Evaluation Method for the Maturity Levels of Augmented Reality Industries

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Abstract
Development of an industry follows an objective cyclical law that is an inevitable progression from technological and manufacturing maturity to a developed market for new products. With the development of augmented reality (AR) technology, the more and more strategic emerging industries are developing rapidly in the field of AR and we need the AR industry maturity evaluation method to provide scientific decision-making support for the development of the industry. This paper applies the industrial maturity evaluation method to the AR field, constructs the AR industrial maturity evaluation system from the perspective of product and market, and gives the maturity grade and its evaluation standard. The research shows that the AR industry is still in the cultivation period. It is necessary to improve the manufacturing maturity and technology maturity in terms of products and cultivate consumer habits in terms of market.

Keywords: *Assessment method; Industry maturity level; Emerging industry; Augmented Reality*

1 INTRODUCTION

Augmented reality (AR) technology is a technology that superimposes data (including text, image, video and 3D model) on the real world [1]. Augmented reality technology belongs to digital perception technology, which uses digital means to capture, regenerate or synthesize various sensory inputs from the external world, so as to achieve an immersive sense of immersion. AR is the core entrance from the 2D world to the 3D world. It is a bridge connecting the digital world and the physical world. It is the basis for constructing spatial Internet based on mobile scenes.

The concept of AR appeared as early as 1935. It was not until around 2016 that the industrial chain gradually developed with the progress of technology, the favor of capital and the continuous participation of equipment providers, content providers and other parties. The capital market continues to inject power [2]. In 2016, the investment growth rate of AR industry reached the peak, and the industry ushered in a major outbreak. In the nine technology trends in 2016 released by IEEE, it was considered that 2016 would be the critical point of qualitative change of virtual reality and augmented reality [3]. In 2017, the total investment increased month on month, but the content quality and experience of listed products were lower than expected, and the industry entered the stage of reshuffle. In 2018, driven by the market and technological progress, the industrial chain of AR industry was also evolving, bringing more rich and diversified applications. After years of technical reserves and market brewing, the augmented reality industry has gradually formed.

According to the report released by Goldman Sachs, AR not only has the potential to create new markets, but also will subvert some current markets. The technology can be applied to nine major fields: video games, live events, video entertainment, health care, real estate, retail, education, engineering and military. At present, AR technology is mainly used in entertainment, training and education, medical treatment, navigation, tourism, shopping and R & D of large and complex products [4]. For example, entertainment mainly includes games, movies, concerts, etc. using AR technology. Users can participate 360 degrees with AR glasses and headphones, just like the on-site experience of witnesses. Training and education mainly include educational experience courses and three-dimensional teaching courses using AR technology, such as spacewalk, molecular three-dimensional structure and human anatomy. In terms of medical treatment, doctors can use AR technology to

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make the human body structure clear and present in all directions, and easily complete difficult operations. In terms of tourism and shopping, augmented reality technology can provide users with a more comprehensive and thoughtful experience. For example, where tourists see, AR equipment will present the history, original appearance and other information here. In the research and development of large and complex products, AR technology can realize three-dimensional visual production and improve production efficiency.

More and more companies are involved in the AR industry, including Microsoft, Apple, Google, Lenovo, Baidu and other companies. In 2015, Magic leap, which received more than $500 million from Google, announced that it was developing new augmented reality technologies; Microsoft releases Hololens. Apple is implementing strategic acquisitions in the AR field and acquired technology company Faceshift and German AR company Metaio in 2018. In addition to the acquisition, apple is also actively independently developing AR/VR solutions, such as transparent screen, iPhone based virtual reality system, advanced computer vision technology, etc. The momentum of China's AR industry is also relatively high. In November 2015, HiAR company successively released the first AR binocular stereo vision glasses. Bat and other giants also focus on AR, make efforts to develop AR technology, build AR platform and combine AR technology with existing businesses through investment and establishment of laboratories.

Scientifically identifying the maturity level of AR industry is conducive to scientifically judge the common and differential characteristics of the industry, and then provide decision-making basis for guiding the development of the industry [5]. In 2016, on the basis of technology maturity and manufacturing maturity, Wang Liheng and others established the maturity evaluation method of emerging industries by introducing market maturity, and established the theoretical basis of the maturity evaluation research of emerging industries [6]. On the whole, the theoretical research framework of industrial maturity has been formed, and the evaluation elements cover three basic aspects: technology, product and market, which is suitable for the strategic analysis and evaluation research of the development of emerging industries in various fields [7]. However, due to the differences between different fields or industries, the basic research framework lacks the analysis of field characteristics and industrial attributes. Therefore, the establishment of a general AR industry maturity evaluation method has become an urgent problem to be solved. Based on the basic theory and general method of industrial maturity evaluation, on the basis of identifying the characteristics of AR industry and combined with the industrial development trend, this paper constructs the AR industry maturity evaluation system, and gives the maturity grade and its evaluation standard.

