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Research on Enterprise Intelligent Manufacturing Capability Evaluation Based on Maturity Model

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ABSTRACT. *Based on the relevant theories of capacity evaluation system construction, the evaluation system of German industry 4.0 is summarized. After referring to the experience of typical domestic and foreign enterprises in intelligent manufacturing construction and development level, the key factors affecting intelligent manufacturing capability are analyzed.Then, under the lead of the principles of evaluation index system of overall design, from the five stages of enterprise life cycle and the six factors of intelligent elements, a total of 28 dimension designed the evaluation index, and build ability evaluation model, to determine the index weight, the design of intelligent manufacturing capability level table, intelligent manufacturing capability of the enterprise overall maturity evaluation and research, has been clear about the key elements of enterprise intelligent manufacturing capacity upgrade.*

KEYWORDS: *Maturity model; Intelligent manufacturing; Ability evaluation; Analytic hierarchy process*

1. Introduction

At present, the new scientific and technological revolution and industrial transformation are on the rise, and the global industrial technology system, development model and competition pattern are undergoing major changes.Developed countries have introduced advanced manufacturing industry as the core of "industrialization" national strategy, the United States, Germany, Japan, South Korea, pushing intelligent manufacturing strategy layout and the corresponding intelligent manufacturing strategy development measures, intelligent manufacturing has become the important direction of manufacturing in the developed countries, became the various countries' development the commanding heights of the advanced manufacturing industry.In 2015, the Ministry of Industry and Information Technology of China and the NATIONAL Standards Commission

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jointly issued the Guidelines for the Construction of National Intelligent Manufacturing Standards System, stressing the importance of "Intelligent Manufacturing, standards first" and aiming to give full play to the basic and guiding role of standards in promoting the development of intelligent manufacturing.China tries to sum up a set of evaluation system and implementation methodology in line with the characteristics of enterprises' implementation of intelligent transformation, and points out the ladder target and evolution path that enterprises should achieve in the process of implementation of intelligent transformation.This paper will follow the development trend of the world, explore the construction of enterprise intelligent manufacturing capability evaluation system in the general environment of intelligent manufacturing standard system construction, and promote the world's manufacturing industry to build a complete set of end-to-end integrated solutions oriented to industrial automation, control system and personnel intelligence.

2. Research on intelligent manufacturing capability evaluation system

Intelligent manufacturing capability evaluation is a complete set of solutions including target direction, methodology and implementation guide, which can effectively unify the core competence indicators of intelligent manufacturing, measure and distinguish the level of intelligent manufacturing capability of enterprises, and point out clear paths for enterprises to implement intelligent manufacturing step by step.

Germany published the High-tech Strategy in November 2011, in which the "Industry 4.0" strategy proposed in April 2013 in Hannover Messe is the benchmark for the research of intelligent manufacturing technology in the world.The two themes of "intelligent factory" and "intelligent production" and the research on CPS are of profound significance to the upgrading of world industry.Now, Germany is the key to carry out the related standards for intelligent manufacturing, released in April 2014, surrounding the system architecture, application cases, modeling, system of functional characteristics, technology and solutions such as the standardization of roadmap, intelligent manufacturing technology for the future planning and guiding role in the standardization work.In 2016, the German Industry 4.0 working group, an institution dominated by VDMA, proposed the maturity analysis of industry 4.0 and gave the evaluation system of industry 4.0.This model has a total of six levels from level0 to level5. 0 and 1 are laymen and beginners, 2 are practitioners, 3 are experienced, 4 are experts and 5 are top players.

The Systems Integration Division of the NIST Engineering Laboratory, National Institute of Standards and Technology, published a report titled "Current Standards for Intelligent Manufacturing Systems" in February 2016[1].The report summarizes the standard system on which America's intelligent manufacturing systems will depend in the future.These standards span three major dimensions of the manufacturing life cycle: the product, the production system, and the business.It also points out that the core features of intelligent manufacturing include: interoperability and enhanced productivity of a comprehensive digital manufacturing enterprise;Realize real-time control and small batch flexible production through

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device interconnection and distributed intelligence;Coordinated supply chain management that responds quickly to market changes and supply chain disorders;Integrated and optimized decision support to improve energy and resource use efficiency;The high speed innovation cycle is achieved through advanced sensor and data analysis technology throughout the product life cycle.Therefore, the evaluation of intelligent manufacturing capacity in the United States is mainly composed of the following components, as shown in Table 1:

