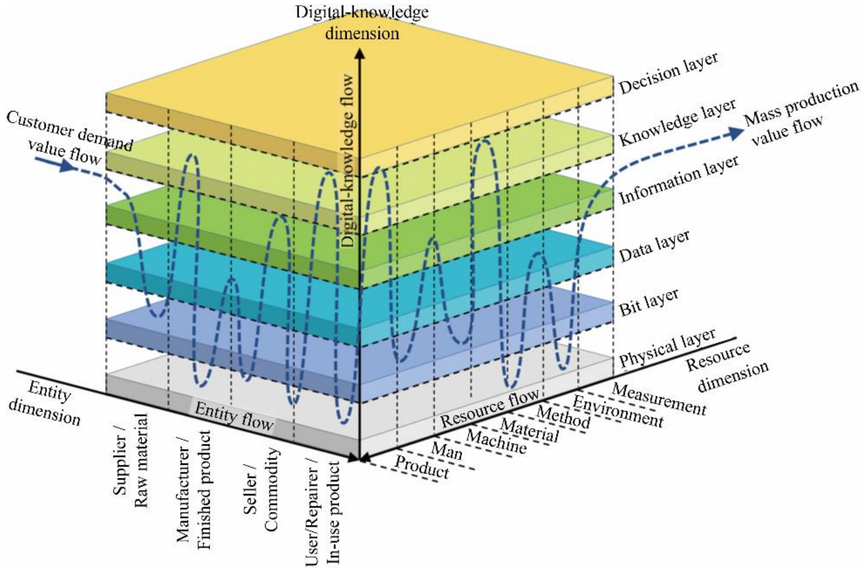

Fig 3. Dynamic value flow in IIEM

Orders are the key driving force for enterprise entities to operate, manage, and conduct business activities. While meeting the demand of upstream and downstream enterprises, the invisible and rigid product manufacturing demand attached to the supply chain carrier strongly drives the flow of manufacturing resources in the form of orders. This is supported by the digital-knowledge flow formed by cloud computing, 5G, and big data to accomplish product entities and realize value.

In the IIEM model, the essence of the up-and-down, cross-layer, and cross-domain flow of digital knowledge is the flow, interaction, and empowerment of value at different levels and in different dimensions. The dynamic value flow is the key object that needs to be controlled, configured, and optimized by the industrial Internet. Industrial enterprises need to control the dynamic value flow to integrate themselves into the digital economy.

The dynamic value flow penetrates the enterprise boundary in the form of data, intersects different life cycles, broadens the value coverage, accelerates the frequency of decision iteration, and enhances the core competitiveness of corporate entities in the business, value, and industry chains through personalized, short-period, and high-value product delivery.

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IIEM is advantageous for enterprises as the model can be integrated into the industrial Internet platform in the future and applied without being sensed by users. This has been verified by the Productized Industrial Internet platform developed by the author [16].

4 Application of the industrial Internet ecosystem model

In this study, we take Qingdao CANAAN Home Furnishing Co., Ltd (hereafter, "CANAAN") as an example to specify the path and basic steps of implementing IIEM.

4.1 Ecological positioning and selection of partners

CANAAN is a traditional small-medium-sized home textile enterprise with low profits and intensive labor input. Consumers' personalized demand is communicated to CANAAN through an inter-enterprise cooperation network that qualitatively changes the structure of the orders. Owing to increasingly multi-species and small-lot orders, the company has transformed its do-it-alone production model into a collaborative and rapid response model in the supply chain of its order delivery.

In the entity dimension, CANAAN takes stock of the strategic cooperation intentions of upstream and downstream enterprises in its supply chain, such as yarn mills, dyeing plants, product maintenance service providers, and customers, and selects close partners who can share data with mutual trust and benefit. Based on the order flow and a value-added path, the company has formulated accurately docked R&D, production, and service plans and has established a resilient supply chain network in the industrial Internet. It has also developed a customer management ecological network module based on the partnership, which has become a basic component of its product-oriented industrial Internet, thereby realizing the superposition and integration of the industrial Internet with the existing entitative relationship.

