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Assessment Method of Industrial System Maturity Levels

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Abstract: This paper proposes the concept of industrial system maturity level, and introduces a new factor, namely, the industry security and controllability level (ISCL), which further comprises autonomous and controllable ability and industry leading ability. Corresponding assessment criteria and models are also constructed. This method considers whether the supply of industrial elements such as technology, equipment, capital, and products are independent. The assessment results can reflect the basic state of a country's ISCL. In response to the urgent need for macro-research on China's strategic emerging industries, this study assessed and analyzed the industrial system maturity levels of 25 emerging industries. It reveals that, among the 25 industries, the industrial systems of only a few are in the developing or mature stage, and most industrial directions achieved unsatisfactory assessment results for their ISCLs. Specifically, only the industrial system of the battery electric vehicle industry is in the mature stage and has a high ISCL. The ISCLs of light-weight augmented reality display module, biomedical bioreactor and complete equipment, and emergency vaccine research and preparation, are relatively low; moreover, the autonomous and controllable ability as well as the industry leading ability of these three industrial directions are weak. Many emerging industries in China have prominent shortcomings in the ISCL. In the process of accelerating the construction of an independent and controllable modern industrial system, attention should be paid to improving the domestic capital's control over core technologies, raw materials, standards, brands, and other elements.

Keywords: industrial system maturity level; strategic emerging industries; assessment method; industry security and controllability level (ISCL)

1 Introduction

China has actively participated in global economic cooperation, proposed strategies to accelerate economic development, and isolated strategic emerging industries as an important direction for industrial transformation and advancement. The objective evaluation of the status of emerging technology research and industrialization development, comprehensive and accurate grasping of industry maturity laws, and reasonable predictions of development trends have become important topics in emerging industry development planning.

The maturity level has become an effective method for evaluating and measuring the state of industry development. The concept originated from the technology readiness levels (TRL) study conducted by the National

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Aeronautics and Space Administration (NASA) in the 1970s [1]. Currently, the evaluation standards of TRL are mature, and the assessment methods and implementation procedures have also been standardized [2]. Domestic and foreign scholars have extended the evaluation method of TRL to the fields of products and market economy. Since 2003, China's aerospace industry has studied product readiness levels (PRL) [3] to adapt from single-piece production to small-batch production. Considering the particularity of aerospace products and the problems associated with the development of small samples, an 8-level frame model of aerospace products was constructed. According to the actual needs of engineering development, assessment methods such as manufacturing readiness levels (MRL) [4], integration maturity [5], software capability maturity [6], and workforce maturity [7] have been developed.

According to the existing literature [8], researchers have deepened exploration and theoretical development of the TRL, MRL, and PRL, proposed the concept of industry maturity level, and established an assessment model of industry maturity level by combining qualitative and quantitative methods. First, the maturity level of technology and manufacturing has been assessed and integrated with other factors to obtain the PRL. Then, the PRL has been combined with the evaluation results of market maturity levels (MML) to form a comprehensive assessment result of the industry maturity level. In a series of consulting studies on strategic emerging industries in China [9], the cultivation and development of emerging industries have been supported by completing the assessment of industry maturity with relevant methods, and exploring key factors faced by specific industries, such as constraints, development needs, potential risks, and industry expected maturity time.

In response to increasing global industrial competition, the long-term existence of Sino–U.S. trade friction, and the increasing importance of the autonomous and controllable ability of technology and industry, China urgently needs to build an independent and controllable modern industrial system. However, the original assessment method of industry maturity level exposes certain limitations: the original method focuses on the overall prosperity level of a specific industry in a country and does not consider whether the supply of factors such as technology, equipment, capital, and products in the industry is independent. Therefore, it is difficult for the evaluation results to reflect the security and controllability of a country's industry. Taking this as a starting point, this paper introduces a new factor, the industry security and controllability level (ISCL), which comprises autonomous and controllable ability and industry-leading capability. Furthermore, a new assessment model for the industrial system maturity level is constructed, evaluated, and applied to many emerging industries.