Table 1 Integration technology and key capability mapping

Components of an intelligent manufacturing system	Critical capability mapping
Product Lifecycle Management (PLM)	Quality, agility and sustainable development
Supply chain management (SCM)	Agility, quality and productivity
Supply chain Management Design (DFSCM)	Quality and agility
Continuous process improvement (CPI)	Quality, sustainability and productivity
Continuous experimental (CCX)	Productivity, agility, sustainability and quality
Manufacturing system oriented / reconfigurable manufacturing system (FMS/RMS)	Agility
Manufacture Pyramid	Quality, agility, productivity and sustainable development
Fast Innovation Cycle	Quality and agility
Design For Manufacture and Assembly(DFMA)	Productivity and agility

The Ministry of Industry and Information Technology of China and the State Standardization Administration Committee jointly issued the guidelines for the Construction of the National Intelligent Manufacturing Standard system (2015 Edition) in December 2015. it defines the overall requirements, construction ideas, construction contents, organization and implementation of the intelligent manufacturing standard system, which plays a guiding role in the standardization of intelligent manufacturing. Relevant Chinese scholars have also carried out relevant research on the evaluation index system of intelligent manufacturing.

Based on the discussion of the concept, system architecture and key elements of intelligent manufacturing, Yin Feng (2016) puts forward the evaluation index of intelligent manufacturing from the four levels of production line, workshop / factory, enterprise and enterprise cooperation. the weight coefficient of each index is determined by Analytic hierarchy process (AHP), and the intelligent manufacturing evaluation index system is constructed to provide methods and standards for manufacturing enterprises to carry out self-evaluation and diagnosis.

Shao Kun, Wen Yan (2017) on the basis of previous studies on intelligent manufacturing, and according to the actual situation of China's development, a set of comprehensive evaluation index system of intelligent manufacturing capability is constructed. Factor analysis is used to analyze 19 provinces in central and eastern

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China. The comprehensive score and ranking of intelligent manufacturing capacity of each province are obtained, and the level and development trend of intelligent manufacturing capacity of each province from 2012 to 2015 are compared. This paper analyzes the main influencing factors of intelligent manufacturing capability, and puts forward reasonable countermeasures and suggestions, so as to improve the development level of intelligent manufacturing industry.

Yi Weiming, Dong Peiwu, Wang Jing (2018), referring to the structure of Chinese intelligent manufacturing standard system, firstly establishes a three-dimensional evaluation index system of enterprise intelligent manufacturing capability based on tensor theory, and then constructs an evaluation model based on Tucker tensor decomposition. Finally, combined with the actual data, the training process and test results of the model are given, which shows that the model is feasible and good evaluation results. It provides a basis for accurately measuring the intelligent manufacturing capability of enterprises.

3. The connotation and characteristics of intelligent manufacturing

3.1 Connotation of intelligent manufacturing

The concept of intelligent manufacturing (IntelligentManufacturing,IM) was put forward very early. As early as the late 1980s, when information technology had not yet played a great power in human production and life, Europe and the United States and other developed countries already put forward the concept of intelligent manufacturing, but did not give an open and complete definition of intelligent manufacturing at that time[2].

In 1998, Wright (PaulKennethWright) and Bourne (DavidAlanBourne) of the United States published the first monograph in the field of intelligent manufacturing, Manufacturing Intelligence. (SmartManufacturing), systematically described the connotation and prospect of intelligent manufacturing, and defined intelligent manufacturing as "modeling the skills and expert knowledge of manufacturing technicians through the integration of knowledge engineering, manufacturing software systems, robot vision and robot control[3]." So that intelligent machines can carry out small batch production without human intervention. On this basis, Professor Williams of the British University of Technology made a more extensive supplement to the above definition, believing that "the scope of integration should also include intelligent decision support systems throughout the manufacturing organization." The McGraw Hill Science and Technology Dictionary defines intelligent manufacturing as "the use of production technology with adaptive environment and process requirements, minimizing supervision and operation, and manufacturing activities[4]."

In the 1990s, shortly after the concept of intelligent manufacturing was put forward, the research of intelligent manufacturing received widespread attention from Europe, the United States, Japan and other industrialized developed countries, and carried out international cooperative research around intelligent manufacturing

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technology (IMT) and intelligent manufacturing system (IMS). In 1991, the "International Cooperative Research Program on Intelligent Manufacturing" jointly launched by Japan, the United States and Europe put forward: "Intelligent manufacturing system is an intelligent activity that runs through the whole manufacturing process and organically integrates this intelligent activity with intelligent machines. an advanced production system that can exert maximum productivity by flexibly integrating the whole manufacturing process from ordering, product design, production to marketing and other links.

