

# The Impact of Emerging Technologies in the Aviation Manufacturing Industry: A Case Study of the Gradual-Change Factors in Shaanxi, PR China

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**Abstract**—As China’s economy becomes more robust, the government has emphasized the need to increase the civil aviation industry’s rapid development and reduce civil aviation’s technological gap compared to other advanced aircraft manufacturers. The use of the appropriate technologies in the aviation industry can help achieve the government’s plan of creating more jobs and increasing its revenue through the civil aviation industry. However, emerging technologies’ uncertainty and dynamic nature have led to significant challenges when these technologies are applied to the aviation manufacturing industry. This article applies the principles and methods of system dynamics based on the gradual-change factors of emerging technologies as identified through expert interviews to construct conceptual models depicting the gradual-change of emerging technologies in the aviation manufacturing field. Historical data from Shaanxi province were used to simulate and analyze the gradual development of emerging technologies. An analysis of the simulation results revealed that the rapid growth of competitive technologies in the growth process inhibits the gradual-change of emerging technologies. Also, increasing enterprise innovation capabilities, market demand expansion, and technology optimization significantly promote emerging technologies’ development and application. Furthermore, the research result shows that competitive products and technologies influence the gradual development of emerging technologies. Finally, the results indicate that the civil aviation industry should optimize the performance and function of emerging technologies during the early development stage instead of at the market application stage.

**Index Terms**—Aviation, causal loop diagram, developmental trends, emerging technologies, gradual-change (GC).

## I. INTRODUCTION

**A**VIATION manufacturing is a high-tech industry, and China wants to invest more in the aviation industries to

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make high-tech breakthroughs to reduce the aviation technological gap between China and the world’s leaders in this field [1]. Emerging technologies represent cutting-edge technologies that can potentially greatly enhance industrial restructuring [2]. Historically, the research of emerging technologies originated from the Wharton School of the United States (US) in 1994 with the publishing of “WHARTON on Managing Emerging Technologies.” Day *et al.* [3] explained emerging technologies as innovations based on science or application, with the potential to create a new industry or transform an existing industry. Also, Rotolo [4] defined emerging technology as a novel technology, which may have some uncertainty at the point of it getting to know, that can make a significant impact on the socioeconomic domains. In this article, the gradual-change (GC)<sup>1</sup> of the aviation manufacturing industry may be both positive or negative. In other words, the GC can be considered a form of development so that the aviation manufacturing industry becomes a more robust enterprise, or underdevelopment that results in the extinction of some technologies.

In recent years, many emerging technologies have emerged in the field of aviation manufacturing, such as additive manufacturing technology, composite material processing technology, recyclable thermoset plastics, and distributed manufacturing technology, which have spawned a group of emerging technology companies. Rosario [5] reported NASA’s technology to reduce air transportation energy costs through hybrid propulsion systems. Chen *et al.* [6] studied 4D direct writing printing technology with smart materials such as shape memory alloys, shape memory polymers, piezoelectric materials, electroactive polymers, light-driven polymers, and water-driven structures as the core. Zhang *et al.* [7] conducted in-depth research on aerospace titanium alloy forging technologies such as isothermal forging, precision rolling, integral forming of large complex components, and forging process simulation. Liang and Guo [8] analyzed the technological innovation of the fourth-generation (4G) aero-engine in the US from the perspective of aero-engine blade structure based on US patent data. Chanzy and Keane [9], designed the new variant wing to reduce the drag of the unmanned aerial vehicle when flying in the deflected position by 40%.

Nevertheless, emerging technologies are characterized by a high level of uncertainty in the developmental phase before

<sup>1</sup>Gradual-change is the Chinese interpretation of Yanhua.

being introduced to the market. For example, during the 1990s, McDonnell Douglas designed a famous fighter, namely, the YF-23, that incorporated many of the emerging technologies of its time, including an avant-garde appearance, a fast cruising speed, and a good stealth performance. However, because its use of the V-shaped tail was the first of its kind, it showed obvious poor maneuverability during its test flight; thus, the company lost this project to the Lockheed Martin Company that had not built fighters for 30 years. McDonnell Douglas never recovered from this event in the military aircraft market and was ultimately acquired by Boeing [10]. Yet another example of the previously mentioned uncertainty is that, on October 29, 2018, and March 10, 2019, two Boeing 737 MAXs crashed within just five months of one another, and 346 passengers and crew members died. In a statement following these events, Boeing acknowledged that both accidents had occurred due to misleading by the mobility enhancement system (MCAS) function. This feature was implemented with innovative automatic safety software that was initially designed to assist pilots in preventing aircraft stalls and improving flight stability. After the accident, almost all aircraft of the same type were banned by airlines and governments. Boeing's share price plummeted by more than \$30 billion in a few days [11]. Other examples of the drawbacks that emerging technologies may introduce are potential safety risks [12], network attack risks [13], high R&D costs, and uncertainty [14].

It can be observed that emerging technologies introduce a substantial level of uncertainty and have a significant influence on the rise and fall of enterprises and even that of industries. Therefore, an effective identification of the GC trends of emerging technologies is of great practical significance for reducing the risks inherent to the rapid development of aviation manufacturing technology. In this article, we sorted out some relevant research results of our predecessors and determined the GC elements of emerging technologies through expert interviews. Based on the principles and methods of system dynamics (SD), we construct both a conceptual model and a simulation model depicting the GC of emerging technologies in the aviation manufacturing field, which is a crucial difference from other research related to emerging technology. Additionally, the most concentrated aviation manufacturing industry in China is located in Shaanxi province [15]. Thus, historical data from Shaanxi province are used to simulate and analyze the GC process, and the simulation analysis reveals the key factors of this process and its trends.

Furthermore, the need for emerging technology in China's civil aviation industry can be seen in three significant aspects. First, China aviation market has been forecasted to be the largest aviation market in the world. According to the International Air Transport Association (IATA) prediction in 2018, China would surpass the US as the world's largest aviation market, in terms of traffic to, from, and within the country [16]. Similarly, Boeing made the same forecast in 2020, since China's airlines are expected to purchase 8600 new aeroplanes over the next two decades [17]. Second, China has built the world's largest airport. In 2019, China opened the world's largest airport, which is projected to serve 72 million passengers [18]. Among

the emerging technologies introduced in the new airport are automatic and smart parking, facial recognition technology for self-services such as self-service check-in process, self-service consignment process, self-service security inspection process, and self-service border inspection process. Never before would the immigration inspection process be fully trusted to a machine. Also, the airport benefits from the China railway and subway technology in building the advanced transits system within the airport. Third, the world's busiest airport is in China. According to The Global Time [19], the Guangzhou Baiyun international airport was the world's busiest airport in 2020. Undoubtedly, the ability for China to rapidly develop its civil aviation industry will be highly beneficial, and emerging technologies can be an effective means after considering the risk.