2 BASIC THEORIES AND METHODS OF INDUSTRIAL MATURITY EVALUATION

Industrial maturity (IML) is a quantitative standard to evaluate and measure the process of industrial development from birth to maturity, which reflects the perfection of industrial development [8]. The formation and development of industries follow certain evolutionary laws. Industries in the early formation stage are called emerging industries [9]. When emerging industries go through the initial stage and growth stage and develop to the mature stage, they are called mature industries [10]. Through the analysis of the formation process of 25 industries, the technology management center of Cambridge University summarizes the common process framework from scientific discovery to the formation of emerging industries, which describes how the leading factors such as science, technology, application and market change alternately in the formation process of emerging industries, and depicts the common law of the evolution of emerging industries [11].

According to the above relevant analysis on the industrial evolution process, Wang Liheng believes that the industrial maturity process can be regarded as a process from product maturity to market maturity [12]. Only when the product first realizes the stable and mature technical performance can it create new market demand or meet the existing market demand, and finally realize the maximum value of the product and the sustainable development of the industry. So far, Wang Liheng divided the industrial maturity into four maturity stages (levels) (this paper studies the law of the industry from germination to maturity, regardless of the subsequent decline process), namely the germination stage, cultivation stage, development stage and maturity stage. Embryonic stage (IML1): the industrial embryonic stage dominated by technology R & D, whose main activities are to carry out basic research and R & D of technology; Cultivation stage (IML2): industrial cultivation stage dominated by technology application. The stage mark is that the industrial products or services have achieved the success of commercial application demonstration, and with the promotion of commercial application, the advantages of products or services in performance and cost have been recognized; Development stage (IML3): the rapid development stage of market-oriented industry. After the success of large-scale market promotion and demonstration, it will attract a large number of competitors to enter the market, and the sales volume of products or services can maintain a high growth rate for a period of time; Mature stage (IML4): the mature stage of industrial development dominated by the industrial chain. This stage marks the basic formation of the industrial chain, the application of industrial standards, and the development of the industrial chain towards gradual improvement. With the supply and demand of products or services approaching saturation, the growth

rate of sales volume gradually slows down, large-scale mergers and acquisitions are carried out among enterprises, the industrial concentration continues to improve, and leading enterprises stand out. Based on the industrial maturity evaluation method, it can realize the accurate evaluation of the development process of emerging industries and play an important scientific supporting role in the direction of industrial development and strategic policy decision-making.

3 AR INDUSTRY MATURITY EVALUATION SYSTEM

Industrial maturity evaluation is a qualitative to quantitative integrated method. Firstly, it evaluates the maturity of technology and production, and then integrates the product maturity; On this basis, combined with the market maturity evaluation results, the comprehensive evaluation results of industrial maturity (industrial maturity level) are finally integrated.

3.1 *Product maturity*

Products are goods or services provided to the market to meet the needs of users. From an engineering point of view, a product is the result of an R & D and manufacturing process. Product maturity (PRL) is a quantitative standard to evaluate and measure the development state of product development. It reflects the satisfaction of products to the expected application objectives. Product maturity grade is the standard and scale for evaluating the maturity of specific products. It is divided into five grades, namely five stages: conceptual products, laboratory products, engineering products, market-oriented products and lean market-oriented products, of which grade 1 is the lowest and grade 5 is the highest. Therefore, the maturity of products is mainly reflected in two important aspects: one is the gradual maturity process of external technical performance indicators, which is determined by technical maturity evaluation; On the other hand, it is the internal mature process of manufacturing process, materials and process control, which is determined by manufacturing maturity evaluation. Therefore, the product maturity is mainly obtained by the comprehensive integration of the evaluation results of technology maturity and manufacturing maturity.

Technology maturity refers to the technical maturity of a project (relative to the expected technical maturity of the project) and reflects the technical maturity of the project. Technology maturity focuses on evaluating the development of technology carrier, integration status and verification environment, as shown in Table I.