Since the 21st century, with the rapid development and application of new generation information technology, such as Internet of things, big data, cloud computing and so on, intelligent manufacturing has been endowed with a new connotation, that is, intelligent manufacturing under the condition of new generation information technology. According to the definition and connotation of intelligent manufacturing, different institutions in different countries have different definitions.

The strategy of German Industry 4.0 holds that intelligent manufacturing is "through the extensive application of Internet technology to perceive and monitor the massive data generated in the production process in real time, so as to realize the intelligent analysis and decision-making of the production system." the production process has become more automated, networked and intelligent, making intelligent production, network collaborative manufacturing and large-scale personalized manufacturing into production new business type. " The emphasis of intelligent manufacturing is the application of information physics fusion system (CPS) and the production of new business type.

In 2016, the Ministry of Industry and Information Technology and the Ministry of Finance jointly issued the Intelligent Manufacturing Development Plan (2016-2020) (Joint Regulation of the Ministry of Industry and Information Technology (2016) No. 349). Intelligent manufacturing is based on the deep integration of new generation information and communication technology and advanced manufacturing technology, which runs through all aspects of manufacturing activities, such as design, production, management, service and so on. A new mode of production with the functions of self-perception, self-learning, self-decision-making, self-execution, self-adaptation and so on.

Combined with the research object of this paper, intelligent manufacturing is defined as a new manufacturing system that combines new generation information technologies such as Internet of things, big data and cloud computing with advanced automation technology, sensing technology, control technology and digital manufacturing technology. a new manufacturing system that realizes real-time management and optimization within factories and enterprises, between enterprises and the whole life cycle of products.

3.2 Characteristics of intelligent manufacturing

From the point of view of the combination of software and hardware, intelligent manufacturing is a manufacturing system that combines virtual network with

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physical physics. The combination of virtual network and physical physics is a remarkable feature of intelligent manufacturing, which is reflected by "Industrial 4.0" in Germany and "Industrial Internet" in the United States[5].

From the point of view of functional characteristics, intelligent manufacturing is the general name of advanced manufacturing process, manufacturing system and manufacturing mode. it integrates new energy, new technology and new materials on the basis of new generation information technology, and comprehensively goes deep into all aspects of manufacturing activities. it has the characteristics of information depth self-perception, intelligent optimization self-decision-making, precise control self-execution and so on.

One is the deep self-perception of information. Intelligent manufacturing needs a lot of data support, through the use of efficient and standard methods for real-time information collection, automatic identification, and transfer the information to the analysis and decision-making system.

Second, wisdom optimizes self-decision. Through the mining and extraction, calculation and analysis, reasoning and prediction of massive heterogeneous information for the whole life cycle of the product, the decision instruction to optimize the manufacturing process is formed[6].

Third, dynamic precision self-execution. According to the decision instruction, the state of the manufacturing process is controlled by the execution system, and the stable and safe operation and dynamic adjustment are realized[7].

4. Analysis on influencing factors of enterprise intelligent manufacturing capability maturity model

Through the analysis and description of the typical cases of intelligent manufacturing enterprises in the world, it is considered that the factors that affect the intelligent manufacturing capability of enterprises mainly include external factors and internal factors[8].

4.1 External factors

External factors can be summarized as the new generation of information technology, national policy and talent construction.

(1) New generation information technology. Mainly refers to cloud computing, Internet of things, big data and other information technology. The new generation of information technology is the foundation of intelligent manufacturing and the power engine to realize intelligent manufacturing. The new generation of information technology refers to the intelligent support of the manufacturing system and each link, and it is the channel for the flow of manufacturing information and knowledge, which occupies an important position in the intelligent manufacturing system. The use of cloud computing technology to analyze and mine big data can improve product design, quality control and so on, so that the products can better meet the

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needs of customers. In the Internet environment, the intelligent virtual manufacturing platform is mainly supported by big data. Big data is an important factor that drives the simulation manufacturing platform to accurately simulate or execute production. Manufacturing enterprises may present leaping and nonlinear intelligent manufacturing transformation and upgrading. The development of the new generation of information technology can effectively improve the data and information processing efficiency of manufacturing enterprises, accelerate the interconnection of equipment and production lines within manufacturing enterprises and between upstream and downstream enterprises, and accelerate the vertical integration of different system levels.

(2) National policy. It refers to the technology research and development policy, technology transfer policy and supporting policy related to intelligent manufacturing.