This article aims to identify the uncertainty of emerging technologies in China's aviation manufacturing field over time. This increases the ability for decision makers to make more informed decisions on the risk in the use of emerging technology in the rapid development of China's aviation manufacturing technology. In other words, the primary contribution in this article is the identification of period enterprise innovation ability, and the period market demand can promote the GC of emerging technologies. More importantly, this article provides SD for analyzing the complexity and uncertainty of emerging technology, avoiding a precisely wrong decision. Also, the approach presented in this article can be extended to other domains of emerging technology. The rest of this article is organized as follows. Section II presents a brief literature review. Section III gives the methodology. Section IV presents the result and analysis. Finally, Section V concludes this article.

## II. LITERATURE REVIEW

### A. *Emerging Technologies in Aviation*

The GC of emerging technologies means that over time, the overall development process of emerging technologies also changes [20]. Dosi [21] first introduced the concept of paradigm to technological innovation research and proposed the technological paradigm and trajectory, which led to the technology paradigm and technology track theory [22]. The technology S-curve and life cycle theory were proposed by Becker and Speltz [23]. Antonio [24] presented the trends in communication network technology in the health sector. Huang and Yang [25] believe that the demand environment of emerging industries also impacts the GC of emerging technologies.

Emerging technologies evolve in an ecosystem that includes corporate capabilities, market demand, and social environments. Adomavicius *et al.* [26] believe that the GC and development of technology depend on the entire ecosystem environment of technological progress. Cheng [27] analyzed the relationship between enterprise capability and the GC of emerging technologies based on SD and determined that enterprise capability is necessary for the GC of emerging technologies. Christensen [28] analyzed the impact of the market demand environment on technology GC from the perspective of market segmentation and proposed that the level of market demand affects the GC of technology. Huang and Yang [2] believed that the demand

environment of emerging industries also impacts the GC of emerging technologies. Li [29] classified the external environment of emerging technology GC into categories corresponding to the market environment, social and cultural environment, and institutional and regulatory environment. Based on technology diffusion theory, Zhao [30] proposed that the technical environment consists of the market environment, government policy environment, social capital environment, resource environment, and other components. Regarding the hierarchy of the GC of emerging technologies, Radosevic [31] believed that the GC environment of technology can be divided into four levels for analysis, namely: The national, industry, regional, and micro levels. Additionally, he believed that these four levels have an interactive relationship with one another.

Numerous studies show that the GC of emerging technologies is highly complex. For instance, artificial intelligence is used to improve control systems for autonomous aircraft motion and collaboration for the navigation-related decision-making of flight management operators during emergency landings with conflict detection and resolution [32]–[34]; Big Data is used for topological data analysis, persistent homology, disaster information, flight ticket booking, and air logistics [35]–[38]; training eye tracking is used for automation instructor assistance systems [39]–[41]; computer vision is used to improve alert systems and augmented navigation systems [42]–[44]; specialized aviation computer networks are used for global airport and in-flight connectivity [44]–[46]; smart bag tracking based on the Internet of Things is used in combination with additional sensors in aeroplane cabins to improve passenger's experiences [47]. Magistretti [48] made a deduction that we are in a stage that finding the appropriate existing technology for solving today's problem may be the best approach instead of trying to develop new ones by showing the dichotomies in process and knowledge levels.

### B. Related Works to China's Aviation Manufacturing Industry

In the context of aviation manufacturing, Gao [49] noted that in the process of developing and reupgrading China's general aviation manufacturing industry, the concentration of existing markets, the retention and introduction of talent, the research and development of new products and innovation, and the support of government funds should all be taken into account. Strong guidance provided by government policies is also a key element of this process. Tong [50] examined the technical application efficiency of the aviation industry to analyze the factors affecting the scale of aviation manufacturing, the environment of its human resources, R&D investment, regional environmental characteristics, and policy system. Adner [51] showed that technology is not discontinued, and emerging technology does not sprout in isolation, but they are descendants of the older technology.

From the perspective of Chinese aviation manufacturing industries, Xue and Zhang [52] believe that in the GC of emerging technologies, companies can change their development strategies, actively choose investments, and grasp the future applications of emerging technologies to obtain more significant benefits. Since enterprises are located in a technologically competitive environment, the scientific research is to improve innovation

and overcomes the influence of competitive technology, thereby gaining an advantage in the technology market [53]. The GC of new technologies cannot be carried out independently. It needs to combine various internal and external environmental resources, such as capital, business partners, technology providers, and technology applications. Only new technologies can continue to evolve [54]. Tong [55] analyzed the factors affecting aerospace manufacturing development, such as enterprise-scale, human resource environment, R&D investment, regional environmental characteristics, and policy systems by combining the efficiency of technology application in the aviation industry.

The importance of Shaanxi aviation industry can be deduced from other research. Cao [56] used Shaanxi aviation industry enterprises to analyze the key factors affecting knowledge integration in the aviation industry. Li [57] also used Shaanxi aerospace and aviation to study the influence of Shaanxi government policies on Shaanxi aerospace and aviation. They suggested that the government can first influence the industry, make the industry agglomerate, and then promote enterprises through industrial groups to reduce manufacturing costs.

### C. System Dynamic With Some Applications

Several researchers have applied SD in power system management [58], [59], environmental management [60], [61], business management, and different government levels.

From a business point of view, Khanzadi *et al.* [62] applied SD in evaluating the labor productivity in construction projects by using data obtained from experts. Srijariya [63] used SD in the financial model for budgeting and concluded that the SD approach provides more accuracy in a complex real-world problem than the traditional method such as the regression model. Mai and Smith [64] presented SD as an approach to forecasting planned tourism development in Vietnam. Gebre *et al.* [65] developed sheep fattening strategies using SD modeling.

In the aspect of decision-making for government, Wei *et al.* [67] applied SD model to six alternative scenarios for strategic environmental assessment and discovered that an integrated approach was the best. Koubaa [68] extended the application of SD to the domain of military purchasing. Cunico *et al.* [69] applied SD to investigate European citizens' awareness of cohesion policy intervention to increase the understanding of the underlying mechanism. Khurshid and Khan [70] simulated the impact of the COVID-19 on GDP, energy consumption, and climate change using SD.

Although Spidonov *et al.* [71] forecasted the main factors in evaluating air transportation system safety based on SD, to the best of our knowledge, this article is the first to apply SD to analyze emerging technology using the aviation industry as a case study. Thus, this article fills the gap in the literature.