TABLE I. TECHNICAL MATURITY EVALUATION CRITERIA

TRL	Evaluation criteria
1	Observe the basic principles supporting the technology or see reports of the basic principles
2	The idea of applying the basic principle to products is put forward
3	Key functions and characteristics have been preliminarily verified in the laboratory environment
4	Take laboratory products as the carrier and pass the laboratory environment verification
5	Take the primary demonstration and verification product as the carrier and verify it by simulating the use environment
6	Take the advanced demonstration and verification product as the carrier and verify through the simulated use environment
7	Take the prototype product as the carrier and pass the verification of typical use environment
8	Take the trial product as the carrier to pass the test and delivery test
9	Mature products have passed extensive application and test

Production maturity (MRL) is used to indicate the maturity of production process. It quantitatively reflects the satisfaction of production capacity to project objectives in the process of technology transformation into products or systems. In the process of product research and development, we can not focus solely on the maturity of technology, and the maturity of production capacity is also very important. According to the best practice experience of project production management, the production maturity process covers the whole process from putting forward the concept to forming batch production and lean production capacity, and reflects the general development process from development to industrial production. The classification and standards of production maturity are shown in Table II.

TABLE II. PRODUCTION MATURITY EVALUATION CRITERIA

MRL	Evaluation criteria
1	Determine connotation
2	Determine the scheme
3	The feasibility of the scheme has been preliminarily verified
4	Ability to produce principle samples in laboratory environment
5	Ability to produce prototype parts in relevant production environment
6	Have the ability to produce prototype system or subsystem in relevant production environment
7	Have the ability to produce systems, subsystems or components in a typical production environment
8	The capacity of the trial production line has been verified and is ready to start low-speed production
9	Low rate production capacity has been verified and ready to start full rate production
10	The full rate production capacity has been verified and turned to lean production

The integrated relationship between technology maturity, production maturity and product maturity is shown in Table III.

TABLE III. PRODUCT MATURITY EVALUATION CRITERIA

Product maturity		Technology maturity	Manufacturing maturity
PRL1	Concept product	TRL1 TRL2 TRL3	MRL1 MRL2 MRL3
PRL2	Laboratory products	TRL4 TRL5	MRL4 MRL5
PRL3	Engineering products	TRL6 TRL7	MRL6 MRL7 MRL8
PRL4	Small batch market-oriented products	TRL8	MRL9
PRL5	Mass Lean products or High quality market segment products	TRL9	MRL10

3.2 *Market maturity*

Market maturity (MML) is a standard to evaluate and measure the state of the market relative to full maturity. It reflects the satisfaction of the market scale, market structure and market potential of the products developed by using new technology relative to the expected maturity target after they are introduced into the market. It is a method to quantify the market development process. Market maturity level is the standard and scale for measuring and evaluating the maturity of commodity or service market. It is divided into three levels: introduction stage, development stage and maturity stage. Among them, level 1 is the lowest and level 3 is the highest. The level classification and standards at all levels are shown in Table IV.

TABLE IV. MARKET MATURITY EVALUATION CRITERIA

Market maturity attribute		MML1 (Import period)	MML2 (Growth period)	MML3 (mature period)
Market size	Market revenue	Large initial investment, low market income and scale	Increase the scale of income and realize profitability	Stable income and profit scale

	Number of people engaged	Mainly R & D personnel, but production and sales personnel began to increase	Mainly production and sales personnel, with a significant increase in production and sales personnel	The number and structure of employees tend to be stable
Market structure	Industrial concentration	The products are in the import stage, and the production and sales of products are only concentrated in a few enterprises	The number of enterprises engaged in product production and sales has increased significantly, and the industrial concentration is low	M & A integration and adjustment have formed a complete industrial chain led by a small number of large-scale and powerful enterprises
	Market share	The commercial application demonstration of the product has a low share	Large scale commercial application, with fast growth in share	The market supply and demand are balanced, and the share is high and tends to be balanced
Market potential	Product competitiveness	The product is expected to have strong competitiveness	Product competitiveness advantages appear	Obvious competitive advantages of products
	Barriers to entry	A few enterprises master the core technology and have high technical barriers	Large scale application of core technologies and reduction of technical barriers	The effect of industrial scale economy appears, and the barriers to entry are high

3.3 *Classification of industrial maturity*

The evaluation of industrial maturity adopts a combination of qualitative and quantitative methods, focusing on the development and maturity law from technology, production to products, market and industry, so as to finally determine the level of industrial maturity. Therefore, industrial maturity reflects the comprehensive integration of product maturity and market maturity. The comprehensive integration relationship between them is shown in Table V.