(3) the construction of talents. It refers to the training or introduction of professionals and management talents in key areas of intelligent manufacturing, such as high-end CNC machine tools, industrial robots and so on. Intelligent manufacturing is a comprehensive system engineering, which needs not only senior skilled workers with special skills, but also leading talents who know advanced research and development and understand new business models. With the transformation and upgrading of Chinese traditional manufacturing, more and more high-quality professional talents will be needed. In the process of intelligent manufacturing, product design, production, management and service all need professional personnel, which can improve the product manufacturing rate.

4.2 Internal factors

The internal factors are mainly summarized as internal digital transformation, integration and interconnection, collaborative integration, technological innovation and so on.

(1) Digital transformation. It refers to the comprehensive optimization of the internal equipment and workflow of the manufacturing enterprise, the establishment of a shared database in the whole life cycle of the enterprise products, the formation of useful information through data processing, and the use of relevant data and information to simulate the actual production process. implement digital management of the production process to optimize the production process.

(2) Integrated interconnection. It includes two parts: integration and interconnection. Integration generally refers to the application of advanced technologies such as QR code and radio frequency identification to all kinds of resources needed to realize manufacturing, such as parts, manufacturing equipment, raw materials and so on. to achieve a high degree of integration of vertical data resources from a single equipment, production line, workshop, factory and even the whole industrial chain. Integration is an efficient combination of software systems and hardware equipment for all aspects of life cycle design, production, management and service, including real-time manufacturing data, real-time analysis,

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dynamic instructions and so on. Interconnection usually refers to the interconnection between equipment and equipment, between control system and equipment, and between factory and factory based on wireless communication technology and wired communication technology. Integrated interconnection integrates independent manufacturing equipment, information and functions into an interrelated, coordinated and unified system, which not only contributes to the integration of all kinds of resources and data, but also realizes convenient, efficient and centralized management[9].

(3) Synergetic fusion. On the basis of digital transformation and integration and interconnection, we use the new generation of information technologies such as big data, Internet of things and cloud computing to ensure information security and achieve collaborative sharing of information resources at the same time. Fusion methods include cross-fusion, embedded fusion, composite fusion and cross-border fusion. Integration is the innovative driving force from traditional manufacturing to intelligent manufacturing. It is an important idea for the evolution of traditional manufacturing to continuously develop and upgrade traditional manufacturing and produce more economic growth points at the same time. The deep integration of informatization and industrialization is the key support of intelligent manufacturing.

(4) technological innovation. Technological innovation includes the development of new technologies, or the application and innovation of existing technologies. Artificial intelligence, modeling and simulation technology, process data acquisition and management technology are the key to the development of intelligent manufacturing. Technological innovation is the core of intelligent manufacturing, and innovation comes from technological evolution. At the same time, the equipment layer and control layer of manufacturing enterprises need high-tech support in order to achieve integration and interconnection, and technological innovation can speed up the application of high and new technology. Technological innovation has a positive impact on intelligent manufacturing capability and integration and interconnection.

5. Construction of evaluation index system of intelligent manufacturing capability maturity model

5.1 Determination of evaluation indexes of intelligent manufacturing maturity model

The methodology of maturity in different fields is consistent, and the intelligent manufacturing capability maturity model fully draws lessons from previous experience, which is the application of maturity theory in the field of intelligent manufacturing[10]. We consider the four dimensions of life cycle, system level, intelligent function and knowledge management as a whole, which is summarized as "intelligence + manufacturing", and explain the core composition of intelligent manufacturing from the two dimensions of life cycle level and intelligent element level[11]. further decompose to form design, production, logistics, sales, service,

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resource elements, interconnection, system integration, information fusion, emerging formats, knowledge management and other core competence elements[12].

5.1.1 Lifecycle hierarchy

(1) Design stage

Design is to form the realization scheme of design requirements through the process of product and process planning, design, reasoning verification and simulation optimization. The improvement of design capability maturity is from experience-based design to parameterization / modularization based on knowledge base, modeling design and simulation optimization, and then to the collaboration of the whole life cycle of products such as design, process, manufacturing, inspection, operation and maintenance, etc. reflects the rapid satisfaction of personalized needs. Including: product design, process design, process optimization.

(2) Production stage

Production is through the integration of IT and OT to achieve intelligent scheduling, adjustment and optimization of the whole production process from front-end procurement, production planning management to back-end warehousing and logistics, so as to achieve flexible production. Including: procurement, planning and scheduling, production operations, warehousing and distribution, quality control, safety and environmental protection.