2 Assessment method of industrial system maturity levels

2.1 Model structure

In this paper, an assessment indicator called the ISCL, based on the basic framework of the industry maturity level model [8], as well as strategic needs and requirements for accelerating the construction of an autonomous and controllable modern industrial system, is introduced to build an assessment model of the industrial system maturity (Fig. 1). It should be noted that the TRL, MRL, PRL, and MML have not been adapted from their original forms.

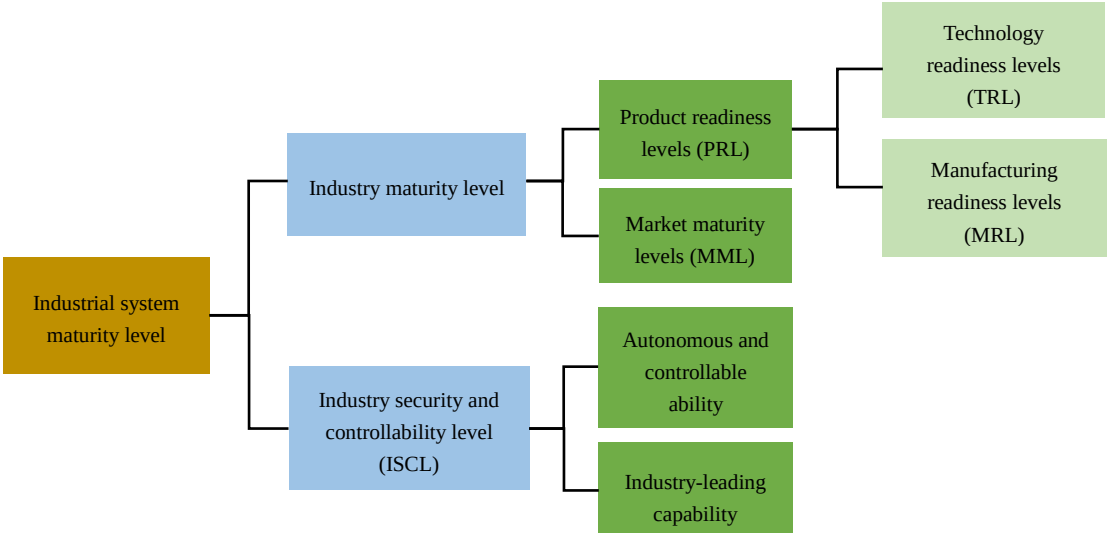

Fig. 1. Architecture of the assessment model of the industrial system maturity levels.

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The ISCL is used to measure and evaluate the degree of industry security and controllability according to two aspects: autonomous and controllable ability and industry-leading capability. The assessment of autonomous and controllable ability involves core raw material autonomy level, core technology autonomy level, key infrastructure equipment autonomy level, and domestic capital autonomy level. The assessment of industry-leading capability involves domestic brand market influence, domestic product sales dependence on foreign exports, and industry standard setting ability. The specific evaluation criteria of ISCL are shown in Table 1.

2.2 Indicator integration relationship

The assessment model of the industrial system maturity level covers the 4-level integration relationship of the ISCL, PRL, industry maturity level, and industrial system maturity level: (1) the ISCL is obtained by integrating autonomous and controllable ability and industry-leading capability, and is divided into four levels: very weak, weak, medium, and strong (Table 2); (2) PRL is derived from the integration of TRL and MRL, and can be divided into five levels: level 1 (conceptual product), level 2 (laboratory product), level 3 (engineered product), level 4 (demonstration product), and level 5 (market product) (Table 3); (3) Industry maturity level is derived from the integration of PRL and MML, and can be divided into four levels: level 1 (emergence), level 2 (cultivation), level 3 (development), and level 4 (mature) (Fig. 2); (4) Industrial system maturity level is derived from the integration of the industry maturity level and ISCL, and can be divided into four levels: level 1 (emergence), level 2 (cultivation), level 3 (development), and level 4 (mature) (Fig. 3).