TABLE V. EVALUATION CRITERIA OF INDUSTRIAL MATURITY

Product maturity	Market maturity	Industrial maturity	
PRL1 PRL2 PRL3	MML1	IML1	Budding period
PRL4	MML1	IML2	Incubation period
PRL5	MML2	IML3	Development period
PRL5	MML3	IML4	Mature period

4 AR INDUSTRY MATURITY EVALUATION AND ANALYSIS

Firstly, determine s core technologies of AR industry, organize experts in this field to fill in the questionnaire and give a qualitative and authoritative judgment on the technical maturity of AR industry. In order to retain the authoritative judgment information of all experts and deal with the difference of evaluation results, the qualitative grade judgment of all experts is statistically analyzed, and the membership degree method of fuzzy mathematics is used for grade measurement. It may be assumed that there are s key technologies to be evaluated in the industry, and a total of K authoritative experts conduct maturity level evaluation (K⩾10). The number of experts evaluating level 1-9 of technology I is $\mathrm{TRL}_1^i, \mathrm{TRL}_2^i, \cdots, \mathrm{TRL}_9^i$,$\sum_{j=1}^{9} \mathrm{TRL}_j^i = k$.

$$\mathrm{RTRL}_j^i = \mathrm{TRL}_j^i / k \tag{1}$$

The maturity membership grade evaluation matrix of s-item Technology is $RTRL_{S*9}$,1≤i≤9, 1≤j≤k.

Similarly, assuming n products and M markets, the r-th level of production maturity of the O-th product is $\mathrm{RMRL}_r^o (1 \le \mathrm{o} \le \mathrm{n}, 1 \le \mathrm{r} \le 10)$, the P-Level maturity membership degree of the e-level secondary index of the Q market is $\mathrm{RMML}_{ep}^{M_2 p}$, the subordinate degree of maturity of level P of the T third level index is $\mathrm{RMML}_{tp}^{M_3 p}$,$1 \le \mathrm{q} \le \mathrm{m}, 1 \le \mathrm{t} \le 10, 1 \le \mathrm{e}, \mathrm{p} \le 4$.Note that the above membership matrices are $RMRL_{n*10}$,$(\mathrm{RMML}_q^{M_2})_{4*4}$ and $(\mathrm{RMML}_q^{M_3})_{10*4}$.

In this paper, the analytic hierarchy process (AHP) is used to determine the weight. For example, for s technologies, the above K experts can form an expert group. Through the comparison of the importance of two technologies and the comprehensive scoring by using the 1-9 scale method, the comparison scoring matrix can be obtained A_{s*s}.

Let's assume that the weight vector of s technology based on AHP method is w^T, the weight vector of N products is w^P, the weight vector of class Q market level 2 evaluation index is $w_q^{M_3}$, the weights of technology, production and market maturity are assigned as follows w_1^I, w_2^I, w_3^I,where $w_1^I + w_2^I + w_3^I = 1$.

Formula 2 is the membership vector of industrial technology maturity level based on multi technology integration.

$$\begin{aligned} \mathrm{RTRL} &= w^T \otimes RTRL_{S*9} \\ &= (w_1^T, w_2^T, \ldots, w_s^T) \otimes \begin{pmatrix} RTRL_1^1 & \cdots & RTRL_9^1 \\ \vdots & \ddots & \vdots \\ RTRL_1^s & \cdots & RTRL_9^s \end{pmatrix} \end{aligned} \tag{2}$$

The technological maturity level of the industry is shown in Formula 3.

$$\mathrm{TRL} = \{\mathrm{i} | max_i(\mathrm{RTRL})\}, (1 \le \mathrm{i} \le 9) \tag{3}$$

Formula 4 is the production maturity level based on multiple products.

$$\mathrm{MRL} = \{\mathrm{r} | max_r(w^R \otimes RMRL_{n*s})\}, (1 \le \mathrm{r} \le 10) \tag{4}$$

Formula 5 is the fuzzy grade membership vector of class Q market maturity level 3 evaluation index.

$$\begin{gathered} \mathrm{RMML}^q = \\ w_q^{M_2} \otimes (RMML_q^{M_2})_{4*4} = w_q^{M_3} \otimes (RMML_q^{M_3})_{10*4}, \\ (1 \le \mathrm{q} \le \mathrm{m}) \end{gathered} \tag{5}$$

Then the comprehensive integration level of market maturity evaluation is formula 6.

$$\mathrm{MML} = \{\mathrm{p} | max_p(w^M \otimes \mathrm{RMML})\}, (1 \le \mathrm{p} \le 4) \tag{6}$$