## III. METHODOLOGY

There is uncertainty in introducing emerging technology in a production facility. The decision problem must be correctly defined, classified, and the appropriate method selected to increase the chance of making the right decision. In this case, we

TABLE I  
MAIN FACTORS AFFECTING THE GC OF EMERGING TECHNOLOGIES IN THE FIELD OF AVIATION MANUFACTURING

Overall Goal	Factors	First-level Criteria	Second-level Criteria	Index	Tally					Weight Scores
					1	2	3	4	5	
GC factors of emerging technologies in aviation manufacturing	Micro-level factors	Technological factors	Technology introduction	1	2	12	25	48	20	3.673
			Technical performance and function	2	2	6	19	53	27	3.906
			Technical maturity	3	2	3	15	48	39	4.112
			Technical transformation	4	3	6	35	38	25	3.709
			Competitive technology impact	5	2	14	19	48	24	3.729
	Meso-level factors	Market environment factors	Emerging technology market competitiveness	6	1	4	29	42	31	3.916
			Barriers to market	7	2	9	32	46	18	3.645
			Market demand and acceptance	8	1	6	26	48	26	3.86
			Technical market value	9	1	6	21	53	26	3.907
			Market risk size	10	1	10	31	46	19	3.673
		Enterprise innovation environment factors	Corporate R&D expenditure	11	1	4	20	52	30	3.991
			Number of patent applications	12	4	6	26	40	31	3.832
			Technical resources	13	3	8	31	45	20	3.664
			R&D staff input	14	2	5	22	54	24	3.869
			Enterprise innovation ability	15	1	3	13	50	40	4.168
	Macro-level factors	Industrial factors	Industrial infrastructure	16	1	6	26	58	16	3.766
			Industrial knowledge network	17	1	10	33	46	17	3.636
			Industrial capital investment	18	1	4	19	62	21	3.916
			Industrial human resources environment	19	1	9	28	49	20	3.729
		Regional macro environmental factors	Government policy support	20	1	7	28	51	20	3.766
			Government supplementary factors	21	1	6	36	51	13	3.645
			Regional economic development level	22	2	5	19	62	19	3.851
			Regional GDP growth rate	23	3	10	20	47	27	3.794

categorize the introduction of emerging technology in the aviation manufacturing industry as increasing uncertainty, thereby making predictions difficult. Therefore, SD provides clarity in the analysis of the speculative nature of introducing emerging technology to the aviation manufacturing industry.

#### A. Criteria Weighting

Based on the literature review and indicators presented by Zhu [72] with other related works [26], [73]–[78], we interviewed more than ten aviation manufacturing enterprise technical experts, aviation manufacturing researchers, and professors of higher education institutions; additionally, we selected topics in the aviation manufacturing field covering technologies, markets, companies, industries, and regions that are relevant to the subject of emerging technologies to comprise our basic data. Then, these data were screened and optimized with the Delphi method [79], [80]. The Delphi method requires experts opinions based on the field of research. Therefore, while we selected the objective to define and justify the evaluation criteria for expert selection, the experts provide high technical aspects in their field accrued during the long years of work experience.

The elements of the model depicting the emerging technology GC in the aeronautical manufacturing field were constructed and classified into five first-level indicators and 23 second-level indicators. Afterward, we designed a questionnaire and collected expert opinions from the field via on-site consultations and emails to determine the weight of each GC factor. A total of 150 questionnaires were sent out, and 115 of them were recovered; 107 (71.33%) of these questionnaires were valid. For the most part, we measured each indicator regarding the GC of emerging technologies using a five-point Likert scale as follows: one, two, three, four, and five correspond to negligible impact, small

impact, medium impact, large impact, and very large impact, respectively.

The scores of the collected questionnaires for the emerging technology in the aviation industry in Shaanxi province is computed using

$$TS = R_1 \times 1 + R_2 \times 2 + R_3 \times 3 + R_4 \times 4 + R_5 \times 5 \quad (1)$$

where  $TS$  is the total score; the ratios of negligible impact, small impact, medium impact, large impact, and very large impact are denoted as  $R_1$ ,  $R_2$ ,  $R_3$ ,  $R_4$ , and  $R_5$ , respectively. The 23 indicators are listed in Table I. Also, weights are the total scores ( $TS$ ), divided by the sample size, i.e., 107 respondents.

#### B. Model Building

The GC of emerging technologies is influenced by technological factors, market environment factors, enterprise innovation environment factors, industrial factors, and regional macro-environmental factors [4], [81]–[84]. The technological factors shown in Table I refer to the characteristics of the technology itself; the market environment factors refer to the demand and competitiveness of the emerging technology market; the enterprise innovation environment factors refer to the ability of an enterprise to research, develop, and invest in emerging technologies; the industrial factors refer to the supply of external resources required for the development of emerging technologies; and the regional macroenvironmental factors mainly refer to the level of regional economic development.

1) *Causal Relationships Between the GC Elements of Emerging Technologies in Aviation Manufacturing*: According to the characteristics of the elements shown in Table I, these elements are divided into macro-level, meso-level, and micro-level elements. These three levels of elements are roughly summarized in the internal and external environments surrounding the GC of emerging technologies in the aviation industry, and they form

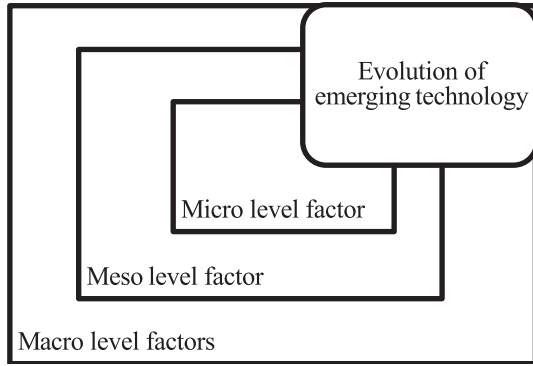


Fig. 1. Schematic diagram of the GC of emerging technologies in the aviation industry.

a system that contains macro-, meso- and micro-GC elements with the GC of emerging technologies at its core. Industrial environmental impact factors and regional macro environmental impact factors are classified as macro factors; they mainly provide a macro-bearing environment for the GC of emerging technologies, envelop the inner meso- and micro- elements of this environment, and affect the overall GC direction of emerging technologies from a macro-strategic perspective. The meso-level market environmental impact factors and enterprise innovation capability elements influence the GC of emerging technologies through the market- and technology-driven technologies. The microlayer technology elements affect the introduction, technical performance and function, and maturity of emerging technologies. These influence their GC by directly affecting the GC direction of technology and the maturity of its GC. Fig. 1 shows the GC of emerging technologies in the aviation manufacturing industry. Table I shows the classified elements.

By analyzing the relationships between factors that affect the GC of emerging technologies in aviation manufacturing, we use Vensim software to map a causal loop diagram depicting the GC of emerging technologies in the aerospace manufacturing field, following [4], [85]. A few of the elements have been merged and modified to facilitate the creation of this SD model.