3 Assessment and analysis for emerging industries

3.1 Overall assessment

Using the assessment model of the industrial system maturity level, an assessment of the maturity levels of 25 specific industries in six fields including new-generation information technology, high-end equipment, biology, new materials, green and low-carbon, and digital creativity were obtained. The relevant evaluation process is divided into four stages: (1) Propose the goals, ideas, and research methods of the maturity level assessment work, and prepare an industrial system maturity level self-evaluation form; (2) educate and train personnel in using the assessment method of the industrial system maturity level; (3) organize experts in various fields to carry out assessments for certain industries in their fields and fill out the self-evaluation form for the maturity level of the industrial system; and (4) based on the self-evaluation forms in different fields, organize experts to carry out comprehensive assessments and data analysis. The results of the industry maturity level assessment and industrial system maturity level assessment in 25 industries are shown in Table 4.

3.2 Results

Among the 25 industries, 14 industries are in the emergence stage and 6 industries are in the cultivation stage. Five industries have entered a higher stage: wind power, water pollution prevention, solar photovoltaic, and the ultra-high-definition (Ultra HD) video industries have entered the development stage, and the battery electric vehicle industry has entered the mature stage. Generally, most industry maturity levels are in the emergence stage and cultivation stage, while the number of industries entering the development and mature stage is relatively small.

Among the 25 industries, 15 industries are in the emergence stage, and 5 industries are in the cultivation stage. Five industries have entered a higher stage: the wind power, water pollution prevention, solar photovoltaic, and ultra HD video industries have entered the development stage, while the battery electric vehicle industry has entered the mature stage. Overall, the development stage of the industrial system maturity of 25 industries is the same as that of the industry maturity of these industries.

The overall assessment results of the ISCL of the 25 industries are not optimistic. Seven industries are assessed as very weak, eight industries are assessed as weak, and nine are assessed as medium. Only the battery electric vehicle industry is assessed as strong. Among the seven industries with very weak evaluation results, three industries, light-weight AR display module, biomedical bioreactor and complete equipment, and emergency vaccine research and preparation, have weak evaluation results in both autonomous and controllable ability and industry-leading capability. The evaluation results of both first-level indicators are weak, indicating that the industrial security is relatively severe. Therefore, it is particularly urgent to strengthen the autonomous and controllable ability and industry-leading capability of these industries.

Table 1. Indicators and definition of ISCL.

First-level indicators	Secondary indicators	Development stage	Definition of development stage
Autonomous and controllable ability	Core raw material autonomy level	1 (weak)	Does not have independent production capacity for core raw materials, which are predominantly imported.
		2 (medium)	Has some core raw material independent production capacity. There is a competitive relationship between domestic manufacturers and foreign manufacturers, but there is still a gap between the domestic level and the international level.
		3 (strong)	Has considerable independent production capacity for core raw materials, and its performance has reached the advanced international level. Although some manufacturers choose to import from abroad based on their own preferences or commercial motivations, domestic core raw material supply can fully meet market demand.
	Core technology autonomy level	1 (weak)	Does not have independent R&D capabilities for core technology, and core technology relies heavily on imports.
		2 (medium)	Has some core technology independent R&D capabilities. A competitive relationship exists between domestic manufacturers and foreign manufacturers, but there is still a gap between the domestic level and the international level.
		3 (strong)	Has considerable core technology independent R&D capabilities, and the technology has reached the advanced international level. Although some manufacturers choose to import from abroad based on their own preferences or business motivations, the domestic core technology supply can fully meet market demand.
	Key infrastructure equipment autonomy level	1 (weak)	Does not have the ability to independently provide key infrastructure equipment, and key infrastructure equipment rely heavily on imports.
		2 (medium)	Has a certain ability to independently provide key infrastructure equipment. A competitive relationship exists between domestic manufacturers and foreign manufacturers, but there is still a gap between the domestic level and the international level.
		3 (strong)	Has considerable ability to independently provide key infrastructure equipment, and its performance has reached the advanced international level. Although some manufacturers choose to import from abroad based on their preferences or business motivations, the supply of domestic key infrastructure equipment can fully meet market demand.
	Domestic capital autonomy level	1 (weak)	Industry funds are invested from abroad, and a small part of the equity of major manufacturers is controlled by domestic funds (less than 30%).
		2 (medium)	To a certain extent, industry funds are invested from abroad, and the equity of major manufacturers is controlled by domestic funds to a certain extent (30%–70%).
		3 (strong)	Industry funds are invested domestically, and the equity of major manufacturers is controlled by domestic capital (over 70%).
Industry-leading capability	Domestic brand market influence	1 (weak)	Domestic brands cannot compete with foreign brands in the industry. Both market share and industry influence are significantly weaker than those of foreign brands.
		2 (medium)	Domestic brands occupy a certain market share, but the mid-to-high-end market is still dominated by foreign brands.
		3 (strong)	Domestic brands have considerable industry influence. Although some consumers still choose foreign brands based on personal preference, domestic brands can provide products of the same quality in the mid-to-high-end market
	Domestic product sales dependence on foreign exports	1 (weak)	The sales of domestic brand products are heavily dependent on exports (over 70%).
		2 (medium)	The sales of domestic brand products depend, to a certain extent, on foreign exports (30%–70%).
		3 (strong)	There is considerable demand within the domestic market for domestic brand products, and domestic manufacturers can also make export decisions based on international market conditions.
	Industry standard setting ability	1 (weak)	The setting of industry standards is controlled by foreign countries, and domestic manufacturers cannot contribute to the process.
		2 (medium)	Domestic manufacturers have certain rights to vote or contribute to the process of setting international industry standards, but they still have no ability to dominate industry standards.
		3 (strong)	Domestic manufacturers have considerable rights to vote or contribute to the process of setting international industry standards and have a strong ability to dominate industry standards.