(3) Logistics stage

Logistics management is the process of transporting products to downstream enterprises or users, using advanced Internet of things technologies such as bar code, radio frequency identification, sensors and global positioning system (GPS). Through information processing and network communication technology platform to achieve automated operation of the transportation process, visual monitoring and optimal management of vehicles and routes, in order to improve transportation efficiency and reduce energy consumption.

(4) Sales stage

Sales management is to take customer demand as the core, using big data, cloud computing and other technologies to analyze and forecast sales data and behavior, and promote the optimization and adjustment of production planning, warehousing, procurement, supplier management and other business.

(5) Service phase

This phase includes customer service and product service.

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5.1.2 Intelligent feature level

(1) Resource elements

Resource elements are the planning, management and optimization of organizational strategy, organizational structure, personnel, equipment and energy, which provides the basis for the implementation of intelligent manufacturing. Including: strategic planning, staff capabilities, equipment digitization, resource management.

(2) Interconnection

Interconnection is the deployment and application of fieldbus, industrial Ethernet and wireless network in the factory, which makes the factory have an environment to organically connect manpower, machinery, materials and so on. Including: network environment and network security.

(3) System integration

The purpose of system integration is to realize the interconnection and interoperation of all kinds of business and information in the enterprise, and finally achieve the state of complete integration of information physics. The improvement of the maturity of system integration is the transformation from the individual application within the enterprise, the interconnection and interoperation between systems, to the integration of all systems within the enterprise and the upstream and downstream integration between enterprises, which reflects the full sharing of resources. Including: application integration, system security.

(4) Information fusion

The core of information fusion lies in the development and utilization of data. Through the application of data standardization and data model, we can optimize the process of design, production and service, and improve the ability of prediction, early warning and independent decision-making. Including: data fusion, data application, data security.

(5) New forms of business

Under the promotion of the Internet, the emerging business format is a new business model formed by enterprises by adopting information means and intelligent management measures to rethink and construct the production mode and organization mode of the manufacturing industry. The capability maturity of the emerging business format is mainly reflected in the advanced stage of intelligent manufacturing, which achieves the purpose of fast and low cost to meet the personalized needs of users, remote control of equipment and interactive sharing of information resources. to achieve collaborative optimization of various links between enterprises and departments. Including: personalized customization, remote operation and maintenance, collaborative manufacturing.

(6) Knowledge management

Knowledge is a resource after value-added processing. The relationship between

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knowledge and resources is relative and can be transformed into each other. For the special level, the high-level object is knowledge, and the low-level object is resources. The higher the maturity level of knowledge management, the higher the wisdom level of the enterprise, the stronger the ability to control knowledge and use wisdom, and the stronger the system management ability and business prediction ability of the enterprise.

Based on the above analysis, the evaluation index system of intelligent manufacturing capability maturity is constructed from the aspects of core competence elements, such as design, production, logistics, sales, service, resource elements, interconnection, system integration, information fusion, emerging business formats, knowledge management and so on. (as shown in Table 2).

Table 2 Evaluation index system of intelligent manufacturing capability maturity

Dimension layer	Core competence layer	Index layer
Lifecycle hierarchy (A)	Design phase (A1)	Product design (A11)
		Process design (A12)
		Process optimization (A13)
	Production stage (A2)	Procurement (A21)
		Planning and scheduling (A22)
		Production operation (A23)
		Quality Control (A24)
		Safety and environmental protection (A25)
		Warehousing and distribution (A26)
	Logistics stage (A3)	Logistics management (A31)
	Sales stage (A4)	Sales management (A41)
	Service phase (A5)	Customer service (A51)
		Products services (A52)
Intelligent feature level (B)	Resource elements (B1)	Strategic planning (B11)
		Employee ability (B12)
		Equipment digitization (B13)

		Resource management (B14)
	Interconnection (B2)	Network environment (B21)
		network security (B22)
	System integration (B3)	Application integration (B31)
		System security (B32)
	Information fusion (B4)	Data fusion (B41)
		Data application (B42)
		Data security (B43)
	New forms of business (B5)	Personalized customization (B51)
		Remote operation and maintenance (B52)
		Cooperative system (B53)
	Knowledge management (B6)	Enterprise intelligence (B6)

5.2 Determination of Evaluation Index weight of Intelligent Manufacturing capability maturity Model

The maturity model index system is generally evaluated from two dimensions: quality and quantity. Therefore, after constructing the evaluation index system of intelligent manufacturing capability maturity model, it is necessary to determine the weight of the index.