The causal loop diagram shows that the GC of emerging technologies in the aviation industry is a complex process involving the interaction of many elements. It can be seen from the upper-right portion of Fig. 2 that the GC of emerging technologies reflects the maturity of these technologies. The more mature the technology is, the more successful the GC of that technology will be. The maturity of a technology is not only directly affected by factors such as micro-level competitive technologies, technological GC, technological transformation, and enterprise innovation capabilities but also indirectly affected by macroeconomic development, market demand, government support, and R&D investment. The maturing process of emerging technologies also affects the level of demand in the technology market, which impacts the scale of the industry, the incomes of related businesses, and the number of people employed in the industry. Promoting and inhibiting relationships are indicated by a “+” or a “-” next to the corresponding arrow, respectively. The

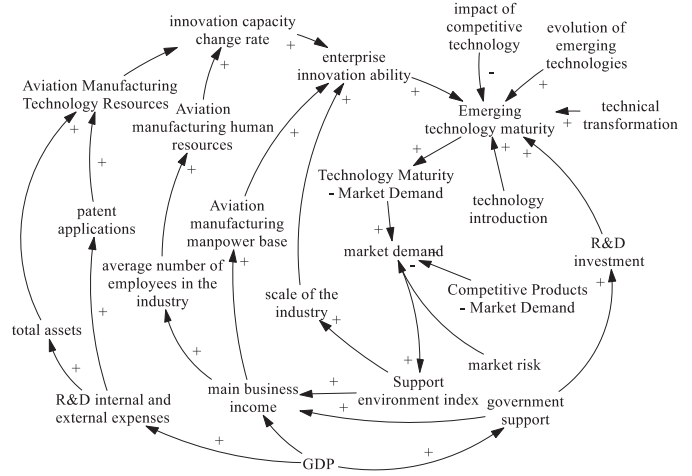


Fig. 2. Causal loop diagram of the GC of emerging technology.

interactions between the many elements shown in this diagram form multiple feedback causal loops that drive the development of the entire GC system [82], [86]. Most of the factors contribute to reinforcing loop, as shown in Fig. 2. The main causality rings are as follows.

- a) *Loop Number 1 of Length 5:* Emerging technology maturity  $\rightarrow$  + market fit  $\rightarrow$  + market demand  $\rightarrow$  + supporting environment index  $\rightarrow$  + industry scale  $\rightarrow$  + corporate innovation capability  $\rightarrow$  + emerging technology maturity.
- b) *Loop Number 2 of Length 6:* Emerging technology maturity  $\rightarrow$  + market fit  $\rightarrow$  + market demand  $\rightarrow$  + supporting environment index  $\rightarrow$  + main business income  $\rightarrow$  + aviation manufacturing foundation  $\rightarrow$  + corporate innovation capability  $\rightarrow$  + emerging technology maturity.
- c) *Loop Number 3 of Length 5:* Shaanxi GDP  $\rightarrow$  + R&D internal and external expenditures  $\rightarrow$  + patent applications  $\rightarrow$  + aviation manufacturing technology resources  $\rightarrow$  + innovation capability change rate  $\rightarrow$  + corporate innovation capability  $\rightarrow$  + emerging technology maturity.
- d) *Loop Number 4 of Length 8:* Main business income  $\rightarrow$  + average number of employees  $\rightarrow$  + aviation manufacturing human resources  $\rightarrow$  + Change rate of innovation capability  $\rightarrow$  + corporate innovation capability  $\rightarrow$  + emerging technology maturity  $\rightarrow$  + market fit  $\rightarrow$  + Market demand  $\rightarrow$  + Supporting environment index  $\rightarrow$  + Main business income.

2) *GC Strength of Emerging Technologies in Aviation Manufacturing:* Fig. 2 shows the causal relationships between the GC elements of emerging technologies in aerospace manufacturing. The following is an analysis of the effects of these different factors using a flow inventory map drawn from SD. According to the causal relationship diagram, the GC environment of emerging technologies can be decomposed into three district segments: The internal GC of emerging technologies, enterprise innovation capabilities, and the industrial market environment.

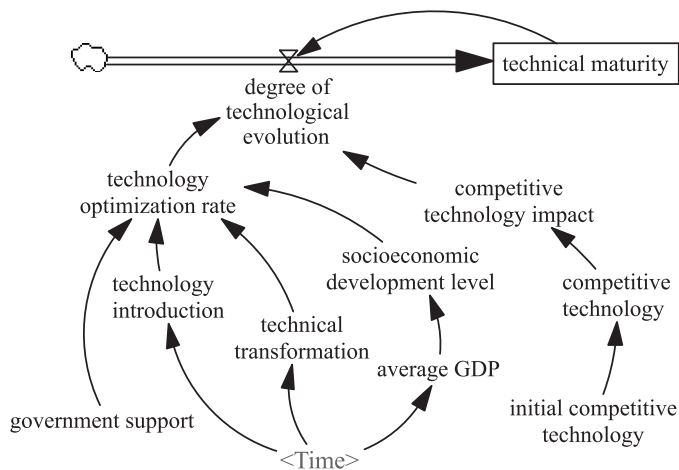


Fig. 3. Internal GC subsystem of emerging technologies.

a) *The internal GC subsystem of emerging technologies:*

The internal GC factors of emerging technologies mainly include introducing new technology, technical transformations, competitive technologies, and the technology optimization rate. According to historical data, actual conditions, and the existing literature, the intensity of technology introduction and the intensity of technological transformation were obtained by the ratio of imported technology expenditures and technical renovation funds to the total funds for scientific and technological activities, respectively. R&D investment is mainly measured by the ratio of new product development funds to fiscal technology expenditures. The model of this subsystem is shown in Fig. 3. The box labeled as technical maturity represents the degree of technological GC. The single arrow represents the influence of the tail element on the head element. The double line arrow represents the influence of many factors on the level of technological maturity at a certain rate.

b) *Enterprise innovation environment subsystem:*

The level of enterprise innovation ability in the enterprise innovation environment subsystem depends on the economic environment. The factors influencing this ability include the three aspects of the aviation manufacturing industry environment, the external economic environment, and the existing human resource conditions. These environmental factors of the aviation manufacturing industry mainly include the new product expenditure change rate and the industrial foundation. The new product expenditure change rate is primarily affected by the available combination of technical and human resources. The aviation manufacturing industry is mainly affected by the fixed assets that are added to it each year. The industry's investment in R&D is mainly measured at the regional GDP level. Based on this information, the enterprise innovation environment subsystem is shown in Fig. 4.

c) *Industrial market environment subsystem:*

Market demand is the main factor affecting the GC of emerging technologies in the industrial market environment subsystem. Market changes indirectly affect the GC of