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Table 2. Integration relationship of the ISCL.

Attributes	Development stage	Description
Autonomous and Controllable Ability	A1 (weak)	There is a secondary indicator with an evaluation result of 1
	A2 (medium)	There are no secondary indicators with an evaluation result of 1, but not all secondary indicators have an evaluation result of 3.
	A3 (strong)	The evaluation result of all secondary indicators is 3
Industry-leading Capability	I1 (weak)	There is a secondary indicator with an evaluation result of 1
	I2 (medium)	There are no secondary indicators with an evaluation result of 1, but not all secondary indicators have an evaluation result of 3.
	I3 (strong)	The evaluation result of all secondary indicators is 3
ISCL	ISCL1 (very weak)	The evaluation result of both first-level indicators is 1
	ISCL2 (weak)	Of the two first-level indicators, one is 1, and the other is 2 or 3; or the evaluation result of both first-level indicators is 2
	ISCL3 (medium)	Of the two first-level indicators, one is 2, and the other is 3
	ISCL4 (strong)	The evaluation result of both first-level indicators is 3

Note: First-level indicators and secondary indicators are defined and shown in Table 1.

Table 3. Integration relationship of the PRL.

PRL	Product level	TRL	MRL
PRL 1	Conceptual product (1)	TRL 1	MRL 1
		TRL 2	MRL 2
		TRL 3	MRL 3
PRL 2	laboratory product (2)	TRL 4	MRL 4
		TRL 5	MRL 5
		TRL 6	MRL 6
PRL 3	Engineered product (3)	TRL 7	MRL 7
			MRL 8
PRL 4	Demonstration product (4)	TRL 8	MRL 9
PRL 5	Market product (5)	TRL 9	MRL 10

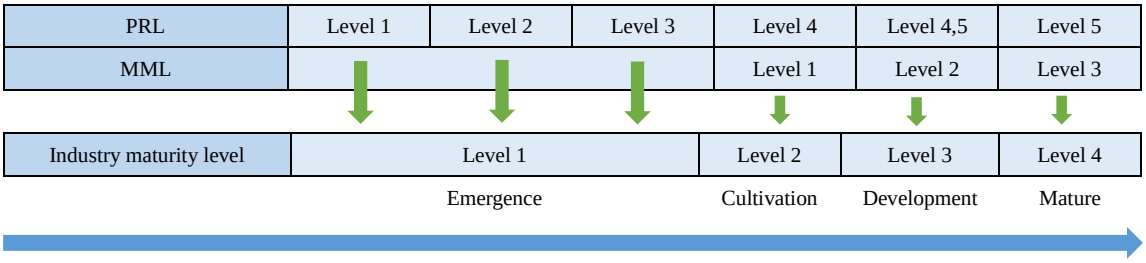

Fig. 2. Integration relationship of the industry maturity level.