The evaluation index system of intelligent manufacturing capability maturity model is divided into three levels, namely, dimension layer, core competence layer and index layer. AHP is mainly used to weight the evaluation index of intelligent manufacturing capability maturity model. In the first step, experts are invited to compare the indexes in pairs to judge their importance, and the proportional scale of the ninth quartile (such as Table 3) is used to score. The second step is to construct the judgment matrix according to the expert score. According to the eigenvalues and Eigenvectors of the judgment matrix, the consistency test is carried out and the weight is determined. Taking the empowerment of the five core competencies at the life cycle level as an example, this paper explains in detail how to use the analytic hierarchy process to empower the index system.

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Table 3 proportional scale of the ninth quartile

Meaning	Extremely important	Very important	important	Slightly important	Equal	Slightly minor	Secon dary	Very minor	Extreme and minor needs
Scale	9	7	5	3	1	1/3	1/5	1/7	1/9

Note: the importance of 8 is between 7 and 9, and 2Jing 4 and 6 is also used as the intermediate judgment value of adjacent scales.

(1) Construct judgment matrix

According to the score of experts and the scale table, a pairwise comparison judgment matrix is obtained $A=(\mathrm{a}_{ij})_{n\times n}$ .Judgement matrix $A=(\mathrm{a}_{ij})_{n\times n}$ is an orthogonal matrix that satisfies both the following attributes:

$$\mathrm{a}_{ij} = a_i / a_j \quad (1)$$

$$\mathrm{a}_{ij}=1\,(\mathrm{i}=\mathrm{j}) \quad (2)$$

$$\mathrm{a}_{ij} = \frac{1}{\mathrm{a}_{ji}} (3)$$

In this study, according to the scores of experts on the life cycle level, the following judgment matrix is constructed.

$$A_1 = \begin{bmatrix} 1 & 6 & 4 & 4 & 5 \\ 1/6 & 1 & 3 & 2 & 2 \\ 1/4 & 1/3 & 1 & 2 & 2 \\ 1/4 & 1/2 & 1/2 & 1 & 3 \\ 1/5 & 1/2 & 1/2 & 1/3 & 1 \end{bmatrix}$$

(2)Weight calculation

The row vectors of the judgment matrix A_1 are geometrically averaged, that is, the values of each row are multiplied to the fifth power, and then normalized to get the weight vector.

$$W = \sqrt[5]{\prod_{j=1}^{5} \mathrm{a}_{ij}}$$

$$W_1 = \sqrt[5]{1\times 6\times 4\times 4\times 5} = 3.44$$

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$$W_2=\sqrt[5]{\frac{1}{6}\times 1\times 3\times 2\times 2}=1.15$$

$$W_3=\sqrt[5]{\frac{1}{4}\times\frac{1}{3}\times 1\times 2\times 2}=0.80$$

$$W_4=\sqrt[5]{\frac{1}{4}\times\frac{1}{2}\times\frac{1}{2}\times 1\times 3}=0.72$$

$$W_5=\sqrt[5]{\frac{1}{5}\times\frac{1}{2}\times\frac{1}{2}\times\frac{1}{3}\times 1}=0.44$$

The weight value of the first-order index can be obtained by normalizing the weight vector $W=(W_1,W_2,W_3,W_4,W_5)$, $W_1=0.53,W_2=0.18,W_3=0.12,W_4=0.11,W_5=0.07$.

(3) Consistency check

The analytic hierarchy process involves many subjective judgments and needs to be integrated into some objective evaluations, so it is necessary to check the consistency of the judgment matrix. Generally speaking, CIor consistency ratio CRis used as the index to check the consistency of the judgment matrix.

When $n\geq 2$,consistency ratio of judgment matrix $CR=\frac{CI}{RI}<0.1$ considered that the judgment matrix passes the consistency test.

If it fails the consistency test, the judgment matrix needs to be reconstructed.

$$CI=\frac{\lambda_{\max}-n}{n-1}$$

$$CR=\frac{CI}{RI}$$

$\lambda_{\max}$ The approximate value of the maximum eigenvalue of the judgment matrix, RI:Average randomness index.