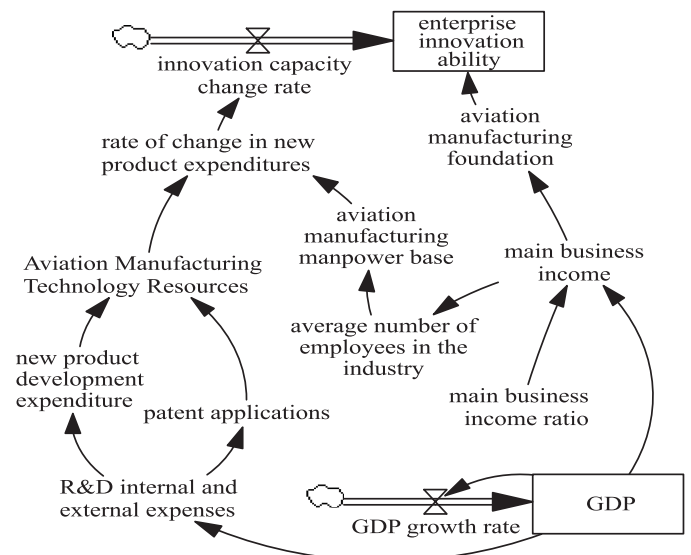


Fig. 4. Enterprise innovation environment subsystem.

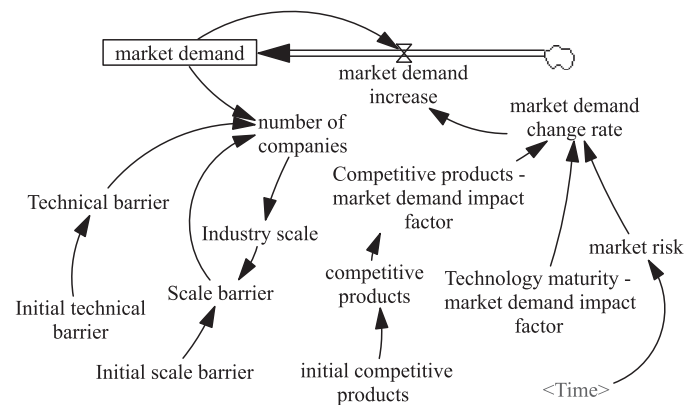


Fig. 5. Industry market environment subsystem.

emerging technologies; these changes mainly include the industrial environment and the market demand change rate. The industrial environment is primarily comprised of the industrial scale, the number of enterprises in the industry, and the technical barriers to market entry. The market demand change rate consists of market demand impact factors relating to competitive products, market demand impact factors relating to technological maturity, and market risk impact factors. The industrial market environment subsystem model is shown in Fig. 5.

3) *Overall Structure of the GC of Emerging Technologies in Aviation Manufacturing:* Each of the abovementioned subsystems is dynamic and complex. There are many interacting and interrelated elements within them. Additionally, all these subsystems are linked by certain connecting elements to form a single system of emerging technology GC in the field of aviation manufacturing, as shown in Fig. 2. This single system consists of three subsystems: The internal GC of emerging technologies, enterprise innovation capabilities, and the industrial

market environment. The internal GC of emerging technologies is fundamental to this system. Influenced by the external economy, technical support, and competitive technologies, the performance and functions of emerging technologies are constantly changing. The main factors in the GC of the internal subsystems of emerging technologies are the degree of influence exhibited by competitive technologies and the degree of GC exhibited by emerging technologies over time; together, these affect the maturity of emerging technologies. The GC of emerging technologies and enterprise innovation environments mainly enables enterprises to use external resources, develop necessary innovations based on changes in the external environment, and improve their innovation capabilities. The GC of emerging technologies and the market demand environment provide the necessary environment to choose an application market. Competitive products and market risks both influence the choice of emerging technologies in terms of an application market. After these emerging technologies choose an application market, the relevant industries provide them with network knowledge and technical resources regarding emerging technology industries, thereby promoting these emerging technologies' development and market competitiveness.

### C. GC Trend Analysis

From Fig. 2, we found that the key elements of promoting the GC of emerging technologies in aviation manufacturing include the technology optimization rate, the degree of the impact of competitive technologies, enterprise innovation capabilities, and market demand. To further reveal the impact of these factors on the GC trends of emerging technologies, we carried out a simulation analysis.

1) *Data Collection*: Many of China's aerospace technology resources are located in Shaanxi province and accounts for one-quarter of China's aviation professionals and high-precision equipment. It is also a major hub for the design, R&D, testing, and production of large and medium aircraft in China. Compared with Tianjin and Shanghai during the same period, the aviation industry of Shaanxi has greater comprehensive strength, a higher research level, a better support capacity, and a higher number of employees, and it ranks among the top aviation industries in the country. Specifically, its comprehensive strength ranks first in the country. Shaanxi province has one of the most representative aviation manufacturing bases in China. Therefore, we take the Shaanxi aviation manufacturing industry as a case study and conduct a simulation analysis on the GC of emerging technologies in aviation. The original data of the simulation were obtained from the official reports of China's high-tech industry statistical yearbook, the Shaanxi statistical yearbook, the Shaanxi science and technology yearbook, and the Shaanxi intelligence network. These data come from official government reports collected from 2010 to 2018. First, based on these data, the model test is carried out. After the model is tested, a simulation prediction analysis of the emerging technology GC over the next five years (2019–2023) is carried out.

2) *Simulation Analysis Environmental Settings*: This article uses the SD software Vensim PLE Plus from the Ventana System

TABLE II  
MAIN FACTOR VARIABLES AND THEIR SIMULATION ANALYSIS  
FUNCTION EQUATION

Feature Name (Unit)	Variable	Calculation Equation
Degree of technological GC		$(0.2 \times \text{Enterprise innovation ability} + 0.3 \times \text{Market demand} + 0.2 \times \text{Technology optimization rate} - 0.3 \times \text{Degree of the impact of competitive technology}) \times \text{Technology maturity}$
Technical optimization rate		$0.50 \times (\text{LN}(0.3 \times \text{Technical introduction} + 0.3 \times \text{Technical transformation} + 0.1 \times \text{Government support} + 0.1 \times \text{Social and economic development level} + 0.2 \times \text{Industry scale}))$
Impact of competitive technology		$0.40 \times (0.15 \times \text{EXP}(3 \times \text{Competition technology}))$
Market demand change		$\text{Market demand} \times (0.35 \times \text{Technology maturity} - \text{Impact of market demand factor}) - 0.25 \times \text{Competitive products} - \text{Impact of market demand factor} - 0.35 \times \text{Market risk}$
Technology Maturity – Impact of Market Demand Factor		$\text{Technology maturity} - \text{Market demand} \times \text{Technology maturity}$
Competitive Products – Impact of Market Demand Factor		$0.01 \times \text{EXP}(\text{DELAY}1(\text{Competitive product}, 1))$
Technology Maturity – Market Demand		$\text{WITHLOOKUP}(\text{Time}, ((2010, 0), (2023, 0.5)), (2010, 0), (2011, 0), (2012, 0.17), (2013, 0.27), (2014, 0.3), (2015, 0.38), (2016, 0.42), (2020, 0.5), (2023, 0.5)))$
Innovation capacity change rate		$0.4 \times \text{Aviation manufacturing technology resources} + 0.2 \times \text{Aviation manufacturing human resources} + 0.4 \times \text{Production scale}$
Industry scale		$0.1 \times \text{Industrial knowledge network} + 0.1 \times \text{Enterprises} + 0.4 \times \text{Market demand} + 0.3 \times \text{Aviation manufacturing Base} + 0.1 \times \text{Technical barriers}$