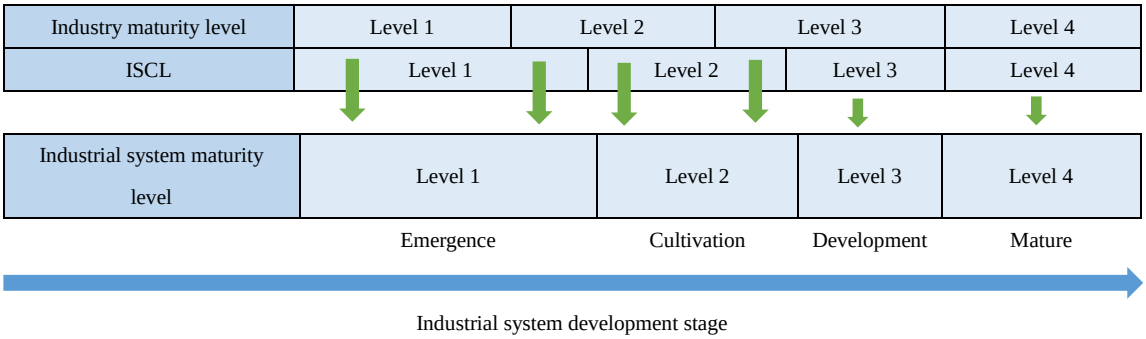

Fig. 3. Integration relationship of the industrial system maturity level.

Table 4. Results of the industry maturity level and industrial system maturity level of strategic emerging industries in China.

Field	Industries	TRL	MRL	PRL	MML	Industry maturity level	Autonomous and controllable ability	Industry-leading capability	ISCL	Industrial system maturity level
New-generation information technology	Light-weight augmented reality display module	7	7	3	1	1 (Emergence)	1	1	1	1 (Emergence)
	Micro LED display industry	7	7	3	1	1 (Emergence)	2	2	2	1 (Emergence)
High-end equipment	Large-scale civil aircraft high-end coating industry	7	8	3	1	1 (Emergence)	2	3	3	1 (Emergence)
	Graphite processing equipment	7	9	3	2	1 (Emergence)	2	2	2	1 (Emergence)
	Laser processing of flexible display panel	7	7	3	1	1 (Emergence)	3	2	3	1 (Emergence)
	Large turbine cargo oil pump system	8	9	4	1	2 (Cultivation)	2	1	1	1 (Emergence)
	Additive manufacturing of arc fuses for large high-performance metal components	7	7	3	1	1 (Emergence)	2	3	3	1 (Emergence)
	Deep-sea intelligent fish farming equipment	8	9	4	1	2 (Cultivation)	3	2	3	2 (Cultivation)
	Intelligent computer numerical control machine tool	6	6	2	1	1 (Emergence)	2	1	1	1 (Emergence)
	Electron beam additive manufacturing equipment	7	7	3	1	1 (Emergence)	2	1	1	1 (Emergence)
	Complete set of intelligent technical equipment for the whole process of chemical fiber filament winding operation	9	9	4	2	2 (Cultivation)	2	1	1	1 (Emergence)
Biology	Bio-based materials	7	8	3	1	1 (Emergence)	2	2	2	1 (Emergence)
	Biomedical bioreactor and complete equipment	7	7	3	1	1 (Emergence)	1	1	1	1 (Emergence)
	Emergency vaccine research and preparation	7	7	3	1	1 (Emergence)	1	1	1	1 (Emergence)
New materials	Key technologies and equipment for high-throughput preparation of low-dimensional composite material chips	6	7	2	1	1 (Emergence)	2	2	2	1 (Emergence)
	High-temperature resistant polyarylene ether high-performance engineering plastics	8	9	4	2	2 (Cultivation)	3	2	3	2 (Cultivation)
	New generation of advanced ultra-high strength steel for automobiles	6	6	2	1	1 (Emergence)	2	2	2	1 (Emergence)
Green and low-carbon	Air pollution prevention industry	9	9	4	2	2 (Cultivation)	2	2	2	2 (Cultivation)
	Wind power industry	9	9	4	3	3 (Development)	3	2	3	3 (Development)
	Water pollution prevention industry	9	9	4	3	3 (Development)	3	2	3	3 (Development)
	Solar photovoltaic industry	9	9	4	3	3 (Development)	3	2	3	3 (Development)
	Battery electric vehicle industry	9	10	5	3	4 (Mature)	3	3	4	4 (Mature)
Digital creativity	Virtual reality industry	8	9	4	2	2 (Cultivation)	3	2	2	2 (Cultivation)
	Ultra-high-definition video industry	8	9	4	3	3 (Development)	3	2	3	3 (Development)
	Intelligent content generation industry	6	5	2	1	1 (Emergence)	2	2	2	1 (Emergence)