Table 4 Average randomness index RI

Order number	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.9	1.12	1.26	1.36	1.41	1.49

Through the consistency test of the above judgment matrix, it is concluded that:

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$$\lambda_{\max} = 5.348$$

$$CI = \frac{\lambda_{\max} - n}{n-1} = 0.19$$

$$CR = \frac{CI}{RI} = 0.094 < 0.1$$

Therefore, through the consistency test. That is, the weights at the lifecycle level are:

$$W_1 = 0.53, W_2 = 0.18, W_3 = 0.12, W_4 = 0.11, W_5 = 0.07 .$$

According to the above methods and steps, the judgment matrix is constructed for the dimension layer, the core competence layer and the index layer respectively, and the consistency test is carried out to get the qualified weight (as shown in Table 5).

Table 5 Index weights

Dimension layer	Single layer weight	Core competence layer	Single layer weight	Comprehensive weight	Index layer	Single layer weight	Comprehensive weight
Lifecycle hierarchy (A)	0.35	Design phase (A1)	0.53	0.186	Product design (A11)	0.64	0.118
					Process design (A12)	0.24	0.045
					Process optimization (A13)	0.12	0.023
		Production stage (A2)	0.18	0.063	Procurement (A21)	0.43	0.027
					Planning and scheduling	0.23	0.014
					Production operation (A23)	0.14	0.009
					Quality Control (A24)	0.11	0.007
					Safety and environmental	0.05	0.003
					Warehousing and distribution	0.04	0.003
		Logistics stage (A3)	0.12	0.042	Logistics management	1.00	0.042
		Sales stage (A4)	0.11	0.039	Sales management (A41)	1.00	0.039

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		Service phase (A5)	0.07	0.020	Customer service (A51)	0.20	0.004
					Products and services	0.80	0.016
Intelligent feature level (B)	0.65	Resource elements (B1)	0.39	0.254	Strategic planning (B11)	0.61	0.155
					Employee ability (B12)	0.11	0.028
					Equipment digitization	0.22	0.056
					Resource management	0.06	0.015
		Interconnection (B2)	0.23	0.150	Network environment	0.17	0.025
					network security (B22)	0.83	0.125
		System integration (B3)	0.18	0.117	Application integration	0.83	0.097
					System security (B32)	0.17	0.020
		Information fusion (B4)	0.11	0.072	Data fusion (B41)	0.66	0.048
					Data application (B42)	0.26	0.018
					Data security (B43)	0.08	0.006
		New forms of business (B5)	0.05	0.033	Personalized customization	0.61	0.020
					Remote operation and maintenance	0.27	0.009
					Cooperative system (B53)	0.12	0.004
		Knowledge management	0.04	0.024	Enterprise intelligence	1.00	0.024

5.3 Construction of cobweb model of intelligent manufacturing capability maturity

In order to evaluate the advantages and disadvantages of an enterprise's intelligent manufacturing capability more intuitively, in order to give full play to its advantages, overcome its shortcomings and comprehensively enhance its intelligent manufacturing capability, and at the same time, it is easy to compare the differences of intelligent manufacturing capability among different enterprises. the construction of intelligent manufacturing capability maturity cobweb model is a more convenient choice. It can be seen from figure 1 that each level of intelligent manufacturing capability maturity model is the relationship between inclusion and inclusion, and the higher the level of intelligent manufacturing capability is, the more mature the

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intelligent manufacturing capability is[13].