to simulate the GC of the emerging technologies in aerospace manufacturing. Based on the method used in SD, each item in the GC model of aeronautical manufacturing emerging technology shown in Fig. 2 is regarded as a variable. The process of the simulation consists of assigning an actual function value to each variable and attaching the actual corresponding data value or function relationship to reflect the mathematical relationships between the elements and obtain the degree of influence between them. Combined with the table function (TF), step function, ramp function, and delay function of the SD method, mathematical equations are added to the relevant variables in the model. By establishing the abovementioned variable function relationships, the GC of emerging technologies in aviation manufacturing is quantitatively analyzed. The periodic parameters evolved in this article are INITIAL TIME = 2010, FINAL TIME = 2023, and TIME STEP = 1. The simulation time spans from 2010 to 2023, and the analysis time period is in years. The main GC factors are the technology optimization rate, the impact of competitive technology, enterprise innovation capability, and aerospace manufacturing market demand. Table II lists only the major factor variable equations in the model; the others are omitted.

- 1) The initial value of emerging technology maturity is 0.8 (2010), (the maturity of emerging technology is divided into 9 levels: 1 and below represent the lowest emerging

technology maturity level, and 9 represents the highest emerging technology maturity level). It should be noted that emerging technology maturity is when the technology is at its plateau of productivity. In contrast, the GC of emerging technologies is the entire process from technology trigger to plateau of productivity.

- 2) The intensity of technology introduction, expressed by TF, is measured as the ratio of expenditures involving technology introduction to expenditures involving science and technology activities in Shaanxi Province.
- 3) The intensity of technological transformation, expressed by TF, is measured as the ratio of technical renovation expenditures to expenditures involving science and technology activities in Shaanxi Province.
- 4) The initial value of competitive technology, expressed by the ramp function, is 0.175 (determined by the average growth rate of the sales revenue of new products); that is, the annual rate of competitive technology is initially set at 0.175.
- 5) The innovation capability change rate is determined by the technical resources of aviation manufacturing, the human resources of aviation manufacturing, and the scale of the industry, with proportions of 0.4, 0.2, and 0.4, respectively.
- 6) The internal and external expenditures of R&D are determined through historical data, regression analysis of R&D internal and external expenditures, and the Shaanxi GDP.
- 7) The initial GDP is 1.0123 trillion yuan, the initial technical barrier is 0.1, the initial industrial knowledge network is 0.1, and the initial market risk is 0.1.

#### IV. RESULTS AND DISCUSSION

##### A. Preliminary Results Display

The simulation results show that the level of GC and the maturity of the emerging technologies in aviation manufacturing have maintained steady growth during the early, middle, and late stages of GC. With the continuous optimization of emerging technologies, the enhancement of enterprise capabilities, and the increasing market demand, the GC of emerging technologies shown by these results is in line with the actual theory of technology maturity. As emerging technologies evolve, the degree of influence held by competitive technologies increases.

1) *Impact of Technical Optimization:* The technical optimization rate (variation range 0 ~ 1) has an impact on technical maturity (variation range 0 ~ 9) and the degree of technological GC (variation range 0 ~ 9). As shown in Fig. 6, during the early stage of the GC of emerging technologies, the technology optimization rate exhibits a transient jump fluctuation. Between the early stage of the GC of emerging technologies and their selection of an application market, to meet market's needs and improve the function and performance of emerging technologies, the technology optimization rate accelerates over the short term. During the middle and late stages of GC, the rate of technological optimization tends to rise steadily. The technology maturity, technological GC, and technology optimization rates are shown in the figure below.

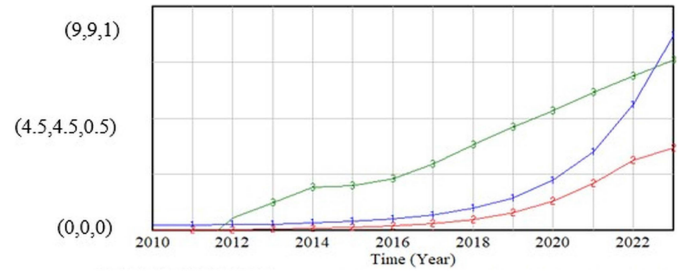


Fig. 6. Impact of the technology optimization rate on the GC of emerging technologies (1. Technology maturity. 2. Technological GC degree. 3. Technology optimization rate).

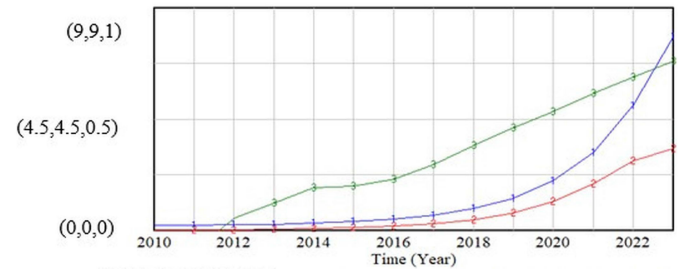


Fig. 7. Impact of competitive technology on the GC of emerging technologies (1. Technology maturity. 2. Technological GC degree. 3. Competition technology impact).

2) *Impact of Competitive Technology:* The impact of competitive technology (variation range 0 ~ 6) on technology maturity (variation range 0 ~ 9) and technological GC (variation range 0 ~ 9) is discussed in this section. As shown in Fig. 7, competitive technology emerges before emerging technology begins to evolve. Since emerging technologies do not form a market application scale when the market is initially selected, the degree of influence of competitive technologies is higher than the GC level between the early stage of the GC of emerging technologies and the medium-term. During the mid-term of technology GC, emerging technologies undergo GC, the GC of emerging technologies exceeds the impact of competitive technologies, and the maturity of technology increases rapidly. However, due to the delayed impact of competitive technologies and competitive products on emerging technologies, the GC of emerging technologies tends to accelerate slowly, and the impact of competitive technologies tends to increase. Emerging technologies must achieve innovative breakthroughs in technological performance and functionality to become industry-leading technologies.