4.2 Identifying and coordinating the strengths and weaknesses of enterprise resources

Guided by the resource dimension, an analysis was conducted to identify the strengths and weaknesses of the existing enterprise resources and connect the enterprise's product, human, machine, material, method, environment, and measurement resources to the industrial Internet. The other purposes were to clarify the temporal and spatial location, availability, and security of the existing resources and determine the resources that can be mapped to the digital space to develop phased and targeted digital content of the enterprise as well as better coordinate, optimize, and allocate resources. Subsequently, CANAAN classified according to major products and processes and digitized quilting equipment and workers' operation—the process digitization for products, human, machines, and methods.

4.3 Transforming the data carrier to align business data

In the past, CANAAN recorded data/knowledge using the traditional carrier of "human brain memory + paper," with data/knowledge dissemination and reusability limited by time and space and frequent data errors in production. Therefore, based on the digital-knowledge dimension, CANAAN strongly advocated the conversion of traditional carrier data into computer data so that the data empowered by software could move through the enterprise's various business processes. Thus, it could constantly deconstruct and reconstruct the original business model along the digital-knowledge dimension of bits ↔ data ↔ information ↔ knowledge ↔ decision-making and solidify the digital foundation suitable for industrial Internet. Additionally, CANAAN focused on cultivating employees' professionalism in speaking with data, emphasized the use of data from the production site and personnel management, and conducted business based on the industrial Internet to eliminate data transmission barriers fundamentally.

4.4 Exploiting knowledge to improve human and machine intelligence

CANAAN used the automatic flow of data and intelligent flow of knowledge in the industrial Internet to form data/knowledge-informed decisions/predictions so that both the management and employees could speak with data, thus changing the traditional style of enterprise management. The intelligent flow of knowledge can enhance machine intelligence and feedback to enterprise employees and improve employee intelligence (human intelligence). The quantity and quality of employees with new human intelligence will form the competitive advantage of an enterprise in the future.

4.5 Upgrading management and the business model

With data and knowledge as production factors, CANAAN upgraded its corporate management, thereby forming management standards, process standards, and talent standards and exporting these standards to its suppliers and customers through the newly created “group intelligence” team. Thus far, CANAAN has been transformed from a manufacturing enterprise to a production-oriented service enterprise, promoting the common improvement of its supply chain ecological partners and the change of business models. Under IIEM, the company has now entered the process of changing “hard equipment” to “soft equipment,” thus changing products to services and rivals to partners, finding new profit points, and forming new business models. After several rounds of iterations, the construction of CANAAN’s industrial Internet ecosystem has been completed, driving the common growth of other partners. In the past three years, the company’s sales has increased steadily, thereby verifying the guiding value of IIEM for SME implementation of industrial Internet.

The process described above presents the basic steps for implementing industrial Internet, and other enterprises can choose or add steps appropriate for them. At the end of the fourth or fifth step, when enterprises are expected to achieve some initial results, they are recommended to return to the first step to select a wider range of ecological partners and help them build the industrial Internet “community” under the principle of common prosperity and inclusive development, thus progressing toward the industrial Internet ecosystem.

5 Conclusion

The intrinsic mechanism of an industrial Internet ecosystem constitutes the following layers: enterprise entities build an ecology together, demand orders drive resources, resources converge to make digital-intelligent decisions, data empower value flow, and product enterprises rise in value together.

The overlay of industrial Internet with the existing entitative relationship network of enterprises effectively improves the success rate of IIEM application. Under the guidance of IIEM, SMEs can fully use their regional collaboration, family relationships, and local cooperation networks, benefited by quick decision-making, short links, and easy deployment, to build an industrial Internet ecosystem based on the productized industrial Internet solution. A certain degree of generality of IIEM can meet the needs of enterprises to choose a personalized industrial Internet implementation path. In the future, IIEM can be directly integrated into the industrial Internet platform to achieve the ideal goal of “using the model in unawareness” for any size and type of enterprise so that China’s industrial Internet construction can form an ecosystem and benefit tens of millions of enterprises. Looking ahead, the IIEM model may be promoted and validated in more enterprises and industries to provide a reference for the construction of China’s industrial Internet.

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