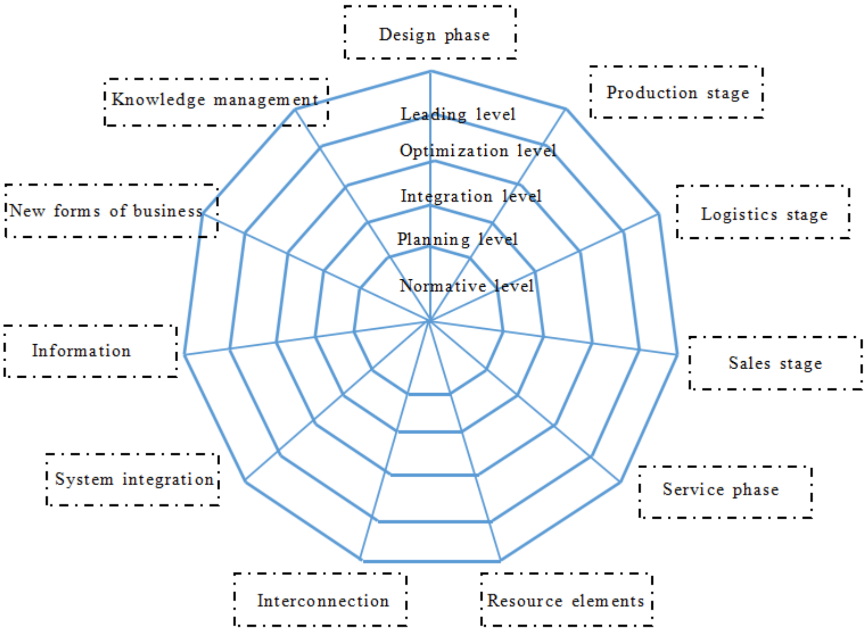

Figure. 1 Cobweb model of intelligent manufacturing capability maturity

In order to evaluate the advantages and disadvantages of an enterprise's intelligent manufacturing capability more intuitively, in order to give full play to its advantages, overcome its shortcomings and comprehensively enhance its intelligent manufacturing capability, and at the same time, it is easy to compare the differences of intelligent manufacturing capability among different enterprises. the construction of intelligent manufacturing capability maturity cobweb model is a more convenient choice. It can be seen from figure 1 that each level of intelligent manufacturing capability maturity model is the relationship between inclusion and inclusion, and the higher the level of intelligent manufacturing capability is, the more mature the intelligent manufacturing capability is[14].

(1) level 1-Planning level

At this level, enterprises have the idea of implementing intelligent manufacturing and begin to plan and invest[15]. Some of the core manufacturing links have realized business process informationization, and have some infrastructure to meet the needs of future communication and integration. Enterprises have begun to carry out manufacturing activities based on IT, but they only have the basic conditions to implement intelligent manufacturing, and have not really entered the category of intelligent manufacturing.

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(2) level 2-Normative level

The enterprise has formed the planning of intelligent manufacturing, invested in the equipment and systems supporting the core business, and made the main equipment have the ability of data acquisition and communication through technological transformation. it has realized the automation and digital upgrade covering the important links of the core business. Through the development of standardized interfaces and data formats, some of the information systems supporting production operations can achieve internal integration, data and information can be shared within the business, and enterprises begin to enter the threshold of intelligent manufacturing.

(3) level 3-Integration level

The focus of investment in intelligent manufacturing has shifted from individual inputs such as infrastructure, production equipment and information systems to integration, and important manufacturing operations, production equipment and production units have been digitalized and networked. It can realize the information system integration among design, production, sales, logistics, service and other core businesses, and begin to focus on the sharing of data within the factory. The enterprise has completed the preparatory work for the improvement of intelligence.

(4) level 4-Optimization level

The production system, management system and other supporting systems in the enterprise have been fully integrated and the factory-level digital modeling has been realized. and begin to analyze the data collected by personnel, equipment, products, environment and the data formed in the production process, and optimize the production process and business process through the knowledge base, expert base, etc., can realize the action of the information world and the physical world. From level 3 to level 4 reflects the process of quantitative change to qualitative change, and the ability of intelligent manufacturing of enterprises is improved rapidly.

(5) level 5-Leading level

The leading level is the highest degree of intelligent manufacturing capacity building. at this level, the analysis and use of data has run through all aspects of the enterprise, all kinds of production resources are optimized, and autonomous feedback and optimization are realized between equipments. personalized customization, network collaboration, remote operation and maintenance have become the main mode for enterprises to carry out business, and enterprises have become the benchmark of intelligent manufacturing in this industry.

For an enterprise, when constructing the cobweb model of intelligent manufacturing capability maturity, first of all, the scores of 11 dimensional indexes of the core competence layer should be calculated according to the weight of each index and the expert score of the index layer, and then, according to the score, determine the position of each dimension in the cobweb model, and evaluate the development status of each dimension of enterprise intelligent manufacturing capability, that is, advantages and disadvantages. Finally, the scoring position of

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each dimension in the cobweb model is connected sequentially to get an irregular eleven-sided area, which can evaluate the overall status of intelligent manufacturing capability maturity of related enterprises.

6. Conclusion

Both the "made in China 2025" strategy put forward by China and the strategy of "bringing manufacturing back" put forward by the United States emphasize the importance of intelligent manufacturing. Aiming at the problems of how to judge the development degree of intelligent manufacturing, where the intelligent manufacturing level of the region or enterprise is, and how to develop it, the maturity analysis of enterprise intelligent manufacturing level is put forward, and the specific evaluation system is given. It is hoped that it can help enterprises to clarify the current situation of intelligent manufacturing level and provide help for enterprises to find ways to improve the level of intelligent manufacturing. Of course, the research is far from over, and we will also devote ourselves to using excellent case studies to find the key to the treasure chest of high-level intelligent manufacturing.

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