3) *Impact of Market Demand:* The impact of market demand (variation range 0 ~ 1) on technology maturity (variation range 0 ~ 9) and technological GC (variation range 0 ~ 9) is discussed in this section. Fig. 8 shows that during the early stage of GC, when emerging technologies enter the application market, market demand is experiencing a downturn due to the relatively low level of technology GC and technology maturity and the poor technical performance and functionality of the existing technology. With the GC of emerging technologies and that of the market environment, the performance and functions



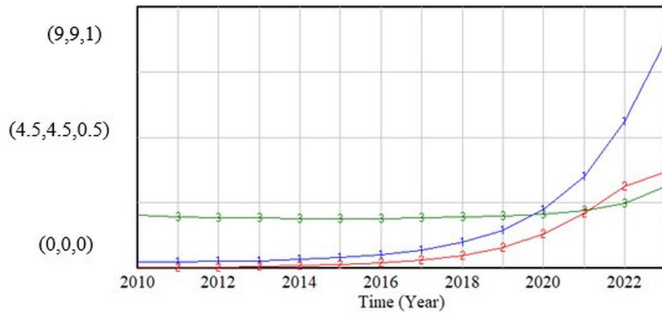


Fig. 8. Impact of market demand on the GC of emerging technologies (1. Technology maturity. 2. Technological GC degree. 3. Market impact).

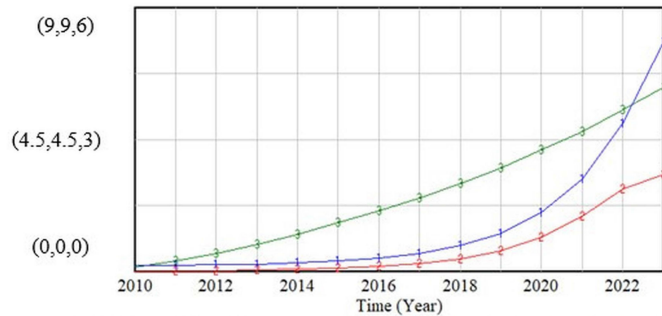


Fig. 9. Impact of enterprise innovation capabilities on the GC of emerging technologies (1. Technology maturity. 2. Technological GC degree. 3. Enterprise innovation capabilities).

of emerging technologies are constantly improving. When the maturity of emerging technologies exceeds a value of 3, the market demand begins to cause demand intensity to accelerate as technology maturity increases.

4) *Impact of Enterprise Innovation*: The impact of enterprise innovation capability (variation range 0 ~ 6) on technology maturity (variation range 0 ~ 9) and technological GC (variation range 0 ~ 9) are discussed in this section. Fig. 9 shows that due to the complex dynamics of emerging technologies, the innovation capability of enterprises in relation to emerging technologies starts at a value of zero. During the early stage of GC, when emerging technologies enter the application market, enterprises increase their contribution to the changes occurring in the competitive market by accelerating their own emerging technological innovation capabilities. Over the medium term, in addition to effectively integrating their internal resources, these companies also analyze the emerging technology market demand situation and improve the innovation capability of the emerging technology industry.

## B. Main Factor Simulation Analysis With Results

1) *Simulation of the Degree of Influence of Competitive Technology*: Through the adjustment of the key variable coefficients, the technical optimization rate and the degree of influence of competitive technology are simulated. The original coefficients of the technical optimization rate and the degree of influence of competitive technology are set to 0.50 and 0.40, respectively. The simulation results are shown in curve 1 of Fig. 10 and curve

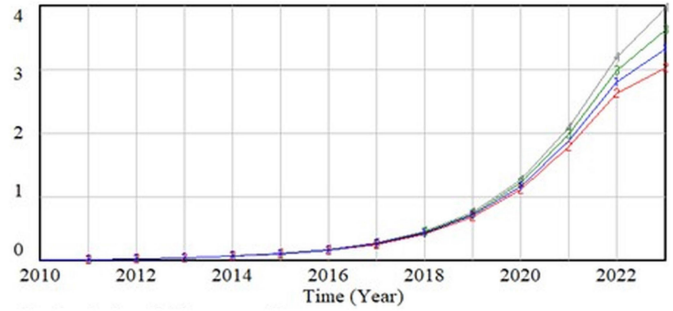


Fig. 10. Impact of the technology optimization rate on the GC of emerging technologies under the influence of different technology optimization rates (1. Technological GC curve 1. 1. Technological GC curve 2. 3. 1. Technological GC curve 3. 4. Technological GC curve 4).

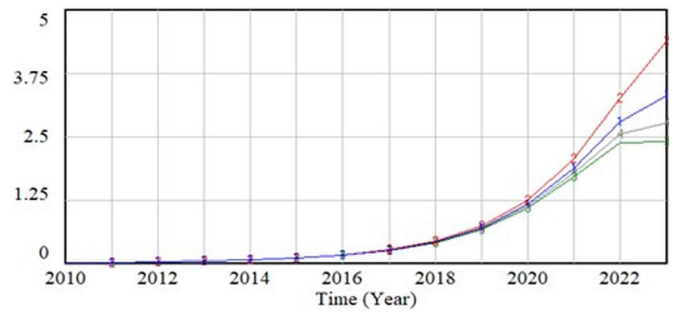


Fig. 11. Impact of competitive technology on the GC of emerging technologies under the influence of different competitive technologies (1. Technological GC curve 1. 1. Technological GC curve 2. 3. 1. Technological GC curve 3. 4. Technological GC curve 4).

1 of Fig. 11. When the other conditions remain unchanged, the coefficients of the technical optimization rate are adjusted to 0.45, 0.55, and 0.60, respectively; consequently, Curves 2, 3, and 4 of Fig. 10 are obtained. Similarly, the degree of influence of competitive technology is adjusted to 0.35, 0.45, and 0.50 to obtain Curves 2, 3, and 4 of Fig. 11.

The GC of emerging technologies accelerates as the technology optimization rate increases, as shown in Fig. 10 by the four gradually rising curves. In 2020, these four curves simultaneously diverged, indicating that the impact of optimization rates on the GC of emerging technologies decreases during the later stages of the GC of emerging technologies. Similarly, competitive technology promotes emerging GC during the early stage shown in Fig. 11. Later, competitive technology has a negative impact on the GC of emerging technologies. The larger the competitive technology coefficient is, the lower the GC rate of emerging technologies will be. This is because information exchanges occur in the GC of emerging technologies, and the elements of this GC interact with each other. During the early stage of the GC of emerging technologies, these technologies occupy the application market to win over competitive technologies. Aviation companies and emerging technology industries have increased their technology introduction and technological transformation to promote emerging technologies. When the impact of competitive technology is too large, it inhibits the GC of emerging technologies.