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The key points that need to be addressed in these 25 industries to achieve future development are listed in Table 5. Furthermore, there are 17 industries that urgently need solutions. These industries are selected according to the following criteria: If TRL < 8, MRL < 9, MML < 2, and ISCL < 2, then a solution is needed in the corresponding link. The result of this research combines micro and macro factors, and can be used as a direct reference for industry research and policy-making institutions of strategic emerging industries in China.

Table 5. Key points need to be addressed in various industries.

Industries	Key points that need to be addressed
Light-weight augmented reality display module	Technology, manufacturing, market, industry security and controllability
Micro LED display industry	Technology, manufacturing, market, industry security and controllability
Large-scale civil aircraft high-end coating industry	Technology, manufacturing, market
Graphite processing equipment	Technology
Laser processing of flexible display panel	Technology, manufacturing, market
Large turbine cargo oil pump system	Market, industry security and controllability
Additive manufacturing of arc fuses for large high-performance metal components	Technology, manufacturing, market
Deep-sea intelligent fish farming equipment	Market
Intelligent computer numerical control machine tool	Technology, manufacturing, market, industry security and controllability
Electron beam additive manufacturing equipment	Technology, manufacturing, market, industry security and controllability
Complete set of intelligent technical equipment for the whole process of chemical fiber filament winding operation	Industry security and controllability
Bio-based materials	Technology, manufacturing, market
Biomedical bioreactor and complete equipment	Technology, manufacturing, market, industry security and controllability
Emergency vaccine research and preparation	Technology, manufacturing, market, industry security and controllability
Key technologies and equipment for high-throughput preparation of low-dimensional composite material chips	Technology, manufacturing, market
New generation of advanced ultra-high strength steel for automobiles	Technology, manufacturing, market
Intelligent content generation industry	Technology, manufacturing, market

4 Conclusion

In this study, the concept of an industrial system maturity level is proposed and a new factor for evaluating the industry security and controllability level, including autonomous and controllable ability and industry-leading capability, is introduced. The corresponding evaluation results can reflect the basic status of a country's industrial security and controllability. An analysis of the industrial system maturity levels of 25 emerging industries in China shows that the number of industries in which the industrial system has entered the stage of development or maturity is relatively small, and the ISCL of most industries is poor. This conclusion provides new theoretical support for the optimization of strategic emerging industries in China.

Industries with poor ISCL performances should focus on strengthening the core raw material autonomy level, core technology autonomy level, key infrastructure equipment autonomy level, and domestic capital autonomy level to enhance the industry's autonomy controllability and solve the problem that restraining the development. These industries should also enhance their industry-leading capability by focusing on enhancing the influence of the domestic brand market, reducing the dependence of domestic product sales on exports, and strengthening the industry standard-setting ability. For industries with a relatively high technology and manufacturing maturity level, while improving industry security and controllability, it is advisable to promote commercial demonstration applications, increase policy support to promote market-oriented development, and encourage technological innovation to accelerate the transformation from scientific and technological R&D achievements to large-scale commercial applications.

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