Membership vector of product maturity grade is shown in formula 7.

$$RPRL = \left(\frac{w_1^I}{w_1^I + w_2^I}, \frac{w_2^I}{w_1^I + w_2^I}\right) \otimes \begin{pmatrix} RTRL^5 \\ RMRL^5 \end{pmatrix} \tag{7}$$

The product maturity level is formula 8.

$$\mathrm{PRL} = \{\mathrm{i} | max_i(\mathrm{RPRL})\}, (1 \le \mathrm{i} \le 5) \tag{8}$$

The membership vector of industrial maturity level is shown in formula 9.

$$RIML = (w_1^I + w_2^I, w_3^I) \otimes \begin{pmatrix} RTRL^4 \\ RMML \end{pmatrix} \tag{9}$$

Formula 10 is the maturity level of AR industry.

$$\mathrm{IML} = \{\mathrm{i} | max_i(\mathrm{RIML})\}, (1 \le \mathrm{i} \le 4) \tag{10}$$

We selected 22 core technologies of AR industry for industrial technology maturity evaluation. According to the fuzzy level, the technology maturity of AR industry is estimated to be at TRL8.

The hardware manufacturing maturity, platform construction maturity and content production maturity of AR industry are selected to evaluate the industrial production maturity. According to the fuzzy level, the production maturity of AR industry is at MRL9. Based on the results of technology maturity and production maturity, it can be concluded that the product maturity level of AR industry is PRL4.

Selecting two dimensions of market income and number of employees to quantitatively evaluate the market maturity and market scale of AR industry, we can get that the market income is MML1, the AR industry has a large market investment, mostly in technology R & D. compared with the smart watch market income, the AR market income scale is low. The number of employees is at MML1. At present, the AR industry is dominated by R & D personnel, accounting for more than 75% of the total

employees on average. So we get the market scale at MML1.

We select the two dimensions of industrial concentration and market share to quantitatively evaluate the market maturity and market structure of AR industry. The entering manufacturers of AR industrial chain are mainly small and medium-sized innovative enterprises, and the powerful manufacturers are in the state of reserve and wait-and-see. We can get the industrial concentration at MML1. The AR market presents a decentralized situation. The upstream and downstream manufacturers of the industrial chain have a low market share and low market share. We can get the market share at MML1. Baidu, byte, Alibaba, Huawei and other enterprises are reserving relevant core capabilities. HiAR, Lenovo, Shunyu and other enterprises have innovation research departments to carry out application demonstration research and exploration. So we can get that the market structure is in MML1.

We select the two dimensions of product competitiveness and import and export barriers to quantitatively evaluate the market maturity and market potential of AR industry. AR products have great market potential and will be highly competitive in the future. As an iPhone accessory, AR glasses will use iPhone's computing, network and positioning capabilities to play a display role. Apple glass is expected to replace the demand of iPhone within 10 years. In 2020, Tencent's annual magazine put forward the concept of "all real Internet", emphasizing the connection between the virtual world and the real world. AR technology will become the key foundation. Product competitiveness can be obtained at MML1. AR related technologies include near eye display, rendering processing, perceptual interaction, network transmission and content production, with high core technical barriers. Taking the optical waveguide technology as an example, only a few enterprises such as Lochn, Huynew and Nedplusar have mastered it at present. So we can get the market potential at MML1.

According to the comprehensive market scale, market structure and market potential, the maturity of AR market is MML1 introduction period. Then, by integrating the maturity of AR products and market, it is concluded that the maturity of AR industry is the cultivation period of IML2. At this period, the AR industry is still dominated by technology application. Some products or services have achieved the success of commercial application demonstration. It is necessary to improve the production maturity and technology maturity in terms of products and cultivate consumer habits in terms of market.

5 CONCLUSION

Industrial maturity evaluation is a comprehensive and integrated evaluation method combining qualitative and quantitative. Based on the basic theory of industrial maturity, this paper constructs the AR industrial maturity evaluation system from the perspective of products and market, and gives the maturity level and its evaluation criteria. The research shows that the AR industry is still in the cultivation period. It is necessary to improve the production maturity and technology maturity in terms of products and cultivate consumer habits in terms of market. AR technology is a new technology that changes the next generation of human-computer interaction mode. It can promote product research and development, improve learning effect, trigger the revolution of entertainment industry, change marketing means, stimulate market demand and promote the upgrading of information industry. The Chinese government should properly introduce certain preferential policies to promote the development of this industry.

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