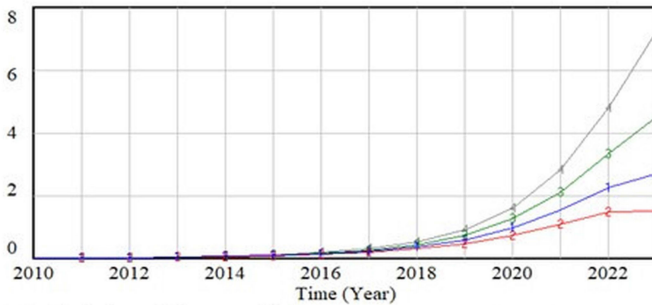


Fig. 12. Impact of innovation capability on the GC of emerging technologies under the influence of different levels of enterprise innovation capability (1. Technological GC curve 1. 1. Technological GC curve 2. 3. 1. Technological GC curve 3. 4. Technological GC curve 4).

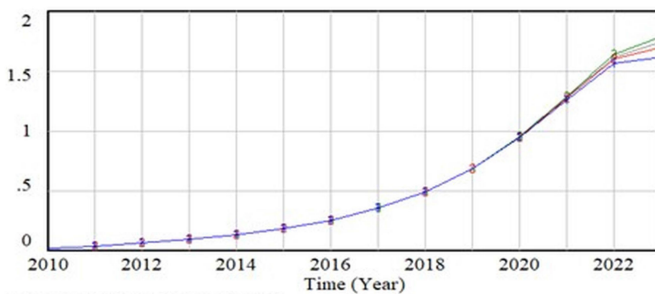


Fig. 13. Impact of innovation capability on the GC of emerging technologies under the influence of different levels of enterprise innovation capability (1. Technological GC curve 1. 1. Technological GC curve 2. 3. 1. Technological GC curve 3. 4. Technological GC curve 4).

2) *Simulation of Enterprise Innovation Capabilities and Market Demand:* The model's original coefficients of enterprise innovation ability and market demand are 0.45 and 0.40, respectively. The coefficient of the innovation ability of enterprises is adjusted to observe the GC of technology development while keeping the other influencing factors constant. GC curve 1 is obtained from the initial data, and enterprise innovation ability is adjusted from its initial coefficient of 0.45 to 0.40, 0.50, and 0.55 to obtain simulation curves 2, 3, and 4, respectively; these curves are shown in Fig. 12. In the same way, market demand is adjusted from its initial coefficient of 0.40 to 0.45, 0.50, and 0.55, respectively; consequently, simulation Curves 2, 3, and 4 in Fig. 13 are obtained.

The simulation results show that the adjustment of enterprise innovation ability has a positive impact on the GC of emerging technologies; as enterprise innovation capability increases, the GC rate of emerging technologies accelerates. Beginning in 2019, the influence of enterprise innovation capability on the GC of emerging technologies started to increase. In this relationship between the innovation capability of enterprises and the GC of emerging technologies, the impact of initial innovation capability on the GC of emerging technologies is not obvious. However, due to the dynamics and uncertainties inherent to the GC of emerging technologies, this impact is reinforced by the GC of emerging technology GC systems. Market demand has a positive impact on the GC of emerging technologies. The degree of the GC of emerging technologies

increases with an increase in market demand, as shown in Fig. 13. During the latter stage of GC, the impact of market demand on the GC of emerging technologies continues until 2022. This impact gradually decreases thereafter. Most importantly, these results contribute to decision theory for decision-makers such as engineers, managers, policy-makers, and the government.

Forecasting is of paramount importance in setting up for success using emerging technologies. The enterprise would benefit from allocating more resources toward their long-term strategic plan using more precise models, such as SD in the aviation manufacturing industry. This implies that the success of the aviation industry depends on the accuracy of the forecast. No emerging technology can be put into use without adequate funding. The research result would increase the government's confidence during the implementation stage because the model shows the GC of emerging technologies. Accurately knowing the reasonable period that emerging technology can make its peak contribution to the industry can help managers decide to buy the patents or the licensing to use these technologies. Also, to a great extent, the enterprise budgets depend upon a well-aligned emerging technology to its long-term strategic plan. Furthermore, success in implementing emerging technology depends on accurate forecasting by knowing when it is useful. Thus, managers become more aware of the strengths and weaknesses of an emerging technology due to forecasting and the incite provided in the form of GC in emerging technology.

## V. CONCLUSION

Through a model analysis of the GC of emerging technologies, this article shows that the technology optimization rate, competitive technology, market demand, and enterprise innovation ability are the main factors influencing the GC process of emerging technologies.

First, the speed of the GC of emerging technologies increases as an investment in technology optimization capital increases; however, when emerging technologies have evolved to a certain extent, the impact of technological optimization capital on the GC of emerging technologies gradually decreases.

Second, the GC of emerging technologies is influenced by competitive technologies and competitive products. During the early stage of GC, to improve the performance and functional structure of emerging technologies, aviation companies and emerging technology industries increase their rate of technology introduction and technological transformation to prompt the GC of emerging technologies. When the impact of competitive technologies is too large, it inhibits the GC of emerging technologies.

Third, the simulation results showed that the GC of emerging technologies was affected to varying degrees by changes in the coefficients of the influencing factors. Within a given simulation time period, market demand had a longer lasting impact on the GC of emerging technologies than do the other factors. The aviation industry should optimize the performance and functions of emerging technologies during the early stages of GC rather than seeking to improve their technical performance opportunities during the market application stage.

Finally, enterprises are the mainstay of emerging technology development; to a certain extent, they are also the leading provider of applications. There are mutual influences and dependencies between enterprises and emerging technologies. In the complex GC environment of emerging technologies, there are many uncertain factors; however, enterprise capability represents a relatively minuscule element of the emerging technology GC environment.

Further research can be done on the application of this work and extend it to other areas in management science and engineering as well as aviation and aeronautics engineering, such as the use of knowledge graphs to identify the uncertainty of emerging technologies to enrich the research methods of technology management science. Interestingly, the micro, meso, macro levels of the model in this article may be extended to microfoundation. Since the case presented in this article is a predominantly reinforcing loop, more investigation can be conducted and an additional balancing loop to provide more explanation to the aviation industry. Lastly, more immediate direct application of this research for managers can be analyzed from the perspective of emerging technology into the foreseeable future.

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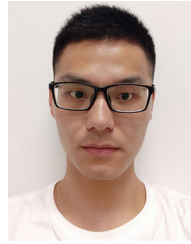
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